Conservation prospects of the Kashmir Red Deer (*Cervus hanglu hanglu*) beyond Dachigam National Park, in Jammu and Kashmir, India

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India's only extant red deer species, the Kashmir red deer, or hangul (*Cervus hanglu hanglu*) is restricted today to the confines of the 141 sq. km Dachigam National Park (NP) in Jammu and Kashmir, with about 200 surviving individuals. A continual population decline of hangul has necessitated the identification of relict populations and suitable habitats outside Dachigam NP, so that a meta-population approach to its conservation may be employed. Extensive surveys in 2008–2012 across the Kashmir valley, helped identify three distinct areas, where the presence of the red deer was confirmed year-round. Ecological Niche Factor Analysis results indicated that hangul exhibits high global marginality (1.24) and low global tolerance (0.28). Habitat suitability modelling predicted 610.75 sq. km area of conifer and temperate broad-leaved forests as highly (61–100%) suitable and 980.25 sq. km as moderately (31–60%) suitable, primarily in two distinct areas of Wanghat Naranag and Chandaji, which also showed presence of the hangul year-round. This suggests that apart from Dachigam NP, suitable habitats bearing hangul populations still exist in Kashmir valley (935.46 sq. km), emphasizing the need to urgently direct protection and conservation focus to these areas to conserve hangul successfully in this landscape.

Keywords: Corridor, habitat suitability, Hangul, Kashmir stag, red deer.

RED deer is one of the most widespread deer species in the world[1]. Yet several red deer species have gone locally extinct from Albania, Mexico and Nepal[2], and several others are severely threatened[3–5]. Among the latter, the hangul or the Kashmir red deer (*Cervus hanglu hanglu*)[6] is the only surviving sub-species of red deer in the Indian sub-continent, and also classified as critically endangered (IUCN Redlist, 2017). Once thought to be a single population cline, contiguous through Sindh and Iran, and converging with the Central Asian red deer populations, today these deer thrive within a single 141 sq. km protected area, the Dachigam National Park, in the state of Jammu and Kashmir harbouring about 200 individuals[7,8]. Its population within Dachigam also underwent a decline in the recent past, primarily due to poaching, habitat fragmentation and degradation[9]. Hangul is also the state animal of Jammu and Kashmir.

Most of what is known about hangul is from brief studies in Dachigam National Park[8–14]. Indeed, even population estimates represent largely the Dachigam population along with few adjoining protected forests such as Daksum, Thajwas–Baltal and Overa–Aru covering about 808.32 sq. km (refs 8, 9).

Despite recognition as the state animal, and their understood importance as a prey species[14,15], hangul continues to face increasing risks of local extinction[7,16]. Although hangul populations were historically known to occur in several areas outside Dachigam[11,17], long-term conservation focus on hangul has been confined only to the Dachigam population, and a majority of these sites have lost populations substantially over recent years. One study also highlighted a steady population decline at around 5% per annum in the Dachigam population[8]. Such a situation of geographic isolation poses high risks of local extinction due to inbreeding bottlenecks[18,19], as well as stochastic events, such as disease outbreaks[8]. Indeed, a recent study on the genetic structure of the Dachigam population also suggests that the hangul population in the park is highly inbred[16].

Genetic isolation and inbreeding risks are important factors that are implicated in the risk of local extinction[20]. It is in this light that identification and studies of meta-populations are today utilized to understand and conserve a variety of species[21–24]. Consequently, studies have also focused on factors affecting metapopulation dynamics of various species such as, source and sink systems[25,26], migratory or dispersal corridors[27,28] as well as suitable habitat availability[29,30]. Although relatively recent, these and several other studies exemplify the importance of understanding population structures of a species at landscape levels, before developing conservation and management

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strategies. In the case of hangul, it is of paramount importance to realize that the Dachigam population is vulnerable to extinction risks, and to resolve whether sub-populations still do exist outside Dachigam. Also critical is to understand the availability of sufficient suitable habitats to facilitate re-colonization and thus, the conservation of hangul. The present study highlights specifically, the extent of suitable habitat availability, and the interconnectivity of such habitat with Dachigam National Park. This information is expected to greatly help in the recovery of hangul or the Kashmir stag, through revision of management strategies incorporating protection of identified sub-populations and their vital habitat patches, in the state of Jammu and Kashmir.

Materials and methods

Study area

The findings presented here emerge from extensive surveys conducted from 2008 to 2012. Based on the available literature and anecdotal accounts of hangul presence (Figure 1, Shikar map of 1940), 33 sites within 17 watershed catchments in the Kashmir valley were shortlisted and local communities were interviewed extensively for first-hand accounts of hangul presence (Figure 2). Based on data gathered from the secondary survey, six watersheds were identified as potential relict sites where hangul still occurs year-round – Chandaji–Diver–Lolab, Guraiz–Telail, Wanghat–Naranag, Rajparian–Daksum, Overa–Aru and Thajwas–Baltal. These catchments largely comprise a gradient of alpine habitats, ranging from mixed alpine grasslands and meadows with juniper patches, to coniferous and broad leaved forests, and also harbour several large mammalian fauna, including the musk deer (*Moschus* spp.), Asiatic black bear (*Ursus thibetanus*), common leopard (*Panthera pardus*) and red fox (*Vulpes vulpes*).

Out of the six shortlisted catchments, five catchments were surveyed extensively (the sixth catchment could not be surveyed because of security restrictions) through trail surveys to detect evidence of hangul presence. Presence of the species (through indirect signs and direct sightings) as well as various habitat characteristics were recorded within each surveyed catchment. Geographic locations

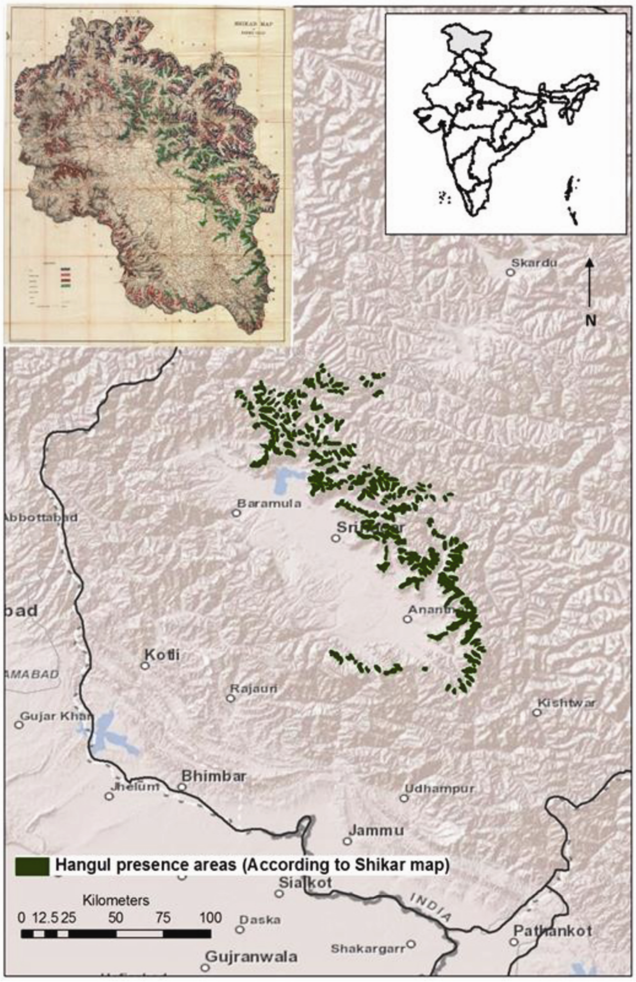

Figure 1. Digitized areas of hangul presence as depicted in Shikar Map of 1940 (left inset), overlaid on a shaded relief map of Kashmir valley.

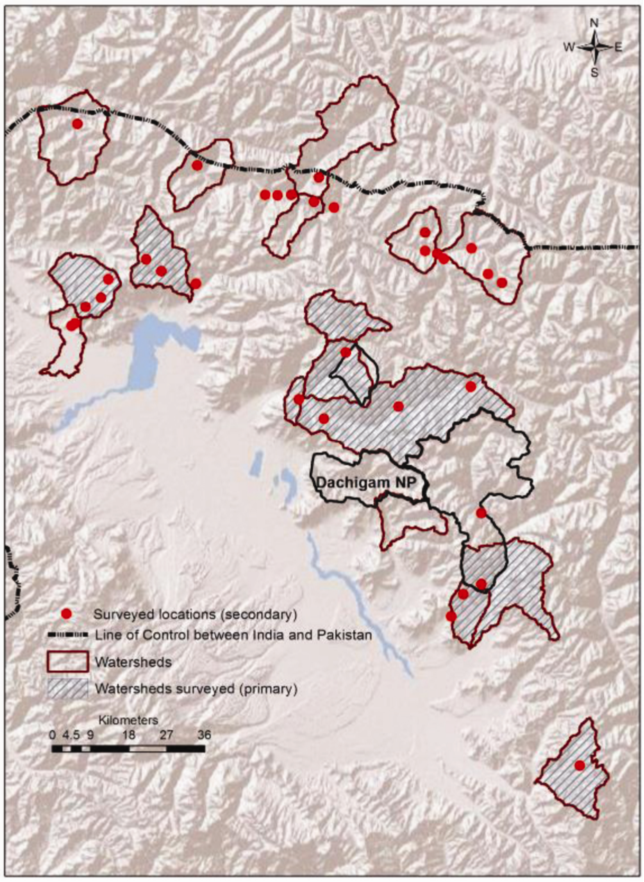

Figure 2. Boundary of catchments surveyed for secondary information of hangul presence and protected areas overlaid on a shaded relief map of Kashmir valley.

Figure 3. Evidences of the Hangul (***a***) pellet cluster (***b***) Hoof mark (***c***) tree-scrape and (***d***) direct sighting in Wanghat–Naranag.

with signs of hangul presence recorded from these surveys were used to develop a habitat suitability model for the entire Kashmir valley. Additionally, geographic locations of sites from which hangul were rescued by the Department of Wildlife Protection, Jammu and Kashmir ($n = 6$) as well as opportunistic records of sightings by local villagers, army personnel and forest department staff ($n = 19$), from 1993 to 2012, were used to evaluate the habitat suitability model.

Field methods

Individual watershed catchments were selected as the unit of assessment as mountainous watersheds follow clear delineations through natural boundaries of elevated ridges. Within each selected catchment, surveys were conducted along natural trails and paths, and all secondary signs of presence of hangul and other mammals were recorded, geo-tagged and photographed [pellets ($n = 21$) and tracks ($n = 30$)]. Hangul pellets were differentiated from the pellets of domestic ungulates (e.g. sheep and goat) by their characteristic large sizes and bullet like shape with one sharp tapering end (Figure 3 *a*). Similarly, hangul tracks were positively identified through their characteristically large and flayed hoof prongs, with tapering tips (Figure 3 *b*). All hoof impressions below a minimum size of about 8 cm and/or with any other ambiguities were rejected. Often, hangul presence was ascertained based on spatial aggregation of multiple sign types ($n = 12$), such as hoof marks, pellets, feeding signs and antler rubbing signs on the trees besides direct sightings (Figure 3 *c* and *d*). Surveys were conducted within select sites twice a year, i.e. in the spring and winter seasons.

Analysis

Habitat suitability modelling

Since false absences can induce considerable bias into models designed to evaluate or predict habitat use by a species[31,32], a presence-based method was adopted, as it does not make strict assumptions about absences. Ecological niche factor analysis (ENFA) was employed using the program Bio Mapper[31,33], which evaluates species occurrences in relation to a background matrix of environmental (habitat) characteristics called Eco-Geographic Variables (EGV)[31].

We determined the extent of habitat suitability model by connecting all 17 catchments where preliminary surveys had been carried out. Sixty three connecting catchments (situated in between the surveyed watersheds) were added to complete an inter-connected landscape. After collation, the entire stretch represented a considerable area (8931.44 sq. km) of the Greater Himalayan range situated as an arc, extending from North to East of the Kashmir Valley (Figure 4). The data was first prepared into GIS data-layers for eleven EGVs (Table 1), following a 500 m × 500 m grid structure. ArcGIS 10 was then used to determine elevation, slope and aspect for each cell of the study area, using a 90 m cell resolution Digital Elevation Model (DEM) of the study area (SRTM data http://srtm.csi.cgiar.org/). As a surrogate to the vegetation cover, Normalized Differential Vegetation Index (NDVI) for each cell from the satellite imagery of the study area (Landsat data for the year 2010 downloaded from http://glovis.usgs.gov/) was calculated. The euclidean distance of different land-cover classes (cropland, alpine grassland, temperate broadleaved forest, conifer forest and subalpine birch forest) in each grid using ArcGIS 10, from supervised vegetation class map as prepared using GRASS 6.4, was also calculated. Additionally, a layer of terrain ruggedness index for each cell using SAGA GIS was also prepared. All hangul presence locations ($n = 63$) were then plotted over the 500 × 500 m grid map of the study area and 50 such grids were used to generate the species map for the analysis.

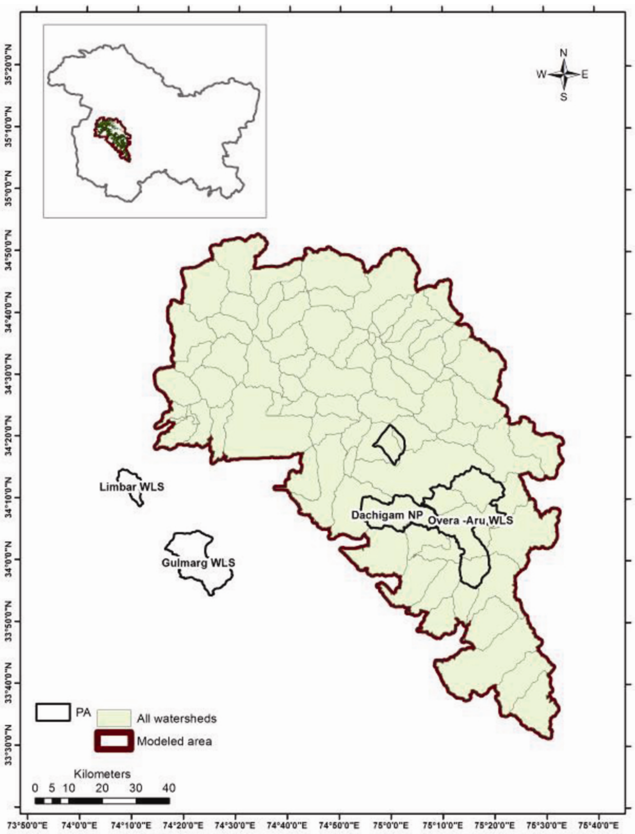

Figure 4. Map of the effective area in Greater Himalayan range of Kashmir valley selected for habitat suitability modelling.

The EGVs were first normalized as far as possible through Box-Cox transformations[34]. Although multi-normality is theoretically needed for factor extraction through eigen system computation[35], this method seems quite robust to deviations from normality[36]. McArthur's broken-stick model was followed to select the number of factors to be used in preparing the habitat suitability model[33], and the geometric mean algorithm was used for the computation of habitat suitability index, as it computes habitat suitability in space without assuming any distribution of the species[37].

The predictive power and accuracy of the habitat suitability (HS) model was evaluated using a Jackknife 10-fold cross-validation procedure[38] in Biomapper 4.0. The absolute validation index (AVI; 0 to 1), contrast validation index (CVI; 0 to AVI) and continuous Boyce index (−1 to +1, 0 indicating a random model[39,40]) were used to provide a more continuous and reliable measure of accuracy of the model's predictions.

Finally, the Shikar map (1940; only the hangul distribution patches) was digitized and the total area of hangul presence was calculated, which was then compared to the findings of the present habitat suitability model particularly with the area of highly suitable class.

Results

A total of 51 days were spent surveying the five selected catchments, with an average of 3.6 ± 1.6 days per catchment in winter and 5.4 ± 1.7 days in each catchment, in spring and summer. On an average, each catchment was surveyed for 35 ± 15.74 daylight hours in winters and 55 ± 20.62 daylight hours in spring/summer season.

Confirmed presence of the hangul, based on direct and indirect evidences, was found only in Wanghat-Naranag ($n = 34$), Chandaji-Diver-Lolab ($n = 14$) and Overa-Aru ($n = 15$; Figure 4).

Ecological niche factor analysis

The analysis exhibited high global marginality value (1.24), indicating that hangul presence adheres to relatively few sets of environmental conditions (as defined by the EGVs), in Kashmir. The global tolerance index (specialization) was low (0.28), indicating low tolerance to deviations from the species' optimal conditions. Table 2 depicts the coefficients of each EGV with respect to marginality and first specialization factors for hangul presence in Kashmir. The marginality factor signifies the best combination of all EGVs illustrating the ecological niche of hangul at the geographical scale of the spatial reference set (the extent of Greater Himalayan part of Kashmir valley). Marginality was also found to be important for hangul as it explained 57% of the total model variance. Occurrence of hangul was negatively correlated

Table 1. Descriptions of eco-geographical variables used for ENFA of hangul in Kashmir valley

Eco-geographic variable	Description
Elevation	Mean elevation (m) of individual 500 × 500 m^2 grid
NDVI	Normalized difference vegetation index reflectance based on satellite data
Northing	Cosine of slope (aspect)
Distance to agriculture	Euclidean distance of the grid to agriculture
Distance to alpine	Euclidean distance of the grid to alpine
Distance to broadleaved	Euclidean distance of the grid to broadleaved
Distance to conifer	Euclidean distance of the grid to conifer
Slope	Mean slope of all pixels in one 500 × 500 m^2 grid
Distance to subalpine	Euclidean distance of the grid to subalpine
Distance to temperate forest	Euclidean distance of the grid to temperate forest
Topographic ruggedness index	TRI value of each grid cell of the DEM of the study area was computed using SAGA GIS

Table 2. Coefficients of eco-geographical variables on the marginality and specialization factor (first only) for hangul

Eco-geographic variable	Marginality	Specialization
Elevation	0.04	0.06
NDVI	–0.30	0.10
Aspect	–0.08	0.03
Slope	0.23	0.05
Ruggedness	0.26	0.07
Distance to agricultural area	–0.21	0.91
Distance to alpine zone	–0.19	0.28
Distance to subalpine forest	–0.14	0.12
Distance to temperate forest	–0.45	0.20
Distance to coniferous forest	–0.62	0.05
Distance to broad-leaved forest	–0.30	0.06

with distance to coniferous forests and temperate broadleaved forests. Interestingly though, the presence of hangul was also negatively correlated with NDVI, suggesting that although the hanguls seem to prefer forested patches, they also preferred relatively open temperate and broadleaved forests. Hangul presence was found to be positively correlated with terrain ruggedness index and slope. Inspection of the first specialization factor provides further insights on the ecological niche breadth of hangul in Kashmir (Table 2). This factor alone explains 29% of the variation. Hangul shows the highest level of specialization to distance from agricultural areas, suggesting its high impact in limiting suitable hangul habitats to open conifer and broadleaved forest patches that are distant from agricultural areas.

Habitat suitability map

Three ENFA factors were retained with a broken-stick distribution, which explained 95% of total information and almost 90% of total specialization, and these were used to prepare habitat suitability maps. The habitat suitability map for hangul predicts 610.75 sq. km area of conifer and temperate broadleaved forests as highly suitable (61–100% suitability) and 980.25 sq. km as moderately suitable (31–60% suitability). The predicted highly suitable area was less than the area calculated from the Shikar map (935.46 sq. km). The model predicts Wanghat–Naranag, Chandaji–Diver Lolab, Overa–Aru, and Rajparian–Daksum areas to be highly suitable habitats for hangul presence (Figure 5) outside Dachigam National Park. All the reported hangul locations were found inside the predicted suitable habitats when plotted over the HS model (Figure 5).

Cross validation of HS map

The accuracy of HS maps was evaluated through 10-fold cross-validations. The presence-only evaluators AVI and CVI were around 0.5 (0.50 ± 0.11 and 0.45 ± 0.1 respectively), indicating that the HS model could discriminate between suitable and unsuitable habitats and that the set of EGVs allowed for the distinguishing of specific habitats preferred by hangul, from the overall available area in Greater Himalayan part of Kashmir. Further, a high positive Boyce's index (0.70 ± 0.14) provided a more continuous assessment of the model and predictive map accuracy. The reclassified HS map could reliably predict the distribution of hangul throughout the Greater Himalayan part of Kashmir, as indicated by the high and positive value (0.96 ± 0.10) of the Boyce B4 index. We used the reclassified HS map to refine the predictive power of the existing model[38]. When only the grids with >50% probability of hangul occurrences were classified as suitable habitats, 24 out of 25 locations were found inside the predicted suitable grids (Figure 6). The reclassified model also indicates clear connectivity through suitable habitat patches between Dachigam and Daksum areas, via Overa–Aru (in south of Dachigam) and a contiguous suitable habitat patch from Wanghat to Chandaji. Connectivity was also predicted between Dachigam and Wanghat across the coniferous forest patches of Kulan-Razel, MamarYachama and Akhal (north of Dachigam) regions.

Discussion

At a broad level, the results of the analysis indicate that Kashmir valley still harbours sufficient suitable habitat for the hangul all across its extent. Although human-induced damage upon natural ecosystems is on an increase, hangul still survives in several of these identified areas. The results indicate that about 1591 sq. km of broadleaved and coniferous forest patches, on relatively open but steep and rugged terrain are suitable for hangul.

Given a high level of predicted sensitivity to deviations from these broad habitat characteristics, the results highlight the vulnerability of the species to certain key habitat types, especially to the presence of anthropogenic effects like agriculture. But despite its sensitivity to habitat change, it is also admirable how the species has managed to survive in several pockets of unprotected spaces. This is because in some parts of this distribution range, like Wanghat–Naranag, Gurez, Diver–Chandaji–Lolab and Ismarg, human populations are still relatively small, and exert lesser pressure on these small patches of habitats. However, unlike Dahcigam and adjoining areas, these patches are unprotected and important wintering and fawning grounds at lower altitudes are afflicted with human disturbance, potentially dampening population growth.

Our results show a year-round presence of hangul in both Wanghat–Naranag and Chandaji (spanning approximately 292 sq. km) suggesting their high potential to increase further, given adequate conservation attention and legal protection, especially in lower altitude areas which serve as important wintering and fawning grounds. Of the five catchments, Overa–Aru is the only catchment recognized earlier to harbour small hangul sub-populations besides Dachigam. The current survey not only re-affirms this, but also shows a year-round presence of the species in this area. The remaining two catchments, Rajparian–Daksum, and Thajwas–Baltal, did not reveal any evidence of hangul presence, although local accounts still provide some indication of their existence here, albeit as seasonal vagrants.

Results also indicate a substantial amount of optimal vegetative connectivity between these catchments and Dachigam (Figure 5), which is the primary source of dispersing individuals. Thus, the population in Dachigam, along with the relict populations in these identified catchments could constitute a meta-population needing to be preserved in its entirety. Several studies have emphasized on the importance of preservation of isolated habitat

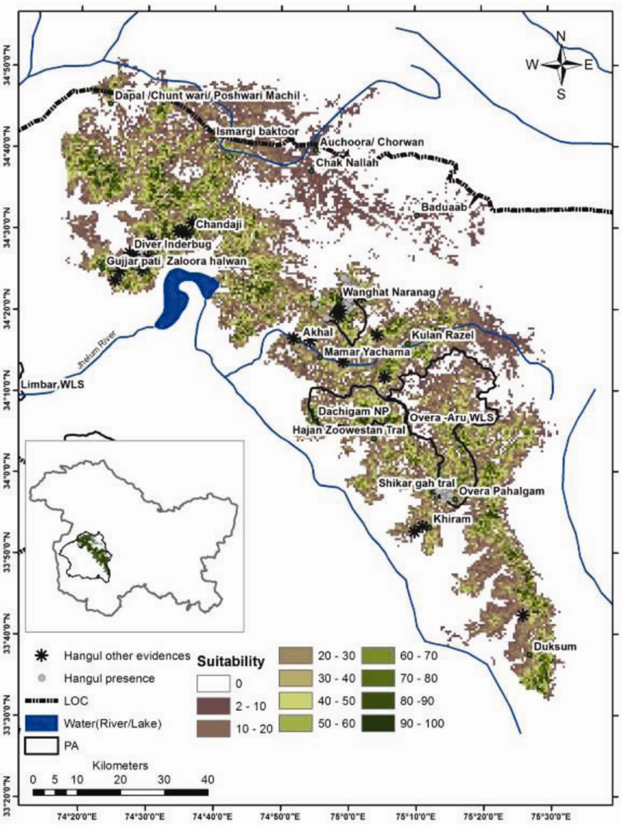

Figure 5. Habitat suitability map predicted for hangul in Kashmir valley based on the factor maps derived through Ecological Niche Factor Analysis (location of hangul presence as available from Forest Department and recorded opportunistically after the survey are plotted as 'hangul other evidences').

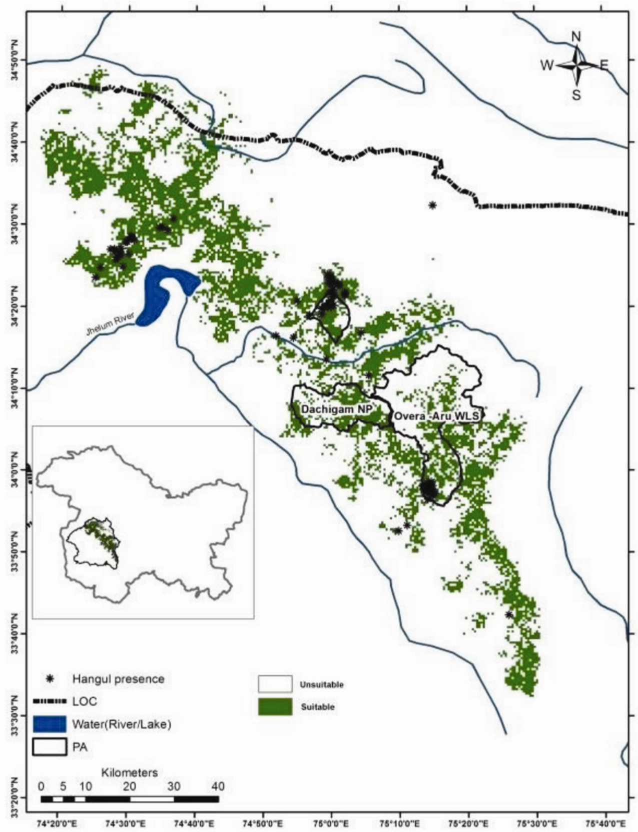

Figure 6. Potential connectivity patches between Dachigam National Park and other suitable habitats of hangul in Kashmir.

patches and their interconnectivity, in conserving locally threatened species (e.g. Siberian roe deer (*Capreolus pygargus*)[41]; *Canis lupus*[42] and *Cervus elaphus*[28]; Florida blackbear (*Ursus americanus floridanus*)[43]. It is also understood that high mortality in sink populations can impact multiple source populations[44]. Some studies have also emphasized on how restoration of movement or migratory corridors can help resume long-distance animal movement (e.g. Plains Zebra (*Equus burchelli*)[45]).

Future conservation efforts for the hangul therefore are required to be multifaceted and implemented at a landscape level considering the surviving relict populations identified in this study. While hangul population in the Overa–Aru and Tajhwas–Baltal catchments may increase as a direct consequence of population increase in Dachigam, the population in Wanghat–Naranag and Chandaji require assisted population augmentation over time to develop them as alternate source populations. These therefore need to be considered as primary release sites under the conservation breeding programmes undertaken by the forest department and the central zoo authority. Further, adequate protection and eradication of all anthropogenic threats, in particular, grazing[8,10], would make more habitats available for population growth. Grazing has in recent times emerged as a major threat to wild ungulates in the state, for instance, hangul in Dachigam and Markhor (*Capra falconeri*) in Hirpora[46–48]. This therefore calls for a concerted grazing policy, keeping the interests of wildlife and livestock farming in mind. It is also of critical importance to validate the functionality of identified interconnectivities between different populations by assessing the gene flow patterns across them. These critical links would then need to be preserved allowing the hangul to successfully thrive within a metapopulation network across the Kashmir Valley landscape, for future generations to come.

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