Distribution and winter habitat use of Bhutan Takin, *Burdocas taxicolor whitei*, in Bhutan

(A National Report for the National Animal)

Nature Conservation Division
Department of Forests and Park Services
Ministry of Agriculture and Forests

2019

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DIRECTOR

FOREWORD

Bhutan, despite its small size is one of the biologically diverse countries in the world. Today Bhutan harbours close to 200 mammals including the charismatic tiger, snow leopard, Asian elephant, and many lesser known species. Amongst them, Bhutan takin, Budorcas taxicolor whitei, which is believed to be a unique creation of the great saint Drukpa Kuenleg during the 15th century is the national animal of Bhutan.

Over the years, the use of robust wildlife survey designs and technologies has helped enhance the scientific information on many of our charismatic and flagship species. Today, we know the number of tigers, snow leopards and elephants thriving in their pristine habitats, and information on many other mammals are being generated each year. However, takin, despite being the national animal of Bhutan has lagged behind in terms of scientific information due to scanty research on this species.

The Department of Forests and Park Services felt the necessity to enhance the scientific information on our national animal before pervasive threats challenge the survival of this iconic animal. To this, the first ever nationwide survey to ascertain the habitat use probability of takin during the winter was conducted in 2018 and I am glad to learn that the report is now out. This report, which was motivated by the need of enhancing scientific information on our national animal is expected to serve as stepping stone towards bigger surveys to assess the summer habitats and then ascertain the population of our national animal.

The report will also guide our conservation efforts in protecting our national animal. Linear infrastructure such as roads and transmission lines, if not properly planned, causes grave hindrance to the wildlife movement and this report clearly identified the need to prioritize proper land-use planning with particular emphasis on roads. It is expected that prime winter habitat of takins are secured with proper placement of infrastructure obviating the jeopardy between conservation and socio-economic development.

I thank and congratulate the Nature Conservation Division for conducting this much needed survey and publishing this valuable report. I also thank the field crews who painstakingly conducted the field survey and collected data in 2018. Lastly, I thank Bhutan Trust Fund for Environmental Conservation for generously funding this important work.

Tashi Delek and Best Wishes!

(Lobzang Dorji)

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The Nature Conservation Division, on behalf of the Department of Forests and Park Services, would like to sincerely thank the Chief Forestry Officers from the six field offices for their support in coordinating the first ever national survey on our national animal. Your enthusiasm and dedicated conservation efforts have helped ensure safe habitat to the vulnerable Bhutan takin despite having lesser conservation fund for its protection.

We also express our heartiest gratitude to all the focal officers for coordinating the field work in their respective jurisdiction; Mr. Pema Dendup (Jigme Dorji National Park), Mr. Lungten Dorji (Wangchuck Centennial National Park), Mr. Jangchub Gyeltshen (Phrumsengla National Park), Mr. Tshering (Paro Forest Division), Mr. Chimi Rinzin (Wangdue Forest Division), and Ms. Lekey Wangmo (Thimphu Forest Division). We also would like to extend our appreciation to all the field colleagues who were painstakingly engaged in collecting the data from the remote terrains. Without your dedication and enthusiasm, we could not have reached this stage.

We are also very thankful to Dr. Sangay, Ugyen Wangchuck Institute for Conservation and Environmental Research for providing us with firsthand information on Bhutan takin for planning our survey works, and for his critical inputs in the final report.

We remain grateful to Bhutan Trust Fund for Environmental Conservation for funding the field survey and the publication of this report. It is through their generous funding that we could accomplish the field survey, publish the work, and establish baseline information on the winter habitat use of takin in Bhutan. We also acknowledge our conservation partners like WWF Bhutan and Bhutan Foundation for their constant support in conserving our natural heritages and we request for their continued support always.

Nature Conservation Division, 2019

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EXECUTIVE SUMMARY

Bhutan takin is one of the four subspecies of takin and it is endemic to Bhutan. It exhibits a distinct identity in the phylogeny. Bhutan takin is a large bovid ungulate found along the warm broadleaved forest through the alpine region between the altitudinal range of 1,200 m in warm broadleaved forest and 5374 m in northern Bhutan. Bhutan takin is deeply affiliated to Buddhism and has a strong cultural and religious significance. According to a Bhutanese legend, the takin was miraculously created by embellishing the head of a goat to a body of a cow by the famous Tibetan saint Lama Drukpa Kuenleg. Hence, in Bhutanese ethos, Bhutan takin holds a special place as an entity of worship and mascot. The animal was declared as the national animal of Bhutan in 1985.

This national survey for takin, first of its kind, covered most of the potential takin habitats in northern Bhutan encompassing three protected areas (Jigme Dorji National Park, Wangchuck Centennial National Park, Phrumsengla National Park) and three forest divisions (Paro Forest Division, Thimphu Forest Division, and Wangdue Forest Division). The study was conducted to assess the winter habitat use and distribution of takin in Bhutan, using the robust field survey that combined both transect walk and camera trapping. The survey was conducted between February and March 2018 when the takins had already migrated to their winter habitat in the warmer temperate valleys from their summer habitat in the alpine meadows. The analytical method for evaluating the habitat suitability of takin involved the use of generalized linear model (GLM) and occupancy models. Covariates thought to influence takin occupancy and/or habitat use were selected based on past studies of generic takin species.

Takin habitat use was strongly but negatively associated with road density and slope. This suggests that takin select habitats on gentle terrains and strongly avoids human-made linear infrastructure such as roads. The habitat use was also positively associated with conifer forest and roughness (a quintessential characteristic of shy ungulates) and negatively with meadow, terrain wetness and snow cover (which would essentially constitute summer habitats in the far north). The predictive map shows that JDNP and WCNP are the strongholds of winter habitat for takin. Other study sites had moderate to low habitat suitability. This also means that for the long-term sustenance of takin population in Bhutan, landscape contiguity is essential and calls for strict protection of habitat in these low-occurring areas.

This study revealed a stark but truthful reality that takin habitats are under predisposal threat from human-induced change, in particular due to the expansion of road. Therefore, the study recommends reducing anthropogenic pressure from infrastructure development to the winter habitats of takin, which are imminently at a closer edge to human settlements and are highly vulnerable.

1. INTRODUCTION

1.1. Global Status

The Takin, *Budorcas taxicolor* Hodgson, 1850, is a large-bodied (>300 kg live weight), social and mountain-dwelling bovid ungulate native to the temperate and alpine forests of eastern Asia (Zeng *et al.* 2008). It inhabits steep forests extending into the timberline and mountain valleys in the Eastern Himalayas and adjoining mountain ranges of Bhutan, India, Myanmar and China (Sharma *et al.* 2015). There are four extant subspecies which are found in different parts of this range (Figure 1), namely the Golden Takin *Budorcas taxicolor bedfordi,* Mishmi Takin *Budorcas taxicolor taxicolor,* Sichuan Takin *Budorcas taxicolor tibetana,* and Bhutan Takin *Budorcas taxicolor whitei.*

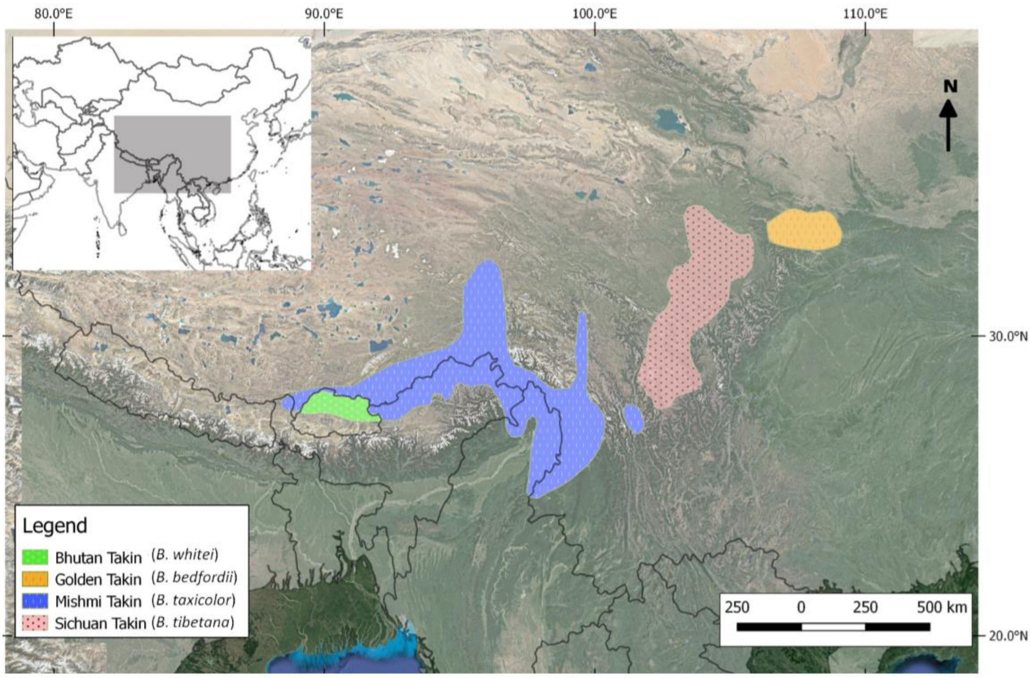

Figure 1: Global Takin distribution map (Sangay *et al.* 2016)

There is very little information on many aspects of takin including the distribution and population estimate of takin populations, partly due to inaccessibility of their habitat. The Golden takin and Sichuan takin are both confined to China. The golden takin is confined to the Qinling Mountains in southern Shaanxi between elevations of 1,500 to 3,600 m (Schaller *et al.* 1986) while the Sichuan takin is distributed along the eastern margin of the Tibetan plateau from the Sichuan-Gansu provincial border to the border of Yunnan Province (Song *et al.* 2008). The Mishmi takin is found in the southeast of Tibet and northwestern Yunnan in China with the central part of its range occurring in Arunachal Pradesh, India and northern Myanmar (Song *et al.* 2008; Dasgupta et al. 2010). The Bhutan takin is mostly distributed in Bhutan (Sangay *et al.* 2016) but has also been reported from Xizang in China and Sikkim, and Arunachal Pradesh in India. There is no known estimate of the global takin population but the best available estimate is between 7000 – 12000 individuals (Song *et al.* 2008). Among the four sub-species, *B. t. bedfordi* has the most reliable estimate of 3000-5000 individuals, followed by *B. t. taxicolor* estimated at about 3,500 individuals in China (Song *et al.* 2008) and about 220-300 individuals in India (Dasgupta *et al.* 2010). For *B. t. tibetana,* there is no estimate and for *B. t. whitei,* it is estimated between 500-700 individuals (Sharma *et al.* 2015).

The Bhutan takin was declared as the national animal of Bhutan in 1985 and is strictly protected under the Schedule I of the Forests and Nature Conservation Act of Bhutan 1995 (RGoB 1995). The takin is legally protected in China under Class I species of the National Wildlife Law (1988) prohibits from hunting (Guan *et al.* 2013). Legal hunting of takin is not permitted in India with the species listed under Schedule I of the Indian Wildlife (Protection) Act (1972). Though found in protected areas, the legal conservation status in Myanmar is unknown. Deforestation, habitat fragmentation, hunting, competitive exclusion and zoonotic disease transmission from domestic livestock are some of the perceived threats to takin survival across its entire range and the population is currently on a decreasing trend (Song *et al.* 2008; IUCN 2019). The takin is categorized as Vulnerable (A2cd) in the IUCN Red List of Threatened Species (Song *et al.* 2008).

1.2. Bhutan Takin *Budorcas taxicolor whitei*

Budorcas taxicolor whitei (Figure 2) is the only sub-species of Takin found in Bhutan between elevation of 1,200 in warm broadleaved forests and 3,500 m in alpine valley at a very few known locations (Wangchuk *et al.* 2004). Highest elevation record at which takin was observed however, was 5374 m (T. Sangay, personal communication). The species is deeply affiliated to Buddhism and has a strong cultural significance. According to a Bhutanese legend, the takin was created by merging the head of a goat to the body of a cow by the famous Tibetan saint Lama Drukpa Kuenleg (Wangchuk *et al.* 2004), also known as the Divine Madman, a Buddhist teacher of crazy wisdom during the 15th century. As such the Bhutan takin has a unique appearance with its head resembling to a goat and the body to that of a cow.

Despite, having a cultural significance and national importance, there is limited information on the species ecology and population. No census has been carried out hitherto to estimate the takin population in Bhutan and no nationwide distribution survey was conducted in the past. However, local knowledge and incidental records from parks and divisions suggest that takin is sparsely distributed on the mountain habitats of

Bhutan's northern region (Wangchuk *et al.* 2004). The presence of takin in the northern region of Bhutan exhorted the Royal Government of Bhutan in creating protected areas in the north in 1974 namely Laya Wildlife Sanctuary, Gasa Wildlife Sanctuary and Jigme Dorji Wildlife Sanctuary to protect this iconic national animal of Bhutan (Sangay *et al.* 2016). These wildlife sanctuaries were later consolidated as Jigme Dorji Wildlife Sanctuary before being upgraded to Jigme Dorji National Park in 1993 (Thinley and Tharchen 2014). Besides JDNP, the presence of takin was confirmed in Wangchuck Centennial National Park, Phrumsengla National Park and Divisional Forest Offices of Paro, Thimphu, Wangdue (T. Sangay, personal communication). The eastern most range of the species was recorded in the mixed fir and rhododendron forests of Thomtthom area in northeastern part of Lhuentse District, which also forms a part of the upper watersheds of Kurichu River in the eastern part of Wangchuck Centennial National Park (27˚56'03.8''E & 91˚04'53.7''N) (Dhendup *et al.* 2016).

Figure 2: Bhutan takin *Budorcas taxicolor whitei* photo captured from Gomthang, Bumthang

Takin is a shy animal and inhabits remote areas away from high-density human habitation (Sharma *et al.* 1995). In Bhutan, they are found along the river valleys and are associated with areas of natural salt licks (Wangchuk *et al.* 2016). Tsharijathang under Jigme Dorji National Park is one of the prime summer habitats of takin in Bhutan where a congregation of over 100 takins are recorded. Takin also infrequent natural salt lick areas in Shingju in Laya and Ralam in Lingzhi (Sharma *et al.* 2015). Seasonal movement and migration along an altitudinal gradient is a common characteristics in many ungulates inhabiting mountainous habitats (Brazda 1953; Vuren 1983; Guan *et al.* 2013). Golden takins in the Qinling Mountains of China have exhibited a complicated seasonal movement pattern and have been observed to migrate as many as four times a year (Zeng *et al.* 2008) while Sinchuan takins in China have been observed to exhibit two migration cycles in a year attaining highest elevation during summer and lowest during the spring and autumn seasons (Guan *et al.* 2013). In Bhutan, the Bhutan takin exhibits (annual) seasonal migration from alpine valleys to lower forests in autumn and return to the summer habitats in early spring (Wollenhaupt 1991; Wangchuk 1999 as cited by Wangchuk *et al.* (2016). Such movements are presumably an adaptation to spatial patterns of plant phenology and solar radiation (Zeng *et al.* 2010), to find potential mating partners (Liu *et al.* 2005; Wang *et al.* 2013), to avoid harsh environmental conditions (Zeng *et al.* 2008) and to seek protection from predation by carnivores such as tigers and wild dogs (Fryxell *et al.* 1988). The Bhutan takin migratory routes follow steep river courses and ridges and there is an elevation difference of over 2500 m between summer and winter habitats across a horizontal distance of less than 15–20 km. Wangchuck *et al.* (2016) observed that spring migration is slow, starting in April and extending to early May, and consists of movement by discrete, small groups, and then congregating in large groups in the summer habitats in June in Tsarijathang area. Takins have a typical breeding phenology: mating takes place in mid-summer and birth and parturition takes place in the wintering habitat in March after a relatively long gestation period (210 to 240 days). Hence, the calves are about three months old when they arrive on the summer pastures in June (Wangchuk *et al.* 2016).

Studies on Bhutan takin are very scarce and most of the information about their distribution comes from anecdotes and observational records. The first study on takin in Bhutan was conducted by Wangchuk *et al.* (2016) where they studied the habitat and diet during the summer of 1998 in Jigme Dorji National Park, Bhutan. The second study was conducted by Sangay and colleagues in 2016 where they reported on the distribution and conservation status of takin based on a questionnaire survey (Sangay *et al.* 2016).

In this study, we report on the distribution and winter habitat use of takin in Bhutan, obtained from robust survey and field methods. The summer habitat use could not be determined as the study was conducted during the winter which extended up to early spring thus covering only the winter habitats of the takin.

2. MATERIAL AND METHODS

2.1. Study area

Bhutan is a small, landlocked country with a total geographical area of 38,394 km^2 and share its borders with the Tibetan Autonomous Region (TAR) of China to the north and India to the east, west, and south. Bhutan straddles the Eastern Himalayas and is endowed with rich forest and scrubland covering 80% of the total land area of the country (FRMD 2017). With the altitudinal gradient ranging from less than 100 m in the south to over 7000 m in the snow-capped mountains in the north, there is a great variability in weather and climate, thus creating variation in vegetation types along the gradient, which are classed in to six vegetation zones (Wangda and Ohsawa 2006). These zones correspond to the following climatic zones: tropical (< 1000 m), subtropical (1000 – 2000 m), warm-temperate (2000 – 3000 m), cool-temperate (3000 – 3500 m), subarctic (3500 – 4000 m), and arctic (alpine) zone (> 4000 m). Besides there are four distinct seasons in Bhutan; winter (December to February), spring (March to May), summer (June to August), and autumn (September to November). The monsoon occurs between July and September and brings precipitation ranging less than 100 mm in the north to more than 5000 mm in the sub-tropical regions in the south. These enabling biophysical conditions have created an ideal and outstanding range of ecosystems and biodiversity, a mix of both Palearctic and Indo-Malayan origin. Close to 200 mammals are expected in Bhutan including the charismatic and endangered Bengal tiger (*Panthera tigris tigris*), snow leopard (*Panthera uncia*), Asian elephant (*Elephas maximus*), red panda (*Alilurus fulgens*), and endemic Bhutan Takin.

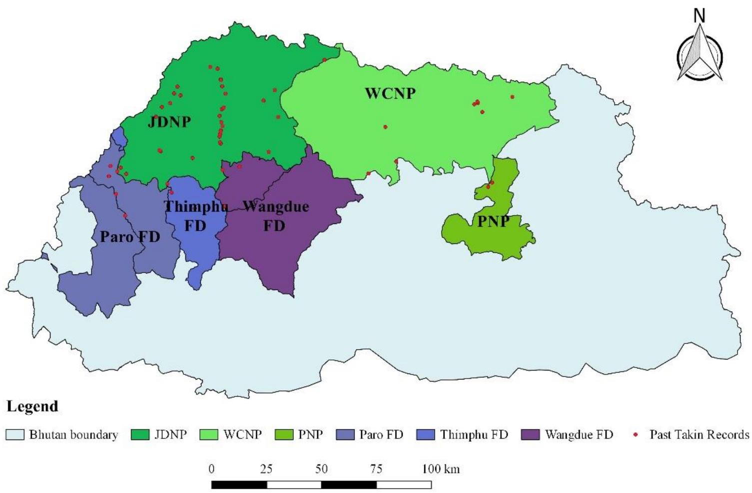

Figure 3: Past locations of Bhutan takin records in Bhutan. (JDNP-Jigme Dorji National Park, WCNP-Wangchuck Centennial National Park, PNP-Phrumsengla National Park, FD-Forest Division)

The survey was conducted in the northern region of the country encompassing Paro Forest Division, Thimphu Forest Division, Wangdue Forest Division, Jigme Dorji National Park, Wangchuck Centennial National Park and Phrumsengla National Park (Figure 3). All the survey sites fall in temperate and alpine regions covering the potential habitats where previous records show takin presence.

2.2. Field survey

This survey combined two detection methods to record takin presence/absence, viz transect and camera trap. The sites were gridded with 5 x 5 km square cells (Figure 4) based on the putative home range estimate of takin in Bhutan (25 km^2, T. Sangay, UWICER, unpublished data). Albeit, no home range estimate of Bhutan takin is available to date, the home range estimates are comparable to other subspecies such as the golden takin (Song *et al.* 2008; Guan *et al.* 2013). Therefore, the 25 km^2 grid size was selected as the potential home range size to survey takin presence/absence. The summer habitats were excluded from this survey which is mostly the alpine meadow in the north because almost the whole population of takin would have migrated to lower valleys by mid-November (Wangchuk *et al.* 2016). The study sites were chosen based on the past records of takin in Bhutan (data provided by T. Sangay, UWICER). The grids were used to guide the placement of camera traps and laying of transects. In each accessible grid, a transect of 5 km (maximum length) was laid to record direct or indirect animal observation. The total length of the transect differed between sites in the context of terrain and accessibility. The transects were laid in such a manner that the total maximum length covered all representative habitat within the grid and not just concentrated to one site or selective location. In each grid, field surveyors recorded takin evidence through direct sighting or indirect animal signs such as dungs and tracks at locations 500m apart (i.e. 0, 500m, 1000m, 1500m…5000m). At every 500th metre along the transect, observers virtually laid a 100m circular buffer. Taking that interval as the center of the plot, takin evidences were searched for about 20 minutes. They also recorded elevation, forest type and topography as site covariates thought to influence takin habitat use at these intervals.

For analysis, observations from the transect surveys were collated into a binary data at the grid level to indicate takin detection by giving a value of one and non-detection by zero. Such binary data can be easily used under occupancy modelling framework or for that matter any logistic regression modeling to assess habitat suitability or species-habitat relationship. The observers also recorded habitat type and weather condition (cloudy, sunny and rainy) during the transect walk. The transect walk and camera trap survey were conducted between February and March 2018 when the takins have already migrated to their winter habitat in the warmer temperate valleys from their summer habitat in the alpine meadows. Each transect was visited more than once at an interval of two weeks to assume sufficient temporal independence (minimum visit=1, maximum visits=3). This was done to ascertain whether the animal was completely absent or was present but undetected during the first visit. For camera trapping, a systematic random grid sampling was employed by choosing grids which were representative of habitat type but further from each other to minimize spatial autocorrelation. In each camera grid, an unpaired camera trap was installed along the animal trail to maximize detection probability. The camera traps were allowed to operate for 45 days to assume closure (no permanent movement/migration of animals within that period).

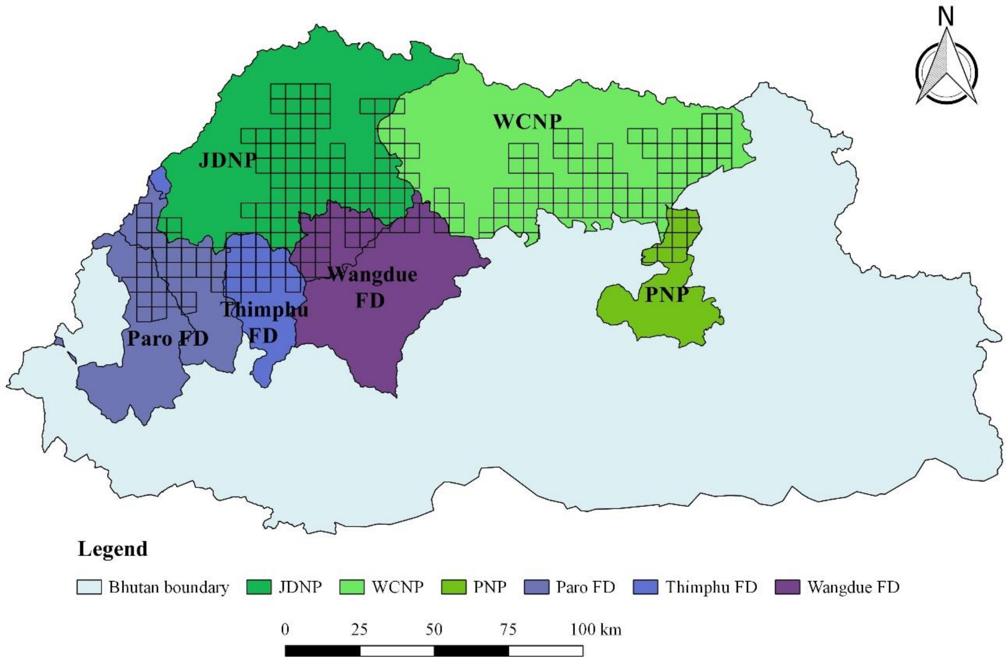

Figure 4: Study area and survey grids for the National Takin Survey, 2018

2.3. Occupancy and detection covariates

Covariates thought to influence takin occupancy/habitat use were selected based on past studies of generic takin species (Zeng *et al.* 2003; Guan *et al.* 2013; Table 1). The land cover (broadleaved forest (BLF), conifer forest (CON), agriculture land (AGR), settlement (SET), road (ROA), snow cover (SNO), meadow/shrub (MEA), and bare areas (BAR)) data was obtained from GIS unit of Department of Forests and Park Services, Bhutan. The 30m digital elevation model (DEM, USGS 2018) was used to extract altitude (ELE) and derive slope (SLO), compound topographic index (CTI) and roughness (ROU) for each grid center using the geomorphometry and gradient tool (Cushman *et al.* 2010) in ArcMap 10 (ESRI 2015). The occurrence/habitat use of a species is scale dependent. It may not be apparent but habitat requirement at a finer scale is very different from habitat use at a broad scale. To account for scale-dependency in the species-habitat relationship, a test to ascertain the influence of three varying spatial scales for each predictor variable (viz, 500m, 1km, 2km) was performed. For each land cover type, the percentage of land (focal mean) area at three scales (see above) using a circular moving window in ArcMap was calculated and the covariate values were extracted in the continuous form. During the field observation, weather condition (WEA) and vegetation cover (VEG, field measured) are thought to influence detection probability. Thus, these covariates were used to model detection heterogeneity. Both of these variables were categorical (later converted to factors in R for the ease of analysis). All continuous covariates were standard to a zero mean and unit standard deviation prior to analyses.

Table 1. Environmental and anthropogenic variables with hypothesized effects and tested over multiple spatial scale.

Covariates	Scales tested	Hypothesized effect
Meadow/shrub cover	500m, 1km, 2km	Negative
Conifer forest	500m, 1km, 2km	Positive
Broadleaved forest	500m, 1km, 2km	Positive
Agriculture cover	500m, 1km, 2km	Negative
CTI	500m, 1km, 2km	Negative
Elevation (DEM)	500m, 1km, 2km	Negative
Settlement density	500m, 1km, 2km	Negative
Road density	500m, 1km, 2km	Negative
Roughness	500m, 1km, 2km	Negative
Slope	500m, 1km, 2km	Negative
Forest cover	500m, 1km, 2km	Positive
Bare area	500m, 1km, 2km	Negative
Snow cover	500m, 1km, 2km	Negative

2.4. GLM and Occupancy modelling

Due to a large number of predictor variables, a step selection method was employed to screen out variables which were less informative in predicting habitat use. In the first approach, a binomial univariate generalized linear modeling approach (GLM) was used to test the effects of scale on detection and occupancy/habitat use. The best performing scale for each variable was selected by modeling each variable at each scale and retaining only one scale which had the lowest AIC score. Through this approach, we were able to select the best scale for each predictor thought to highly influence habitat use. For the scale-optimized variables, multicollinearity was checked using Pearson's correlation (with threshold of $|r| < 0.6$) and subsequently removed a variable from the correlated pair higher AIC value. This further reduced the number of predictors which were still less informative than those retained for the final occupancy modeling.

In the next step, a hierarchical occupancy model was constructed using predictor variables from the previous step and by including an additional logistic regression model to account for the variation in detection probability under the Bayesian framework. Each grid was treated as our site. The transect observation record were binned into binary data indicating 1 for takin detection and 0 for non-detection for each grid. Our observation data consisted of repeated visits to each grid (n=3) with missing information (indicated as NA) and a combination of camera trap data (binary indicated by 1 for the station with takin image capture and 0 otherwise). Though camera traps were deployed for more than a month which would be appropriate for occupancy modelling on its own, the observations were combined into binary data for each station due to very low capture rate. Such data if analyzed under occupancy framework would yield estimates with high uncertainty and wide credible intervals. Takin is considered having a large home range size and encompasses large foraging area (Song *et al.* 2008). Thus, we assumed that the random movement of takin during the study period would have caused the change in occupancy status of sites (MacKenzie *et al.* 2005) even though our grids were designed based on putative home range to assume independence between sites. Thus, we cautiously interpret occupancy as the probability of use (i.e. the proportion of site used by takin at any time; MacKenzie *et al.* 2017). The final occupancy (ψ) and detection (p) probabilities were modeled as a function of covariates as,

$$\text{logit}(\psi_i) = \beta_{\text{random intercept}} + \beta_1\text{MEA}_i + \beta_2\text{CON}_i + \beta_3\text{CTI}_i + \beta_4\text{ROA}_i + \beta_5\text{ROU}_i + \beta_6\text{SLO}_I + \beta_7\text{SNO}_I + \beta_8\text{SNO(q)}_i$$

$$\text{logit}(\text{p}_i) = \alpha_{\text{intercept}} + \alpha_1\text{WEA}_i + \alpha_2\text{VEG}_i$$

Where, $\beta_{1\text{-}8}$ and $\beta_{1\text{-}2}$ are the slope estimates for occupancy and detection covariates at site i, respectively. Please see above for the expansion of parameters in the model above. 'q' refers to the quadratic term (non-linear relationship) tested. The variability in topography and management regimes across the survey landscape and study areas was accounted for by including a random intercept in the occupancy model with normal distribution priors ($\beta_{\text{random intercept}}$).

GLM models were implemented in R (R Core Team 2018) using the glm function. Bayesian models were implemented in JAGS v4.3 (Plummer 2003) called through R using the package jagsUI (Kellner 2018). We simulated MCMC (Markov Chain Monte Carlo) iterations for three parallel chains of 500000 each, discarding 100000 during the adaptation phase and retaining every 100^{th} sample for the economy of computer space and to reduce spatial autocorrelation. We used uninformative uniform priors on intercepts and slopes for both occupancy and detection probabilities. The convergence of the model was assessed through visual inspection of trace plots and Gelman-Rubin statistic for each parameter (< 1.1; Gelman *et al.* 2013). Further, we also checked if the priors were constraining our posteriors using the overlap percentage between them. The model fit was assessed through the posterior predictive check (PPC). The mean, standard deviation and credible intervals (CrI) were calculated from 15000 posterior samples. We interpret the magnitude and direction of parameter effects using the coefficient estimates and their credible interval range (zero included or not between the range but see also Ogle *et al.*, 2019).

2.5. Model validation

The prediction accuracy of the model was validated through k-fold cross validation (Hooten and Hobbs 2015). The data were divided into training (80%) and test (20%) subsets to predict whether our model was able to correctly classify takin presence and absence at each site. We employed five folded validation and compared expected detection at each site to the observed detection for each fold through accuracy rate (proportion of 1s and 0s correctly classified), sensitivity (proportion of sites with takin presence correctly classified) and specificity (proportion of sites with takin absence correctly classified). We present the results in the form of graphs in the Results section.

2.6. Prediction mapping

All the site covariates use in the model were rasterized to 90m pixel resolution in ArcMap. The percentage of land area for each class was calculated using the moving window radii of 500 m, 1km and 2 km. Two separate maps were produced for glm and occupancy models to compare the predictions. The beta coefficients from the final model output were used to predict habitat suitability across the study area. The coefficients were fit under logit link with standardized rasters and then back transformed using the following formula,

$$\psi = \frac{exp^{logit\psi}}{1 + exp^{logit\psi}}$$

Where ψ is the habitat use probability.

3. RESULTS

Takin evidences were observed in 50 out of 160 sites giving us a naïve estimate of 0.3 (number of sites with takin observation divided by the total survey sites). The mean transect length in the surveyed grids was 4.25 km; SD= 1.72 (range 0.5-11 km). The univariate glm revealed the following best spatial scales for predictor variables: meadow/shrub at 1 km, conifer forest at 2 km, broadleaved forest at 1 km, agriculture at 2 km, CTI at 2 km, elevation at 500 m, settlement density at 2 km, road density at 2 km, roughness at 2 km, slope at 2 km, forest cover at 500m, bare areas at 2 km and snow cover at 1 km. We used the Pearson's coefficient threshold of 0.6 (Figure 5) to employ strict screening of less informative predictive variables. Based on Pearson's coefficient and AIC score for predictor variables, following variables were retained for the final occupancy analysis: Meadow/shrub (1 km), conifer forest (2 km), CTI (2 km), road density (2 km), roughness (2 km), slope (2 km) and snow cover (1 km) (Table 2).

Table 2. Scale-optimization of habitat use covariates

Covariates	Scale
Meadow	1 km
Conifer forest	2 km
CTI	2 km
Road	2 km
Roughness	2 km
Slope position	2 km
Snow (linear)	1 km
Snow (quadratic)	1 km

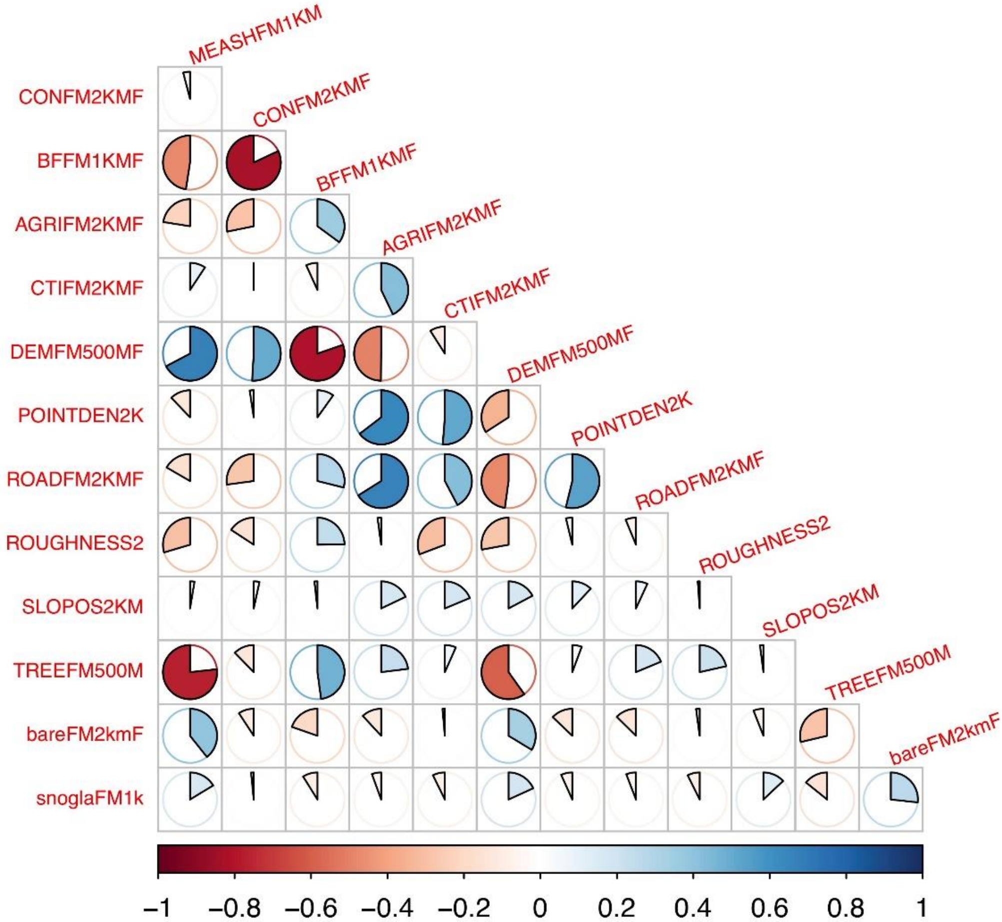

Figure 5: Pearson's correlation matrix of site covariates represented as pie charts. The size of pies corresponds to values between -1 and +1. -1 indicates a high negative correlation and +1 indicates a high positive correlation.

The posterior predictive check revealed adequate model fit (Figure 6; Bayesian p-value = 0.61). The hierarchical Bayesian model indicated a moderate correspondence between predicted and actual observations. The accuracy rate or the correct classification rate was 0.66 (95% credible interval 0.59 to 0.71), sensitivity or classification of the proportion of sites with takin presence was 0.50 (95% credible interval 0.38 to 0.62) and specificity or classification of the proportion of sites with takin absence was 0.73 (95% credible interval 0.65 to 0.79) (Figure 7).

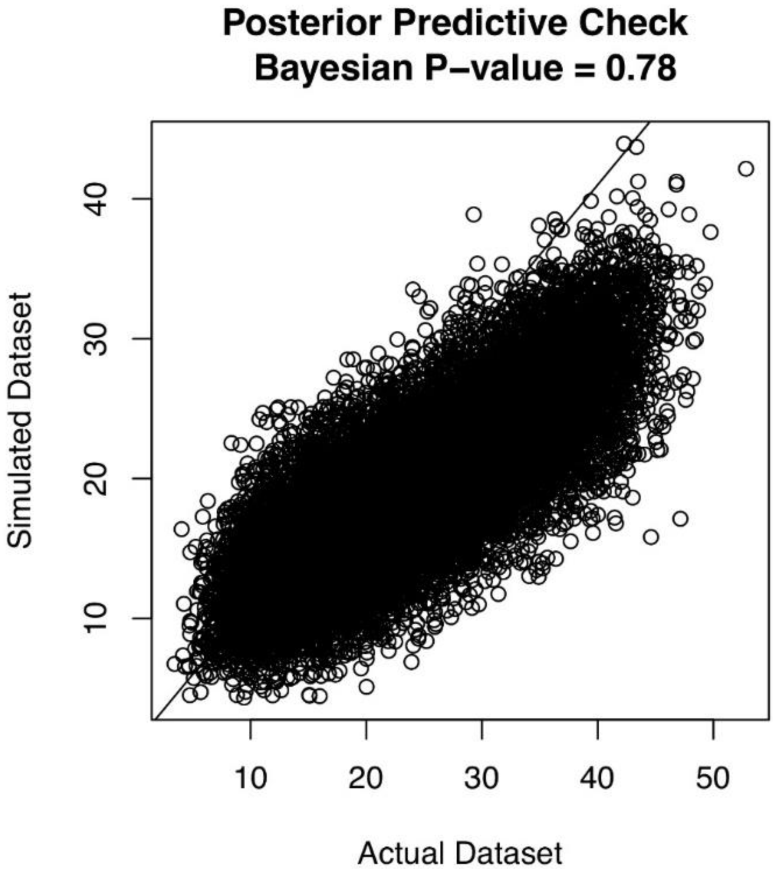

Figure 6: Chi-square discrepancy of observed versus simulated data. The posterior predictive check (PPC) is a measure of the Bayesian model fit and is indicated by the Bayesian p-value. Models with values between >0.05 and <0.95 indicate a good fit. The takin model had a reasonable fir with a p-value of 0.78.

There was a high variability in detection probability for different weather conditions and vegetation types (Appendix I). Detection probability was positively associated with sunny and rainy weathers and in broadleaved, conifer and mixed conifer vegetation types (Appendix 1). Takin habitat use was strongly but negatively associated with road density (β =-1.03, 95% CrI -2.68 to – 0.08) and slope (β =-1.52, 95% CrI -3.39 to –0.53) suggesting selection of habitat on gentle terrain and strongly avoiding roads. The habitat use was positively associated with conifer forest (β=1.24) and roughness (β =0.44) and negatively with meadow (β =-1.22), CTI (β =-0.59) and snow cover (β =-0.37) but the effects were weak with their credible intervals overlapping zero (Table 3; Figure 8; Figure 9). Though weak influence, the effects show the positive influence of forest cover and mixed topographical feature for takin in the winter habitat.

RESULTS

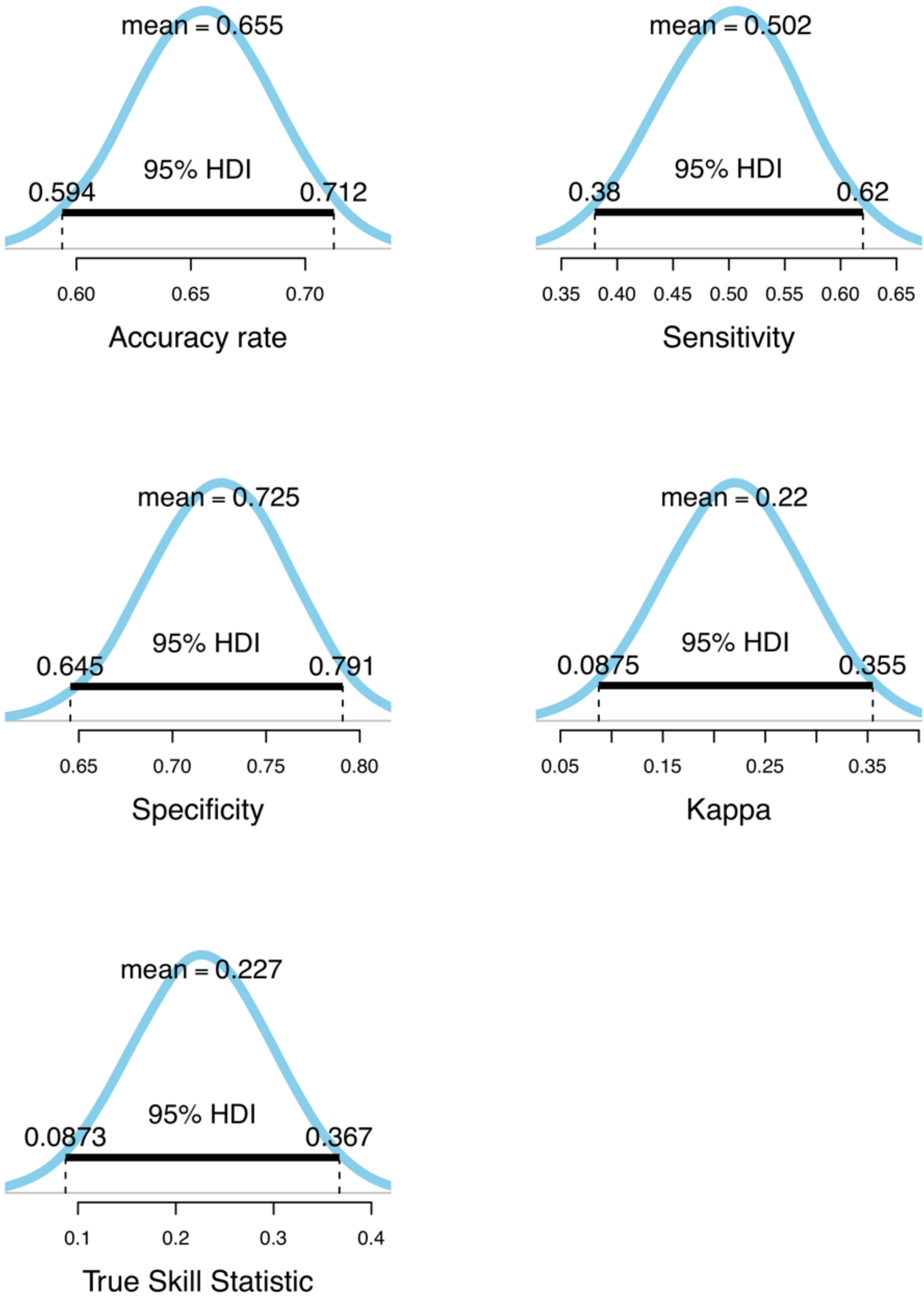

Figure 7: Results from the 5-fold cross validation of the occupancy model indicating the prediction accuracy of the model

Table 3. Parameter estimate of habitat use covariates (mean) and uncertainties (standard deviation and 95% Bayesian credible intervals). The covariates were standardized prior to analysis; hence the effect sizes are comparable amongst variables and represents the effect of 1-SD difference in the covariate values.

Covariates	Mean	SD	2.50%	50%	97.50%
Intercept	2.869	1.247	0.69	2.87	4.9
Meadow	-1.217	0.869	-3.26	-1.11	0.1
Conifer forest	1.243	1.213	-0.21	0.81	4.29
CTI	-0.59	0.867	-2.79	-0.4	0.63
Road	-1.026	0.642	-2.68	-0.92	-0.08
Roughness	0.437	0.932	-0.76	0.2	3.02
Slope position	-1.516	0.717	-3.39	-1.37	-0.53
Snow (linear)	0.256	2.749	-4.63	0.34	4.76
Snow (quadratic)	-0.365	2.854	-4.77	-0.66	4.7

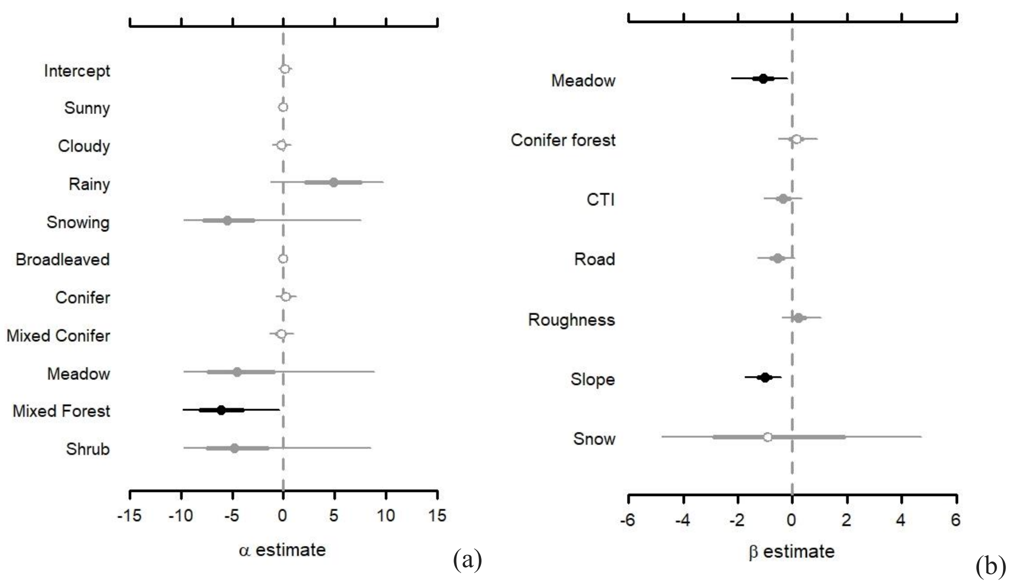

Figure 8: Untransformed beta coefficient plots of parameter effect on (a) the detection probability which was modelled as a function of weather and forest type, and, (b) habitat use probability modelled as a function of environmental and anthropogenic variables. The circles represent the mean effect, thick lines are the 50% credible intervals and thin lines are the effect within 95% credible intervals. Black plots represent that the 95% credible intervals do not overlap zero (indicating stronger effects).

The mean posterior habitat use probability of Bhutan takin in the winter habitat is 0.48 (sd=0.38, 95% CrI 0.21 to 0.83) (Figure 10, Figure 11). This shows that there is limited area of takin occupancy in winter habitat and entails stricter protection of these habitats from encroachment or land use change. The overall detection probability was 0.43 (sd=0.22, 95% CrI 0.24 to 0.71). While the naïve occupied sites (number of grids with takin detection) was 50, the overall estimated sites expected to be occupied by takins are 78 (sd=11, 95% CrI 60 to 102) which is about 1.5 X higher than the naïve, thus, emphasizing the need and importance of accounting for detection probability in such analysis.

4. DISCUSSIONS

4.1. Habitat use probability

Our analysis revealed that Bhutan takin habitat use is strongly and negatively associated with road density and slope. Weaker observations were made for conifer forest cover, meadow cover, topographic wetness, roughness and snow cover. Simply put, Bhutan takin selected its winter habitat in the coniferous forest with low road density and on gentle terrain. Meadow and snow cover are characteristic of summer habitat, which is found in higher elevations, so, the negative relationship is not unexpected.

The combined effort of two detection methods to record takin presence/absence in its wintering habitat, viz., transect and camera trap yielded a naïve estimate of 0.3 (50 sites). The mean posterior habitat use probability of Bhutan takin in winter habitats was 0.48, about 1.5 × higher than the naïve. While this low habitat use probability of less than 50% opens avenue for discussion, the increased probability as compared to the naïve estimate emphasizes the importance of accounting for detection error, and in doing so substantially improve the predictive ability of occupancy models (e.g. Penjor *et al*. 2018). Imperfect detection is inherently a common problem in ecological studies where animals absent from a site may be either due to permanent absence or present but unobserved during the survey (MacKenzie *et al*., 2002). Thus, discounting imperfect detection will lead to underestimating of species distribution or occupancy and will only give us superficial information when repeated observations are not made or lead to spurious habitat use estimates.

Takin being a migratory ungulate (Zeng *et al*. 2008; Guan *et al*. 2013; Wangchuk *et al*. 2016) exhibit different habitat preferences at different seasons of the year (Zeng *et al*. 2010; Wang *et al.* 2013). The habitat use probability of Bhutan takin decreased with increasing road density (Figure 9), indicating that they selected habitats away from linear infrastructure and human disturbances. Similar observations were made by Guan *et al*. (2013) for the Sichuan takin where no takin was observed in the habitats with road network. Sharma *et al.* (1995) also reported that takin inhabit remote areas away from high-density human habitation. This suggests that building roads closer to or in the takin habitats will not only alter the animal behavior but will also highly fragment the habitats.

Although roads are considered as a lifeline for economic development, the negative impacts on environment and biodiversity far outweigh its benefits (Laurance *et al.* 2014). Building roads into the wilderness area opens up opportunities for spawning secondary and tertiary roads which are consequently linked to habitat loss, fragmentation, poaching, illegal timber felling and environmental degradation (Laurance *et al.* 2014). The economic cost associated with long-term maintenance of roads and investment in mitigating erosion and landslide due to construction of roads in fragile mountain terrain

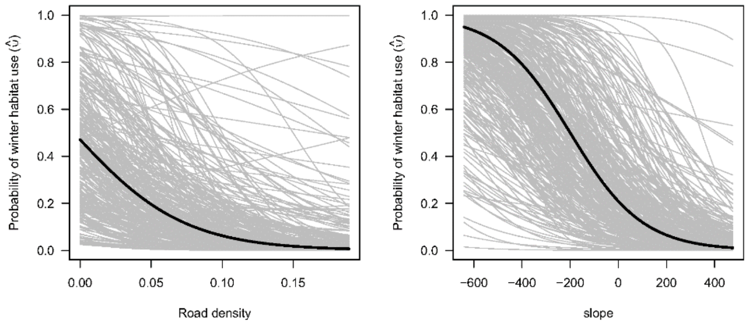

Figure 9: (a). Relationship between habitat use probability and site covariates with significant influence (95% credible intervals non-overlapping zero)

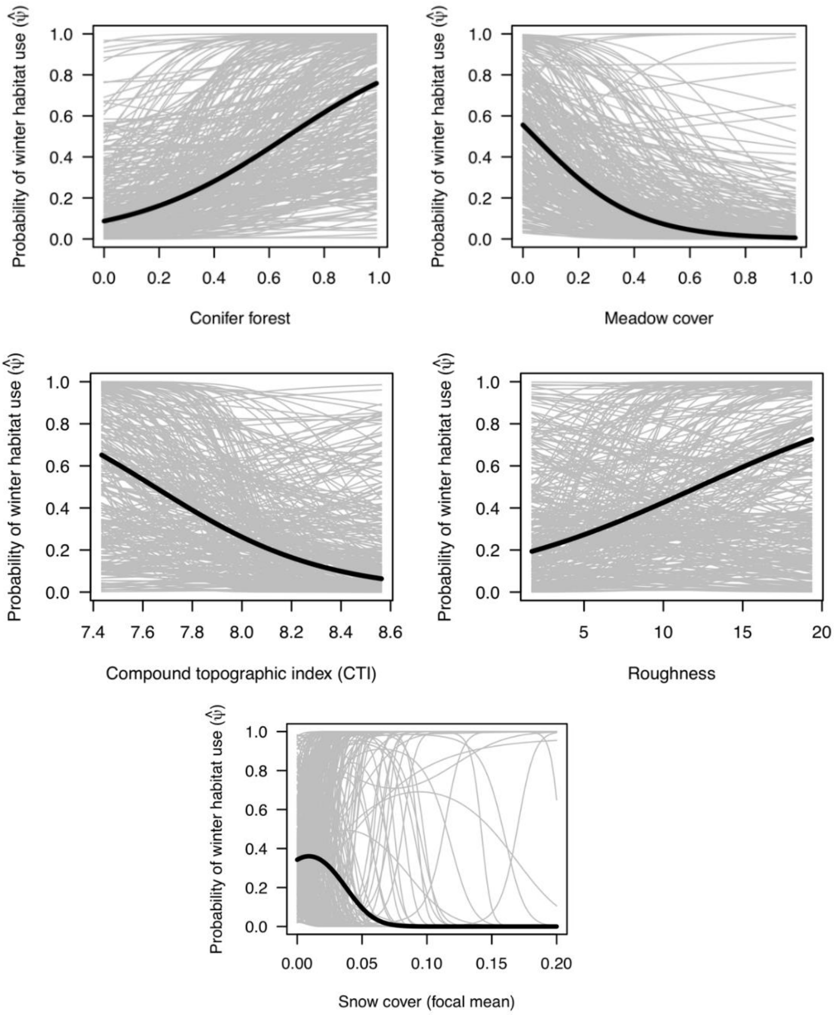

Figure 9: (b). Effect of non-significant site covariates on the takin site-use probability

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would increase economic debt in addition to causing environmental damage (Laurance and Arrea 2017). It has been found that the indirect revenue lost due to cascading impacts on the aquatic ecosystem, agriculture, recreation, aesthetics, and ecological restoration as a result of the construction of roads on steep terrain would entail an insurmountable amount of money to the government. Furthermore, World Bank has classed large infrastructure projects such as major roads as a blunt investment and one of those which accrue very meager benefit to poor people (World Bank, 1994).

Roads, besides causing collateral damage to the environment, have been the main cause of wildlife mortality due to collision with speeding vehicles (Bennett 2017) Numerous indirect impacts of roads on wildlife have been documented such as being physical barrier for movement and dispersal, causing displacement due to vehicle movement and noise, habitat degradation and fragmentation, loss of connectivity, alteration of behavior and activity patterns and ultimately affecting abundance and long-term persistence (Laurance *et al.* 2014; Bennett 2017). Keeping these in mind we recommend that instead of building new roads across the country, the government should focus on strategizing and building a few, if the need is dire, and take precautions to minimize environmental damage. We recommend maintaining the existing farm roads rather than building new because the current road network almost reaches every village in the country. Building new roads also entail high ensuing maintenance costs. This is apparent in the rainy season where poor-quality roads built on ecologically unstable terrains are washed away and hinders transportation sector. In a mountainous country where the terrain is geologically fragile, road impacts are pronounced on biodiversity than any other human-made infrastructure (Laurance *et al.* 2014). Further, we also recommend that environmentally amicable road construction methods be adopted. The current method of “cut-fill” involves high cost and is environmentally damaging. Thus, we strongly recommend adopting the cost-effective and environmentally less damaging method of building the road and learning and/or adopting from countries who have similar geographic terrain but have built robust mountain roads. Lastly, our finding of takin strongly avoiding roads indicate that the takin habitat is fragile and susceptible to change and for large-bodied bovids, contiguous undisturbed habitat is vital for foraging, finding mates and long-term persistence.

Slope also had a strong negative influence on Bhutan takin habitat use suggesting takin prefers habitats on gentle terrain (Figure 9). Takin being a large ungulate, their preferences towards gentler terrain could be attributed to the ease of movement while grazing because mountainous terrain with fragmented resources would decrease group stability (Powell *et al.* 2013). In terms of management, this shows that for our national animal, the suitable habitat is geographically limited and warrants stern protection of the remaining habitat from road construction and land-use change such as conversion of forest land to agriculture or permanent built-up areas.

DISCUSSIONS

Among the vegetation types, conifer forests had a positive influence on habitat use while meadows and snow cover had a negative influence (Figure 9). Such habits can be directly linked to the food availability because during the winter most of the alpine meadows are dry and scant of fodder resources (Song *et al*. 2008). Similar habitat preferences were exhibited by Sichuan takin in China during the winter months (Pengju *et al*., 2009; Guan *et al*. 2013) and Mishmi takin in India (Sharma *et al*. 1995) as coniferous forests can be associated with bamboo understory and other shrubs, which are preferred food resources. Winter fodder of takin consisted mostly of twigs and of evergreen leaves from woody species which are low in protein (Schaller *et al*. 1986). Therefore, our result support the findings from Zeng *et al*. (2010) and Wang *et al*. (2013) where they relate altitudinal migration of takin (Sichuan takin and Golden takin) to phenological development and changes in plants. Furthermore, Pengju & Endi (2006) suggested that food might play a key role in vertical migration of takin, whereas salt might also influence takin movements in summer. We did not account for grazing competition from domestic cattle in our study. We did not have data on grazing intensity from the study areas, but we presume that the untended lax herding practice, which is common in Bhutan, would impose a fierce grazing competition to wildlife and in particular to ungulates such as the Bhutan takin. The competition from grazing not only displaces wild ungulates but also poses a high risk of zoonotic disease transmission (Sangay *et al*., 2016). A foreseeable and grave repercussion of disease transmission would be an extirpation of entire local takin population.

The probability of habitat use increased with terrain roughness indicating that takin preferred mixed topographic features, albeit the relationship was weak. Ruggedness prove especially useful in areas where topography represents a key habitat component and taking roughness as a habitat covariate was found important for ungulates because it forms a powerful tool for analyzing habitat use by individual animals (Nellemann and Fry 1995). Further, rugged landscape is less suitable for human habitation and thus, are largely uncolonized. The topographic wetness or CTI, on the other hand, had a negative influence on takin habitat use and this can be closely related to the influence of soil moisture on the plant growth. This finding is congruent to takin selecting rugged landscape because wetness on rugged landscape is low compared to lower valleys. The moisture requirement for large ungulates is normally met from small streams and rivers.

The mean posterior habitat use probability of Bhutan takin in the winter habitat is 48% of the total study landscape (Figure 10), showing there is a limited area/habitat for takin occupancy in winter. With anthropogenic covariates like road density negatively influencing the habitat use of takin, the findings suggest we need stricter protection of the takin winter habitats from encroachment or land-use change. Disruption of migration routes has been identified as a potential threat to all takin species (Song *et al.* 2008; IUCN 2019), therefore, non-compliance to such findings will hinder the long-term

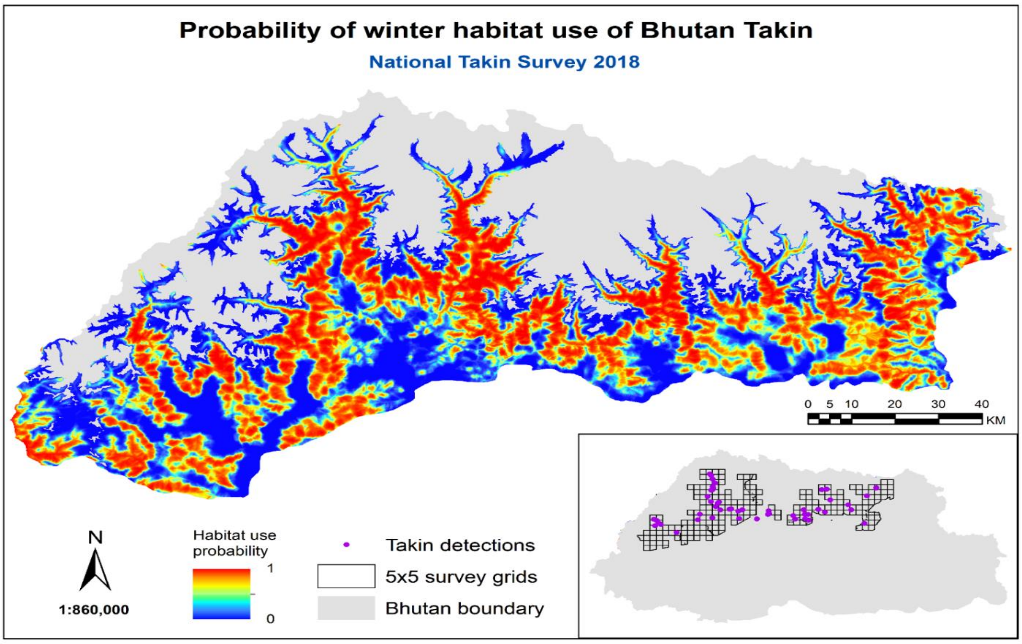

Figure 10: Probability of winter habitat use of Bhutan takin predicted across the study areas

conservation of the national animal of Bhutan. Other perceived anthropogenic threats of concern include resource competition with domestic yaks and disturbances (possibly through pack hunting) by feral dogs (Sangay *et al*. 2016; Sangay *et al*. 2019) in the winter habitats.

The predictive habitat use probability maps generated by the two methods showed a similar pattern of site use probability, which affirms that irrespective of scale, there was no significant methodological biases in the prediction. However, the map produced by occupancy modelling gives a clearer distinction between the highly suitable and less suitable pixels, which can be attributed to detection probability accounting imperfect detections. Further, there was a clear pattern of avoidance of human settlement in maps produced by occupancy models. Among the six different study sites, JDNP has the highest suitable winter habitat for takin followed WCNP and Wangdue Forest Division. Paro Forest Division, Thimphu Forest Division and PNP have very limited suitable winter habitat (Figure 11; Appendix II). However, the fact that these divisions have their northern border sharing with the two biggest protected area in the country gives us hope for better habitat contiguity and connectivity. Habitat suitability decreased as we move further eastwards and down southwards. This suggests that priority conservation efforts should be given to the prime habitats by reducing threats that jeopardize the habitat and takin population, but without compromising conservation intervention in the other potential habitats.

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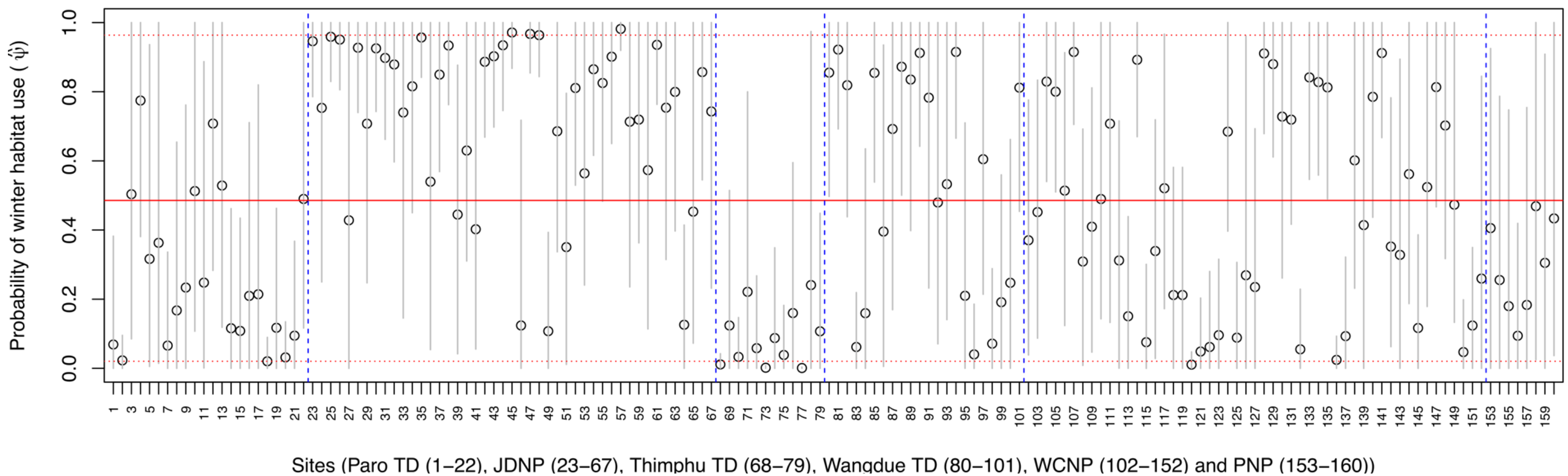
4.2. Management recommendations

Throughout its global range, deforestation, hunting, disturbance, and habitat fragmentation are pressing concerns (Song *et al*. 2008) for takin conservation. While hunting incidences are not reported in Bhutan, anthropogenic disturbance towards Bhutan takin is perceived as a serious threat (Dhendup *et a*l. 2016; Sangay *et al*. 2019). Being a large ungulate dwelling on alpine meadows during the summer and forested areas in temperate valleys during the winter, availability of food resources is also a serious concern, as the availability of food is thought to be one of the driving forces in takin migration (Pengju and Endi 2006; Zeng *et al*. 2008; Wang *et al.* 2013). The Bhutan takin often shares its habitat with yaks both during the summer and winter (Wangchuk *et al*. 2016; Sangay *et al*. 2019), and threats from human disturbances and grazing pressure from yaks are ever increasing. The overlapping use of the grazing grounds by yak and takin calls for further investigation and surveillance of ungulate diseases that could be transmitted in both directions (yak to takin, or takin to yak) affecting their health and survival.

With the infrastructure development such as road construction and installation of electric transmission lines at the fringes of takin habitats and unforeseeable risks of its penetration into prime habitats to reach the far-flung villages, it is vital that smart green infrastructure with precautionary measures are put in place to minimize disturbance to the habitat and takin. The survey has beyond doubt proven that road has an adverse negative impact on takin habitat use and similar finding was also observed by Sangay *et al*., (2016). With geographically limited habitat for our National animal, the government must strive to protect the habitat at any cost and refrain from establishing any permanent structure like roads or other human-made infrastructures. Roads, in general, have been found detriment to all taxa of mammals in Bhutan (Ugyen Penjor, unpublished data) and it provides further strength to our proposition of limiting road construction and instead to focus on maintaining the current road network. This necessitates urgency that policymakers should ponder twice before planning an alternate road in every part of the country when most villages are already connected. The ecological services and benefits that we enjoy as a result of habitat protection for wildlife must be taken into account while planning infrastructure development.

Anti-poaching and patrolling should be a high priority activity for the conservation of migratory animals. It was observed that Bhutan takin is highly susceptible to snaring and illegal trapping (Sangay *et al*., 2016). There are few incidental records of Bhutan takin being illegally hunted for meat. The species who use the same seasonal migration route annually is vulnerable and easy target of poachers. Therefore, efforts to monitor illegal activities along the migration route must be the priority. To garner supports of local communities in conservation, education and awareness programs should be taken up periodically. Community groups should be provided incentives and employment opportunities through the provision of improved cattle breeds, and alternative livelihood options by engaging community members in patrolling and anti-poaching. Population census and monitoring should be conducted by field offices as an annual activity. Research on habitat use, migration, and interaction with domestic animals should be undertaken to enhance information on the ecology of Bhutan takin.

Future climate predictions show that as a result of human-induced climate change, novel climates will be introduced, and current climates will shift (McGuire *et al*., 2016). For seasonal migrants like the Bhutan takin, novel climates will alter their habitat and make food resources scant. Large bovids require large unfragmented habitat to adapt to or respond to novel climates. While we might flaunt the total tree cover of 71%, we might be losing forest integrity due to the enormous amount of road construction. There is a tacit difference between having a high forest cover and unfragmented high forest cover. A high forest cover but fragmented and degraded is less suitable for wildlife and gradually results in defaunation ultimately leading to what has been described as an 'empty forest' syndrome (Redford 1992). Based on our finding, potential low-altitude forested habitat outside of protected areas should be incorporated into takin management plan and should be protected as inviolate takin habitats. With increasing human footprint and economic development, we will see interference with takin seasonal altitudinal movement. Thus, we recommend strict protection of takin and their habitat and meticulous planning of infrastructure development. With Bhutan takin highly revered as a unique creation of the great saint Drukpa Kuenleg and considering its significance as the national animal of Bhutan, our conservation efforts towards takin should be staunch and unconditional.



represent the mean and the gray lines represent 95% credible intervals. The solid red line shows the overall mean winter habitat use probability (0.48) of Bhutan takin. Blue dotted lines separate the number of sites in each study area.

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APPENDICES

Appendix I. (a) Intercept estimates of habitat use of Bhutan takin across six study sites (bAREA: areas are ordered in alphabetical order viz bAREA [1] = JDNP, bAREA[2] = Paro Division, bAREA[3] = PNP, bAREA[4] = Thimphu Division, bAREA[5] = Wangdue Division and bAREA[6] = WCNP). Study areas were included as a random intercept in occupancy model to accommodate differences in topography, vegetation and time of survey. (b) Coefficient estimate of detection probability. aWEA represents weather condition in alphabetical order and AVEG represents vegetation type in alphabetical order. aVEG = 0 because it was considered a reference vegetation type due to highest takin detection. Please refer to Methodology for the details.

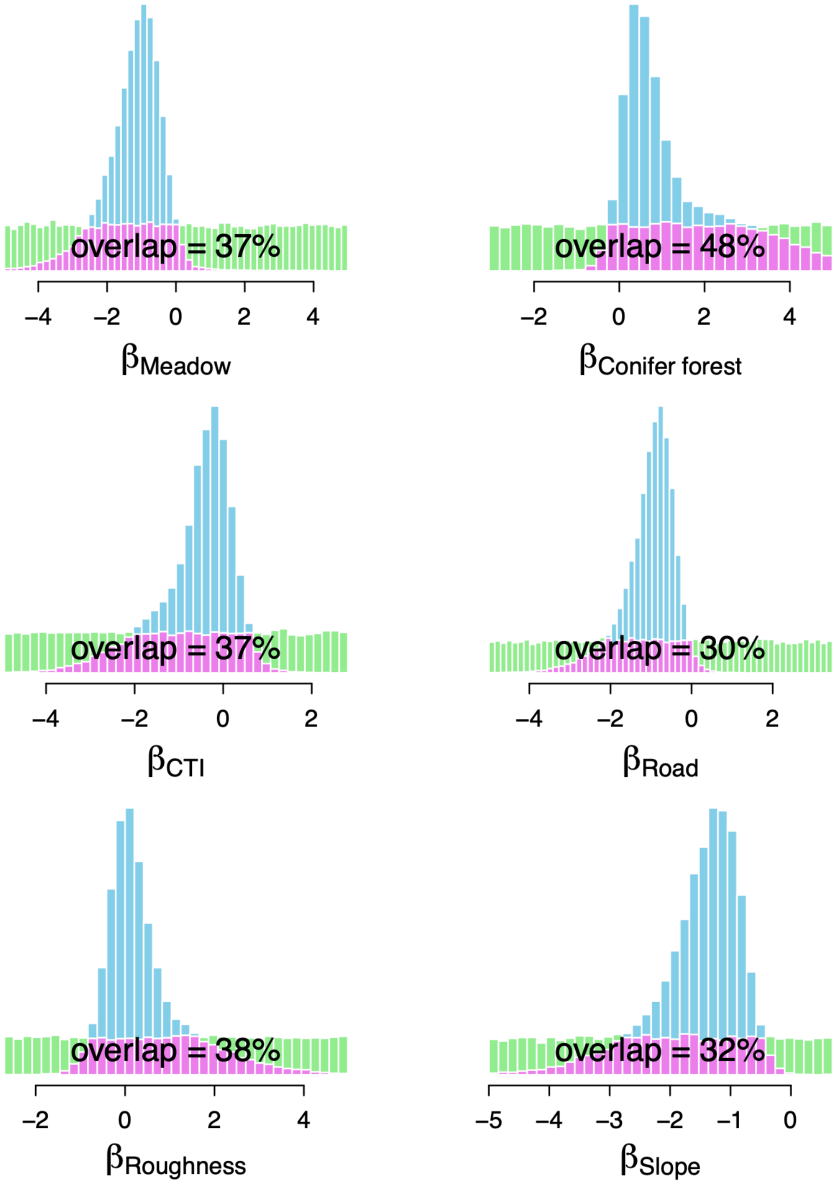
(a)

Covariates	mean	sd	2.50%	50%	97.50%
bAREA [1]	1.87	2.246	-0.66	1.10	7.71
bAREA [2]	-1.525	1.772	-5.36	-1.45	1.96
bAREA [3]	-1.17	1.982	-4.57	-1.34	3.37
bAREA [4]	-4.598	2.631	-10.79	-4.15	-0.66
bAREA [5]	-0.641	1.143	-2.42	-0.80	2.13
bAREA [6]	2.267	2.665	-0.81	1.40	9.19

(b)

Covariates	mean	sd	2.50%	50%	97.50%
aWEA[1]	0	0	0	0	0
aWEA[2]	-0.179	0.473	-1.086	-0.187	0.772
aWEA[3]	4.732	3.212	-1.249	4.884	9.74
aWEA[4]	-4.68	4.185	-9.753	-5.463	7.539
aVEG[1]	0	0	0	0	0
aVEG[2]	0.224	0.506	-0.75	0.219	1.238
aVEG[3]	-0.22	0.588	-1.359	-0.227	0.964
aVEG[4]	-3.343	5.107	-9.741	-4.528	8.837
aVEG[5]	-5.832	2.84	-9.818	-6.097	-0.374
aVEG[6]	-3.689	4.886	-9.736	-4.81	8.529

Appendix II. The overlap between the coefficients of priors and posteriors for winter habitat use of Bhutan takin.

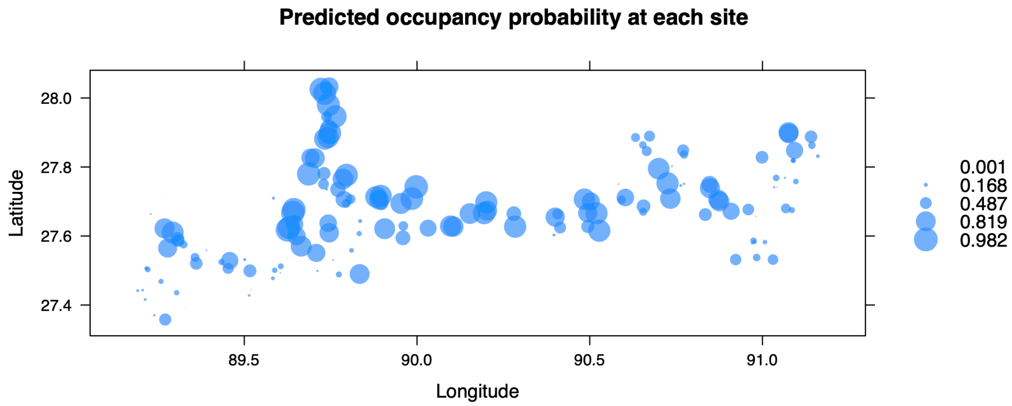


Blue bars are the posterior estimates, green bars are priors and purple bars indicate the percentage of overlap (the degree to which the priors contribute to posteriors).

APPENDICES

APPENDICES

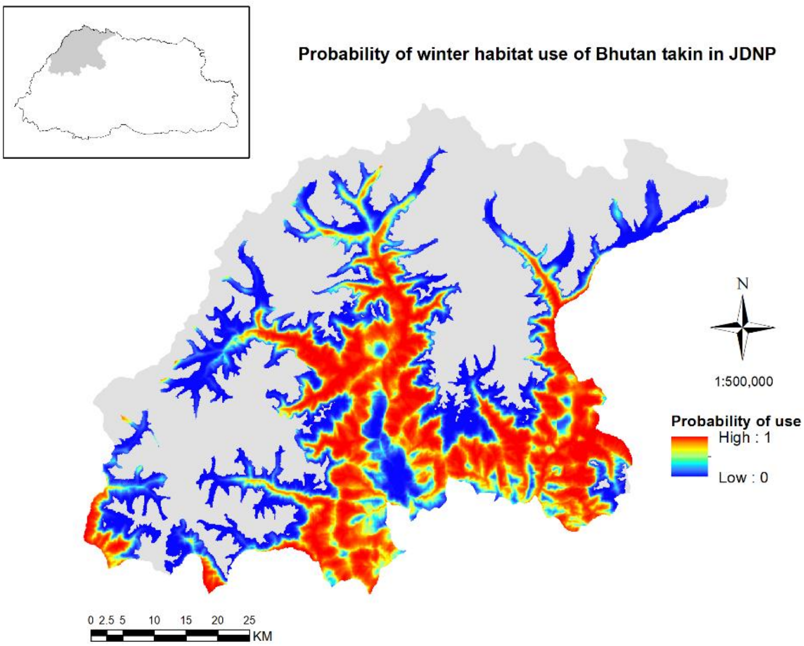
Appendix III. The predicted probability of takin occupancy (habitat use) probability.



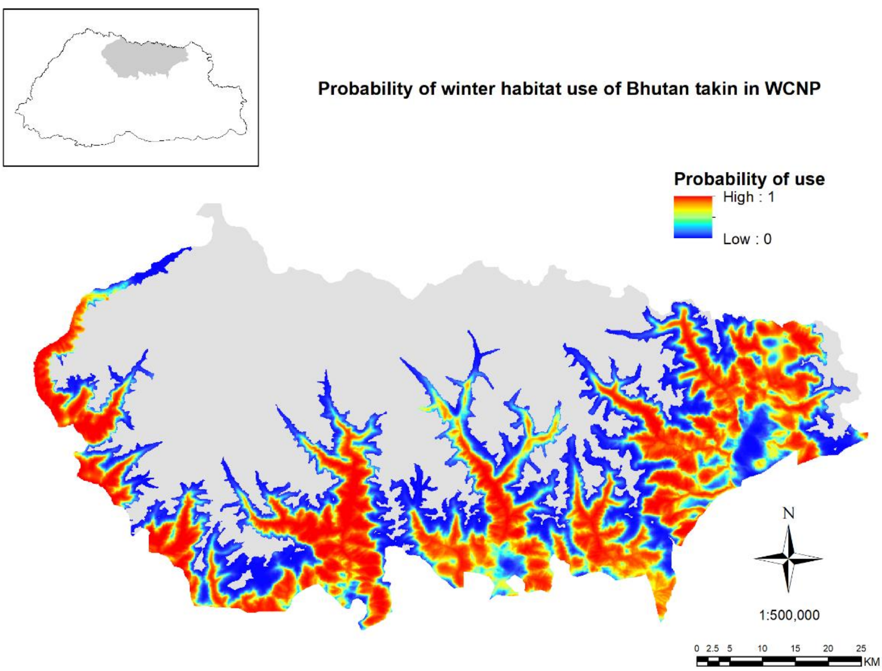
The bubbles represent the sites and the size of bubbles indicate the probability.

Appendix IV. Site wise winter habitat use probability of Bhutan takin.

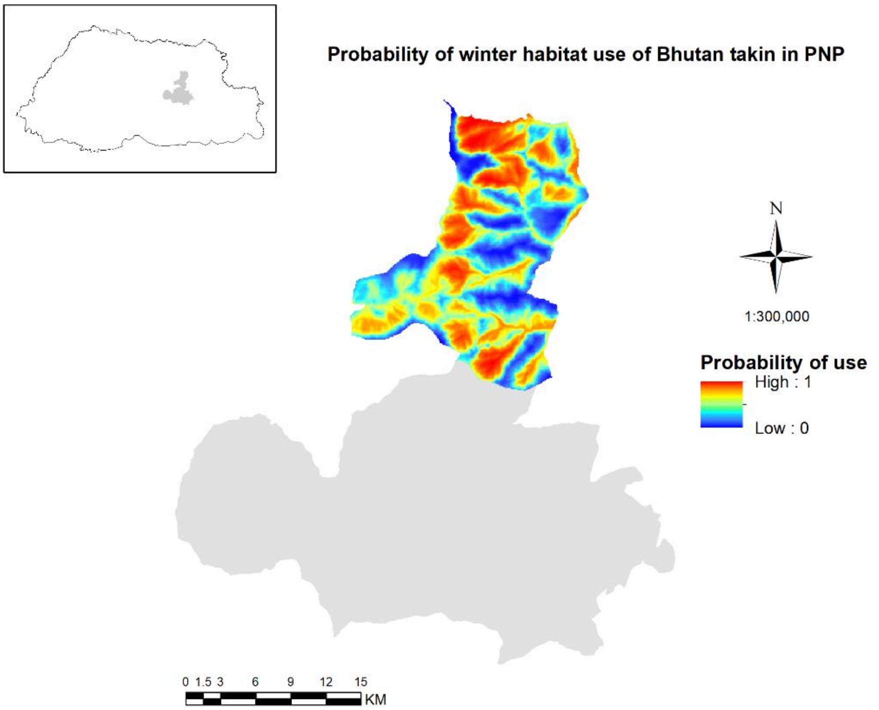
i) Jigme Dorji National Park



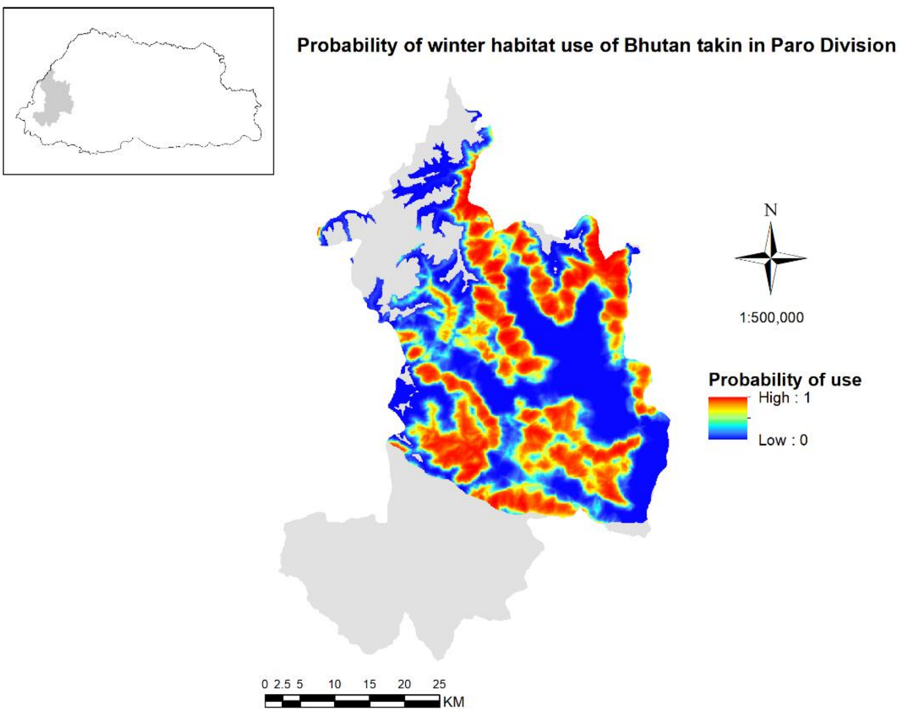
ii) Wangchuck Centennial National Park



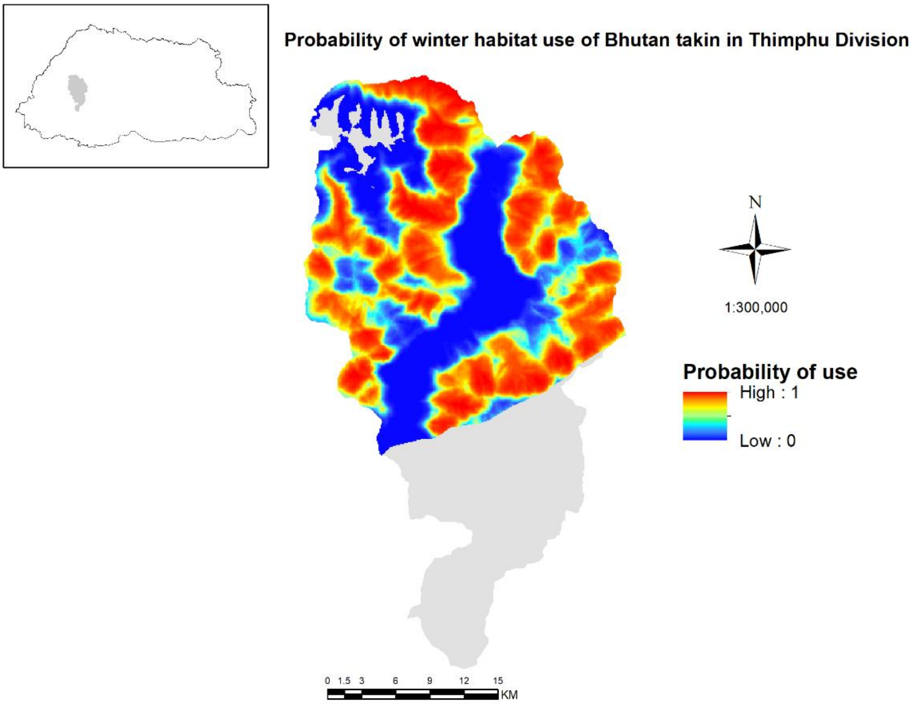
iii) Phrumsengla National Park



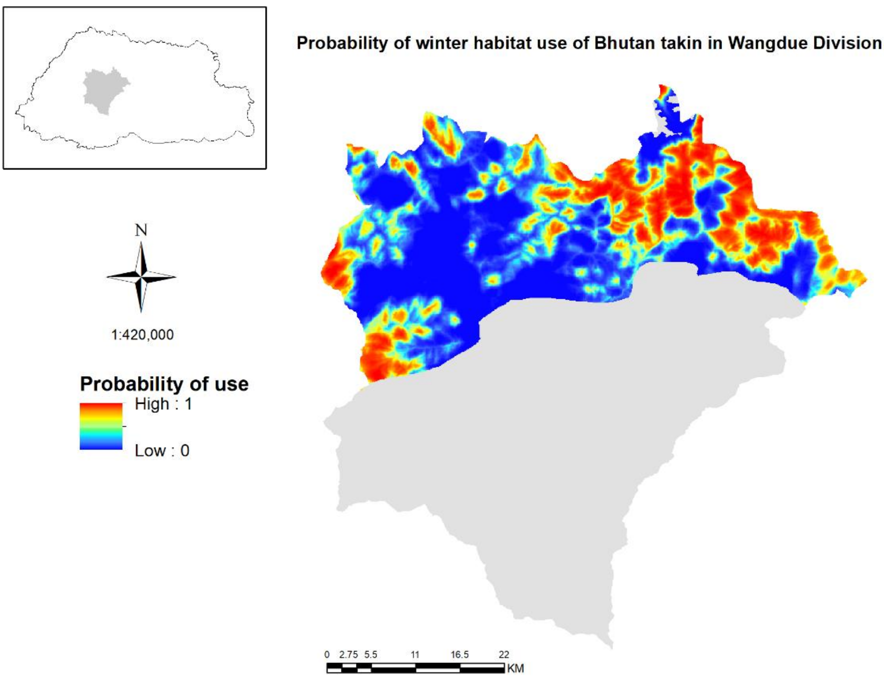
iv) Paro Forest Division



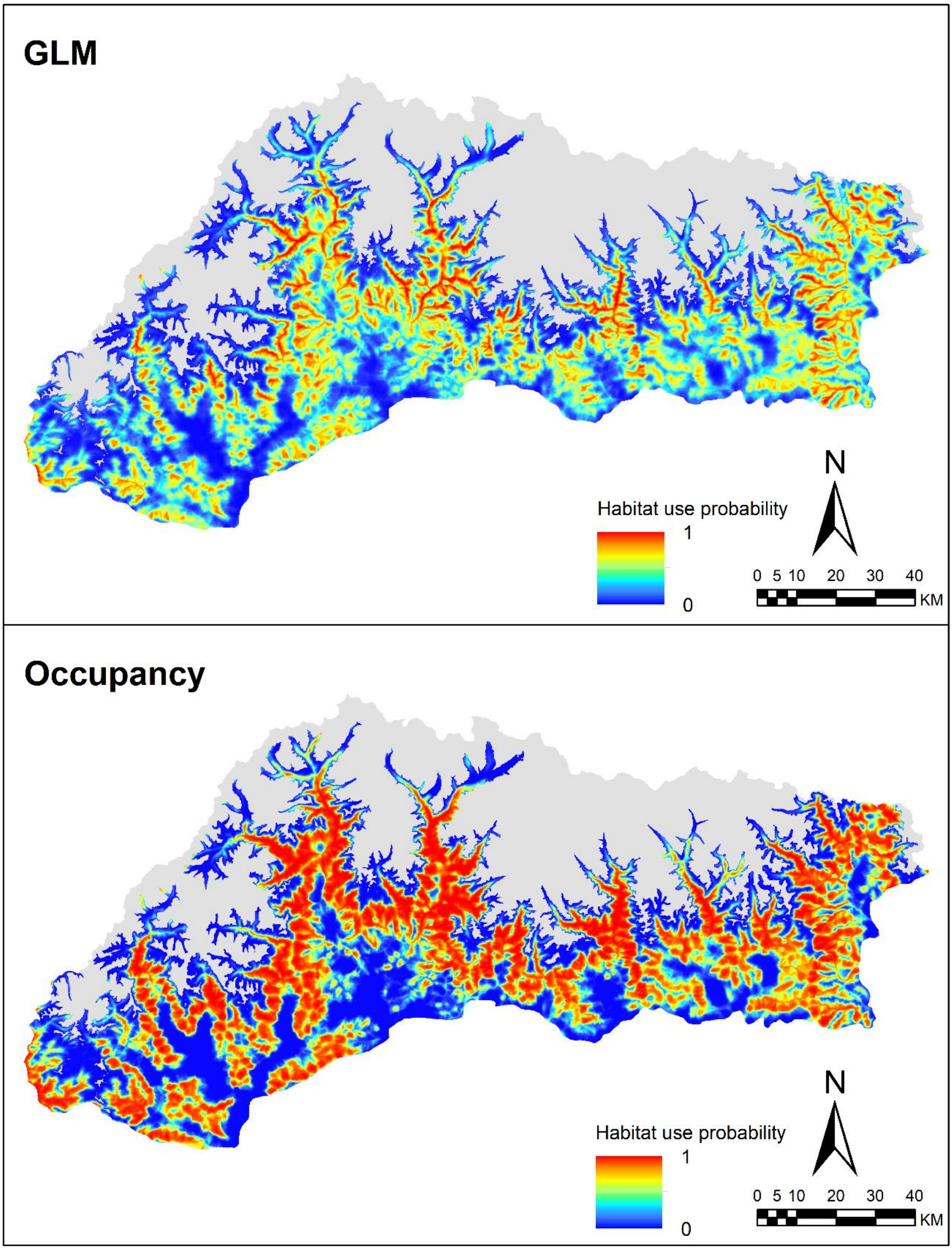
v) Thimphu Forest Division



vi) Wangdue Forest Division



Appendix V. Comparison between winter Habitat use probability from general linear modelling (GLM) and occupancy modelling.



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