frontiers

Supplementary Material

Modeling the distribution of bharal (*Pseudois nayaur*) in Bhutan

Bharal is the main prey of snow leopards in Bhutan. Occurrence data for bharal were collected during the national snow leopard sign survey from August 2014 to July 2015, and during a camera trap survey from October to December 2015 (Lham et al., 2016; Thinley et al., 2016). A total of 505 occurrences (422 from the sign survey and 83 from the camera trap survey) were recorded. To reduce sampling bias and model overfit, the occurrence data were spatially filtered to maximally one occurrence per 1 × 1 km^2 grid cell. This grid size corresponds to the spatial resolution of the bioclimatic data (Fick & Hijmans 2017; Watts et al., 2019). After spatial filtering, 99 occurrence records were available to predict bharal distribution in Bhutan.

Based on the ecology of bharal, we used livestock density, habitat type, elevation, slope, aspect, and the bioclimatic factors annual mean temperature (BIO1), annual precipitation (BIO12), and isothermality (BIO3) as predictive factors for bharal distribution (Chetri & Pokheral, 2005; Aryal et al., 2016; Filla et al., 2020). Three bioclimatic factors were selected due to their influence on bharal distribution in Nepal (Aryal et al., 2016). All the factors were calculated as for the modeling of snow leopard distribution (see main text). We removed highly collinear variables ($|r| > 0.5$) and used livestock density, elevation, and annual mean temperature to model bharal distribution. We followed the same approach for the modeling of the snow leopard distribution. We built an ensemble model based on seven species distribution models (SDMs; Figure S2) that had mean TSS and ROC values > 0.7 (Ahmed et al., 2020). The ensemble model had a TSS of 0.81 and a ROC value of 0.96.

Results of the ensemble model

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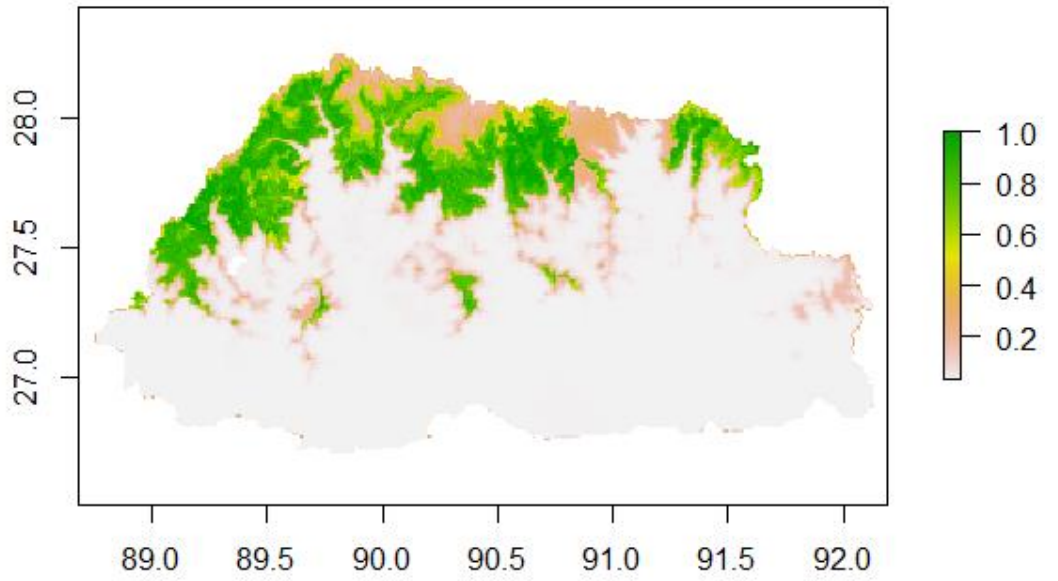

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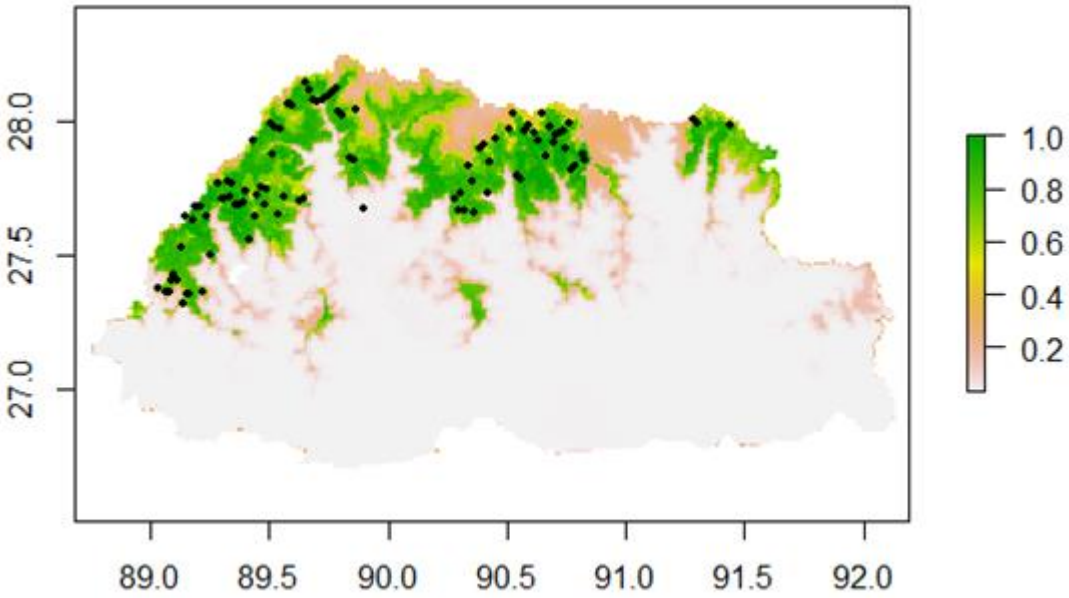
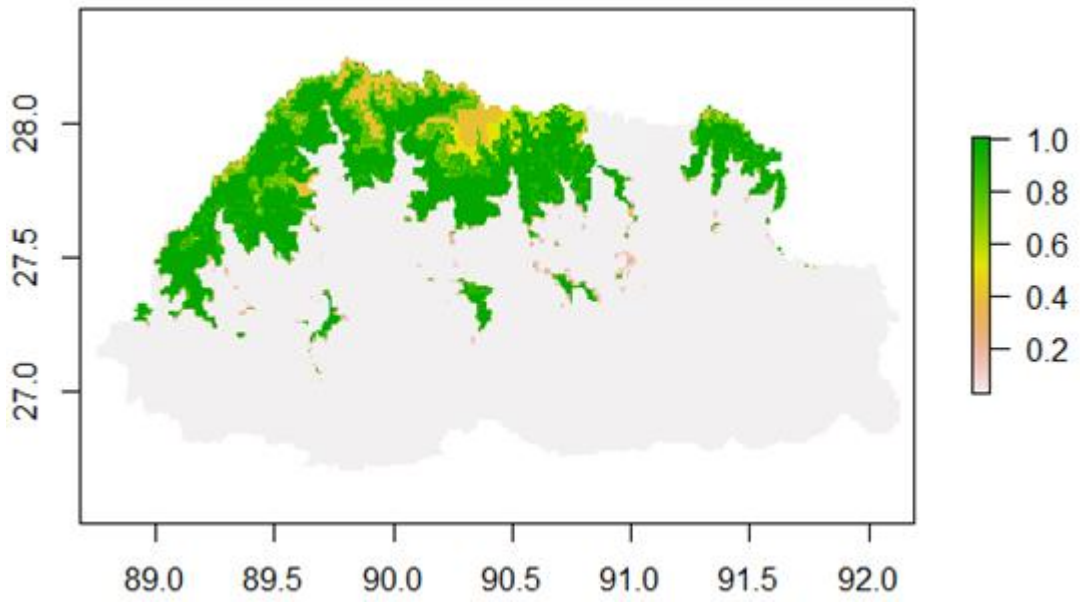


Figure S1 a. Predicted bharal distribution in Bhutan as a function of elevation, livestock density, and annual mean temperature (BIO1) from an ensemble model of seven SDMs (CTA, FDA, GBM, GLM, MAXENT.Phillips, RF and SRE). Black dots indicate bharal occurrence points overlaid on the distribution map. b. Prediction uncertainty of bharal distribution.

Results of the SDMs for the bharal

a. CTA



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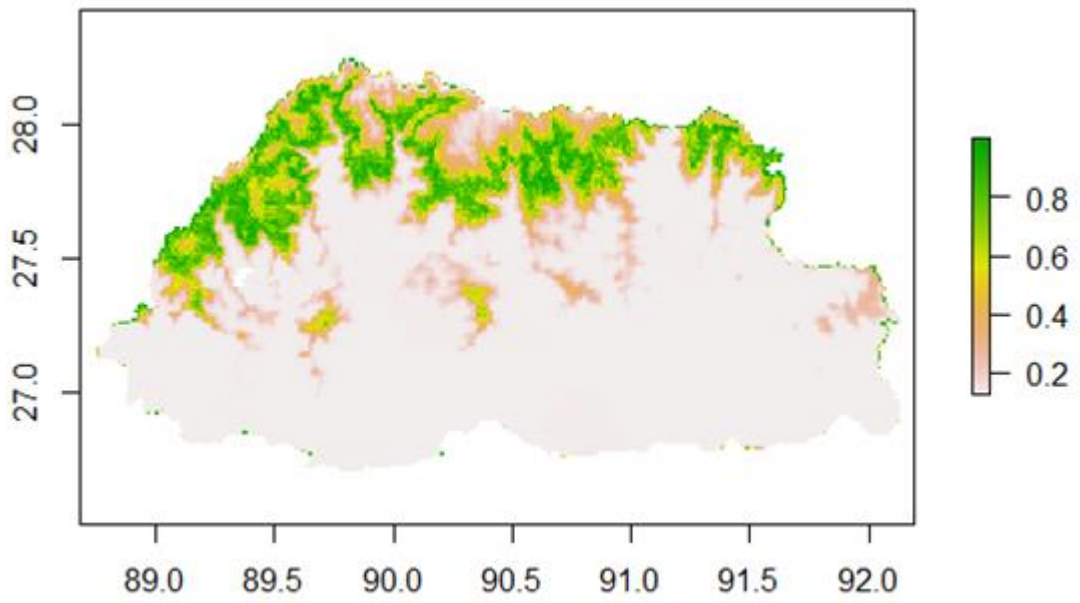
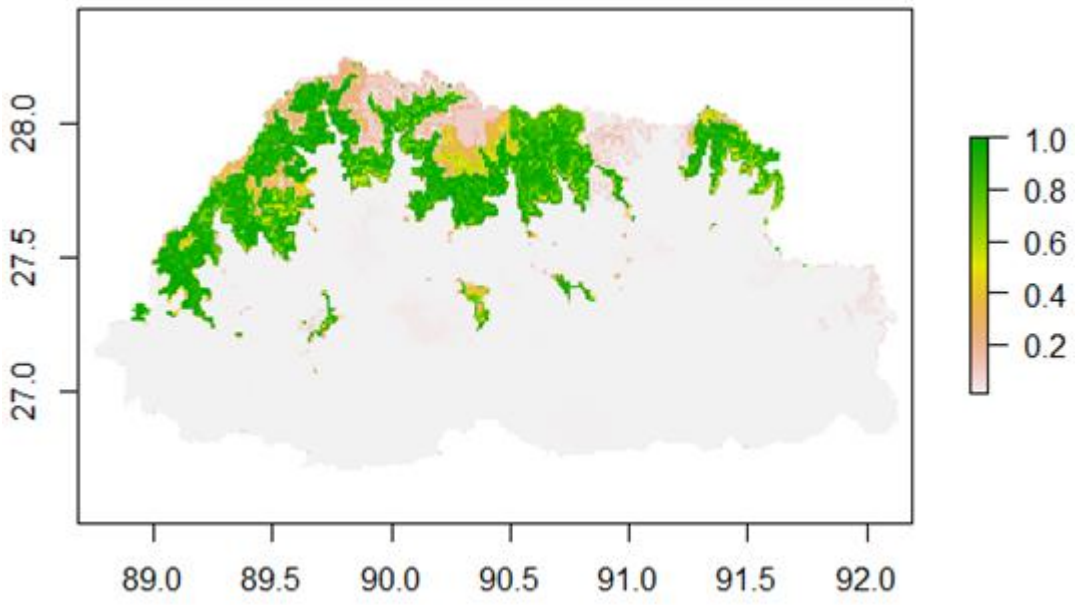


c. GBM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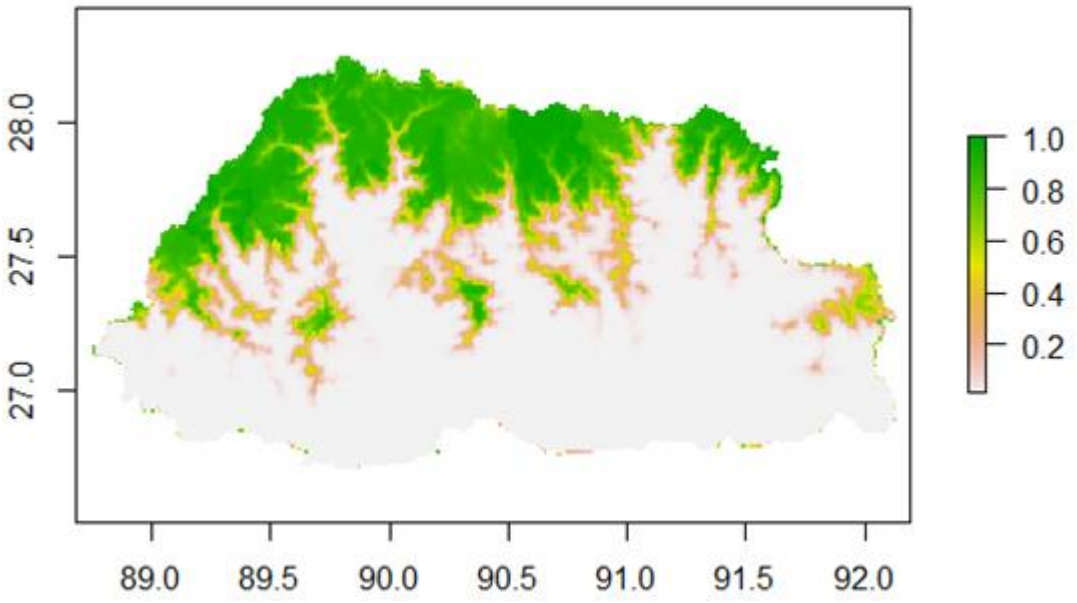
d. GLM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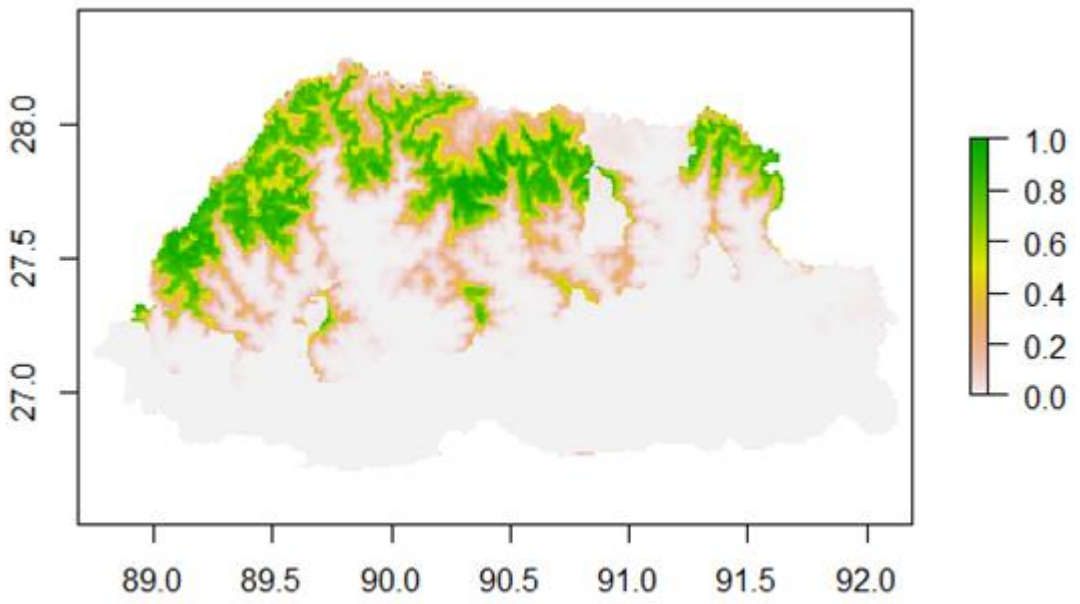
e. MaxEnt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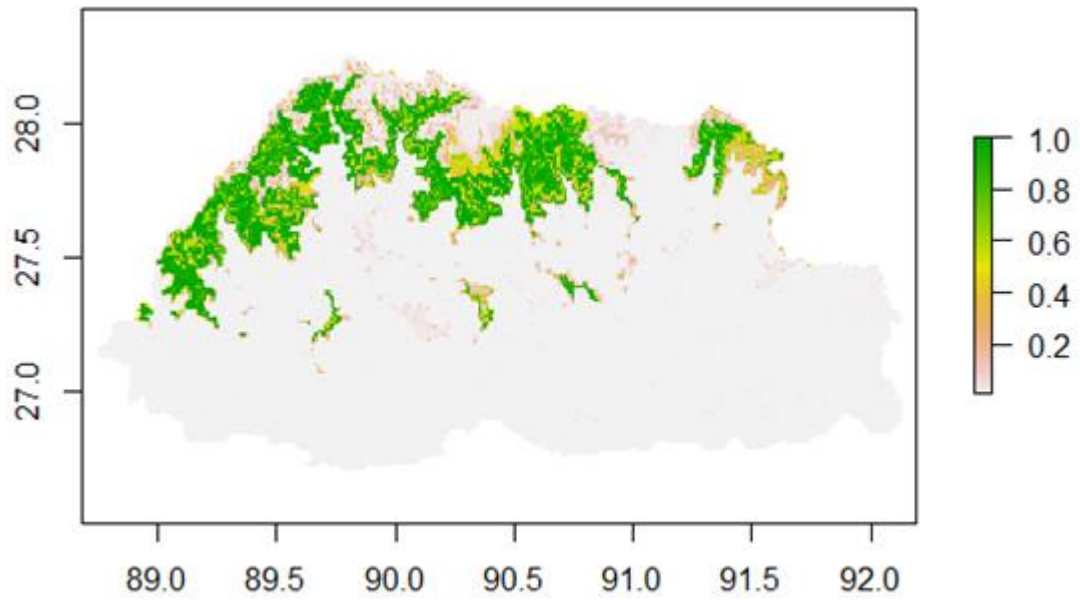
f. RF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g. SRE

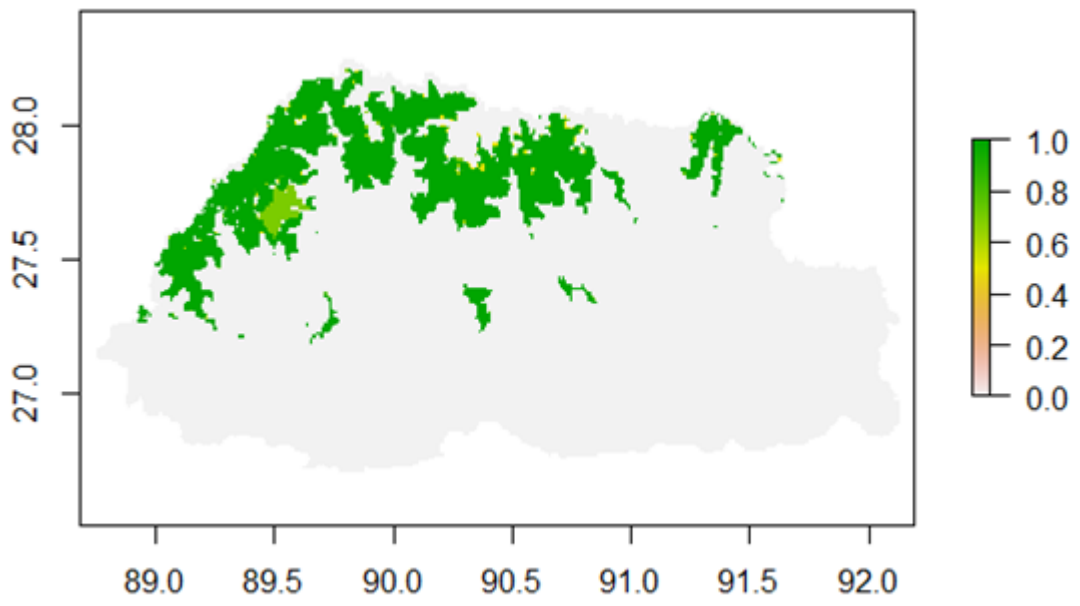


Figure S2. Predicted bharal distribution from seven SDMs: a. Classification tree analysis (CTA), b. Flexible discriminant analysis (FDA), c. Generalized boosting model (GBM), d. Generalized Linear Model (GLM), e. Maximum entropy (MaxEnt), f. Random forest (RF), and g. Surface range envelope (SRE). Predicted bharal distribution is modeled as a function of annual mean temperature (BIO1), elevation, and livestock density.

Main habitat types

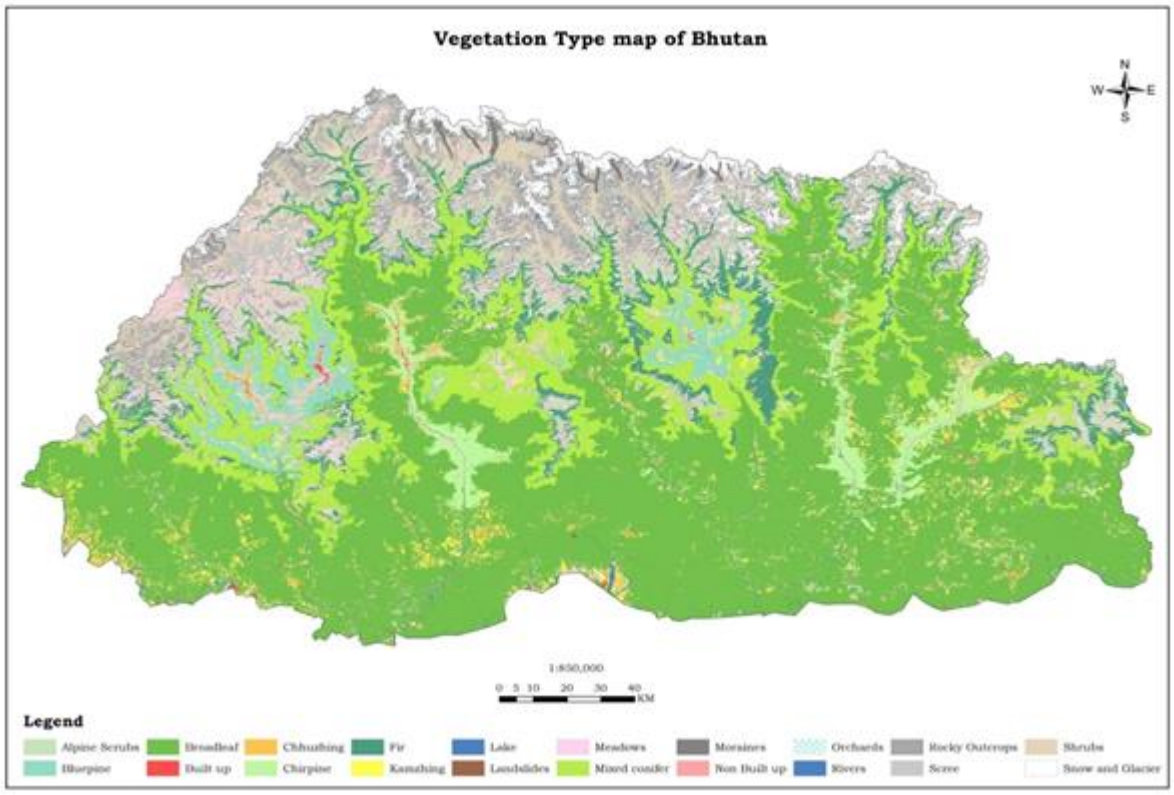
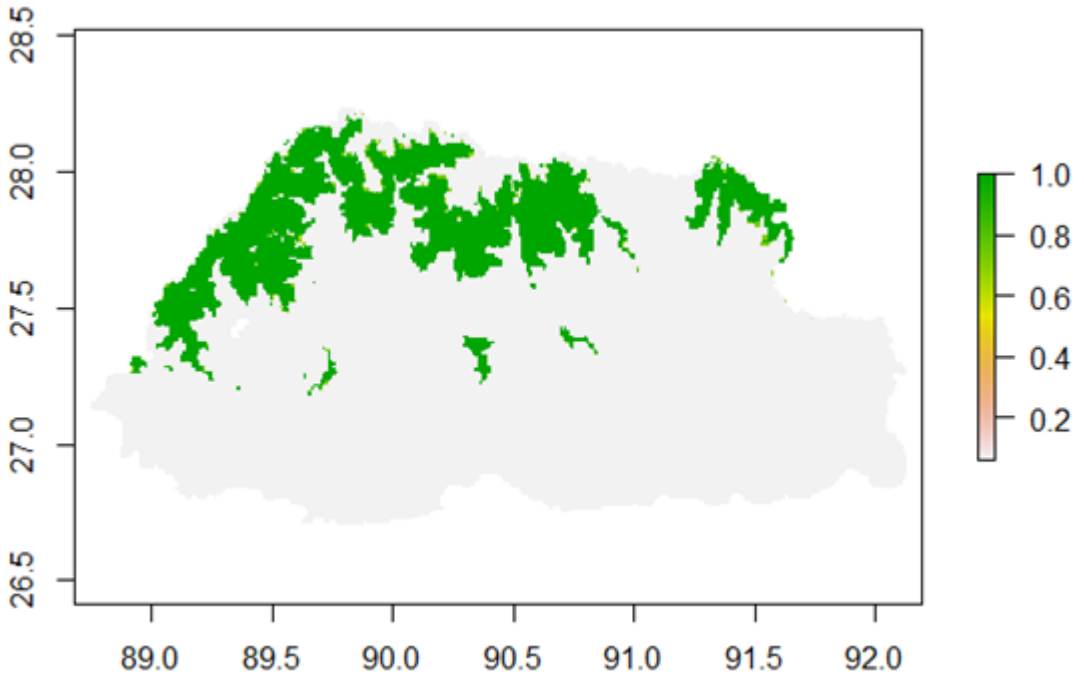


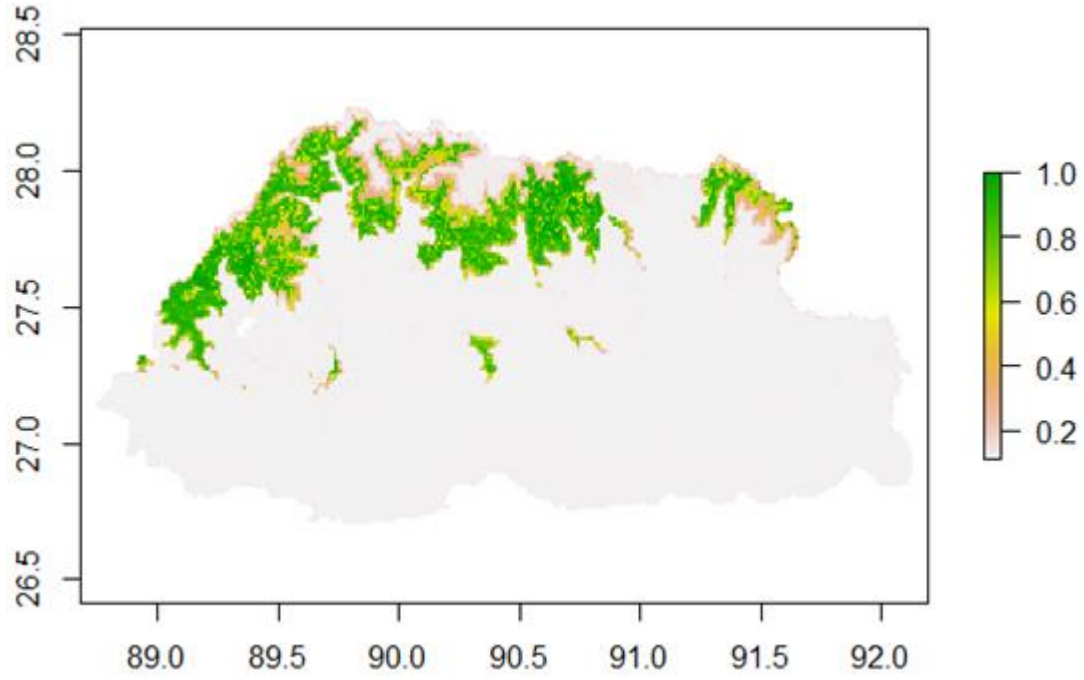
Figure S3. Vegetation map of Bhutan composed of 20 vegetation types (LULC 2016). For the analyses, we first cropped the map to include only our study area. Then, we merged the 20 vegetation types into five major habitat types: forest, rocky outcrop, meadow, scrub, and other.

Results of the SDMs for the snow leopard

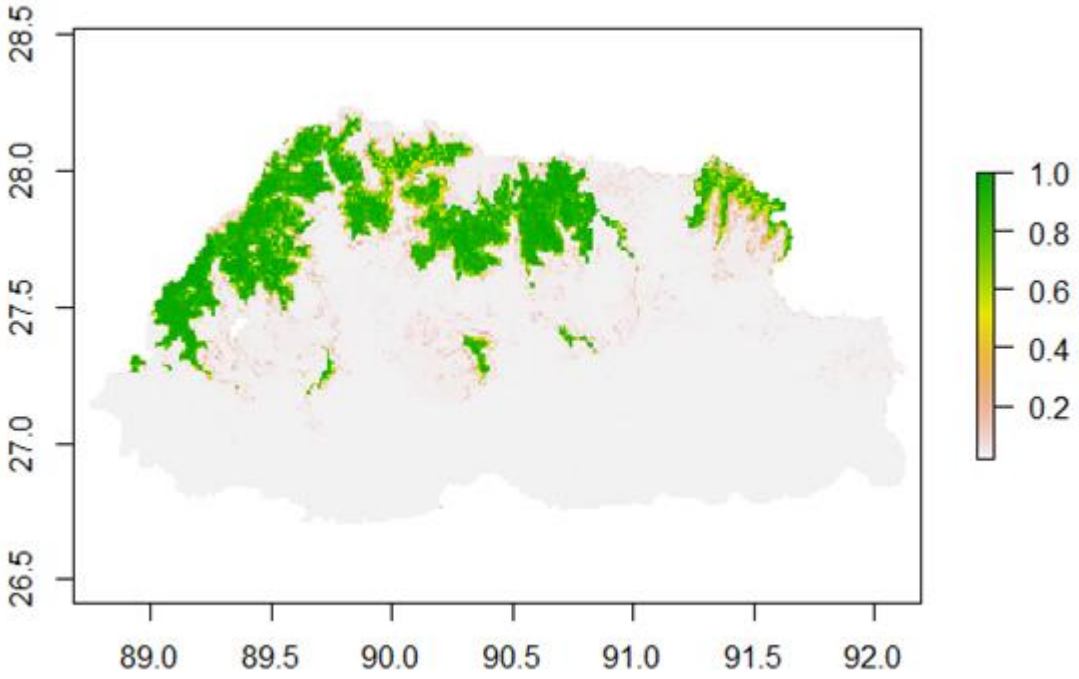
a. CTA



b. FDA



c. GBM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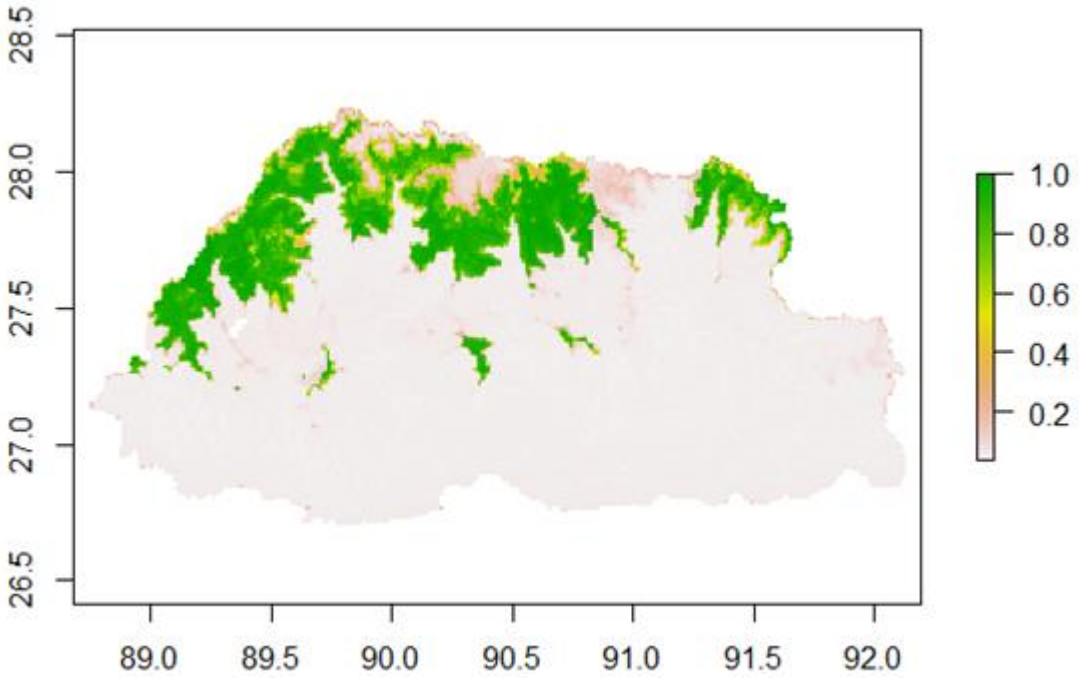
d. GLM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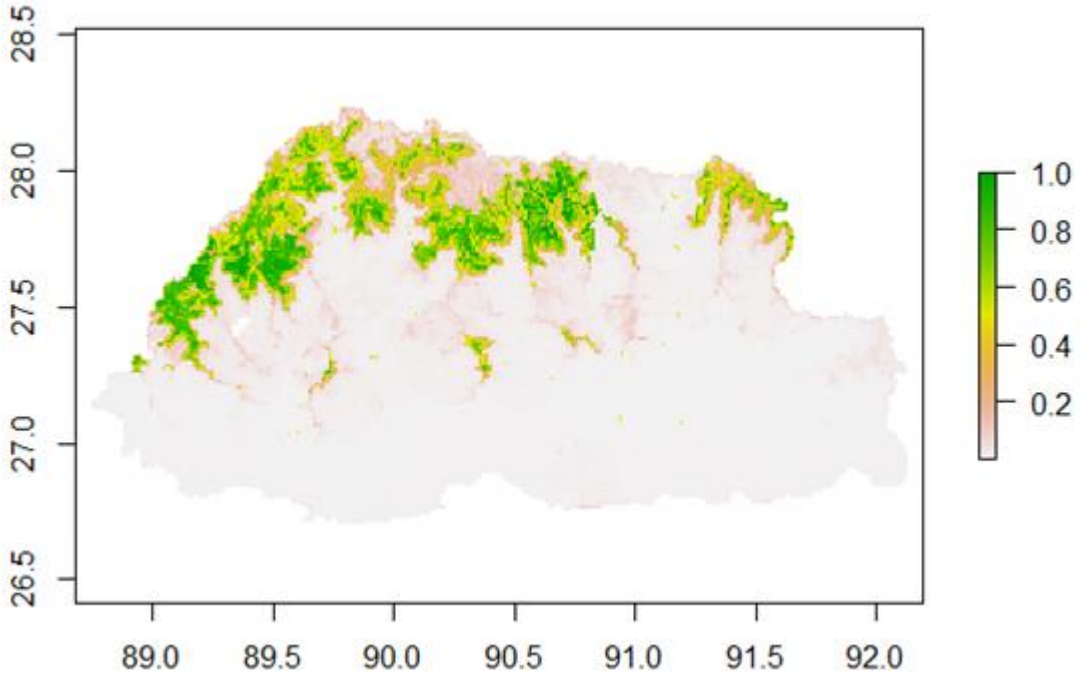
e. MaxEnt



f. RF

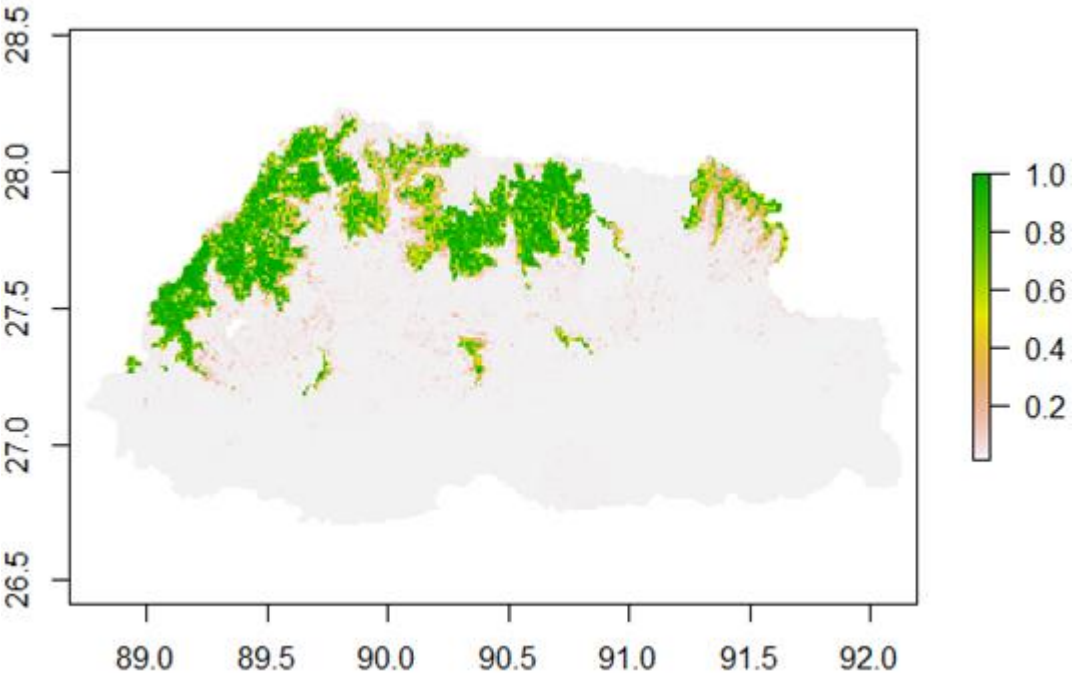


Figure S4. Predicted snow leopard distribution from six SDMs: a. Classification tree analysis (CTA), b. Flexible discriminant analysis (FDA), c. Generalized boosting model (GBM), d. Generalized Linear Model (GLM), e. Maximum entropy (MaxEnt), and f. Random forest (RF). Predicted snow leopard distribution is modeled as a function of bharal distribution, livestock density, and slope.

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