MODELLING OF METAPOPULATION DYNAMICS AND DISTRIBUTION OF *VARANUS FLAVESCENS* IN NEPAL TARAI: IMPLICATIONS TO CONSERVATION

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Central Department of Zoology

Institute of Science and Technology

Tribhuvan University

Kirtipur, Kathmandu

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October, 2014

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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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
AUC	Area under Curve
CITES	Convention on International Trade in Endangered Species of Wild Flora and Fauna.
DDC	District Development Committee
EGV	Eco-geographical variables
EOO	Extent of Occurrence
ESA	European Space Agency
GAM	Generalized Additive Modelling
GIS	Geographical Information System
GLM	Generalized Linear Modelling
ISODATA	Iterative Self-organising Data Analysis
ISRIC	International Soil Research and Information Centre
IUCN	International Union for Conservation on Nature and Natural Resources
no. par.	number of parameters
PA	Protected Area
ROC	Receiver Operating Characteristics
SDM	Species Distribution Modelling
sq. km.	Square kilometres
TM	Thematic Mapper
VDC	Village Development Committee
WISE	World Inventory of Soil Emission Potentials.

ABSTRACT

Human presence within the Jagdishpur reservoir and associated wetlands has largely fragmented the wetland habitats. In attempt to understand the metapopulation dynamics of Golden Monitor Lizard (*Varanus flavescens*), these dynamics of the species were modelled from surveys of two consecutive years in 2012 and 2013. A land cover classification was performed to categorise land cover patterns and recognition of landscape variables. Surveys to determine dynamic occupancy state of the species was performed in 40 grids; 1 sq km each, enclosing Jagadishpur Reservoir and associated wetlands and analyzed in Program PRESENCE. Impact of landscape variables on species distribution and other factors used as covariates upon parameters were modelled in the program. Available presence data were modelled for predicting potentially suitable habitat using Program MAXENT. Land cover classification recognized five major landcover types with greater proportion of forest and settlement areas. Other identified classes were grassland, marshlands and bare lands distributed over the area. The study revealed higher rate of recolonization probability over local extinction rate thus higher occupancy in 2013. A patchy subpopulation type metapopulation in the study area was documented. Occupancy of Golden Monitor Lizard was shown to be negatively affected by distance to settlements while positive correlation existed between the state variable and distance to nearest water source. MAXENT model predicted entire Tarai and some river valleys as potential area but GIS analysis revealed a relatively less Extent of Occurrence available for the species. The study concluded unstable metapopulation existed as human disturbance increases. Identification and monitoring of other metapopulation of the species, providing better protection or extension of PA networks, landscape level conservation and enlistment of the species in national red data list as endangered will help to conserve the species if implicated.

1. INTRODUCTION

1.1. Landscape, Metapopulation and Conservation

Natural or human induced disturbance, regeneration or fragmentation of a land cover type, persistence differences in environmental resources or introduction by humans creates heterogeneity in the space (Forman and Godron 1986, Thapa 2011). Population growth and regulation, succession and dynamics of evolutionary change constitute temporal dynamics of any species within the space (Pickett and Cadenasso 1995). Spatial heterogeneity and temporal dynamics are the necessary elements within the space that constitute a landscape. Changes in landscape patches at different time and places lead to a shifting mosaic within the landscape (Pickett and Cadenasso 1995). Human beings play an important role in deciding the fate of these elements within the landscape which make them an essential component of landscape studies (Forman and Godron 1986, Turner 1989, Hanski and Gilpin 1991, Forman 1995, Pickett and Cadenasso 1995). A rapid population boom following industrial revolution and unsustainable natural resources consumption of human has became the root threat to biodiversity (Groom, 2006), fragmentation of habitat being one of the major among them. Fragmentation creates a small patch of natural habitat embedded within unsuitable or poorly suitable human modified matrix (Noss et al. 2006) for any species. Habitat fragmentation has been known to affect population dynamics of a species (Fahrig 2002, Noss et al. 2006) by producing patches that may be too small to support populations or too isolated to interact with other patches (Harisson and Taylor 1997). Many studies (Schoener and Spiller 1987, Kindvall and Ahlén 1992, Hanski 1994a) demonstrated that small populations in small habitat fragments have higher extinction rates. Despite of such risk of extinction, population persistence on these fragmented habitats can be regulated by local extinction within patches and recolonization among already empty patches. Thus an adequate knowledge of these dynamics of any species in relation to these landscape element and fragments is crucial for understanding the species' ecology and ultimately to conservation goals.

Process of extinction and colonization for the regulation of species richness within isolated oceanic islands as determined by area and isolation to other islands was identified by MacArthur and Wilson (1967) in their "Equilibrium Model of Island Biogeography". A metaphor to this model on mainland landscape, classical metapopulation model (Levins 1969) demonstrated extinction and colonization to determine stability of local populations within fragmented patches. As metapopulation deals with a set of local population within some larger area, linked by limited migration (Hanski and Simberloff 1997), studies on metapopulation have found great importance in conservation biology, conservation genetics and reserve design. Metapopulation dynamics helps in understanding local population dynamics of species in fragmented habitats and help to prevent extinction of such species through management (Hanski and Gilpin 1991) while also increasing genetic differentiation among population (Whitlock and McCauley 1990; cited in Barton and Whitlock 1997).

1.2 Species Distribution Modelling and Conservation Implication

An understanding of how and why species are distributed in space is a central tenet of bio-geographical research (Miller, 2010). Species Distribution Modelling (SDM) estimates the actual or potential geographic distribution of a species (Pearson 2010) based on the environmental conditions of sites of known occurrence (Phillips et al. 2006). Thus SDM quantifies correlation between environmental factors and distribution of species (Miller, 2010). Various group of algorithm like Ecological Niche Factor Analysis (Hirzel et al. 2002), Maximum Entropy (Phillips et al. 2006), Genetic algorithm (Stockwell and Peters 1999), Regression (Lehman et al. 2002, Elith et al. 2006) etc are used to model potential habitat. As such, these models help estimate direct relationship between occurrence of the species and environment, they have found practical utility in protected area management, reintroduction and conservation ecology.

An accurate estimate of the spatial distribution of the intended species is necessary for a conservation plan to be effective (Hernandez et al. 2006). With appropriate data and application at hand these models assist in identifying unknown distribution, determining sites of high candidacy for reintroduction, guiding additional surveys and informing selection and management of protected area (Graham et al. 2004). Although of their vast application these models may have higher risk of 'over predicting' range size of given species (Graham and Hijman 2006) as they are based on eco-geographic variables (EGV) and are unaware of species interaction or limited dispersal ability (Anderson et al. 2002, Guisian and Thuiller 2005). This error of commission can be controlled by use of regularization multiplier (parameter that focuses on how closely fitted the output distribution is), a feature present in Maxent (Phillips et al. 2006) not in other models, outperforming other models in modelling distribution.

Maximum Entropy (Maxent) is a machine learning technique using maximum entropy (distribution that is most spread or closest to uniform) to calculate probability of occurrence of the species (Phillips et al. 2006). It uses presence only occurrence data but utilizes environmental data for the entire study area to predict distribution. Using presence only modelling is usually more practical in the sense that presence only data are largely available while absence data are rare (Anderson et al. 2002) while also refraining from the problem of unreliability of absence records. Thus modelling techniques that require presence only data are valuable (Graham et al. 2004). Phillips et al. (2006), Elith et al. (2006), Hernandez et al. (2006) conducted various studies on distribution modelling for groups of species and concluded that Maxent was more efficient and exact to predict geographic distribution even with comparatively smaller data sets (Hernandez et al. 2006) for the species amongst other competitive models.

1.3 Species Introduction, Distribution and Threats

Monitor lizards (family Varanidae) are distinguished with its nearest allies; Family-Agamidae, on the basis of their long slender body, mobile head and a long neck. In Nepal two species of monitor lizards are found *viz. Varanus flavescens* and *Varanus bengalensis* The *Varanus flavescens* (Hardwick and Gray 1827) is commonly called as Golden Monitor, Yellow Monitor, or Short Toed Monitor Lizard.

The *Varanus flavescens* is a medium sized and stocky monitor lizard measured up to 90 cm in length (Visser 2004). It is light brown above with reddish hue while ventral surface is light yellowish (Shah and Tiwari 2004) (Photoplate: Photo “a”), but it shows a variation in colours (Auffenberg et al. 1987, Bennet 1995, Visser 2004) even within a single population and among adults of more or less equal size (Auffenberg et al. 1987). Fused light yellow transverse bars are always present on the body but their length and numbers varies (Auffenberg et al. 1987) while the background colour may be black rarely or black pigment may form reticulated pattern (Auffenberg et al. 1987; Visser 2004). Seasonally, individuals have a suffusion of brownish red to deep red mid-dorsally (Auffenberg et al. 1987) giving the dorsum a reddish hue (Bennet 1995, Shrestha 2001, Shah and Tiwari 2004, Visser 2004). Correlated with mating season, the coloration of both sexes becomes more intense during the monsoon season (Bennet 1995, Visser 2004), a feature not known in other monitor species (Visser 2004). The temporal stripe is black (Visser 2004). Compared with most monitors, body scales are large (Auffenberg et al. 1987, Visser 2004). Slit like nostrils are closer to the tip of the snout than to the eye (Visser 2004, Shah and Tiwari 2004). Skull is short, broad and relatively high while toes are short (Visser 2004). Nostrils being closer to snout than eye, toes of hind feet shorter, claws relatively straight and absence of black reticulated pattern differentiate it from Bengal Monitor Lizard *(Varanus bengalensis)*, the other monitor lizard from Nepal.

The Golden monitor Lizard is found south of Himalayas in Pakistan, India, Nepal and Bangladesh (Auffenberg et al. 1987, Bennet 1995, Shah and Tiwari 2004, Visser, 2004). The range of this species is restricted to Indo-Gangetic plains (Visser 2004). The prime habitat of the species is marshy land but is also found in small number in rice field, along coast, riverbanks (Visser 2004), forests and cultivated land (Shah and Tiwari 2004). In Nepal it is found mostly in the banks of Gandaki, Koshi, Karnali, and Mahakali rivers (Shrestha 2001).

Golden Monitor Lizard is a poorly known and considered to be one of the most endangered monitor lizards (Auffenberg et al. 1987, Bennet 1995). It has disappeared from parts of their historic ranges during the last century due conversion of swamps and marshes by mankind for agricultural purposes (Auffenberg et al. 1987). This factor appeared to be the most important factor causing depletion in the population of golden monitor in most parts of its range (Chakrborty and Chakrborty 1987). Conversion of marsh to paddy on massive scale throughout much of Indo-Gangetic plain plus natural long term trend of desertification of at least half of the range of this species and restriction of marshy areas to flood plains accounts for spotty distribution of the species (Auffenberg et al. 1987).

Use of its skin for making shoes, belts, purses etc. and for making local drum like musical instrument (Chapagain and Dhakal 2002) has made it vulnerable to the hunting. Oil from the monitor lizard is also used as medicine (Chakrborty and Chakrborty 1987). Use of its oil in traditional medicine in China has promoted its illegal trade from northern borders of Nepal (Chapagain and Dhakal 2002). It is listed in CITES in Appendix I (Chapagain and Dhakal 2002, Shah and Tiwari 2004). IUCN lists it as a Least Concern species (WCMC 1996). It is legally protected by the government of Nepal under Schedule 1 (Section 10) of the National Parks and Wildlife Conservation Act and banned illegal hunting and exporting its skin and other parts (Chapagain and Dhakal 2002, Shah and Tiwari 2004).

In this study, an attempt to study metapopulation behaviour and predict potential suitable habitat of Golden Monitor Lizard was made. The study concluded a patchy subpopulation type metapopulation and occupancy determined mainly by distance to settlement and distance to water. Potential suitable distribution map was produced and concluded a discontinuous distribution for the species, suitability increasing from east to central region and decreasing westwards.

1.4 Rationale

While most of the research work has been carried on large mammalian fauna, little attention has been given to study of other fauna though they are also important for smooth functioning of the ecosystem. Herpetofauna are little studied group resulting in lag of adequate data to assess the ecological and conservation status of any herpeto-fauna. Lack of enough baseline data for a species might make the enlistment of the species in any criteria of national or international threat status quite unscientific and might misplace them on unsuitable category. Further, indiscriminate use of their habitat, resources or even exploitation of the species leads to serious threats to their survival. Thus baseline data are essential for proper positioning of the species in the specific categories or even helpful for reviving such categories.

Subpopulation level declination of Golden Monitor Lizard as a synergistic effect of fragmentation, heavy use of pesticides and drying up of wetlands, prime habitat of the species is reported (Auffenberg et al. 1987, Khatiwada and Ghimire 2009). A study to predict potentially suitable habitat is important to evaluate priority areas for conservation of the Golden Monitor Lizard. Modelling of metapopulation dynamics can help to assess spatial structure of the subpopulation and effect of modelled covariates to the species. Considering these factors at regional and local level for conservation planning will help in a landscape based programme to be implicated for efficient conservation of most endangered monitor lizard from Asian mainland.

1.5 Objectives

The broad objectives of this study were to determine metapopulation dynamics of the Golden Monitor Lizard in Jagadishpur Reservoir and associated wetlands and predict distribution of the species within the country. The specific objectives were:

- To classify land cover types in the Jagadishpur and associated wetlands,
- To estimate recolonization and local extinction rate of Golden Monitor lizard in Jagadishpur and associated wetland and
- To predict the species distribution of Golden Monitor Lizard in Nepal Tarai.

1.6 Limitations of the study

- The study was limited to a period of two years.
- Logistic and resource limitations made the study to be confined in small area.

2. LITERATURE REVIEW

2.1 Theoretical Aspects on Metapopulation

Metapopulation was explicitly defined for the first time by Levins (1969) as local populations within heterogeneous landscapes characterized by local extinction and migration within patches. But the concept of oscillations in populations, frequent local extinctions and possibility of reestablishment of population within vacant sites was recognized by Andrewartha and Birch (1954; cited in Hanski and Simberloff 1997). Wright (1931, 1940 cited in Hanski and Simberloff 1997) recognized the significance of local extinction and recolonization for evolution of such spatially structured populations. Levins (1969) introduced a model to define rate of extinction and migration within heterogeneous environment of insect pest for efficient control strategy. This model was later known to be Classical Metapopulation Model, the first of such model which explained the role of local population dynamics under heterogeneous landscapes and presented important insights for relationship between space and such dynamics. Generalizations of models of local population to several local populations were extended later by Akçakaya (1994), Hanski et al. (1994), Thomas and Jones (1993), Kindvall (1996) and Hanski (1994a,b). These models have been classified into 3 basic types by Hanski (1997). Spatially Realistic Simulation models are group of models that generalize models of local dynamics to several local populations connected by migration, dynamics of each local population modeled separately (Hanski 1997) complemented with specific assumptions about migration and are linked with GIS based information about particular landscapes (Akçakaya 1994). State transition and Incidence Function Models or alternatively patch occupancy model are discrete time stochastic model.

Incidence function models (Hanski 1994a, b) are linear first order Markov Chain in which each habitat patch has constant transition probabilities between the states of being empty or occupied. Based on certain assumptions this class of modelling is mostly used for metapopulation studies. Shortcoming of these studies was that they were negatively biased to the non-detection because only detection does not mean the presence of species but non-detection may also indicate presence (Mackenzie et al. 2002). The estimation method presented by Mackenzie et al. (2003, 2006) does not require such assumption on population parameters and allows for direct estimation of recolonization and local extinction, dynamics of metapopulation.

2.2 Empirical Studies on Metapopulation

Due to its wide range of implication in conservation biology and genetics, metapopulation has found a large interest of population biologist from around the world and include a diverse area of study between many taxa and ecosystems. It has been described in a variety of ecosystems including marine ecosystems (Smedbol and Wroblewski 2002, Grimm et al. 2003), grasslands (Scheiman et al. 2007, Stoll et al. 2009), forest ecosystems (Verhayen et al 2004, Guiney et al. 2010) and micro-ecosystems (Gonzalez et al. 1998) and in a wide range of taxa such as plants (Snäll, Ehrlen and Rydin 2005), bush cricket (Kindvall 1996a, b), butterfly (Hanski 1994, Hanski et al. 2004), fish (Gotelli and Kelly 1993), amphibians (Marsh and Trenham 2001), skink (Cameron 2007), owl (Lahaye et al., 1994), birds (Padilla 2012), gnatcatcher (Akçakaya and Alwood 1991), field vole (Corne et al. 2001), pika (Moilanen 1999, Moilanen et al. 1998), Shrew (Janquiéry et al. 2008), kodkod (Acosta-Janett et al. 2003), lynx (Gaona et al.1998), cougar (Sweanor, Logan and Hornocker 2000) and cheetah (Hedrick 1996).

Recently dynamic site occupancy model (Mackenzie et al. 2003) is finding interest to model metapopulation dynamic rate for species with low detectability to estimate local extinction and recolonization rate. Mackenzie et al. (2003) introduced and used the model to predict dynamic occupancy rates for Northern Spotted Owl and Tiger Salamander as metapopulation parameters. Olson et al. (2005) used this dynamic rate to model the effect of an invasive owl on detection, occupancy, local extinction and recolonization of Northern Spotted Owl. The same study was then extended by Kroll et al. (2010) to include larger area and larger time frame. Hudson (2011) used dynamic site occupancy model to explain a dynamic state of a critically endangered Alaotran Gentle Lemur (*Hapalemur alaotrensis*) was largely determined by human impact over the habitat. Multistate occupancy dynamics have not been used for metapopulation studies in Nepal but single state static occupancy have been used for large carnivores like tiger (Karki 2011, Thapa 2012, Barber-Meyer et al. 2013) or leopard (Thapa 2011, Thapa 2012) to determine status of large carnivores (Thapa 2012) or effect on detection due to prey species (Thapa 2011) or impact of prey depletion and human disturbances upon large carnivores (Karki 2011).

2.3 Species Distribution Modelling: Approaches and Implications

Species Distribution Modeling (SDM) has been performed using two different broad modeling approaches: mechanistic approach and correlative approach (Pearson 2010). Mechanistic approach model incorporates environmental condition and physiological limiting mechanism of species (Chuine and Beaubien 2001, Pearson 2010) while correlative approach make use only of environmental conditions prevailing around presence and absence point or background value (Stockwell and Peters 1999, Lehman et al. 2002, Hirzel et al. 2002, Elith et al. 2006, Phillips et al. 2006).

A vast number of algorithms that perform correlative approach of SDM are made. These include Gower Metric (Carpenter et al 1993), Ecological Niche Factor Analysis (Hirzel et al. 2002), Maximum Entropy (Phillips et al. 2006), Genetic Algorithm (Stockwell and Peters 1999), Artificial Neural Network (Pearson et al. 2002) or regression (Lehman et al. 2002, Elith et al. 2006, Leathwick et al. 2006, Elith et al. 2007). Phillips et al (2006) compared Maximum Entropy (Program Maxent) and Genetic Algorithm (Program GARP), and concluded that both approaches provided reasonable estimates species range, Maxent presenting higher discrimination over GARP. Similarly Elith et al. (2006) compared 16 types of modelling method over large region and species, and concluded that Maxent was ranked higher over other methods for distribution modelling. Hernandez et al. (2006) compared four modelling methods for their efficiency to correctly predict distribution range for small sample size as low as five where Maxent outperformed other methods. Kumar and Stohlgren (2009) used Maxent for determining potential suitable habitat for a threatened tree species with small samples and obtained low omission rate and statistically significant result.

2.4 Golden Monitor Lizard: Excerpts from literature

A poorly studied species, the Golden Monitor lizard (*Varanus flavescens*) has found only few citations on its natural history, ecology or conservation measures. Minton (1966), Smith (1932), Swan and Leviton (1962), Auffenberg et al. (1987) reported the presence of the species in Bangladesh, India, Nepal and Pakistan. Auffenberg et al. (1987), in his comprehensive study of the species confirmed marshland as its prime habitat. The conversion of marshland to agricultural land had caused the species to colonize in human dominated ecosystems (Auffenberg et al. 1987, Bennet 1995, Visser 2004, Shah and Tiwari 2004). The density at suitable habitat was estimated to be 7.5 individuals per sq. km in Bangladesh (Khan 1988). Average length of 700 mm. (Auffenberg et al. 1987) is common though individual as long as 952 mm. (Ghimire 2012) is reported. They shelter in burrows, crevices of river bank or termite mould (Auffenberg et al. 1987) and seal the entrance of the burrow with earth plug (Bennet 1995).

Conversion of prime habitat into agricultural area depletes habitat quality of the species and poses a significant threat to the Golden Monitor lizards (Auffenberg et al. 1987, Khatiwada and Ghimire, 2009). Other threats identified were trade (Bennet 1995, Chakraworty and Chakraworty 1987), retaliatory killing (Khatiwada and Ghimire 2009, Ghimire 2012), poaching and heavy use of pesticides (Khatiwada and Ghimire 2009).

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

The study area extends between 24.60- 24.65°N and 83.04- 83.12°E, within Jayanagar Village Development Committee (VDC), Niglihawa VDC and Jahadi VDC of Kapilvastu district. Intensive study area of 40 square kilometres comprises of Jagadishpur Ramsar site, smaller lakes like Lambusagar and Niglihawa lake complex, Banganga River and its floodplains, and surrounding agricultural fields and tropical moist broad leaved forests. Ubiquity of human presence within the site demonstrated the dominance of human and depletion of much of the wetland ecosystem that prevailed during most of the history in the area (Fig. 3.1)

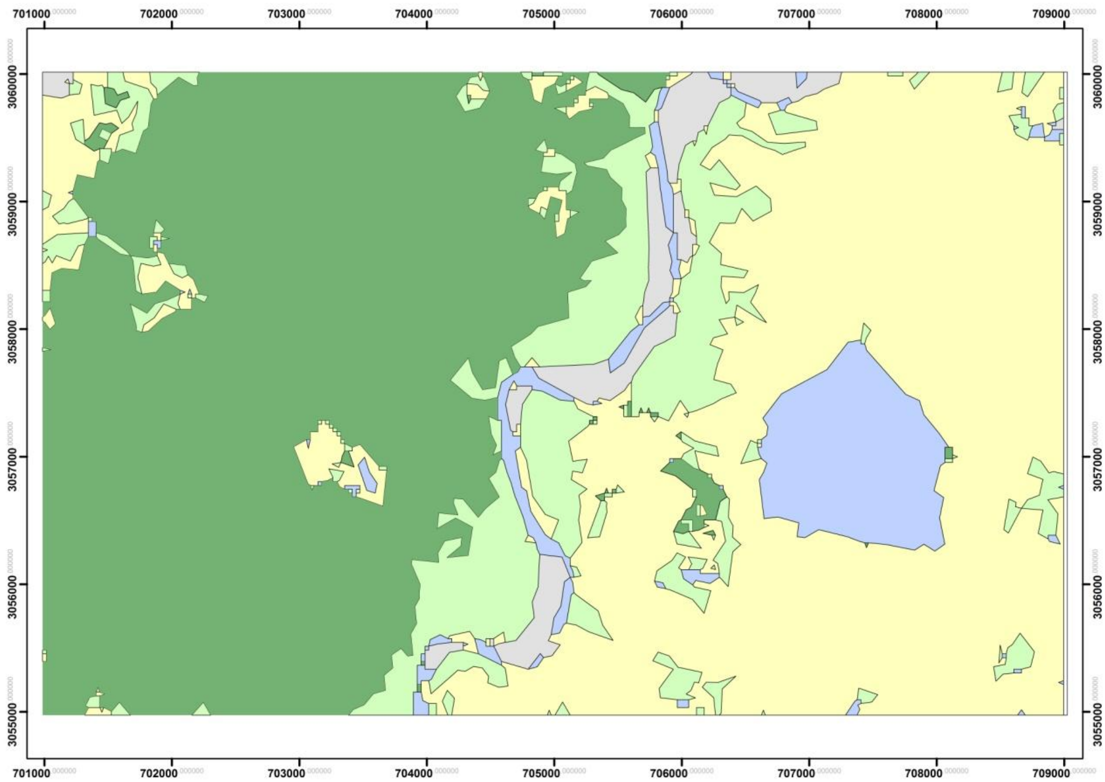

Fig. 3.1 Jagadishpur Reservoir and associated wetland.

3.1.2 Climate

Sub tropical climate prevails in the study area with three distinct seasons characterized by differences in precipitation, temperature and humidity occurring along time gradients across the year.

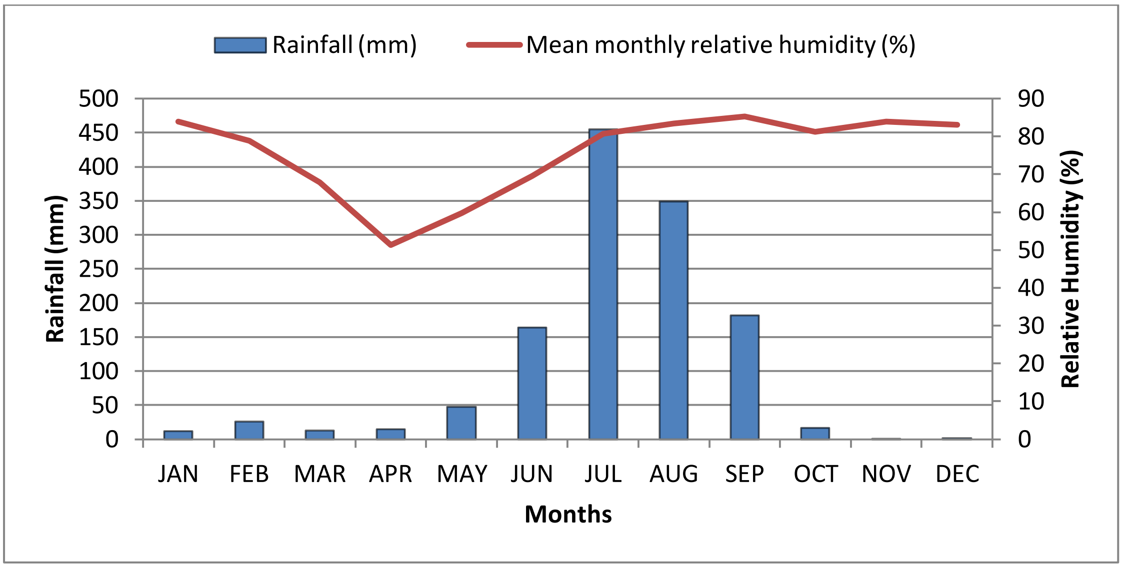

Fig. 3.2: Average Rainfall and humidity pattern for the study area from 2003-2012

Precipitation along with humidity had a major role in determining climate of the study area. Monsoon rain experienced during midyear (Fig. 3.2) differentiated the years into three distinct seasons: i) pre-monsoon dry season- humidity significantly reaching to its lowest and receiving slight rainfall due to western winds, ii) monsoon or rainy season; highly humid with high rainfall starting from May reaching its peak in July and decreasing conspicuously after September which marks the end of the season followed by iii) post monsoon season with very little precipitation and high humidity continuing till it is replaced by hot and dry season again.

While precipitation is major in determining season in the study area, temperature is also critical for defining climate of the area. Though mean maximum and minimum temperature changed insignificantly (Fig. 3.3) throughout most of the year, marked change in these variables can be seen. These changes mark the onset of summer and winter season with former starting from February, reaching a peak at April followed by a slow and steady fall up to October with another marked change, onset of winter season. Maximum temperature reaches its peak in dry summer season while both the maximum and minimum remains low during cold winters.

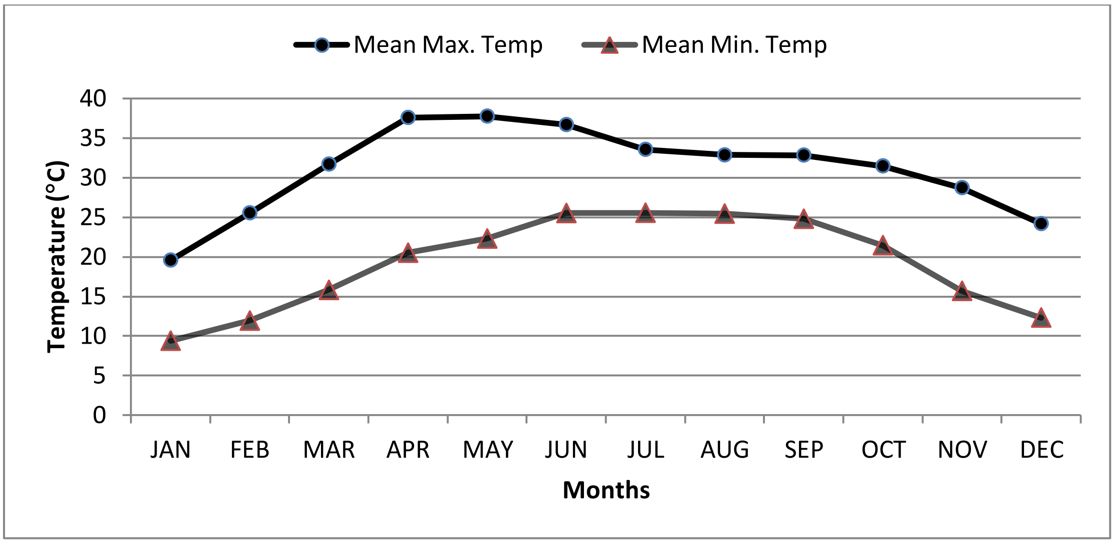

Fig. 3.3: Average maximum and minimum temperature for the study area from 2003-2012

3.1.3 Biodiversity

The vegetation in the lake is mainly in a submerged succession stage with patches of floating species and reed swamp formations. The terrestrial vegetation around is dominated by Sisoo (*Dalbergia sisoo)* and khair (*Acacia catechu)* along the dyke. The lake provides shelter for an assemblage of some rare species of plants, which include threatened Serpentine (*Rauvolfia serpentine)*, pondweed (*Potamogeton lucens)*, and lotus (*Nelumbo nucifera)* (Baral and Thapa 2008). Fauna include 6 species of mammals, 45 birds including protected Sarus Crane (*Grus antigone*), 9 herpeto-fauna including protected Golden Monitor Lizard (*Varanus flavescens*) and 18 fish species (Bhuju et al. 2007). Due to the assemblage of some rare, endangered, monogeneric plant species of genetic importance, aquatic macrophytes supporting feeding, rearing and staging of waterfowls, fishes and aquatic invertebrates and home for regionally vulnerable Ferriginous duck (*Aythya nyroca)* and regionally endangered Sarus crane *(Grus antigone)*, it has been designated as Ramsar site in 2003 (Siwakoti and Karki 2009). It is also highlighted in the Directory of Asian Wetland (Bhuju et al. 2007) and an important bird area (Baral and Inskipp 2005).

Forested area on the study site almost represents more than half of the area (Table 1). The forest is mostly contained of Sal (*Shorea robusta)*. Other species includes Khair (*Accacia katechu),* Sisoo *(Dalbergia sissoo),* Kapok *(Bombax ceiba*), etc. Faunal elements of the forest include Rhesus Macaque (*Maccaca mullata*), Hare (*Lepus nigricolis*), Nilgai *(Boselaphus tragocamelus),* Barking Deer *(Muntiacus vaginalis),* Common Leopard (*Panthera pardus)* etc (DDC 2003).

3.2 Methods

3.2.1 Reconnaissance Survey

A preliminary visit on April 2012 was done to be familiar with the site. During preliminary survey, interaction with locals and a field reconnaissance was done for recognition of land cover patterns and accessibility to the field.

3.2.2 Land-Cover Mapping

LANDSAT 5 TM satellite imagery of the year 2010 (glovis.usgs.org) was obtained and used to classify the land cover types. Image pre-processing and classification was done by spatial analysis software ERDAS IMAGINE 9.1 (Leica Geosystems) and final image preparation was done by ArcGIS 10 software (ESRI). The satellite image was geo-rectified with the spatial data obtained from topographic map. The image was then used for classification process. Classification scheme based on Anderson et al. (1976) was used for classifying land cover. Anderson et al. (1976) classified rangeland (coded as grassland in the study) as vegetation with predominantly grass, grass like plants, forbs or shrubs. In present study savannah like vegetation was also considered as grassland. Crown closure percentage of 10% or more was classified as forest. Water body were land masses persistently covered with water and wetland were area where water table is at the land surface for significant part of year. Area of thin soil, sand or rocks was classified as exposed area while land primarily used for food and fibre or small built up area was classified as agricultural and settlement area.

A combination of both unsupervised and supervised classification algorithm was used to classify the land feature types. Unsupervised classification with ISODATA (Iterative Self-organizing Data Analysis) was used for classification of 25 classes which were iterated 20 times with convergence threshold of 0.98. The classified land cover types were identified using topographic maps and field knowledge. Classes that are likely to be confused; agricultural areas, grassland, shrub land, and open forest areas, during unsupervised classification were removed by addition of known class features signature using AOI (Area of Interest) tool to signature file obtained during unsupervised classification. A supervised classification using Maximum Likelihood was rerun to delimit these classes. Thus obtained classes were given final classes. The classified image was smoothened using neighbourhood function (3x3 kernel) finally. UTM WGS 1984 projection was applied for final map preparation.

3.2.3 Occupancy Survey

3.2.3.1 Survey Design

Dynamic site occupancy model with associated detection probability (MacKenzie et al. 2002, 2003) was used to determine the site occupancy of the species for post-monsoon season of two years 2012 and 2013. For this study, entire area was divided into grids of 1 sq km. The grid size was slightly larger than estimated home range of the Golden Monitor Lizard (Guarino 2002). A total of 40 grids were surveyed to estimate the occupancy rate (Annex 1). Assuming the cost of the initial survey is equal to subsequent survey for estimated values of ψ and p, under standard design for occupancy modelling (MacKenzie & Royle 2005), the number of repeat survey at each site were 3 (Fig. 3.4). Repeat surveys were done on the same visit based on multiple subplots within the grid (MacKenzie et al. 2006).

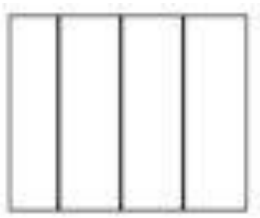

Fig. 3.4: Generalized transect-lay for survey in each grid

The rate of change in occupancy of two consecutive years was analyzed to estimate recolonization and extinction rate for the Golden Monitor Lizard. Covariates likely to affect occupancy and detection probability of species were introduced using a logistic model (Mackenzie et al. 2002) which were finally incorporated to site occupancy dynamics for estimation of local extinction and recolonization within the sites. The covariates used in the field were water condition, time of day, distance to water, distance to settlement and habitat type. For land cover and metapopulation modelling only Jagadishpur Reservoir and associated wetland of Nepal Tarai was surveyed.

3.2.3.2 Observation of Species

Time Constrained Search method (Corn and Bury, 1990) was used to observe the species. Active search of burrows within transects with sampling strip of 20 m along each side of transect was also done for indirect sightings of the species. Surveyors were made to move in the selected site at a constant speed of 2 km/hr looking at both sides for direct or indirect evidence (earthen plugged burrows) of presence or absence of species while also noting identified measurable covariates.

3.2.3 Species Distribution Modelling

The presence data of the species were collected through extensive survey in the study area. Presence data apart from this study were collected from literature review (Rai 2003, Khatiwada and Ghimire 2009, Ghimire 2012) covering east-west range of the country. A total of 50 geo-referenced presence points were available for the modelling. Environmental variables included six variables likely to affect distribution of the species were used for modelling. Of these variables four bioclimatic variables and altitude were generated by Worldclim (Hijmann et al., 2005 (www.worldclim.org)), land cover on Globcover-Ionia (ESA, 2008) (http://ionia1.esrin.esa.int/) and soil course volumetric fragment on ISRIC-WISE (ISRIC-World Soil Information 2013) (http://soilgrids1km.isric.org). These data were formatted by ArcGIS 10. Program Maxent which uses Maximum Entropy Algorithm for modelling distribution was used for data analysis.

Of the total presence data available 50% were used to build the model. These randomly generated points were recorded in file type as required by the software (.csv). Similarly, environmental layer in raster format were also extracted from the country's shapefile, resampled whenever necessary and converted to the format required which was finally imported to the software. The model was then run using default auto features (linear and quadratic). Regularization multiplier value was taken as 1.

Fifty percent of the data separated for model validation was also formatted in .csv file type and used in the analysis as testing model fit. Two type of model accuracy assessment was applied for validation of the model; discrete threshold (5, 10 and minimum presence value threshold) and continuous ROC curve.

Finally the output was classified into four habitat suitability categories as "Unsuitable or Poorly Suitable" (0-0.09), "Low" (0.1-0.39), "Medium" (0.4-0.59) and "High" (0.6-1) (Kumar and Stohlgren 2009). The Extent of Occupancy (EOO) as defined by IUCN (2001) was calculated using a threshold value of 0.5; above which the species is more likely to be present (Li et al. 1997, Manel et al. 1999). Areas for these parameters were calculated using Arc GIS 10.

3.2.4 Secondary Data

All the relevant journal papers, books, published and unpublished reports were also analyzed to present them in the thesis.

4. RESULTS

4.1 Land Cover Classes

Five general land use pattern were identified (Fig. 4.1; Table 4.1) which, after modification were used for generating habitat covariate for modelling procedure.

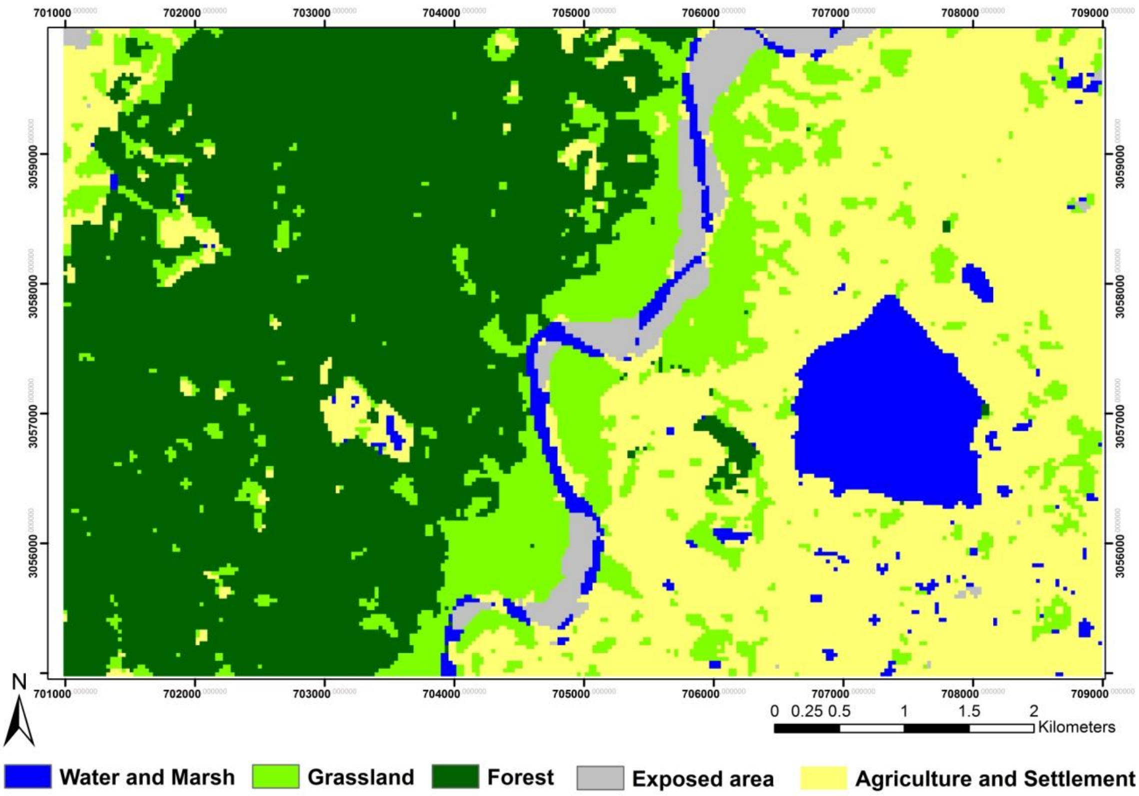

Fig.4.1: Classified Land-Cover types of Jagadishpur Reservoir and associated wetland.

While following basic classification scheme by Anderson et al. (1976), the class generated after final recoding showed “Forest” cover as largest land cover prevailing within the study area. It covered an area of 41.2% of the study site. “Agricultural land and Settlement” area was found to be second largest cover types covering 35.25% of the area surveyed. “Grassland” followed agricultural area covering 14.9%. “Large water body and marsh” and “Exposed Area” contributed very little to the cover owing to 6.2% and 3.1% respectively.

Table 4.1 Landcover Types identified in Jagadishpur Reservoir and associated wetland

Land Cover Type	Water and Marsh	Exposed Area	Grassland	Forest	Agricultural Area and Settlement	Total
Area (sq. km.)	2.50	1.24	5.99	16.5	14.05	40

4.2 Metapopulation Dynamics

4.2.1 Observation overview

A total survey effort of 235 km documented 19 direct observations and 13 indirect signs for the year 2012 and 2013 (Annex. 2). Total length surveyed for the first season was greater with higher observation while direct observation was greater in second season. The mean encounter rate for the species for both survey occasions was found to be 0.135 individual/km (Table 4.2).

Table 4.2: Summary of Observation for the species

Year	**Total Length Surveyed**	**Direct Observations**	**Indirect Observation**	**Encounter Rate (Individual/km)**
2012	120	9	9	0.15
2013	115	10	4	0.12

4.2.2 Metapopulation Structure and Parameter Estimates

Twelve final models were run to describe metapopulation behaviour of the species and to derive the estimates of metapopulation dynamics; probabilities of local extinction and recolonization rate and associated parameters; detection probability and occupancy. Model selection procedure (ΔAIC<2) considered the introduction of metapopulation dynamics parameters to weight more over than without them. Models with constant occupancy: ψ (.),p(.) , and seasonal change in occupancy without explicit introduction of metapopulation parameters: ψ (2012),p(.), had very little support owing to 0.6% and 0.3% of model weight and were ranked lower to models with dynamic occupancy and metapopulation dynamic parameters included. Similarly static occupancy models (Model weight=0.03%) performed low over dynamic occupancy models (Model weight= 99.97%). Detection was shown to be a function of measured covariates with a support for survey specific probabilities (Table 4.3).

Table 4.3: Summary Statistics for Model

Model	AIC	ΔAIC	AIC wgt	no. Par
ψ(2012,DS),γ(.),ε(.),p(water)	170.14	0	0.2652	7
ψ (2012,DS), γ (.),ε (.),p(survey,water)	171.49	1.35	0.135	12
ψ (2012,DS,DW), γ (.),ε (.),p(water)	171.62	1.48	0.1265	8
ψ (2012,DS), γ (.),ε (.),p(survey,time,water)	172.01	1.87	0.1041	13
ψ (2012,DS,DW), γ (.),ε (.),p(survey,habitat,water)	172.75	2.61	0.0719	15
ψ (2012,DS), γ (.),ε (.),p(habitat,water)	172.92	2.78	0.0661	9
ψ (2012,DS), γ (.),ε (.),p(survey,habitat,water)	172.98	2.84	0.0641	14
ψ (2012,DS,DW), γ (.),ε (.),p(survey,water)	173	2.86	0.0635	13
ψ (2012,DS,DW), γ (.),ε (.),p(survey,time,water)	173.29	3.15	0.0549	14
ψ (2012,DS,DW), γ (.),ε (.),p(habitat,water)	173.99	3.85	0.0387	10
ψ (2012), p(.)	177.52	7.38	0.0066	4
ψ (.),p(.)	178.93	8.79	0.0033	3

4.2.2.1 Detection Probability

Of all the model analyzed water condition was considered an important covariate to account for the detection probability for the species. Water condition had highest weight for all and top set of models (Table 4.4). The best model had only water condition as supporting covariate for detection while there was also little evidence to support that detection varied within each survey or time (Table 4.3). Top model showed that detection was negatively related to dry water condition (β=1.41) and water logged condition (β=-0.19).

4.2.2.2 Occupancy

Distance to settlement was considered as most important covariate to determine the occupancy of the species (Table 4.3). "Distance to Settlement" showed greater weight in determining occupancy of the species for top and all sets of model. A negative association (β=-0.9) was found for occupancy of the species and the distance to the settlement. 'Distance to water' was also found to be an important variable for determining occupancy of the species. Occupancy was positively related (β=0.41) to distance to large water sources.

Model averaged estimates for occupancy estimated a rise of 22% of the rate during second season over first season (Table 4.5).

Table 4.4: Support for each covariate in all models and the model sets used in model averaging (AIC<2). DW= Distance to Nearest Water Source, DS= Distance to Nearest Settlement)

	DW	DS	Habitat	Time	Water Condition
Detectability					
Top Set	-	-	0%	10%	63%
All Set	-	-	24%	16%	99%
Occupancy					
Top Set	13%	63%	-	-	-
All Set	36%	99%	-	-	-
Recolonization					
Top Set	-	-	-	-	-
All Set	-	-	-	-	-
Local Extinction					
Top Set	-	-	-	-	-
All Set	-	-	-	-	-

'-'indicates covariates were not modelled for the parameter.

4.2.2.3 Recolonization and Local Extinction

Model averaged estimates for population turnover rates showed higher rate of recolonization over local extinction (Table 4.5) thus presenting a higher rate of occupancy for the second season.

Table 4.5: Model averaged estimates of the parameters modelled from top models. (Figure in parenthesis denotes standard error)

Model	ΔAIC	W	ψ_1	ψ_2	p_{11}	p_{12}	p_{13}	p_{21}	p_{22}	p_{23}	γ	β
ψ(2012,DS),γ(.),ε(.),p(water)	0	0.2652	0.43 (0.17)	0.58 (0.19)	0.23 (0.10)	0.25 (0.12)	0.29 (0.11)	0.21 (0.12)	0.21 (0.11)	0.25 (0.11)	0.58 (0.25)	0.41 (0.31)
ψ (2012,DS), γ (.),ε(.),p(survey,water)	1.35	0.135	0.43 (0.21)	0.51 (0.20)	0.26 (0.17)	0.16 (0.12)	0.35 (0.19)	0.10 (0.10)	0.28 (0.19)	0.42 (0.22)	0.48 (0.24)	0.45 (0.23)
ψ (2012,DS,DW), γ (.),ε (.),p(water)	1.48	0.1265	0.42 (0.21)	0.57 (0.22)	0.24 (0.12)	0.25 (0.17)	0.30 (0.19)	0.21 (0.14)	0.21 (0.17)	0.25 (0.13)	0.57 (0.23)	0.44 (0.30)
ψ(2012,DS),γ(.),ε(.),p(survey,time,water)	1.87	0.1041	0.38 (0.25)	0.59 (0.3)	0.32 (0.18)	0.17 (0.11)	0.38 (0.16)	0.05 (0.12)	0.23 (0.17)	0.36 (0.23)	0.59 (0.34)	0.41 (0.37)
Model Averaged Estimate			0.27 (0.13)	0.33 (0.14)	0.16 (0.08)	0.14 (0.08)	0.20 (0.10)	0.10 (0.08)	0.14 (0.09)	0.19 (0.10)	0.35 (0.16)	0.27 (0.19)

4.3 Habitat Suitability Distribution

Potential habitat suitability distribution for the species was predicted for the species with available data and EGVs. Model validation performed on basis of discrete threshold value and continuous AUC under ROC showed close agreement with the output models.

Threshold values used to evaluate performance of the model were 5, 10 and minimum training presence. The model predicted potential suitable habitat with high success rate for all threshold 100% for 5, 91.7% for 10 and minimum training presence with statistically significant figures ($p<<<0.05$). The graph plotted against specific threshold and omission (Fig. 4.2) showed a closed agreement with expected value for any threshold explaining the model fit.

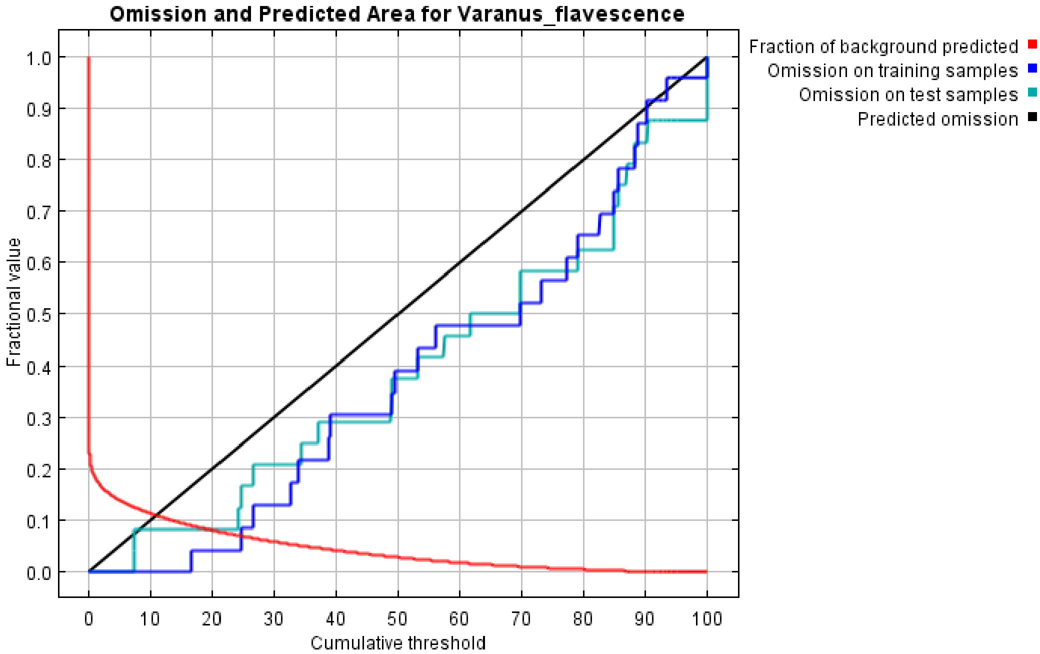

Fig. 4.2: Graph for omission against threshold values.

For AOC under ROC, sensitivity and 1-specificity were plotted against each other to assess the omission rate to predicted fractional area. Curves for both training (AUC=0.975) and test (AUC=0.970) (Fig. 4.3) reported model fit.

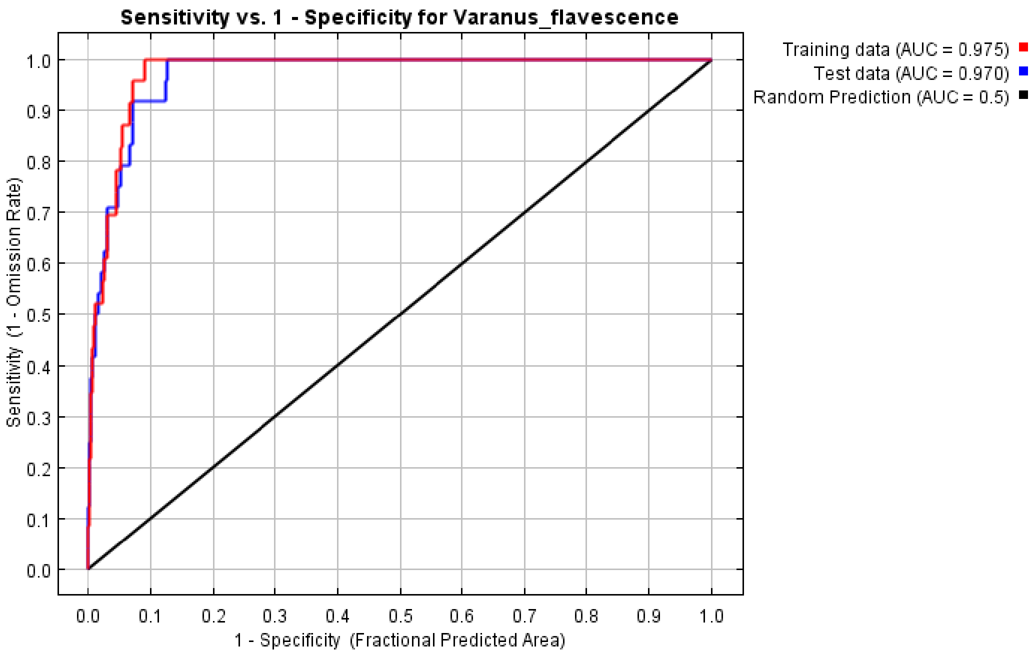

Fig. 4.3: AUC value for test and training data

The distribution of the species in the Tarai of Nepal was discontinuous (Fig. 4.4). A long and thin strip of moderate to highly suitable habitat existed in the eastern Tarai with patches of highly favoured regions. Central region covered mostly of highly suitable habitat. This consists of districts *viz*. Chitwan, Nawalparasi, Rupandehi and Kapilvastu. Rupandehi and Kapilvastu jointly represented largest continuous most suitable habitat for the species while eastern districts- Mahottari, Dhanusa and Jhapa also showed patches of highly suitable habitat. Apart from the Tarai region some mid-hill districts also showed a potentially suitable habitat along river valleys of these districts.

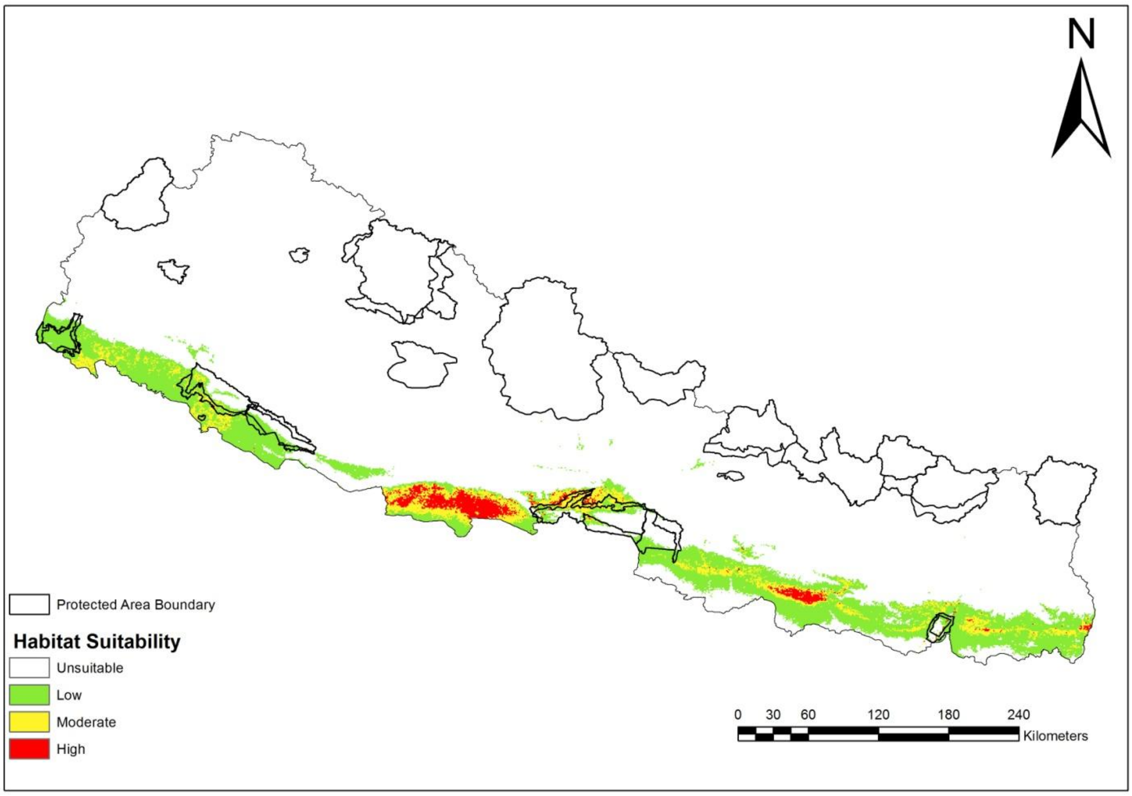

Fig. 4.4: Distribution of suitable habitats for Golden Monitor Lizard in Nepal Tarai.

The highly suitable, moderately suitable and poorly suitable areas were approximately 1703.25 km^2, 4767.98 km^2 and 16536.25 km^2 respectively. The extent of occupancy (EOO) with a threshold of 0.5 was found to be 3310 km^2.

Table 4.6: Percent Contribution of Environmental Variables in Distribution Modelling. (alt =altitude, bio1=annual mean temperature, cfv=coarse fragment volumetric, bio17=precipitation of driest quarter, bio16= Precipitation of wettest quarter, bio12= annual precipitation.

Environmental Variable	Percent contribution
alt	64.1
bio1	13.5
landcover	10.7
cfv	5.7
bio17	4.9
bio16	1.2
bio12	0

The Maxent model's internal jackknife test of variable importance showed that altitude and annual mean temperature to be the major environmental variables to describe the occurrence of the species (Table 4.6; Fig.4.5). The gain for the model without any variable was slight but the model showed high training gain when elevation and mean annual temperature were used singly.

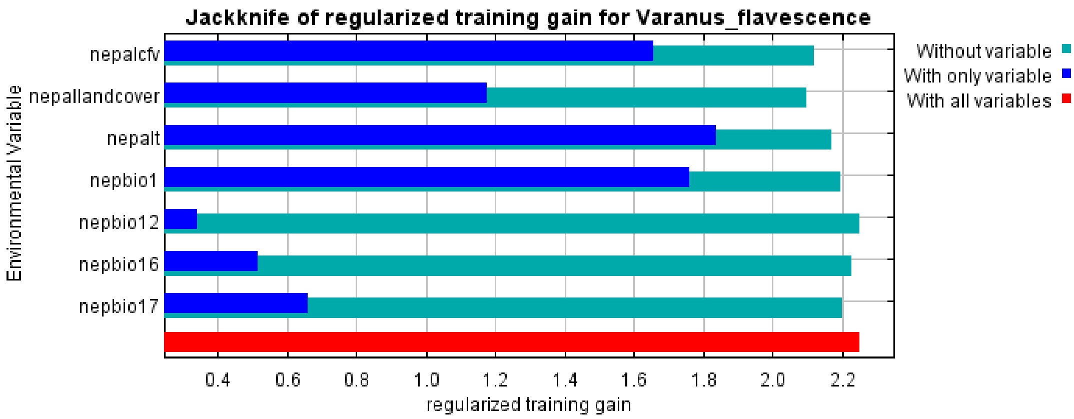

Fig. 4.5: Relative importance of predictor variables for *V. flavescens* determined by Maxent model (Jackknife Evaluation).

5. DISCUSSION

5.1 Land Cover Mapping

Landscape analysis has great importance in resource management application and conservation biology (Linkie et al. 2005, Wang et al. 2010). Use of remote sensing for inputs on landscape pattern analysis have provided practical means in landscape analysis (Wang et al. 2009) in terms of accuracy and cost effectiveness (Thapa and Lichtenenegger 2005). Landscape metrics derived from the remote sensing analysis has variously been used to explain species presence (Linkie et al. 2005), occupancy (Krishna et al. 2008, Hudson 2011), habitat suitability (Thapa and Lichtenenegger 2005, Thapa 2005) or habitat selection (Homer et al. 2003).

While attempts to derive landscape matrices from remotely sensed data to incorporate in model building for occupancy and detection probability was key objective of the study, an approach similar to Krishna et al. (2008) and Hudson (2011) for four- horned antelope and Alaotran gentle Lemur respectively, the result also presented a landcover map for the study area as an output. Time and inadequate knowledge prior to data collection constrained accuracy assessment of the model, nonetheless landscape metrics; habitat types, distance to settlement and distance to water source were time efficiently derived from remotely sensed data. Apart from lack of accuracy assessment, the classification of remotely sensed data might have been subjected to various errors like position error, thematic error, or uncertainty pertaining to class nomenclature (Shao and Wo 2008). These probable errors might have effected classification of habitat type within study area; as a result habitat type could not have been included in the final modelling procedure.

5.2 Metapopulation Dynamics

Metapopulation studies largely used Incidence Function, the probability that a species occupies a specific site or the expected fraction of similar sites that are occupied, to explain population turnover within spatially structured local populations with assumption of stationary Markov's Process (Hanski 1992; 1994a; 1997). However to infer dynamics from occupancy state (Mackenzie et al. 2003) is difficult as observed state of occupancy may be explained by processes other than recolonization or local extinction (Clinchy et al. 2002) or species may not always be detected when present (Mackenzie et al. 2002, 2003). This error was addressed by Mackenzie et al. (2003) to estimate these rates when detection probability were less than one and need not to assume a stationary process for estimating turnover rates instead could check the hypotheses about these rates. The present study also used the method to check the hypotheses about metapopulation dynamics through modelling procedure and found a metapopulation regulated subpopulations. Similar study on tiger salamander (*Ambystoma tigrinum*) concluded a static occupancy and hence a closed population within study area (Mackenzie et al. 2003). Other studies presented the probability rate of metapopulation dynamic to be affected by time; linear or quadratic (Mackenzie et al. 2003, Olson et al. 2005, Kroll et al. 2010) or competing species (Olson et al. 2005, Kroll et al. 2010) for Northern spotted owls (*Strix occidentalis caurina*) or human disturbance (Hudson 2011) for Alaotran gentle lemur (*Hapalemur alaotrensis*). Although attempts to model effects of selected covariates on dynamic rates failed in the present study for unknown reasons inclusion of these variables on modelling dynamic occupancy on the Golden Monitor Lizard (*Varanus flavescens*) to determine the impact of these factor may present important facets of metapopulation regulation for the species. The study presented a high population turnover probability rates for the Golden Monitor Lizard which can be explained either as classical metapopulation with high migration rate that is in the state of destabilization or patchy subpopulation type metapopulation where the process might have been produced by instability in habitat rather than local population itself. While Allen et al. (1993) argues that high migration rate within a population is a property of a destabilizing metapopulation but as prime habitat of the Golden Monitor Lizard is affected by seasonal drying up and monsoonal flooding (Auffenberg et al. 1987), these species may change their spatial distribution in response to changing nature of habitat without approaching a dynamic balance between turnover rates, feature of a species adapted to successional habitats (Harrison and Taylor 1997, Mayer et al. 2010).

Modelling occupancy with distance to water showed that the species is primarily associated with water and decreases in occupancy as distance to water increases. This result coincides with the conclusion made by Auffenberg et al. (1987) based on his observation. Therefore water can be an important predictor for distribution of the species. The study also revealed a negative correlation of Golden monitor lizard (*Varanus flavescens*) to human disturbances like settlement areas which concludes that the occupancy might decrease as distance to settlement increases. Distance to water being a limiting factor for the species and decreasing occupancy in relation to the human settlement and the fact that human encroachment upon wetland ecosystem has been increasing rapidly; these may induce significant threat for the wetland dependent species (Gibbs 2000, Bhandari 2009) like the Golden Monitor Lizard (*Varanus flavescens*). The study showed increase in the occupancy in 2013 and also higher rate of recolonization over local extinction. Because of relatively protected Ramsar listed Jagadishpur reservoir and assemblage of smaller lake complexes within the study area, the system would act as a potential source or a large migration to these patches from outside have occurred. While the present study can be considered as a baseline study for estimation of these parameters; a long term monitoring is so needed for concluding stability of the local subpopulation and effect of other measurable covariates on these dynamics using dynamic site occupancy (MacKenzie et al. 2006).

5.3 Habitat Suitability Distribution

Presence only modelling was performed to determine potential distribution map of the species. Program Maxent used for modelling uses presence data and background data for prediction of the model. Though not as robust as GLM or GAM, requiring greater study on regularization or can give very large suitable area as exponential model for probabilities are used, the program is widely used as it requires presence only data. It can utilize both continuous and categorical data and can be used for small number of training data (Hernandez et al. 2006, Phillips et al. 2006). Therefore it is widely used to model habitat suitability distribution.

The model with sufficient accuracy predicted the distribution of the species in Tarai and some river valleys in the mountains of Nepal. The distribution map was consistence with general distribution of species (Shah and Tiwari 2004). Auffenberg et al. (1987) included western part of Nepal as range for the species but eastern part was not included as a potential range for the species. In fact, the present study suggested that eastern part is more suitable than western part for the species. Because of its proximity to water source availability of flooded grassland as prime habitat (Auffenberg et al. 1987) plus high annual mean temperature, an important variable predicted by the model to determine its distribution, central Tarai districts showed high suitability. Except parts of Chitwan National Park's buffer zone, there is very little representation of suitable habitat within protected area (PA) systems of Nepal. Because of poor representation of the suitable habitat in PAs, the species can be vulnerable to extinction as its distribution outside the PA mostly lies in the human dominated agricultural landscapes which are deteriorating. While extending network of PAs within highly suitable habitat for Golden Monitor Lizard may not be applicable but strengthening community based or landscape level conservation program might prove effective for its conservation. A low Extent of Occurrence along with continued decline in quality of habitat (Auffenberg et al. 1987, Khatiwada and Ghimire 2009) and extreme fluctuation in subpopulation fulfills its position on being endangered nationally based on EOO less than 5,000 sq km, continuing decline observed in area and quality of habitat and extreme fluctuation in number of subpopulation [Criteria B1b(iii) and c(iii)] (IUCN 2001).

6. CONCLUSION AND RECOMMENDATION

This study presented some of the fundamental ecological information of neglected taxa while also identifying land cover from the study area. Threats to conservation were identified and conservation implication of the study for the species was discussed. These measures when applied might help conserve a less studied species.

The land use pattern around Jagadishpur Ramsar Site and associated wetland was identified. The identified land cover demonstrated that significant part of the surrounding area was covered by agricultural area and settlement inferring high human influence on the site. Forest represented largest area of the study area. The area represented patches of marshes intermingled within the agricultural lands indicating a good habitat for the species.

The models revealed the metapopulation regulated dynamic of Golden Monitor Lizard within the system. High migration rate within patches possibly represented a patchy subpopulation type metapopulation as response to shifting habitat in the area. Occupancy in the area was determined by human disturbance and distance to water. A positive relation between distance to water and negative relation with distance to settlement existed for the occupancy of the species. High human encroachment in Tarai wetland for agricultural and settlement purpose is likely to decrease occupancy of the species in future. Its detection was related to water condition, detection being highest in swampy area as more signs were easily detected in wet substratum.

Distribution modelling indicated very few suitable habitats for the species. Suitable habitat mostly occurred outside the network of protected areas. High human encroachment in these areas is prevalent which further worsens conservation issues within these landscapes. An increment in protected area network or enhanced protection through community involvement in conservation program is likely to succeed the conservation goal for the species.

Based on these issues, the following recommendations are put forward:

- Identification of subpopulations within recognized potential habitat and its fringes and underlying dynamic within them need to be determined.
- Long term monitoring of the metapopulation to determine the nature of these metapopulation within Jagadishpur reservoir using dynamic site occupancy model most applicably in post monsoon season is to be done.
- Community based conservation program at landscape level to sustain the population within human dominated landscapes to ensure co-existence of human and the species need to be put forward.
- Enlistment of the species in National Red Data List as “Endangered” category based on criteria B1b (iii) and c (iii) need to be implemented and
- Extending the network of protected area to include its potentially suitable habitat along national park boundary might be carried out to preserve the gene pool of the species.

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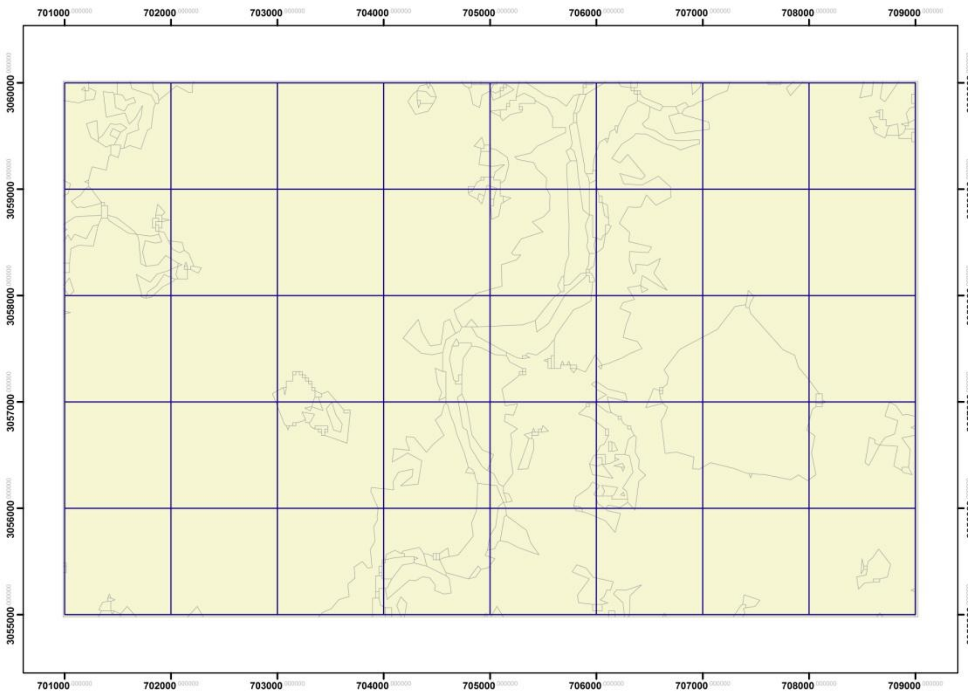
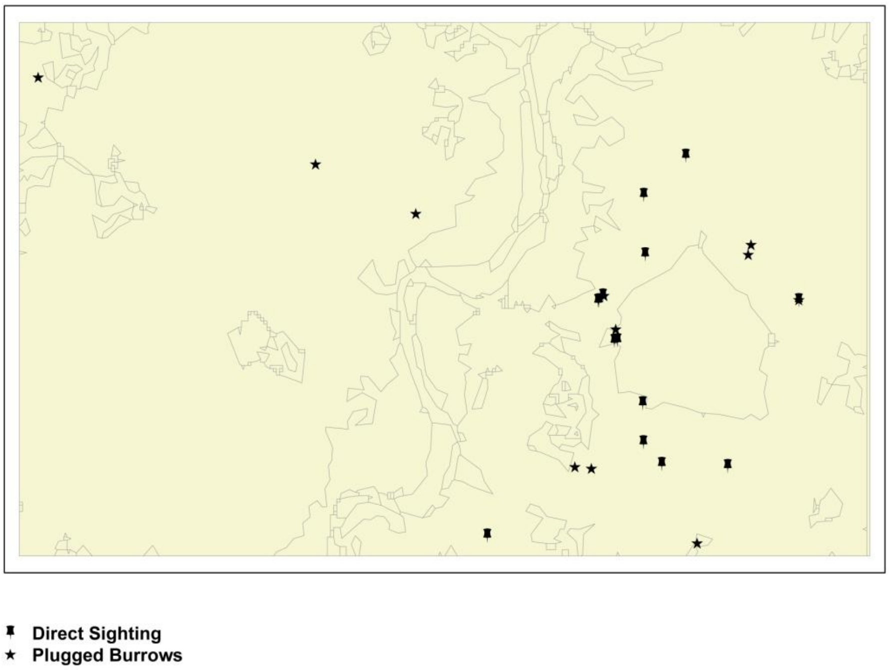
ANNEXURES

1. Surveyed Grids for Metapopulation Studies.



2. Presence Points of Golden Monitor Lizard.



PHOTOPLATES

a) Golden Monitor Lizard in paddy field

b) Indirect signs of Golden Monitor Lizard

c) Forest habitat

d) Swamp along Jagadishpur Lake

e) Earthen Plugged burrows

f) Prime habitat of Golden Monitor Lizard