Suitable Habitat of Yellow-Throated Marten *(Martes flavigula)* in Lower Sunkoshi River Basin, Nepal

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A thesis submitted in partial fulfilment of the requirements for the award of the degree of Master of Science in Zoology with special paper Ecology and Environment

Submitted to
Central Department of Zoology
Institute of Science and Technology
Tribhuvan University
Kirtipur, Kathmandu
Nepal

May 2023

DECLARATION

I hereby declare that this thesis work entitled **"Suitable Habitat of Yellow-Throated Marten (*Martes flavigula*) in Lower Sunkoshi River Basin, Nepal"** 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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RECOMMENDATION

This is to recommend that the thesis entitled **"Suitable Habitat of Yellow-Throated Marten (*Martes flavigula*) in Lower Sunkoshi River Basin, Nepal"** has been carried out by Smriti Shrestha for the partial fulfilment of the requirements for the award of the degree of Master 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 has not been submitted for any other degree in any institution.

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LETTER OF APPROVAL

On the recommendation of supervisor Associate Prof. Dr. Laxman Khanal, this thesis submitted by Smriti Shrestha entitled **"Suitable Habitat of Yellow-Throated Marten (*Martes flavigula*) in Lower Sunkoshi River Basin, Nepal"** is approved for the examination for the partial fulfilment of the requirements for the award of the degree of Master of Science in Zoology with special paper Ecology and Environment.

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CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Smriti Shrestha entitled **"Suitable Habitat of Yellow-Throated Marten (*Martes flavigula*) in Lower Sunkoshi River Basin, Nepal"** has been accepted as a partial fulfilment of the requirements for the award of the degree of Master of Science in Zoology with special paper Ecology and Environment.

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LIST OF ACRONYMS

ABG	Above Ground Biomass
AUC	Area Under Curve
DEM	Digital Elevation Model
SDM	Species Distribution Modelling
TSS	True Skill Statistics
YTM	Yellow-throated marten

ABSTRACT

Yellow-throated marten (*Martes flavigula*, order- carnivora, family- mustelidae) is a very adaptable medium sized carnivore that is widely distributed over northern eastern globe. Their diet and habitats are diverse. Despite its wide distribution and ecological importance, it is one of the least studied species. So, this study aimed to identify the distribution of yellow-throated marten (YTM), to predict its suitable habitat and to identify the important environmental variables for the prediction of its distribution in Lower Sunkoshi River Basin, central Nepal. Total area of the basin was divided into 190 grids of 3×3 km^2 each and a line transect survey was done to collect the species occurrence data. Two to three transects, each of about 1000 m were traversed in 26 selected grids. The total 72 (37 from indirect signs, 33 from interviewee and 2 from opportunistic sightings) occurrence points were recorded for the species in the study area. A total of 13 predictor variables and the 72 species occurrence points were used to run the species distribution model under maximum entropy (MaxEnt) algorithm with settings of bootstrapping 100 replicates, regularization multiplier of 1 and background points of 10000 points with threshold rule of Maximum training sensitivity plus specificity. The score of AUC was 0.967 indicating good performance of the model. A total of 430 km^2 (11%) area in the Lower Sunkoshi River Basin was found to be suitable habitat for the YTM. The predicted suitable habitat ranged between the elevation 428 m and 3027 m a.s.l. The model suggested that suitable habitat for the YTM lies in mosaic type of habitats that are mixture of shrubland, cropland and forests. The five of the most important predictors of YTM distribution were, maximum temperature of warmest month, slope, topographic wetness index, above ground biomass and isothermality. This study has identified the potential distribution areas and their major predictors for the YTM in the Lower Sunkoshi River Basin. However, future research using additional survey methods including camera traps for such cryptic species might provide more detailed distribution records and use of additional environmental variables and multiple algorithms for modeling the potential distribution might yield better predictions.

1. **INTRODUCTION**

1.1 Background

Yellow-throated marten (*Martes flavigula* Boddaert, 1785) is a medium sized carnivore belonging to the family Mustelidae in genus *Martes*. It can be distinguished by its peculiar body coloring consisting of lighter shade of orange and yellow anteriorly in the neck and dorsum, while more of darker brown or black posteriorly at the feet, tail and head (Mallick 2013). Its body and tail lengths are 400–600 mm and 380–430 mm respectively and weighs 3.4 kg having lifespan of 14 years. They mate in August and give birth in April (Lekhakun & McNeely 1977). There remain speculations over whether the animal is solitary or social due to lack of appropriate studies on ecology and behavior of the animal (Grassman et al. 2005). It had been considered as solitary but many studies have reported Yellow-throated martens in duo, trio and a small group (Harrison et al. 2004, Choi et al. 2011, Mallick 2013). Yellow-throated marten is considered as a crepuscular animal, viz active during dawn and dusk, though it has been addressed as a diurnal animal (Payne et al. 1985, Mallick 2013, Bu et al. 2016). They seem to be diurnal in an undisturbed forest and nocturnal in anthropogenic habitat. Being a very shy and cryptic nature, Yellow-throated marten seemed to avoid encounters with humans and less likely to tolerate human disturbances (Lee et al. 2017).

Yellow-throated marten is distributed only in the eastern northern hemisphere. It is widely distributed throughout Asia, from Indonesia in the south to far eastern Russia in the north. It is also found in Himalayas , Korean Peninsula, China, India, Vietnam, Taiwan other Malayan countries (Harrison et al. 2004, Proulx et al. 2005). Yellow-throated marten was recorded from 10 m a.s.l. in lowland peat swamp and mixed dipterocarp forest (Duckworth 1995) to 1452 m a.s.l. in Crocker Range, 1500 m a.s.l. in the Kelabit Highlands and 1700 m a.s.l. at Gunung Kinabalu (Payne et al. 1985), to 4510 m in alpine meadow in the Kanchenjunga CA (Appel et al. 2013). It is a semi-arboreal (Mathai et al. 2010), crepuscular mammal (Payne et al. 1985) feeding wide variety of items from plants to animals to carcass to waste. Its diet includes fruits, sap, flowers, honey, nectar, eggs, birds, invertebrates, small mammals, juvenile ungulates (Zhou et al. 2011, Mallick 2013). Occasionally they have been recorded as feeding on corpses (Pierce et al. 2014). This species is listed as ‘Least Concern’ globally

(Chutipong et al. 2016) while endangered or threatened nationally in some parts of its distribution. Its endangered in India. It is listed under Schedule II (Part II: 2–E) of the Indian Wildlife (Protection) Act 1972. It is protected in Malaysia, under Schedule 2 Part I of the Sabah Wildlife Enactment 1997. In Pakistan, it has been listed as data deficient (Sheikh & Molur 2005)

Species Distribution Modelling (SDMs) is used in biogeography, conservation biology, paleoecology, management ecology. Over the past decades it has been extensively used to explore the relationship between species occurrence to a set of predictor variable. Despite the widespread use of the models, there is still ongoing debates about the strength and limitations of these models (Araújo & Guisan 2006). Soberón & Peterson (2005) believe that these models provide approximation of the fundamental niche while some argue it to be spatial representation of the realized niche (Pearson et al. 2004). There are major two types of Species distribution modelling:- Correlative models and mechanistic models. Correlative models are based on the correlation of occurrence points and the set of environmental variables. Some common approaches of correlative modelling are machine learning (MaxEnt, Random forests), regression models (GLM and GAMs) and ensemble modelling (Dormann et al. 2012). Mechanistic Models on the other hand are based on the limits of species biological, physiological, ecological characteristics. Mechanistic models are biologically more realistic than correlative models as they incorporate the underlying biological processes. But they are more complex, data intensive and expensive (DeMarche et al. 2019).

Maxent is a widely used software for species distribution modelling that is based on the maximum entropy theory. Maximum entropy theory is a mathematical framework that aims to estimate probability distribution of a system based on given constrain (Xiao et al. 2015). In the species distribution modelling, the system is the given set of environment variable and the constraint is the known localities of the species occurrence. Maxent software can work on presence only data and it is robust to small sample sizes. Its strength lies in its ability to handle large set of environmental variables, model non-linear relationships, can handle both continuous and categorical variables simultaneously (Yaworsky et al. 2020). Maxent can provide highly accurate prediction of species distribution, but it does not necessarily provide information on ecological processes underlying the distribution. But its accuracy largely depend on the quality of the data (Merow et al. 2014). Species distribution modelling have wide range of application on ecology:- it can be used in conservation planning to prioritize certain area, in predicting the spread of the invasive species, to assess the impact of climate change on the species, habitat restoration by analyzing suitable habitat, in wildlife management and evolutionary biology (Franklin 2013)

Being one of the top predators, this species can act as a keystone species at places where there are no other predators, and having a large home range it can act as an Umbrella species (Choi et al. 2015). As it prefers to live in pristine forests, martens are regarded as an indicator of healthy forest ecosystems (Jo et al. 2018). The IUCN Red List of Threatened Species classifies the yellow-throated marten as Least Concern (IUCN 2016) and its distribution, population status, ecology, and behavior are poorly studied (Grassman et al. 2005). Despite being very adaptive, its population is declining in North-East Asia (Lee et al. 2021) due to poaching and in Korea, its status is designated as Endangered (Jo et al. 2018). It has been found that marten does not favor bare, disturbed areas and they are more forest oriented (Hon et al. 2016)and seemed unlikely to tolerate high anthropogenic disturbance (Belden et al. 2007). Habitat Fragmentation and road kills are the major cause of population declines in South Korea. Even though the population of the species is estimated to be stable, poaching for fur and habitat loss are the major threats to the species in Nepal (Jnawali et al. 2011) and relatively little is known about its distribution, ecology and behavior in Nepal (Lamichhane et al. 2014). So, the knowledge on Habitat and Distribution of this ecologically important species seems necessary.

1.2 Objectives of the study

The general objective of the study was to predict the suitable habitat for yellow-throated marten in the Lower Sunkoshi River Basin.

Specific objectives of the study were:

i) To identify the distribution of yellow-throated marten in Lower Sunkoshi River basin.
ii) To predict the current distribution of yellow-throated marten in Lower Sunkoshi River Basin.
iii) To identify important variables for prediction of distribution of yellow-throated marten in Lower Sunkoshi River Basin.

1.3 Significance of the study

The yellow-throated marten is the one of the least studied species in the world. There are merely two dozen studies worldwide. In Nepal there is only two papers of yellow-throated marten that too are short communications (Appel & Khatiwada 2014, Basnet & Rai 2020). In the face of climate change this species might be facing threats in the wild. That's why it is very important to have studies on the distribution and ecology of this species.

- This study fills the ecological knowledge gap in habitat and distribution of the species.
- Findings of the study can be used as a reference in future research.
- Study can be used in conservation and management of species in future.

2. LITERATURE REVIEW

2.1 Habitat of yellow-throated marten

The yellow-throated marten is capable of living in a diverse range of habitats, as observed in various studies. These include secondary forests, acacia plantations, forest mosaics, oil palm plantations, and along roads and trails (Payne et al. 1985, Azlan 2003, Grassman et al. 2005, Belden et al. 2007). The species is found in tropical, temperate, and boreal forests, particularly in areas where Rhododendron and Querques spp. are abundant. The marten has been observed in undisturbed hilly terrain, slopes, narrow river valleys, and along stream basins, both in primary forests and logged-off forests of various ages (Mathai et al. 2010, Wilting et al. 2010, Mallick 2013). It prefers broad-leaved forests of the 5th age class and coniferous forests over other mixed forests, and typically inhabits areas between 800-1400m with slopes less than 22 degrees. In addition, the marten is known to prefer forests within 600m of a mountain stream and at least 1400m from human disturbance (Lim et al. 2015). The species has been observed in various other habitats as well, including grassland with dry shrubs, mixed forests, hilly grassland, dense shrubbery, cropland, and among rocks (Khattak et al. 2022). The species utilizes a range of different locations for dens, including crevices in rocks, cavities in trees, spaces under root masses, burrows underground, old bird nests, squirrel nests, and logs (both hollow and solid). It also uses tree branches for shelter, typically found at some height above ground level in the forest canopy or in trees that have been uprooted or blown over (Mallick 2013).

2.2 Geographical distribution

In the 20th century, the yellow-throated marten was observed in various regions of India, including Darjeeling, Kurseong, Kalimpong, and Jalpaiguri, with recent sightings in Singalila and Neora Valley National Parks. However, its presence in southern Jalpaiguri is now very rare, and it may be locally extinct in Cooch (Bihar) (Choudhury 1999). A census conducted in the Darjeeling district in 2002 estimated the population of this species. The yellow-throated marten has also been spotted in the Chamba district of Himachal Pradesh, India, at different sites. In Borneo, the species has been observed over a wide range of elevations, including the lowlands and hills, Mount Kinabalu, the

Crocker Range, Sepilok, Tawau, the Kelabit Highlands, Samunsam, Gunung Palung in West Kalimantan, Kotawaringan in Central Kalimantan, Teluk Pamukan in South Kalimantan, and Peleben and Kayan Mentarang National Park in East Kalimantan, as reported by (Payne et al. 1985). They were recorded from the Kanchenjunga Conservation Area, was among the most frequently camera-trapped carnivores, from an elevation range of 3,252–4,510 m (Appel & Khatiwada 2014).

2.3 Diet of yellow-throated marten

It's diet consists of small mammals Soricomorpha, Sciurinae, Pteromyinae, Artiodactyla, Chiroptera, flying squirrels *(Petaurista spp.),* Irrawaddy squirrel *(Callosciurus pygerythrus lokroids)* and red panda *(Ailurus fulgens)* cubs, eggs, birds (Blood pheasant, *Tragopan satyr*, Himalayan monal, Kalij pheasant), reptiles, insects, fruits, smaller ungulates (Indian Goral *Naemorhedus goral*), primates, nectar, honey or even food waste (Pocock 1941, Payne et al. 1985, Parr & Duckworth 2007, Bahuguna & Mallick 2010, Zhou et al. 2011, Mallick 2013). They are reported to run down a Barking Deer (*Muntiacus vaginalis*) fawn (Wroughton 1916). They are seen consuming ripe fruits of *Rhododendron* spp, lick sap from the bark and nectar from the flowers, and Simul *(Bombax ceiba)* flowers, bees (Mallick 2013). Habituated individuals were observed eating cooked rice placed by people (Parr & Duckworth 2007). In western Thailand, the yellow-throated marten was seen feeding on a dead Red Muntjac *Muntiacus muntjac* inside the river (Pierce et al. 2014). Incident of killing of young muntjac by marten in Myanmar was reported (Pocock 1941). It was recorded chasing a muntjac in India too (Naniwadekar et al. 2013). Marten was also seen chasing Himalayan Tahr, Alpine Musk-deer and Himalayan Goral, but the outcome was not determined whether the chase resulted in predation or not (Sathyakumar 1999).

Studies have indicated that YTM is very adaptive in feeding habits. They can switch diet from small mammal to fruits or from fruits to small mammals according to the abundance of the food item. Moreover, they preferred fruits over mammals when both fruits and mammals are at peak abundance (Zhou et al. 2011). Their diet varies with the varying biogeography (Tsai 2007). They are very clever to eat the venomous insects in the season when they are less aggressive (Zhou et al. 2011). The YTM also has selectivity over some fruits. They prefer black, khaki and yellow fruits and sweet fruits. YTM ingestion and gut transition significantly enhanced the seed germination of some plants. Thus, yellow-throated marten act not only as a predator but also as fruit eater and seed dispersal (Zhou et al. 2011).

2.4 Behavior of yellow-throated marten

Martens are considered obligately solitary (Powell 1979, Zalewski & Jędrzejewski 2006, O'Mahony 2014). Several theories have been made regarding sociality of the YTM. It is believed that physiology of YTM restrict them to store large amount of fats which make them energy conservative and they are solitary to avoid the aggressive interactions which costs them energy (Newman et al. 2011). One observation particularly from Ramnagar, India, reported two YTMs co-operating to kill one adult rhesus monkey. Although YTM have been reported to hunt in pairs and tree (Lekagul & McNeely 1977, Sathyakumar 1999), due lack of enough studies the behavioral aspect of the marten is poorly understood (Grassman et al. 2005).

Yellow-throated marten mate during February to March or June to August and their gestation period lasts for 220 to 290 days. They give birth to their offspring, usually up to 3 kits, in April in the natal dens. Most mustelids exhibit delayed implantation due to the biochemical pleiotropy of oxytocin inhibition (Caldwell et al. 2009). They defecate in open spaces, stone wall and sandbanks. Scats of YTMs are black, elongated spiral strip tapering at one end, 8-9.2 cm in length, 1-1.5 cm in width, weight 2-8.3 g (Mallick 2013).

2.5 Ecological importance of yellow-throated marten

Carnivorous mammals being at the top of the food chain, play important role in ecosystem by controlling population size of prey. Mammals of carnivora have relatively low population density and wide home range. In South Korea, where other large sized carnivores have already disappeared, YTM plays very important role in the ecosystem. Very little is known about their ecology, while they are already listed as an endangered species (Lim et al. 2015). M. flavigula is considered to be an endangered species (Class II) by the Ministry of Environment of South Korea (Choi et al. 2015).

YTMs are threatened by loss of habitat, forest cover, poaching for pelt, hunting for meat (Mallick 2013). The ecology and behavior of yellow-throated martens have received less attention (Grassman et al. 2005). The diet of yellow-throated martens has received only superficial investigation and the food habits of yellow-throated marten in sub-tropical and tropical habitats where the fruits are abundant are not well known. There is need of an update on knowledge of socio-ecologies of marten (Twining & Mills 2021). YTM is also blamed for livestock depredation and have conflict with human so study of YTM is important from both conservation and management point of view.

3. MATERIALS AND METHODS

3.1 Study area

The Lower Sunkoshi basin is the lower parts of Sunkoshi Basin starting from the junction of Sunkoshi and Indrawati and ending at the junction of Sunkoshi and Tamakoshi. Its Geographical extent is from 27.683846°N, 85.428678°E to 27.722109°N, 85.545045°E. It occupies an area of 3888 km^2. The boundary of lower Sunkoshi basin includes parts of Kavrepalanchowk, Sindhupalanchwok, Sindhuli, Ramechhap and Dolakha Districts. Watershed runs its course in 18 Rural munipalities (**Figure 1**). The basin lies mostly at the middle hilly region in between Mahabharata Ranges. The basin consists of closed coniferous old forests at the Bethanchwok, diverse mixed forests, with moist evergreen forests and coniferous forests in parts of Panchkhal and Mudhe to drier and more barren type of environment in Sunkoshi, Roshi and Khadadhevi. Development wise Kavre part of the basin is more developed and urbanized while eastern parts are remote. The elevation range of the study area is 428–3027 m (**Figure 1**).

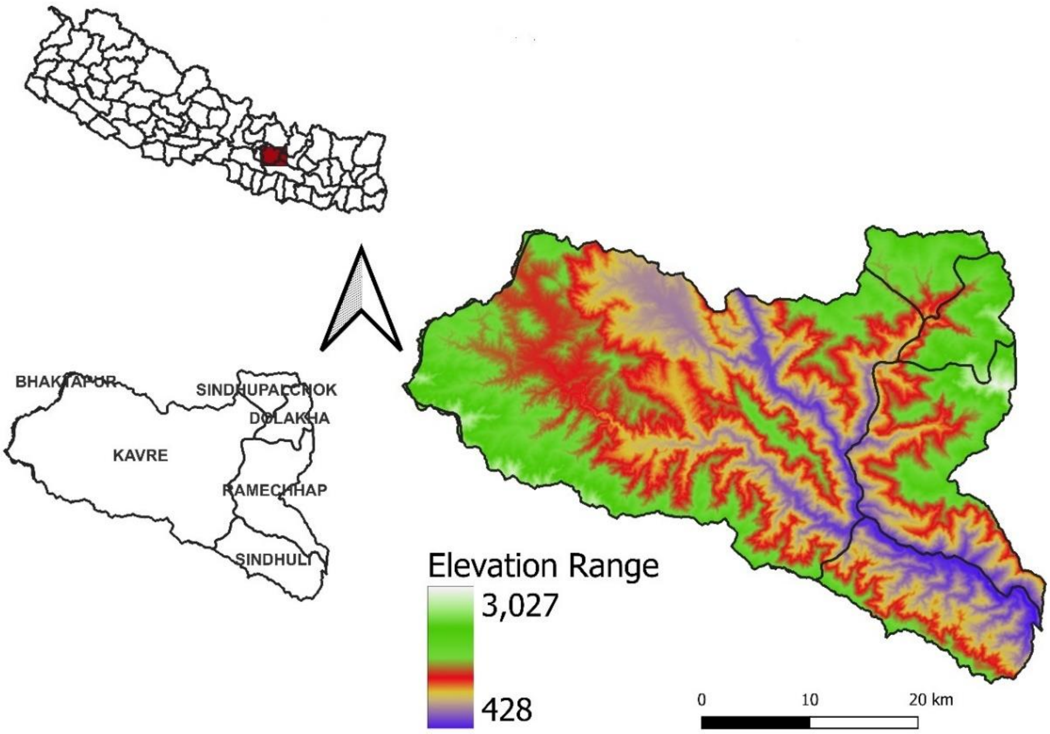

Figure 1. Map of Lower Sunkoshi River Basin

3.2 Data collection

3.2.1 Materials used

- Garmin eTrex 10 GPS
- Range finder
- Hygrometer

3.2.2 Species occurrence data

The study area was divided into 190 girds of 3*3 km^2. Out of which, a total of 26 grids were surveyed by line transect method. Simple random clustered sampling was the grid selection method (**Figure 3**). Two–three transects of ~1km length was traversed in those grids. The sign survey was conducted collecting the co-ordinates of location of feces, pugmark, visual encounter and other signs of the marten. Additional environmental data viz, Canopy Cover, Vegetation type, Landcover, Temperature, Humidity of the location was also collected. Opportunistic interviews were done with the local people to gain the information of presence of species. These interviews were done with the local guide who went for survey and the data of locations were reliable. The feces and pugmark of yellow-throated marten was identified by using, published research paper, books and confirmed by local people (Novikov 1962, Zhou et al. 2008, Choi et al. 2015) The feces of yellow-throated marten can be easily identified by its distinctive black color, black, elongated spiral strip tapering at one end, 8-9.2 cm in length, 1-1.5 cm in width (Mallick 2013). The survey was done in Bethanchwok Rural Municipality, Panchkhal Municipality and Roshi Rural Municipality of Kavrepalanchwok, Sunkoshi Rural Municipality of Sindhuli, Khadadevi Rural Municipaltity of Ramechhap and Lisankhu Pakhar Rural Municipality of Sindhupalchwok (**Figure 3**).

3.2.3 Predictor variables

Various predictor variable from three categories viz, Bioclimatic, Environmental and Topographic variables are acquired from various online databases. Nineteen bioclimatic variables and one topographic variable which is elevation was downloaded from online data base Worldclim (**Table 1**). These bioclimatic variables are based on interaction between atmosphere and biosphere, that define the physiological limits of plants and animals. A total of seven environmental variables were acquired out of which three environmental variables, viz, Above Ground Biomass, Human footprint and Tree canopy cover were downloaded and other variables, Distance to stream, Cropland, Conifer forests and broadleaved forests are made extracted from DEM map and Landcover map of Nepal. All the topographic variables except Elevation, Aspect, Slope, Topographic Wetness Index are extracted from DEM map of Nepal (**Table 1).**

Table 1. Sources of all the variables used in species distribution models.

Categories	Predictor Variables	Spatial Scale	Data Format (Resolution)	Source
Environmental Variables	Above Ground Biomass (AGB)	Nepal	Tiff (30*30 m^2)	(ICIMOD 2015) http://rds.icimod.org/Home/DataDetail?metadataId=23172
	Human Footprint	Global	Tiff (~1 km^2)	(Venter et al. 2016,2018) https://sedac.ciesin.columbia.edu/data/set/wildareas-v3-2009-human-footprint
	Distance to Water Resources (Disttostream)	Basin	Tiff (1 km^2)	Made from DEM map, using QGIS, '*proximity*' tool.
	Tree Canopy Cover (Treecancover)	Regional Granule	Tiff (< 1*1 m^2)	(Hansen et al. 2013) https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.6.html
	Cropland	Nepal	Tiff (30*30 m^2)	Extracted from Landcover map of Nepal (FRTC 2022). https://doi.org/10.26066/RDS.1972729
	Broadleaved Forest	Global	Tiff (300*300 m^2)	Extracted from GlobCover 2009 map (ESA 2010). http://due.esrin.esa.int/page_globcover.php
	Coniferous Forest	Global	Tiff (300*300 m^2)	Extracted from GlobCover 2009 map (ESA 2010). http://due.esrin.esa.int/page_globcover.php

Topographic Variables	Elevation	Global	Tiff (~1*1km^2)	(Fick & Hijmans 2017) https://www.worldclim.org/data/worldclim21.html
	Slope	Basin	Tiff (1*1km^2)	Calculated from DEM map, using QGIS using '*slope*' tool.
	Aspect	Basin	Tiff (1*1km^2)	Calculated from DEM map, using QGIS using '*aspect*' tool.
	Topographic Wetness Index(TWI1)	Basin	Tiff (1*1km^2)	Calculated from DEM map, using QGIS using '*raster calculator*' tool.
Bioclimatic Variables	19 Bioclimatic Variables	Global	Tiff (~1 km^2)	(Fick & Hijmans 2017) https://www.worldclim.org/data/worldclim21.html

3.3 Data analysis

3.3.1 Final variable selection

First of all, maxent was run with auto features using all the variables to test the jackknife test. Then Pearson's Correlation test was done between all continuous variables to remove multicollinear variables (**Figure 2**). According to Jackknife test, Bio5 and AGB were the top two important variables were selected first and all the variables (Bio1, Bio4, Bio6, Bio7, Bio8, Bio9, Bio10, Bio11, Tree Canopy Cover) that have correlation coefficient higher then ($r > 0.7$) with Bio5 and AGB were removed from the second run. And then from the remaining bioclimatic variables Bio2 and Bio3 have highest importance and they were selected. Then Bio18 was selected and all the correlated variables (Bio12, Bio13, Bio15, and Bio16) were removed. Then Bio19, Bio17 and Aspect were removed as it had lowest test gain (**Figure 2**).

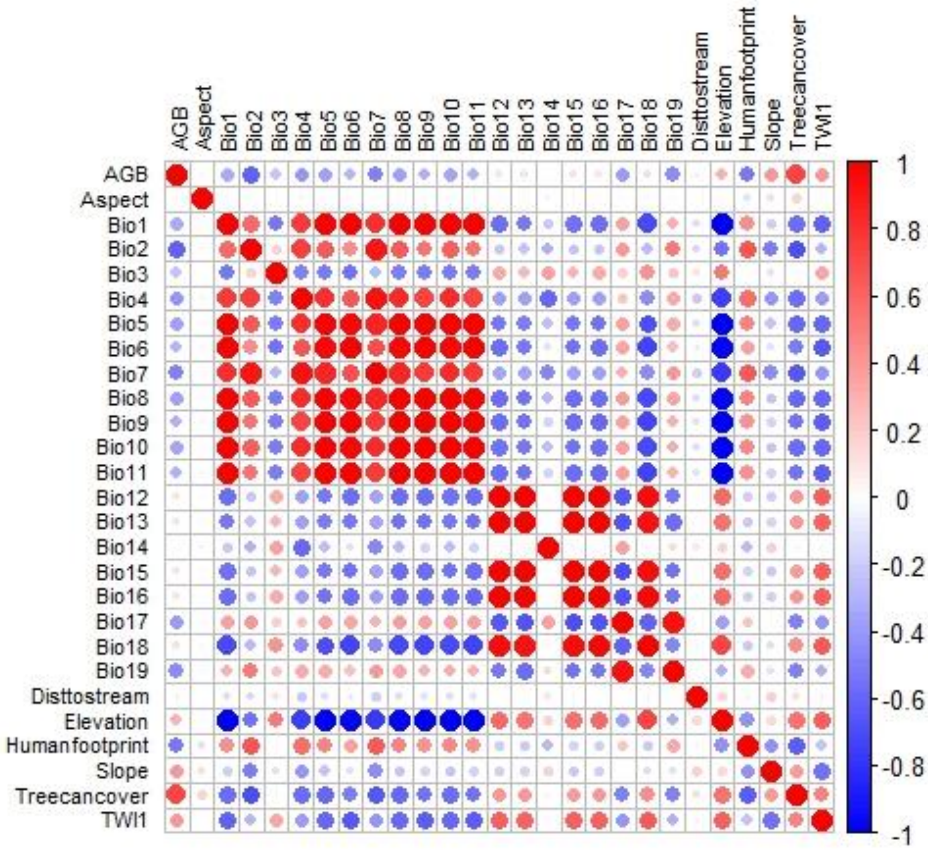

Figure 2. Correlogram between predictor variables.

Table 2. Final selected variables used for predicting the distribution of yellow-throated marten

S. No.	Categories	Predictor variables	Data type
1	Environmental variables	Above Ground Biomass (AGB)	Continuous
		Human Footprint	Continuous
		Distance to Water Resources	Continuous
		Cropland	Categorical
		Broadleaved Forest	Categorical
		Coniferous Forest	Categorical
2	Topographic variables	Slope	Continuous
		Topographic Wetness Index (TWI)	Continuous
3	Bio-climatic variables	Bio5 (Max. temperature of warmest month)	Continuous
		Bio2 (Mean diurnal range)	
		Bio3 (Isothermality)	
		Bio14 (Precipitation of driest month)	
		Bio18 (Precipitation of warmest quarter)	

3.3.2 Data and bias file preparation

Environmental variables such as cropland, broadleaf forest and coniferous forest was extracted as binary map from the Landcover maps using '*raster calculator*' tool of QGIS ver. 3.28.3. Distance to water resources was made by using '*fill', 'channel' and* 'proximity' tool of QGIs. Topographic variables were extracted from DEM raster map of Nepal using QGIS (QGIS 2022). All the selected predictor variables (**Table 2**), were prepared at 1*1 km^2 spatial resolution in Nepal-Nagarkot TM projection system in 'R' software using '*raster*' package. The bias file was made to address the sampling bias. The method of making bias file, is Kernel Density Estimation method by using '*mass*' package of 'R' software (Elith et al. 2010).

3.3.3 Final MaxEnt run and model selection

Maxent software was used to run final maxent run with bootstrap option, with 100 replicates in 25 percent of random test percentage settings on auto feature. The threshold rule was set as Maximum training sensitivity plus specificity with convergence threshold of 0.00001. The maximum number of background points used was 10000. And regularization multiplier was set as '1' and bias file was also incorporated. After the final run, the '*average.asc*' file was used to make probability map and a binary map with threshold of 0.216 as suggested by maximum training sensitivity plus specificity. Model evaluation was done by using AUC (Area under the receiver operating characteristic (ROC)) and TSS (True Skill Statistics).

4. RESULTS

4.1 Observed distribution of yellow-throated marten

Out of 26 surveyed grids, 22 grids have presence of yellow-throated marten. A total occurrence points were 72, (37 from indirect signs, 33 from interviewee and 2 from opportunistic sightings. Yellow-throated marten was observed to be present at almost all of the surveyed grids (**Figure 3**). Signs of yellow-throated marten were recorded from Panchkhal Municipality, Bethanchwok Rural Municipality and Roshi Rural Municipality of Kavrepalanchwok District, Sunkoshi Rural Municipality of Sindhuli District, Khadadevi Rural Municipality and Sunapati Rural Municipality of Ramechhap District and Lisankhu Pakhar Municipality of Sindhupalchwok District (**Figure 3**).

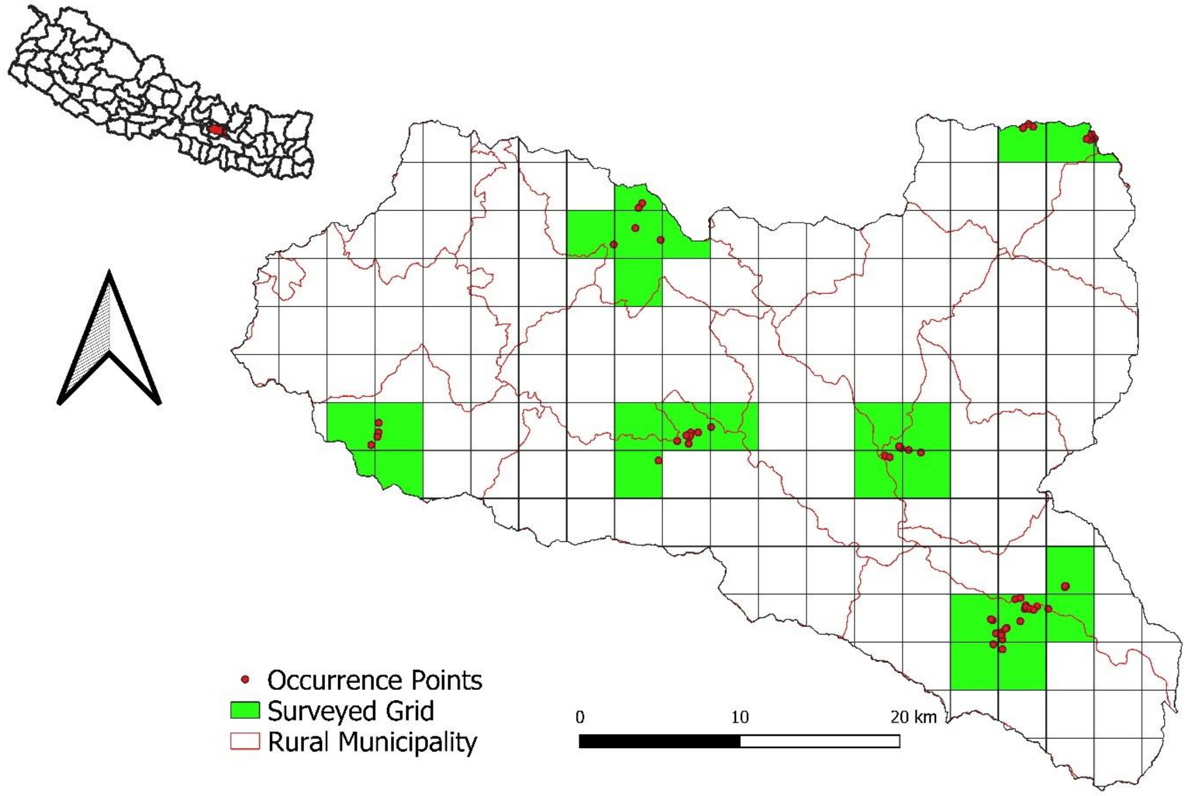

Figure 3. Observed Distribution of Yellow-throated marten in Lower Sunkoshi River Basin

4.2 Predicted distribution of yellow-throated marten

4.2.1 Model evaluation

Habitat suitability map were produced by using model. The model was evaluated using two metrics, AUC (Area under the receiver operating characteristic (ROC)) and TSS (True Skill Statistics). The Mean AUC value of the model was 0.948 (**Figure 4**), and the score of TSS was 0.632, which indicates the performance of the model was good.

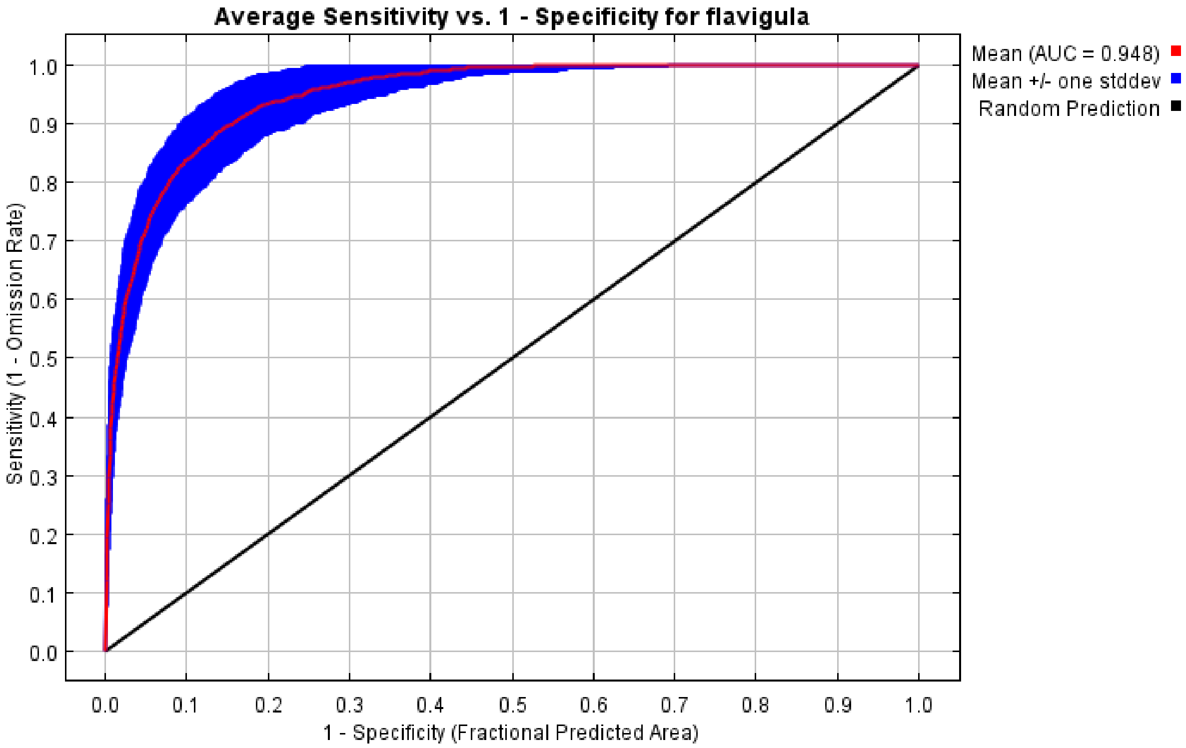

Figure 4. The average area under the receiver operating characteristic (ROC) the curve

4.2.2 Predicted suitable habitat for yellow-throated marten

The total potential suitable habitat occupies the area of 430 km^2 which is 11% of the total study area (**Figure 6**). Model predicted the highly suitable habitat of yellow-thraoted maten lies in Hokse forest, Baluwa, Devbhumi, Tamaghat, Kharbesi, Dhanadevi forest of Panchkhal rural municipality, Devisthan forest of Banepa municipality, Dhungkharka, Kalapani Community forests of Bethanchwok rural munipality, Kalate, Bhumlu of Bhumlu rural municipality, Saramthali of Temal rural municipality, Dorje danda, Simle of Sunapati rural municipality, Kholakhraka, sailungeshwori forests, Khorepani of Doramba rural municipality, Attarpur, Nigale bazar of Lisankhu rural municipality, Bhimkhuri, Mamti Bazar, Mangaltar of Roshi rural municipality, Kusheshwor Dumja, Mainapur, Jhangajholi, Ratamata, Bohoretar of Sunkoshi rural municipality and Sitkha, Bhirpani of Khadadevi rural municipality (**Figure 5**).

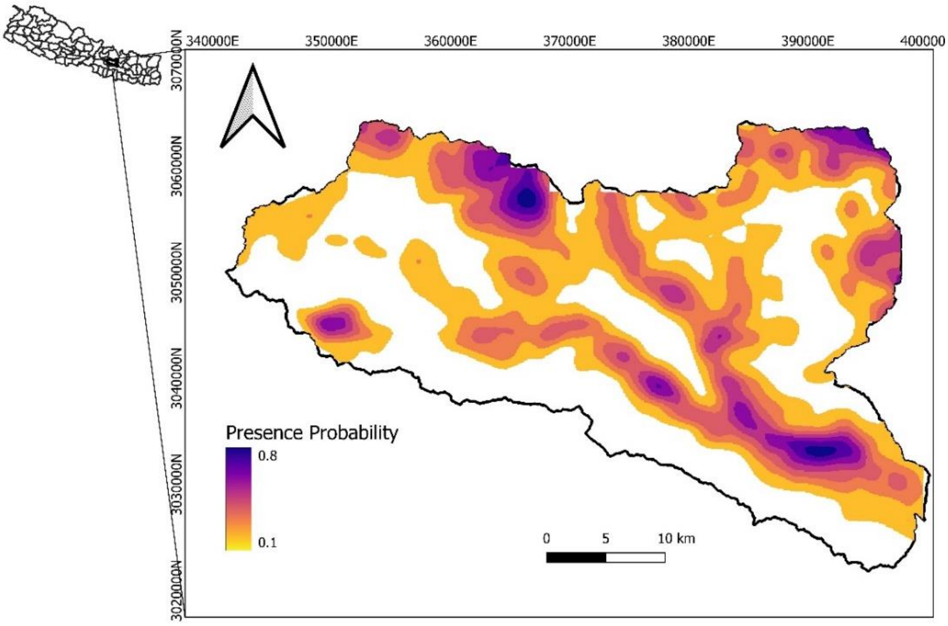

Figure 5. Habitat suitability map of yellow-throated marten in Sunkoshi River Basin showing the presence probabilities.

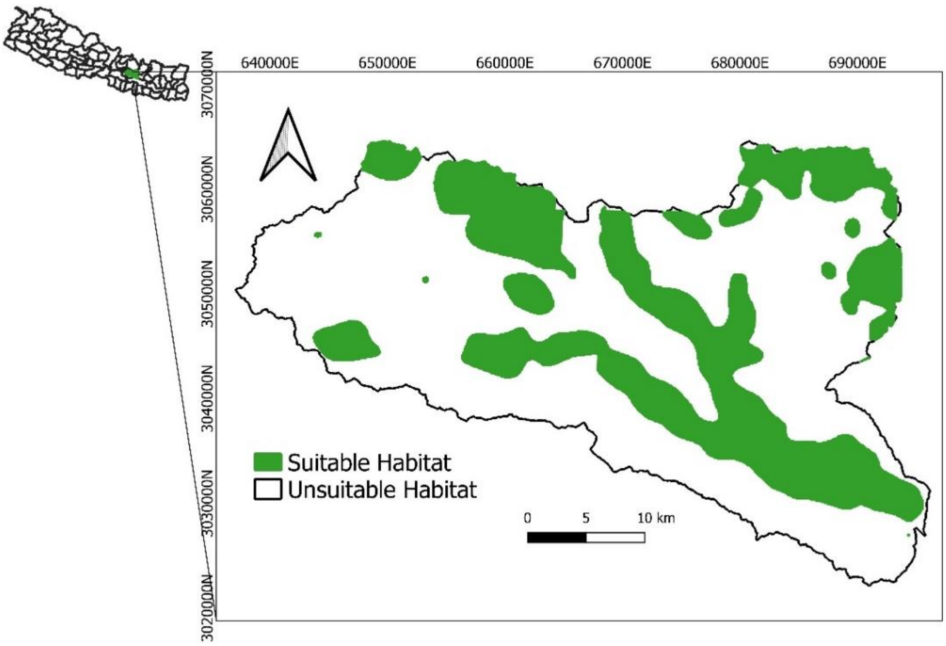

Figure 6. Classified habitat suitability map for yellow-throated marten in Lower Sunkoshi River Basin.

Elevation and landcover wise distribution

The potential suitable habitat was found to lie in all ranges of elevation in the study area. Approximately 47.44% of the suitable habitat lies below 1000 m, 37.20% of the suitable habitat lies from 1000 m to 2000 m and 14.65% of suitable habitat lies from 2000 m to 3000m (**Figure 7**).

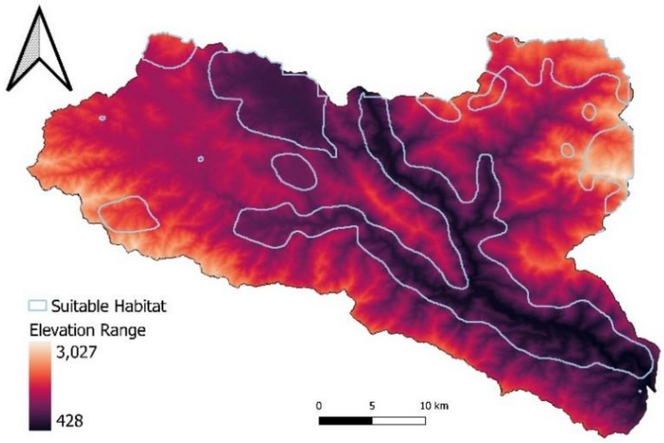

Figure 7. Elevation wise distribution of the YTM in lower Sunkoshi River Basin

The potential suitable habitat mostly lies on cropland and mosaic habitat. These mosaic habitats consist of mixture of shrubland, grassland, forest and cropland. 42% of suitable habitat lies on mosaic habitat and 43% of the potential suitable habitat lies at the cropland area and 15 % of the suitable habitats lies at the forests (**Figure 8**).

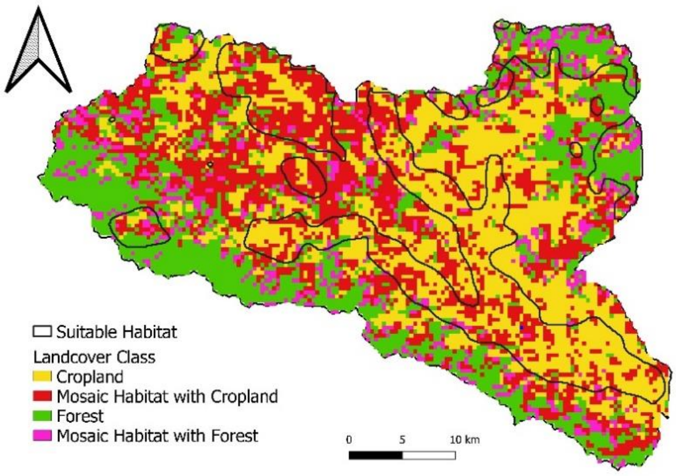

Figure 8. Landcover wise distribution of the YTM in lower Sunkoshi River Basin

4.2.3 Important variables for the distribution prediction of yellow-throated marten

The Jackknife test revealed the most important variable as Bio5 which is maximum temperature of warmest month, as it gained the highest training in model while it was only variable used. The second and third most important variables were slope and TWI (Topographic wetness index) respectively (**Figure 9**). Similarly, the above ground biomass (AGB) was the fourth most important variable in the prediction of distribution of marten. Likewise, Bio2, Bio3, Distance to stream and Human footprint were among other important variables to predict presence of marten. Among the vegetation type, coniferous forest seems to be more important than other two vegetation type viz, broadleaved and cropland (**Figure 9**).

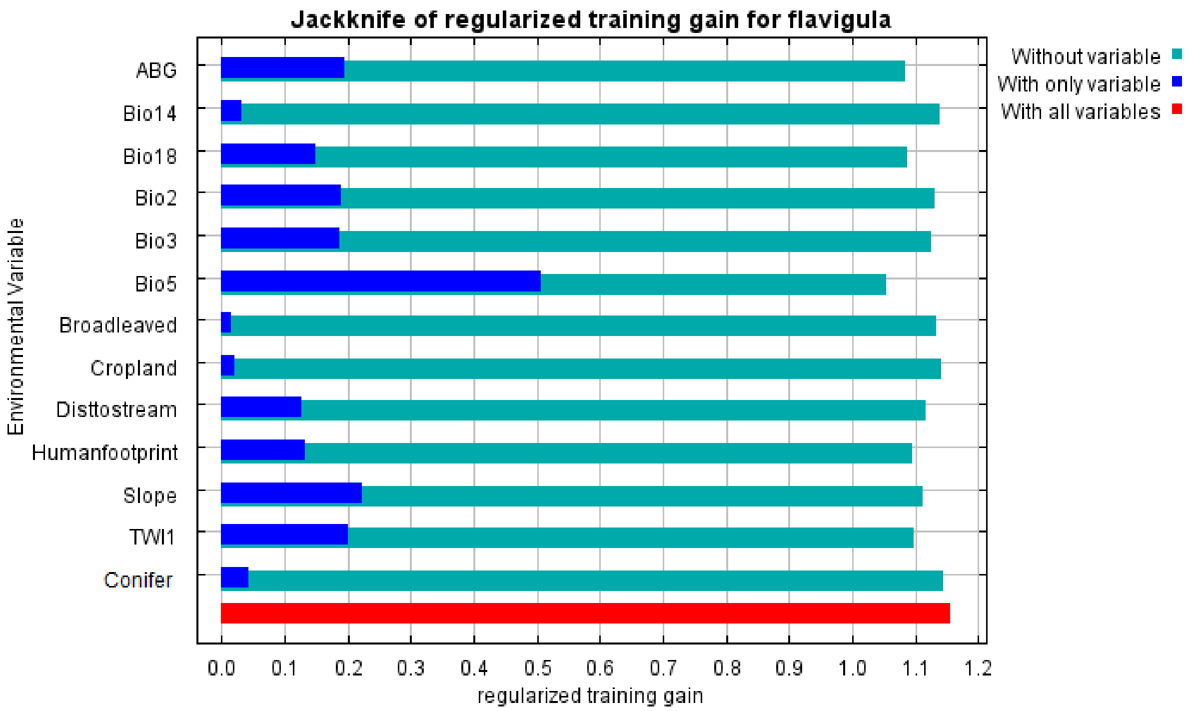

Figure 9. Jackknife test of variable importance.

Response curves generated by MaxEnt show the relationship between the probability of presence and different predictor variables. These curves show how varying values of the environmental variables affect the species' presence.

All bioclimatic variables had non-linear relationship with the marten presence probability. The presence probability was high when the value of Bio5 was 18–19^{o}C and decreased sharply as the temperature increased up to 24–28^{o}C, then increased again upto 31^{o}C, then presence probability decreased sharply (**Figure 10**). Although response curves to Bio3 decreased and then increased, the overall probability of the marten presence increased as the value of isothermality increased and the presence probability was highest when the value of isothermality was 50%. The response curve of presence probability to Bio2 was highest in the intermediate level. The optimum level of the Bio2 for presence probability was 11–11.5°C. Similarly, the response to Bio18 was also increased upto 800mm and decreased upto 1200mm and again increased upto 1400mm and stabilized. Likewise, the response to Bio14 was also high at intermediate level which is 8mm (**Figure 10**).

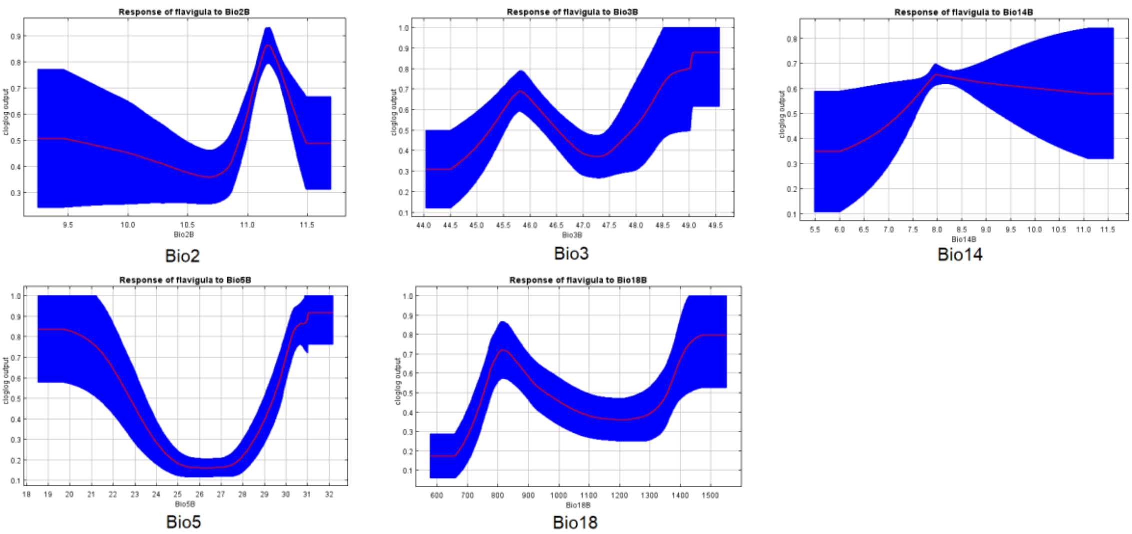

Figure 10. Response to bioclimatic variables.

Marten presence probability decreased as the value of ABG increased. Then, marten presence probability was high in broadleaved forest than non-broadleaved forest area. Similarly, in cropland also, the presence probability was higher than non-cropland area (**Figure 11**). However, in case of coniferous forest the presence probability was lower than non-coniferous forest area. The marten suitability decreased as the distance to nearest stream increased. Presence probability was high when distance to nearest stream was upto 100m. In case of human footprint, presence probability increased from zero-level to low level and then decreased from low level to intermediate level of footprint (**Figure 11**).

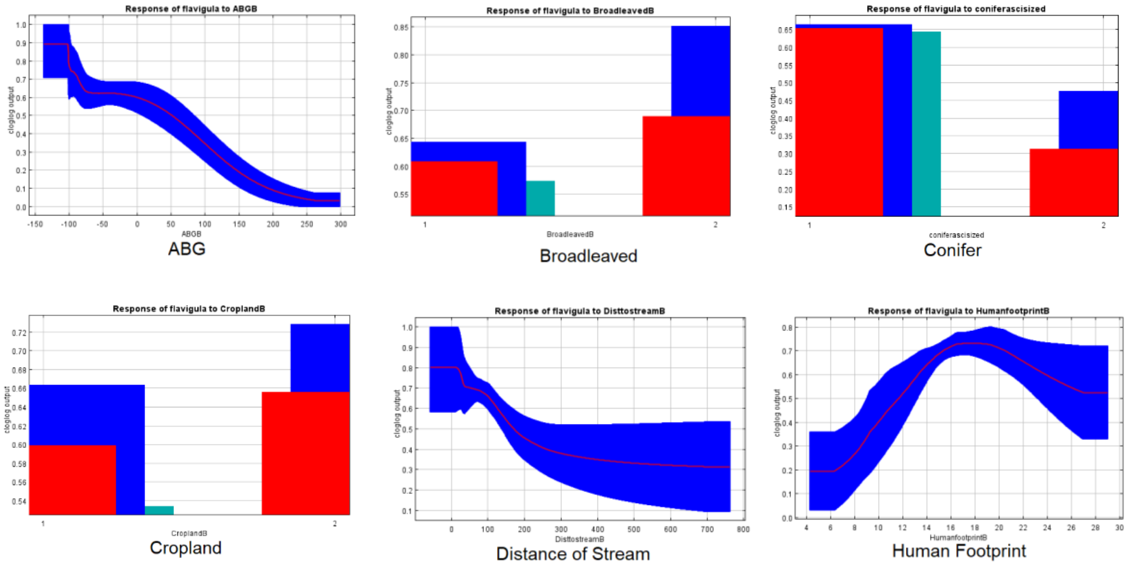

Figure 11. Response to environmental variables.

The response of marten presence probability was negative to slope and optimum level of slope was below 30°. The presence probability decreased from 14–15 and increased afterward in case of topographic wetness index (**Figure 12**).

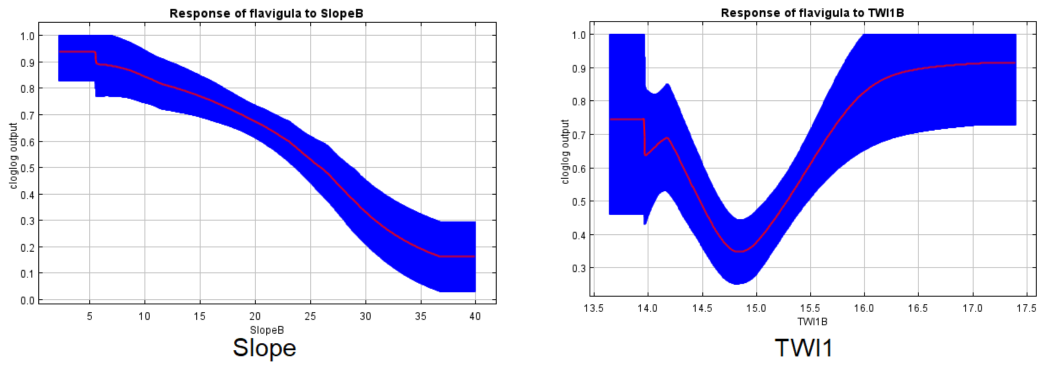

Figure 12. Response to topographic variables

5. DISCUSSION

This study surveyed the distribution of yellow-throated marten (YTM) in the Lower Sunkoshi River Basin in central Nepal by line transect method and recorded a total of 72 occurrence points of the species including direct sightings, and indirect signs. Using those occurrence points and 13 environmental variables, the potential distribution of the species was modeled employing maximum entropy algorithm in the MaxEnt software. It predicted about 11% of the basin as the suitable habitat for the YTM.

5.1 Suitable habitat for yellow-throated marten

The area under the receiver operating characteristic (ROC) the curve is a widely used statistical tool to validate the performance of the models. It is threshold independent method of validation of model. The value of AUC range from 0 to 1 with 0.5 indicating random guessing and 1 meaning perfect performance of the mode (Jimenez-Valverde 2012). The True Skill statistics is a threshold dependent method of validation of model. It is based on sensitivity and specificity of the model. Its value ranges from -1 to 1, negative values referring to poor model, zero referring to not better than random and value greater than 0.6 indicates good model (Somodi et al. 2017). The values of AUC and TSS showed, that model performance was good.

The occurrence points were located in moist deciduous forests at Baluwa, coniferous forest around Hokse, croplands around Panchkhal rural municipality, primitive evergreen coniferous around bethanchwok, rural croplands, river bank stream, coniferous forests, shrubland around Sunkoshi, Sunpati and Khadadevi municipality, mixture of evergreen coniferous and broadleaved forest in Lisankhu-Pakhar rural municipality (**Figure 3**). These all vegetations rural cropland, shrubland, mosaic habitat, coniferous forest and broadleaved forests are considered suitable habitat for yellow-throated marten (Payne et al. 1985, Grassman et al. 2005, Mallick 2013).

The lower Sunkoshi basin lies in midhills of Nepal. It has extensive networks of rivers and streams. The main river in the basin is Sunkoshi River and its tributaries. Another important feature is Mahabharata range. Although the southern slopes of range are steeper than northen ones most of the terrain are well populated especially in the northern slopes of Mahabharata range (Upreti 2001). Most of the landcover of the area is cropland and mosaic habitat. From our observation, the occurrence points were collected from the riverbank, cropland, near human settlement, coniferous forest and mosaic of shrubs and forests. Most predicted potential habitat lies in the lower elevation region from 400–1000 m elevation (**Figure 7**). Though elevation was not included in the environmental variable due its strong negative correlation with Bio5, elevation was an important variable in the first run of maxent and predicted distribution also suggests the same. Elevation was found to be stronger predictor for other *Martes* species (Wasserman et al. 2012, Manlick et al. 2020). Similarly, in case of land cover, most of the potential habitat lies in the mosaic habitat and croplands (**Figure 8**). These mosaic habitats consisted of mixture of grassland, shrubland, cropland and forests in the patches form. These habitats also consisted of patches of broadleaved and coniferous forests. Cropland mostly consisted of the rainfed croplands that are high up the hill with the mixture of forests in patches. Potvin et al. (2000) found that American marten didn't select the pine forests instead select mosaics of mixed forests and shrubland. Similarly, mosaic habitats with the combination of forests plus rural farmland have been found to be preferable habitat for several other *Martes* species (Santos & Santos-Reis 2010, Wereszczuk & Zalewski 2015). Mixed habitats are preferable habitat for small generalist predator as mixed habitat enhanced the predation rate (Storch et al. 2005).

5.2. Important predictor variables yellow-throated marten

The maximum temperature of the warmest month (Bio5) was the most important predictor of the Yellow-throated marten presence (**Figure 9**) with a non-linear relationship. The presence probability was high when the value of Bio5 was 18–19^{o}C and decreased sharply as the temperature increased up to 24–28^{o}C, then increased again upto 31^{o}C, then presence probability decreased sharply (**Figure 10**). Although SDMs done in yellow-throated marten have included Bio5 as environmental variable, none of the paper has indicated it as the most important variable. But Bio5 is an important variable as it is the maximum temperature of the whole year and is directly associated with climate change and warming, which is also associated with productivity of the forest and other species such as birds, other small mammals (Kandel et al. 2015, Thapa et al. 2018), which might indirectly affect food availability for the YTM.

Another important bioclimatic variable was Bio3 (isothermality) in the prediction of the YTMs distribution (**Figure 9**). Isothermality is defined as the uniformity of the temperature or the day-night temperature oscillations relative to summer-winter. It also has non-linear relationship with the species presence (**Figure 10**). In overall, the presence probability of YTM increased with isothermality. Isothermality was found to important predictor of different type of trees and vegetation (Amissah et al. 2014, Ricklefs & He 2016). It was also found to be one of the important predictors for small mammals richness (Ramesh et al. 2016)

Other important bioclimatic predictors were Bio2 and Bio18 (**Figure 9**). Bio2 is Mean diurnal range which also has positive non-linear relationship indicating the increased suitability with the increased hours of diurnal range Most suitable range of Bio2 for YTMs distribution was 11 hours (**Figure 10**). Bio2 was also found to be one of the most important variable in the distribution of other martes species (Ye et al. 2018). The diurnal range have impact on the activity patterns of YTMs (Bu et al. 2016). Bio18 is the precipitation of warmest quarter. The rise and fall curves show the optimal range of Bio18 for YTM distribution is 800–1100 mm (**Figure 10**). Precipitation along with temperature also plays a role in productivity of forests and hence prey availability. Bio18 was found to be important predictor for the association of Enhanced Vegetation Index and Biomass in birds (Ng et al. 2022).Other bioclimatic variable Bio14 (Precipitation of the driest month) had the least training gain among bioclimatic variables (**Figure 9**)

Most important environmental variable as the predictor of YTM distribution was found to be AGB (Above Ground Biomass) (**Figure 9**). Above ground biomass is defined as the biomass of the living vegetation above the ground (Carroll et al. 2012). Meaning biomass of tree trunk, branches, foliages etc. It is measured in mass/area or ton/ha in this study. Tree canopy cover variable was removed in the presence of above ground biomass as they were strongly corelated. From the response curve it can be illustrated that the relationship between AGB and the presence probability of YTM was negative (**Figure 11**). Siren et al. (2022) also found that Forest biomass was negatively corelated with marten presence and explained the reason being the presence of larger predator in the forest with higher biomass region. When addressing ecology of an animal, biotic interactions are as important as other abiotic factor, as animals partition space, time and behavior to fit in the niche and reduce the overall competition with other species. YTMs have found to avoid the larger predators and other species (Bu et al. 2016) and these larger top predator such as leopard prefer deep jungle to avoid human interactions

(Kshettry et al. 2017). The negative relation between the presence and aboveground biomass might be caused by predator presence.

Second most important environmental variable was Human footprint (**Figure 9**). The human footprint map denotes the level of impact humans have in that landscape. Its value ranges from 0-100. Lower value indicates the lower impact and higher value indicates higher impact (Venter et al. 2016). The range of the Human footprint index was 0–30 in the study area which is the least impact (**Figure 11**). The value above 20 indicates moderate level of human impact. Overall, the basin has a low to moderate level of human impact. The response shows that probability of finding YTM decreased from low to moderate level (**Figure 11**). Lee et al. (2021) have pointed out that YTM are affected by direct human encounter rather than stationary human related structure and can exist in high human density area.

Another important variable is distance to nearest stream (**Figure 9**). The Response curves shows the optimum distance from stream for the YTM distribution was 100 m

Figure 11). The presence probability of YTM decreased after 100m (**Figure 11**). It shows the importance of water resources for the distribution of YTM. Distance to nearest water resources was also found to be most important predictor in the distribution of other martes (Balestrieri et al. 2016). Similarly, it was also found to be most important predictor of other small mammals distribution (Valerio et al. 2020).

The vegetation type, cropland, coniferous and broadleaved forest were categorical variables and were the least important variable according to Jackknife test (**Figure 9**). The response bar of cropland shows the probability of finding YTM is higher in cropland than non-cropland area. The response bar of broadleaved forest to species presence shows that the probability of finding YTM in broadleaved forests was higher than other places and inverse was true for conifer which shows that YTM preferred broadleaved forest and cropland than coniferous forest (**Figure 11**). The coniferous and broadleaved forest category consisted of the continuous dense forest devoid of mosaic.

Among topographic variables, slope and TWI (Topographic wetness index) were the second and third most important variables of all the variables (**Figure 9**). The response of slope shows a negative linear relationship with the YTM presence probability. The optimum level of slope for suitable YTM habitat is below 30 (**Figure 12**). Slope affects a number of abiotic factors such as water availability, temperature and soil quality

(Maestre et al. 2009) which are very important factors for survival of plant and species. Slope was found to be an important predictor for other *Martes* species and small mammals (Vaniscotte et al. 2009, Fonda et al. 2021).

TWI (Topographic wetness index) is the terrain driven moisture in the soil. The response curve of TWI shows the non-linear relationship although overall response was positive i.e. the suitability for the potential distribution of YTM increased with increasing topographic wetness index (**Figure 12**). Topographic wetness index have bound to have effect on the vegetations of the area and it was found to be important predictor for birds and vegetation (Kopecky & Cizkova 2010, Besnard et al. 2013).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The Lower Sunkoshi River Basin consisted of 430 km^2 of potential suitable habitat for Yellow-throated marten. Model predicted suitable habitat in all municipalities of lower Sunkoshi River Basin. The model predicted suitable habitat for yellow-throated marten in cropland and mosaic habitats consisting of mixture of grassland, shrubland and forests instead of continuous forest. The model also predicted the distribution ranges in all possible ranges of elevation present in study area. The five most important variables were maximum temperature of warmest month, slope, topographic wetness index, above ground biomass and isothermality. The response of *M. flavigula* to maximum temperature of the warmest month, isothermality, and other bioclimatic variables suggests that this species is sensitive to the climate. The response curve of distance to water resources and above ground biomass was found to be negative.

6.2 Recommendations

Only 11 % of the basin area was predicted to be suitable for the species and, it is also found to be sensitive towards the bioclimatic variables, it is recommended to do further studies on the ecology and population of the species.

- Future research should use additional survey methods including camera traps as it is one of the cryptic species.
- Use of biotic variables such as predator or prey availability could yield better models.
- A systematic recording of location and conflict of yellow-throated marten by the local level government may eventually help the studies to identify the potential drivers of conflicts.

7. REFERENCES

Amissah, L., Mohren, G. M., Bongers, F., Hawthorne, W. D. and Poorter, L. 2014. Rainfall and temperature affect tree species distribution in Ghana. Journal of Tropical Ecology **30**(5):435–446.

Appel, A. and Khatiwada, A. P. 2014. Yellow-throated Martens *Martes flavigula* in the Kanchenjunga Conservation Area, Nepal. Small Carnivore Conservation **50**:14–19.

Appel, A., Werhahn, G., Acharya, R., Ghimirey, Y. and Adhikary, B. 2013. Small carnivores in the Annapurna conservation area, Nepal. Vertebrate Zoology **63**:111–121.

Araújo, M. B. and Guisan, A. 2006. Five (or so) challenges for species distribution modelling. Journal of Biogeography **33**(10):1677–1688.

Azlan, J. M. 2003. The diversity and conservation of mustelids, viverrids, and herpestids in a disturbed forest in peninsular Malaysia. Small Carnivore Conservation **29**:8–9.

Bahuguna, N. C. and Mallick, J. 2010. Handbook of the Mammals of South Asia. In: (Eds). pp xxxiv, 542 p, 531 col. plates, tables.

Balestrieri, A., Bogliani, G., Boano, G., Ruiz-González, A., Saino, N., Costa, S., et al. 2016. Modelling the distribution of forest-dependent species in human-dominated landscapes: patterns for the pine marten in intensively cultivated lowlands. PLoS One **11**(7):e0158203.

Basnet, H. and Rai, A. 2020. An update on the distribution of yellow-throated marten *Martes flavigula* in Nepal. Nepalese Journal of Zoology **4**(2):147–151.

Belden, G., Stuebing, R. and Nyegang, M. 2007. Small carnivores in mixed-use forest in Bintulu Division, Sarawak, Malaysia. Small Carnivore Conservation **36**:35–37.

Besnard, A., La Jeunesse, I., Pays, O. and Secondi, J. 2013. Topographic wetness index predicts the occurrence of bird species in floodplains. Diversity and Distributions **19**(8):955–963.

Bu, H., Wang, F., McShea, W. J., Lu, Z., Wang, D. and Li, S. 2016. Spatial Co-Occurrence and Activity Patterns of Mesocarnivores in the Temperate Forests of Southwest China. PLoS One **11**(10):e0164271. https://doi.org/10.1371/journal.pone.0164271.

Caldwell, H., Stephens, S. and Young, r. W. 2009. Oxytocin as a natural antipsychotic: a study using oxytocin knockout mice. Molecular psychiatry **14**(2):190-196.

Carroll, M., Milakovsky, B., Finkral, A., Evans, A. and Ashton, M. S. 2012. Managing Carbon Sequestration and Storage in Temperate and Boreal Forests. In: M. S. Ashton, M. L. Tyrrell, D. Spalding and B. Gentry (Eds) Managing Forest Carbon in a Changing Climate. Springer Netherlands Dordrecht. pp 205–226.

Choi, M. B., Woo, D. and Choi, T. Y. 2015. Composition of the insect diet in feces of yellow-throated marten, *Martes flavigula*, in Jirisan National Park, South Korea. Journal of Ecology and Environment **38**(3):389–395. https://doi.org/10.5141/ecoenv.2015.041.

Choi, T., Woo, D., Yang, B., Kim, M., Lee, S., Jeong, W., et al. 2011. Management of ecological corridor to conserve wildlife population. National Institute of Environmental Research, Incheon.

Choudhury, A. 1999. Conservation of small carnivores (mustelids, viverrids, herpestids and one ailurid) in north Bengal, India. Small Carnivore Conservation **20**:15-17.

Chutipong, W., Duckworth, J., Timmins, R., Choudhury, A., Abramov, A., Roberton, S., et al.2016. *Martes flavigula*. The IUCN red list of threatened species 2016: e. T41649A45212973.

DeMarche, M. L., Doak, D. F. and Morris, W. F. 2019. Incorporating local adaptation into forecasts of species' distribution and abundance under climate change. Global Change Biology **25**(3):775–793.

Dormann, C. F., Schymanski, S. J., Cabral, J., Chuine, I., Graham, C., Hartig, F., et al. 2012. Correlation and process in species distribution models: bridging a dichotomy. Journal of Biogeography **39**(12):2119–2131.

Duckworth, J. 1995. Mammal records from Similajau National Park. Sarawak Museum Journal **48**:157–161.

Elith, J., Kearney, M. and Phillips, S. 2010. The art of modelling range-shifting species. Methods in Ecology and Evolution **1**(4):330–342. https://doi.org/10.1111/j.2041-210X.2010.00036.x.

ESA.2010. GlobCover 2009 Project European Space Agency GlobCover Portal, ESA.

Fick, S. E. and Hijmans, R. J. 2017. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology **37 (12)**: 4302–4315.

Fonda, F., Chiatante, G., Meriggi, A., Mustoni, A., Armanini, M., Mosini, A., et al. 2021. Spatial distribution of the pine marten *(Martes martes)* and stone marten *(Martes foina)* in the Italian Alps. Mammalian Biology **101**:345–356.

Franklin, J. 2013. Species distribution models in conservation biogeography: developments and challenges. Diversity and Distributions **19**(10):1217–1223.

FRTC 2022. Land cover of Nepal. https://doi.org/10.26066/rds.1972729.

Grassman, L. I., Tewes, M. E. and Silvy, N. J. 2005. Ranging, habitat use and activity patterns of binturong Arctictis binturong and yellow-throated marten *Martes flavigula* in north-central Thailand. Wildlife Biology **11**(1):49–57. https://doi.org/10.2981/0909-6396(2005)11[49:rhuaap]2.0.co;2.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., et al. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. **342**:850–853.

Harrison, D. J., Fuller, A. K. and Proulx, G. 2004. *Martens and fishers (Martes) in human-altered environments: An international perspective*. Springer Science & Business Media. p 247.

Hon, J., Hearn, A. J., Ross, J., Samejima, H., Augeri, D. M., Mathai, J., et al. 2016. Predicted distribution of the yellow-throated marten *Martes flavigula* (Mammalia: Carnivora: Mustelidae) on Borneo. Raffles Bulletin of Zoology %@ 0217-2445.

ICIMOD.2015. Above ground biomass (AGB) data in Nepal 1990.

IUCN.2016. *The IUCN Red List of Threatened Species*. Ver. 3.1, IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, U.K.

Jimenez-Valverde, A. 2012. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modelling. Global Ecology and Biogeography **21**(4):498–507.

Jnawali, S., Baral, H., Lee, S., Acharya, K., Upadhyay, G., Pandey, M., et al. 2011. The status of Nepal mammals: the national red list series, department of national Parks and wildlife conservation kathmandu, Nepal. Preface by Simon M. Stuart Chair IUCN Species Survival Commission The Status of Nepal's Mammals: The National Red List Series **4**.

Jo, Y.-S., Baccus, J. T. and Koprowski, J. L. 2018. *Mammals of Korea*. National Institute of Biological Resources. p 460.

Kandel, K., Huettmann, F., Suwal, M. K., Ram Regmi, G., Nijman, V., Nekaris, K. A. I., et al. 2015. Rapid multi-nation distribution assessment of a charismatic conservation species using open access ensemble model GIS predictions: Red panda *(Ailurus fulgens)* in the Hindu-Kush Himalaya region. Biological Conservation **181**:150–161. https://doi.org/10.1016/j.biocon.2014.10.007.

Khattak, R. H., Teng, L., Khan, N. U., Ali, A., Hadi, A. and Liu, Z. 2022. First Photographic Evidence of Yellow-Throated Marten *(Martes flavigula)* from Nowshera District, Khyber Pakhtunkhwa Pakistan.

Kopecky, M. and Cizkova, S. 2010. Using topographic wetness index in vegetation ecology: does the algorithm matter? Applied Vegetation Science **13**(4):450–459.

Kshettry, A., Vaidyanathan, S. and Athreya, V. 2017. Leopard in a tea-cup: A study of leopard habitat-use and human-leopard interactions in north-eastern India. PLoS One **12**(5):e0177013.

Lamichhane, B. R., Pokheral, C. P., Khatiwada, A. P., Mishra, R. and Subedi, N. 2014. A yellow-throated Marten *Martes flavigula* carrying a small Indian civet *Viverricula indica*. Small Carnivore Conservation **51**:46–50.

Lee, H.-J., Lee, O.-S., Woo, D.-G., Kim, H.-N., Wallace, M. C. and Jo, Y.-S. 2021. Current distribution and habitat models of the yellow-throated marten, *Martes flavigula*, in South Korea. Mammal Research **66**(3):429–441. https://doi.org/10.1007/s13364-021-00567-6.

Lee, S., Lee, S., Song, W. and Lee, M.-J. 2017. Habitat Potential Mapping of Marten (*Martes flavigula*) and Leopard Cat (*Prionailurus bengalensis*) in South Korea Using Artificial Neural Network Machine Learning. Applied Sciences **7**(9):912. https://doi.org/10.3390/app7090912.

Lekagul, B. and McNeely, J. 1977. Mammals of thailand. Association for the conservation of wildlife. Kulusapa, Bangkok.

Lekhakun, B. and McNeely, J. A. 1977. *Mammals of Thailand*. Bangkok, Association for the Conservation of Wildlife. p.

Lim, S.-J., Min, J.-H. and Park, Y.-C. 2015. Analysis of Habitat Characteristics of the Yellow-throated Marten *Martes flavigula* (Carnivora : Mustelidae) Using Geographic Information System (GIS). Journal of Forest and Environmental Science **31**(4):261–266. https://doi.org/10.7747/jfes.2015.31.4.261.

Maestre, F. T., Callaway, R. M., Valladares, F. and Lortie, C. J. 2009. Refining the stress-gradient hypothesis for competition and facilitation in plant communities. Journal of ecology **97**(2):199–205.

Mallick, J. 2013. Himalayan yellow–throated marten (Martes flavigula) in West Bengal, India. TAPROBANICA: The Journal of Asian Biodiversity **5**(1).

Mallick, J. K. 2013. Himalayan Yellow–throated Marten (*Martes flavigula*) in West Bengal, India. TAPROBANICA: The Journal of Asian Biodiversity **5**(1):89. https://doi.org/10.4038/tapro.v5i1.5694.

Manlick, P. J., Windels, S. K., Woodford, J. E. and Pauli, J. N. 2020. Can landscape heterogeneity promote carnivore coexistence in human-dominated landscapes? Landscape Ecology **35**:2013–2027.

Mathai, J., Hon, J., Juat, N., Peter, A. and Gumal, M. 2010. Small carnivores in a logging concession in the Upper Baram, Sarawak, Borneo. Small Carnivore Conservation **42**:1–9.

Merow, C., Smith, M. J., Edwards Jr, T. C., Guisan, A., McMahon, S. M., Normand, S., et al. 2014. What do we gain from simplicity versus complexity in species distribution models? Ecography **37**(12):1267–1281.

Naniwadekar, R., Shukla, U., Viswanathan, A. and Datta, A. 2013. Records of small carnivores from in and around Namdapha Tiger Reserve, Arunachal Pradesh, India. Small Carnivore Conservation **49**:1–8.

Newman, C., Zhou, Y.-B., Buesching, C. D., Kaneko, Y. and Macdonald, D. W. 2011. Contrasting sociality in two widespread, generalist, mustelid genera, *Meles* and *Martes*. Mammal Study **36**(4):169–188.

Ng, W., Fink, D., La Sorte, F., Auer, T., Hochachka, W., Johnston, A., et al. 2022. Continental-scale biomass redistribution by migratory birds in response to seasonal variation in productivity. Global Ecology and Biogeography **31**. https://doi.org/10.1111/geb.13460.

Novikov, G. 1962. *Canivorous mammals of the Fauna of the USSR*. Zoological Institute of the Academy of Science of the USSR. p 293.

O'Mahony, D. T. 2014. Socio-spatial ecology of pine marten *(Martes martes)* in conifer forests, Ireland. Acta theriologica **59**(2):251-256.

Parr, J. W. K. and Duckworth, J. W. 2007. Notes on diet, habituation and sociality of Yellow-throated Marten *Martes flavigula*. Small Carnivore Conservation **36**:27–29.

Payne, J., Francis, C. M. and Phillipps, K. 1985. *Field guide to the mammals of Borneo*. Sabah Society. p.

Pearson, R., Terence, T. P. and Liu, C. 2004. Modelling species distributions in Britain: A hierarchical integration of climate and land-cover data. Ecography **27**:285–298. https://doi.org/10.1111/j.0906-7590.2004.03740.x.

Pierce, A. J., Sukumal, N. and Khamcha, D. 2014. A yellow-throated marten *Martes flavigula* feeding on a red muntjac *Muntiacus muntjak* carcass. Small Carnivore Conservation **51**(1):76–78.

Pocock, R.1941. Fauna of British India. Vol. 2. Mammals. Taylor & Francis, London.

Potvin, F., Bélanger, L. and Lowell, K. 2000. Marten habitat selection in a clearcut boreal landscape. Conservation Biology **14**(3):844–857.

Powell, R. A. 1979. Mustelid spacing patterns: variations on a theme by Mustela. Zeitschrift für Tierpsychologie **50**(2):153–165.

Proulx, G., Aubry, K., Birks, J., Buskirk, S., Fortin, C., Frost, H., et al. 2005. World distribution and status of the genus *Martes* in 2000. Martens and fishers (Martes) in human-altered environments: an international perspective:21–76.

QGIS, D. T.2022. QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Ramesh, T., Kalle, R. and Downs, C. T. 2016. Predictors of mammal species richness in KwaZulu-Natal, South Africa. Ecological Indicators **60**:385–393.

Ricklefs, R. E. and He, F. 2016. Region effects influence local tree species diversity. Proceedings of the National Academy of Sciences **113**(3):674–679.

Santos, M. J. and Santos-Reis, M. 2010. Stone marten *(Martes foina)* habitat in a Mediterranean ecosystem: effects of scale, sex, and interspecific interactions. European Journal of Wildlife Research **56**:275–286.

Sathyakumar, S. 1999. Mustelids and viverrids of the northwestern and western Himalayas. Envis Bulletin Wildlife and Protected Areas **2**(2):39–42.

Sheikh, K. and Molur, S. 2005. Status and red list of Pakistan's mammals, based on conservation assessment and management plan for mammals. IUCN, Pakistan **344**.

Siren, A. P., Sutherland, C. S., Karmalkar, A. V., Duveneck, M. J. and Morelli, T. L. 2022. Forecasting species distributions: Correlation does not equal causation. Diversity and Distributions **28**(4):756–769.

Soberón, J. and Peterson, A. 2005. Interpretation of Models of Fundamental Ecological Niches and Species' Distributional Areas. Biodiversity Informatics **2**. https://doi.org/10.17161/bi.v2i0.4.

Somodi, I., Lepesi, N. and Botta-Dukát, Z. 2017. Prevalence dependence in model goodness measures with special emphasis on true skill statistics. Ecol Evol **7**(3):863–872.

Storch, I., Woitke, E. and Krieger, S. 2005. Landscape-scale Edge Effect in Predation Risk in Forest-farmland Mosaics of Central Europe. Landscape Ecology **20**(8):927–940. https://doi.org/10.1007/s10980-005-7005-2.

Thapa, A., Wu, R., Hu, Y., Nie, Y., Singh, P. B., Khatiwada, J. R., et al. 2018. Predicting the potential distribution of the endangered red panda across its entire range using MaxEnt modeling. Ecol Evol **8**(21):10542–10554. https://doi.org/10.1002/ece3.4526.

Tsai, C. 2007. Food resource partitioning between sympatric yellow-throated marten *(Martes flavigula chrysosphila)* and Siberian weasel *(Mustela sibirica taivana)*. MS thesis.

Twining, J. P. and Mills, C. 2021. Cooperative hunting in the yellow-throated marten *(Martes flavigula)*: Evidence for the not-so-solitary marten? Ecosphere **12**(3). https://doi.org/10.1002/ecs2.3398.

Upreti, B. 2001. The Physiography and Geology of Nepal and Their Bearing on the Landslide Problem, in" Landslide Hazard Mitigation". International Centre for Integrated Mountain Development.

Valerio, F., Ferreira, E., Godinho, S., Pita, R., Mira, A., Fernandes, N., et al. 2020. Predicting microhabitat suitability for an endangered small mammal using sentinel-2 data. Remote Sensing **12**(3):562.

Vaniscotte, A., Pleydell, D. R., Raoul, F., Quéré, J. P., Jiamin, Q., Wang, Q., et al. 2009. Modelling and spatial discrimination of small mammal assemblages: an example from western Sichuan (China). Ecological modelling **220**(9-10):1218–1231.

Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., et al. 2016. Sixteen Years of Change in the Global Terrestrial Human Footprint and Implications for Biodiversity Conservation. Nature Communications:12558.

Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., et al.2018. Last of the Wild Project, Version 3 (LWP-3): 2009 Human Footprint, 2018 Release. Palisades, New York, NASA Socioeconomic Data and Applications Center (SEDAC).

Wasserman, T. N., Cushman, S. A., Wallin, D. O. and Hayden, J. 2012. Multi scale habitat relationships of *Martes americana* in northern Idaho, USA.

Wereszczuk, A. and Zalewski, A. 2015. Spatial niche segregation of sympatric stone marten and pine marten–avoidance of competition or selection of optimal habitat? PLoS One **10**(10):e0139852.

Wilting, A., Samejima, H. and Mohamed, A. 2010. Diversity of Bornean viverrids and other small carnivores in Deramakot Forest Reserve, Sabah, Malaysia. Small Carnivore Conservation **42**:10–13.

Wroughton, R. 1916. Report No. 25 and 26. Bombay Natural History Society's mammal survey of India, Burma and Ceylon. Journal of the Bombay Natural History Society **24**:758–781.

Xiao, X., McGlinn, D. J. and White, E. P. 2015. A strong test of the maximum entropy theory of ecology. The American Naturalist **185**(3):E70–E80.

Yaworsky, P. M., Vernon, K. B., Spangler, J. D., Brewer, S. C. and Codding, B. F. 2020. Advancing predictive modeling in archaeology: An evaluation of regression and machine learning methods on the Grand Staircase-Escalante National Monument. PLoS One **15**(10):e0239424.

Ye, X., Yu, X., Yu, C., Tayibazhaer, A., Xu, F., Skidmore, A. K., et al. 2018. Impacts of future climate and land cover changes on threatened mammals in the semi-arid Chinese Altai Mountains. Science of the total environment **612**:775–787.

Zalewski, A. and Jędrzejewski, W. 2006. Spatial organisation and dynamics of the pine marten *Martes martes* population in Białowieza Forest (E Poland) compared with other European woodlands. Ecography **29**(1):31-43.

Zhou, Y.-B., Newman, C., Buesching, C. D., Zalewski, A., Kaneko, Y., Macdonald, D. W., et al. 2011. Diet of an opportunistically frugivorous carnivore, *Martes flavigula*, in subtropical forest. Journal of Mammalogy **92**(3):611–619.

Zhou, Y.-B., Newman, C., Xu, W.-T., Buesching, C. D., Zalewski, A., Kaneko, Y., et al. 2011. Biogeographical variation in the diet of Holarctic martens (genus *Martes*, Mammalia: Carnivora: Mustelidae): adaptive foraging in generalists. Journal of Biogeography **38**(1):137–147. https://doi.org/10.1111/j.1365-2699.2010.02396.x.

Zhou, Y.-B., Slade, E., Newman, C., Wang, X.-M. and Zhang, S.-Y. 2008. Frugivory and seed dispersal by the yellow-throated marten, *Martes flavigula*, in a subtropical forest of China. Journal of Tropical Ecology **24**(2):219–223. https://doi.org/10.1017/s0266467408004793.

8. PHOTO PLATES

Photographic plate 1. Pugmark of marten in sandy bank of Sunkoshi bank in Ratmata, Sindhuli.

Photographic plate 2. Pugmark of marten in puddle of Gangate Khola in Katahare.

Photographic plate 3 Feces of marten at the abandoned goreto bato near Sadhanbot.

Photographic plate 4 Feces of marten near Kalpanidhar, Mainapur.

Photographic plate 5 Feces of marten on the stone in near Thapabhanjyang.

Photographic plate 6 Feces of marten in stone near Newartol, Ramechhap.

Photographic plate 7 Feces of marten at Rhodhodendron forest, Nigale Bazar, Sindhupalchwok.

Photographic plate 8 Feces of marten on the stone wall at Deyali Dada, Sindhupalchwok.