

Conservation of a fragmented population of blackbuck (*Antilope cervicapra*)

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The Vallanadu Blackbuck Sanctuary (VBS), Tamil Nadu, India is a small protected area (PA) designated to conserve blackbuck. We did a study on habitat use and suitability in the PA that has come under various management interventions. The occupancy of blackbuck was positively correlated with areas lying within the PA, but the encounter rate of blackbuck was significantly higher in areas outside the PA. Being small in size, VBS may not hold a large population of blackbucks, but may help in saving the species which once widely occurred in the southernmost parts of India.

Keywords: Blackbuck, conservation, grasslands, occupancy, protected area.

ESTABLISHING protected areas (PAs) which cover about 13.9% of the Earth's land surface has been a major approach to conserve biodiversity^{1,2}. The ecological basis of establishing PAs depends on features such as species occurring in them, their area, availability of habitats within a PA and their connectivity with other PAs or similar areas for the long-term conservation of biodiversity². However, the above-mentioned factors are not always met before a PA is established for various social, economic and political reasons³. Often PAs are paper parks and serve limited purpose in the conservation of the targeted species. This is especially true for wide-ranging species that use multiple habitats, including agricultural areas and therefore brings them into conflict with humans^{4,5}, thus creating a negative image of PAs among the local communities. Such cases are common in India, where land is at a premium with high human population density and formation of PAs leads to conflicts⁶. Moreover, studies to test the effectiveness of PAs in comparison to the surrounding lands have been few in India⁷.

In the Indian subcontinent, blackbuck (*Antilope cervicapra*), an endemic dryland antelope was once known to be distributed across the country⁸, but is now restricted to small fragmented patches. Conservation of blackbuck has always been a problem since land area is limited, and grasslands in India are one of the least protected habitats. In some cases, the established PA is not only small but the habitat inside it may not be suitable for the target species, which results in the species straying into human-

managed lands. Historically, grasslands and open forests in India have experienced severe habitat modification as a result of exotic species plantations which have developed over the decades. The regrettable concept in the country is 'grasslands are wastelands' either due to forestry or plantations of exotic species^{9,10}, making most grassland species reside outside the PAs.

In the Tirunelveli and Thoothukudi districts of southern Tamil Nadu, historically, dry grasslands and scrub were a prominent feature of the landscape, referred to as Palai. They supported a number of species unique to such habitats, including the now extinct cheetah and its prey, i.e. the blackbuck. The Tirunelveli district has been home to large populations of blackbuck and its predator, and in recent times the landscape has transformed and fragmented leaving a decimated population of blackbuck confined to the Vallanadu hills and its surroundings¹¹. The Forest Department established the Vallanadu Blackbuck Sanctuary (VBS) in 1987 to protect the southernmost population of blackbuck. The status of the species in terms of its habitat use, populations and conflicts is unknown at the locale, even though the sanctuary is reserved for a species facing pressure from various factors. The area is small, dominated by thorny scrub and hills which are not suitable characteristics of a blackbuck habitat. Unlike other blackbuck areas where there is considerable conflict with humans^{12,13}, there is none here so far according to locals and forest officials. The present study is an attempt to understand the habitat use by blackbuck both inside and outside VBS. It also discusses the effectiveness of PA for long-term conservation of blackbuck in the region.

In order to find the mismatch between the established PA and the available habitat for the blackbuck, more specifically, we aim to: (i) Determine the occupancy (area of usage) of blackbuck in VBS and its surroundings and (ii) identify the factors that influence the occupancy of blackbuck in the Sanctuary and its surroundings, and thereby the effectiveness of PA in long-term sustenance of the blackbuck population in the landscape.

Study area

VBS is a PA (8.70 N, 77.88 E) located on an isolated ridge with hillocks in the semi-arid southeastern part of Tamil Nadu, India. It is spread over 14.6 sq. km (ref. 14),

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and is surrounded by private fallow land and large areas under the Tamil Nadu Agricultural College campus. The sanctuary is bound by a chain-link fence, which is porous in many places; a rather ineffective measure adopted by the Forest Department to confine a species that prefers open country within a restricted area. Elevation in VBS and its surroundings ranges from 50 m at the foothills of the ridge to 284 m on top of the ridge. The annual average rainfall is 728 mm, which mostly occurs between October and November¹⁵. The sanctuary holds mainly the southern thorn scrub forests of India¹⁶. Some of the common plant species found in the PA are *Andropogon pumilus*, *Eragrostis viscosa*, *Perotis indica*, *Tragia roxburghii* (grasses); *Biophytum sensitivum*, *Petalium murex*, *Mimosa pudica*, *Mullugo cerviana* (herbs); *Polygala javana*, *Zizyphus mauritiana*, *Canthium parvifolium*, *Pavetta indica* (shrubs) and *Pterolobium hexapetalum*, *Maerua oblongifolia* (climbers) and *Wrightia tinctoria*, *Grewia villosa* (trees).

Methods

Occupancy

Habitat or patch occupancy models were used to estimate blackbuck occupancy¹⁷. The single-species single-season model was chosen with the logit function, as a suitable alternative to represent the area of usage (intensity of usage) by blackbuck, as the population is fragmented and chances of colonization in the intervening short period are nil. The area was girded into cells of 0.5 × 0.5 km to achieve maximum coverage of the potential habitat. Individual blackbucks are likely to range over much larger areas than this, and the cell size was chosen to effectively represent the intensity of usage, in place of true occupancy¹⁸, that can be estimated over larger landscapes. The survey was carried out in October 2012 and January 2013. The cells covered areas inside the reserve and to a distance of about 1 km outside the VBS boundary. Areas beyond 1 km distance from the VBS boundary are urbanized or are non-fallow land, except in the southeastern side of the sanctuary. Several narrow animal trails crisscrossed the cell and we randomly walked trails covering a distance of 150 m. Each cell had 2–3 trails and each was visited at least two times. Indirect evidences of blackbuck such as droppings (middens), which appear different from goat droppings (scattered and larger) sighted within a distance of 3 m on either side of the trail were recorded by at least two observers and formed the basis for generating capture history. Direct sightings of blackbuck while walking the trails were few but were included to generate the encounter rate. A total of 95 cells were surveyed, which included 42 cells inside and 53 sites outside VBS. Grid cells located on steep hill slopes that were rocky could not be sampled or were not found to be suitable for blackbuck.

Factors influencing the presence of blackbuck, such as average elevation (Elev), presence of perennial waterbody (Wb), percentage of habitat types in a grid cell – dense scrub, open scrub and grass-fallow (DSc, Osc and GrFa respectively) – were considered as cell covariates, based on prior information on the ecology of the species^{8,19}. The presence of surveyed trails in cells falling either within the sanctuary (1) or outside the PA (0) was modelled using a categorical variable ‘PA’. Percentage of habitat available under each grid cell was measured by imagery available on Google Earth (2014). Elevation (average) was calculated from Google Earth by considering the elevation values from the four corners as well as the centre of each cell.

Analysis

Site (cell) usage by the blackbuck was measured using probability of occupancy. High probability of occupancy was treated as suitable, since estimation of true occupancy was not feasible given the small area. ψ (probability of occupancy) was modelled as a function of the site covariates considered. Occupancy was estimated using the program PRESENCE 6.9 (ref. 20). We tested multi-collinearity of covariates by constructing a linear correlation matrix and only the non-collinear covariates were used in the models. Elevation, a continuous covariate was z-transformed²¹. As in previous studies, the probability of detection (p) was first modelled as a function of all the covariates^{22,23}. The covariates from the top-ranked model were used to model Psi. Akaike Information Criterion (AIC) values and their differences were used to rank the models. Psi values of individual sites falling inside and outside VBS were calculated.

Encounter rate of blackbuck was estimated from direct sightings along trails in the cells. In addition, we obtained socio-ecological information from interviews with a range of stakeholders in the landscape, including the grazing community, villagers, land owners and Forest Department staff regarding blackbuck presence in and outside the sanctuary, and possible conflicts between blackbucks and humans in these areas. We arrived at the viability of the blackbuck population in the sanctuary based on ecological and socio-ecological information.

Results

Occupancy estimation

Detection probability was modelled as a function of the covariates, keeping ψ constant; the top model (delta AIC values <2) explained more than 99% of the variation (Table 1). Occupancy was estimated keeping detection probability $P(Wb)$ constant for different covariates of ψ (Table 2). The top-ranked model was considered to estimate the overall occupancy probability of the area

Table 1. Summary of model selection procedure for detection probability (p)* with constant probability values of occupancy (Psi)

Model	AICc	delta AICc	AIC wgt	Model likelihood	no. Par.
psi(.), p (Wb)	350.99	0	0.9938	1	2
psi(.), p (GrFa)	361.4	10.41	0.0055	0.0055	2
psi(.), p (.)	367.13	16.14	0.0003	0.0003	2
psi(.), p (PA)	368.82	17.83	0.0001	0.0001	2
psi(.), p (DSc)	369.06	18.07	0.0001	0.0001	2
psi(.), p (Osc)	369.11	18.12	0.0001	0.0001	2
psi(.), p (Elev)	369.16	18.17	0.0001	0.0001	2

Detection probability (P) is not mentioned since the objective is to compare occupancy between areas inside and outside the Vallanadu Blackbuck Sanctuary (VBS), protected area (PA), Tamil Nadu, India.

Table 2. Summary of model selection procedure for probability of occupancy (psi) with habitat covariates

Model	AICc	delta AICc	AIC wgt	Model likelihood	no. Par.
psi(PA), p (Wb)	347.96	0	0.6864	1	2
psi(DSc + Osc + GrFa), p (Wb)	351.4	3.44	0.1229	0.1791	4
psi(Osc), p (Wb)	352.86	4.9	0.0592	0.0863	2
psi(DSc), p (Wb)	352.96	5	0.0563	0.0821	2
psi(Wb), p (Wb)	353.26	5.3	0.0485	0.0707	2
psi(GrFa), p (Wb)	354.89	6.93	0.0215	0.0313	2
psi(Elev), p (Wb)	357.74	9.78	0.0052	0.0075	2

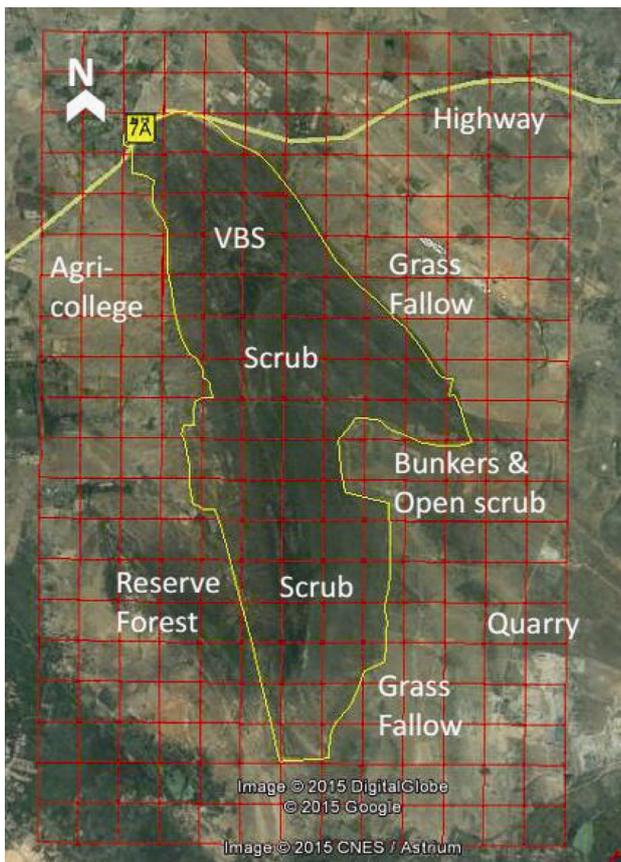


Figure 1. Location map of Vallanadu Blackbuck Sanctuary (VBS), Tamil Nadu, India (8.70N lat. and 77.88E long.) and prominent geographical and land use features around it. Boundary line in yellow represents the approximate extent of VBS; each grid cell represents 0.5 × 0.5 km.

$\hat{\psi}$. The estimated $\hat{\psi}$ for the entire surveyed area was 0.62 ± 0.01 , which was a marginal improvement from the naïve occupancy estimate of 0.58.

Factors influencing occupancy and detection probability

Detection probability is explained by the presence of the covariate Wb – the presence of a waterbody in a grid cell (Table 1). However, the probability of occupancy is explained strongly (68%) by the covariate PA, which is indicative of the cell being within or outside the protected area (Table 2). Estimates of beta coefficients for PA and Wb were 1.24 ± 0.45 and 1.49 ± 0.39 respectively, from the top-ranked model. Support from other habitat factors such as OSc, DSc, Elev and Wb was found to be relatively weaker for estimation of probability of occupancy (Table 2).

Habitat features within and outside VBS were different (Table 3 and Figure 1). Grass fallow was more outside the sanctuary, while within it dense scrub is in steep terrain was predominant, which is considered unfavourable for blackbuck. Water bodies inside VBS are managed by the forest department, and are usually dry, whereas the ones outside, though few in number, are perennial and occur in the form of old quarry pools or shallow open wells.

Spatial distribution of blackbuck occupancy and encounter rate

The estimated occupancy $\hat{\psi}$ for sites within the sanctuary was 0.77 and for those outside it was 0.50. Figure 2

Table 3. Comparison of habitat and other features in cells inside and outside the PA

Habitat features	Inside VBS	Outside VBS
Encounter rate of blackbuck individuals/km (mean ± standard error)	0.54 ± 0.05 (total 12.75 km)	2.94 ± 0.30 (total 14.25 km)
Scrub vegetation	92% (1432/1542 ha); includes hill slopes holding scrub	Present only in RF; 40% (208/512 ha); rest of the habitat in reserve forest holds open scrub and steep slopes
Grass fallow	Nil (present in cleared patches less than 1.5 ha)	320 ha (private land that is either fenced or open)
Tall grass (< 2 ft)	Nil; small patches	15–20 ha present in fenced private land
Elevation range (m)	35–284	27–85
Waterbodies	One perennial waterbody fed by a borewell	Abandoned quarry pools holding rain water
Terrain	Steep and undulating	Flat
Livestock grazing	Minimal	Extensive
Agriculture	–	–
Predators of blackbuck	Occasional domestic dogs	Domestic dogs
Competitors (for water and forage)	High density of Feral cattle	Livestock

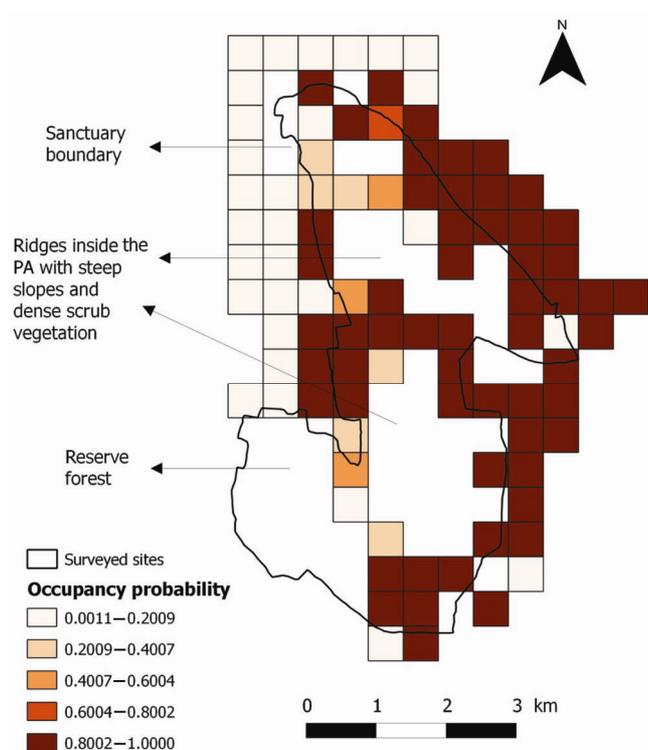


Figure 2. Probability estimates of blackbuck occupancy for individual sites. (Psi-conditional) which takes the value of 1 where the species is detected once or more, and the probabilities are estimated for undetected sites²¹.

maps the probability of blackbuck occupancy. The resulting spatial pattern shows the predominantly higher occupancy in areas outside VBS and on the eastern side. Occupancy is estimated to be low on the western side, with presence detected only along a corridor (a road connecting the eastern and western sides) at the centre of VBS. Similarly, mean encounter rate (mean and standard error) of blackbuck individuals/km outside the sanctuary (2.94 ± 0.30) was significantly higher than that inside it (0.54 ± 0.05 ; Mann–Whitney test; $U = 3666$; $z = -1.99$; $P = 0.04$).

Conflict and disturbances contributing to the movement of blackbucks

From the interviews conducted with land owners and community members in the surrounding areas of VBS, it was evident that conflicts due to crop raiding are absent largely because no agriculture is possible due to poor rainfall, low land productivity and lack of irrigation (Table 3). The private land (patta land) owned by individuals on the eastern side has so far been devoid of conflict since the land has been used for grazing. However, recently, a major part of the patta land has been fenced and is not accessible for the blackbuck anymore. The land on the western side is owned by the Agricultural University and movement of blackbuck is rarely reported. The northern surroundings of VBS are cut-off for the movement of blackbucks due to the presence of a four-lane busy highway and a chain-link fence, erected probably to prevent mortalities of animals while crossing. However, there were no such reports during the present survey. The southern and southwestern sides of VBS are covered with open scrub as part of the Vallanadu Reserve Forest. A tall stretch of chain-link fence that has been installed serves as a barrier only on the northern side of the sanctuary between the forest and the highway, and between the forest and the fire-cracker bunkers on the eastern side. The remaining stretch of chain-link fences is either too low to be a deterrent for the blackbuck, or largely remains porous with wide-open stretches. A jeep track connecting the eastern and western sides is the only corridor for movement of blackbuck through VBS. Blackbuck also faces pressure from feral cattle inside VBS, which compete for water provided by the Forest Department and possibly for forage as well, both inside and outside the sanctuary (Table 3). Water within the PA is usually present only in single artificial trough filled by a borewell. Free-ranging dogs were seen preying on Black-naped Hare (*Lepus nigricolis*) and chasing peafowl (*Pavo cristatus*) and nightjar (*Caprimulgus* species). They are a

source of disturbance since they can predate on the blackbuck or affect its movements.

Discussion

Occupancy and critical habitat features

Blackbuck occupancy, which represents the probability/intensity of area used, was found to be almost ~60% in and around VBS and the covariate 'PA' was shown to influence occupancy probability. However, spatial distribution of occupancy probability shows a predominant presence of blackbuck on the eastern side of VBS. Various factors could be driving the patchiness in occupancy probability. Waterbodies (Wb) is an important covariate for detection probability because blackbuck, even though a dryland species, makes use of functional water resources and is known to move long distances in search of water and grass cover¹⁹. In VBS, though water is provided by the Forest Department in permanent, cemented, saucer-shaped water troughs, blackbuck are found to feed at shallow tanks or wells found outside the sanctuary, which may be due to competition for water from other ungulates, including large herds of feral cattle which are not commonly found on the eastern fallow outside VBS¹⁵. The introduction of cattle as a result of conflict between local herders predates the declaration of VBS as a PA by more than 70 years. Removal of cattle by the Forest Department for several decades now with help from local people has not decreased their population. Apart from feral cattle, VBS has small populations of sambar, chital and wild pig¹⁴. The sambar and chital could have been introduced over the last few decades as their nearest wild populations are far away.

The spatial use of habitats by blackbuck indicates occupancy within VBS is marginally higher than that outside, while encounter rates are higher outside than inside. Total counts of blackbuck on the eastern fallow varied from 10 to 25 animals (scanned from the watchtower). While inside VBS, only one or two animals were encountered even in the open-cleared patches, and most of them were males. The reason for low occupancy outside could be due to variability of the habitat. Large stretches of land outside VBS on the western side even though fallow are devoid of blackbucks due to poor grass, human movements, varying land use and lack of water, which is not the case on the eastern side. Such differences could have contributed to overall low occupancy outside VBS, while the habitat inside is found to be relatively more uniform.

The eastern side supports grass fallow which is important for blackbucks, as it not only provides feeding sites, but the tall grass also helps conceal the blackbuck fawn and therefore offers protection⁸. In VBS blackbucks were seen spending the night in the grass fallow outside and

move towards the forests only when disturbance levels increased in the outside areas. It therefore appears that the preferred habitat lies in the eastern fallow outside the VBS.

It is ironical that even though the primary habitat requirements of the blackbuck were documented by the time VBS was established in 1987 (refs 24, 25), scrub forest was chosen for its conservation possibly because it was the only remaining forest patch where the animal was found. It is also possible that the habitat inside the VBS may have changed after its declaration as a wildlife sanctuary, due to management practices prevalent in other parts of the country such as preventing grazing, fire and planting^{9,26}. For instance, large patches of *Acacia mellifera*, an exotic species was planted in VBS¹⁶, and has occupied prime blackbuck habitats. It is interesting to note that historically populations of blackbuck have declined even in a small reserve (Guindy National Park, Chennai) possibly due to change in vegetation from open to dense habitats²⁷. However, the VBS does not show any decline in the number of blackbucks from the available records, since the number of blackbucks reported in 1989 (ref. 8) is comparable to the total count done on the eastern fallow of a maximum of 24 individuals. There could be several reasons contributing to the low population. One of them could be the open habitats outside, which have remained the same until recently. The habitats are getting fenced, built up and there is a greater human presence in the area now. Moreover, the land use further away from the fallow is highly urbanized, and industrialized due to the presence of quarries. Blackbuck may run into croplands and road networks, all of which could have a negative effect on their populations in the future. Secondly, the blackbuck populations have migrated and established in other areas outside the VBS in private enclosures. Recent evidences point out to blackbucks moving further south along roads, indicating the inadequacy of VBS to support them.

Management intervention: species versus ecosystem approach

Various studies in the past have recognized the problem of managing the habitat available for blackbucks under instances of conflicts and degradation of habitats, and have suggested options for mitigation^{13,28,29}. The suggested practices range from employing 'grama sabhas' to maintain potential habitats, maintain community land sustainably, selective clearance of small areas within a sanctuary coming under exotic plantations, manage preferred species composition if possible, avoid planting of exotics and retard the breeding of unproductive cattle. Given the presence of unsuitable habitat inside VBS, the option of making use of available suboptimal habitats in the periphery or habitat mitigation within the VBS are the only options to conserve blackbuck in the area. The area

outside is optimal for the blackbuck and efforts could have been made to acquire them either by the Forest Department or conservation organizations, even though it is revenue land since it is owned by people with different stakes and therefore bound to come under conflicting land use. Recently, parts of the eastern fallow were acquired and fenced by private land holders, thus preventing the blackbucks from using them. The management of habitat within VBS appears to be the next best step. A patch of reserve forest that comes under the jurisdiction of the Forest Department is available next to VBS, that can be annexed and suitable arrangements made to accommodate the blackbuck population inside the sanctuary. Further, clearing of patches within VBS that have been planted with exotic *Acacia mellifera* which may not have been so earlier when grazing and fire were prevalent could be an option.

The VBS was established for the conservation of blackbucks, but as the present study indicates, the habitat inside is not entirely suitable for them. The Forest Department has been regularly clearing 1–2 ha patches of scrub for use by blackbucks and therefore make VBS more suitable for them. Our earlier analysis has revealed that cleared patches are visited by blackbucks¹⁵. Recently, in response to loss of the eastern fallow due to reclamation, a large area (~100 ha) of native scrub that lies next to the eastern fallow was cleared for use by the blackbucks. This may have led to the loss of habitat for several birds, reptiles such as pythons, small mammals and many other floral and faunal elements (pers. obs.). The challenge in such a scenario is to retain open areas to secure the blackbuck, while preventing harm to local flora and fauna. Though such steps may be essential to increase blackbuck numbers as in other sites, one would be wise to keep in mind two important aspects. First, the scrub and *Acacia*-dominated forests in the region are a natural ecosystem that harbours many plant and animal species unique to this forest/scrub type¹⁴. Therefore, clearing such patches may have indirect effects on biodiversity loss at the cost of a single species. Second, while conservation efforts have led to increase in the number of blackbucks over several years, it has also increased human–blackbuck conflict in many areas^{12,30,31}. Therefore, it would be wise not to give much emphasis on increase in blackbuck numbers alone in the VBS, since this is likely to bring the area under conflict with the national highway, farms and agricultural areas further away unless we find ways to connect widely separated suitable patches. There are increasing evidences to this, as blackbucks are frequently seen 5 km away from VBS along main roads and also in private farms and near irrigation tanks.

The ineffectiveness of PAs serving to conserve a population could be well validated with studies such as that in VBS, even though the formation of a PA remains crucial to the conservation of biodiversity globally³². Thus, conservation efforts need to be approached considering the

surrounding landscape and species-centric approach may not be suitable. While identifying patches suitable for blackbucks in the larger landscape and providing connectivity between them may be ideal, limited habitat intervention inside the VBS such as removing exotic/invasive species can also help sustain a small population of blackbucks, without them multiplying into unmanageable limits.

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