3.1 **INTRODUCTION**

There is a growing focus on agricultural landscapes from being harbingers of biodiversity loss to becoming landscapes supportive of biodiversity (Heath & Rayment 2003). Chemical-free multi-crop agriculture practised by small landholders conserves greater biodiversity, provides more ecosystem services, promotes human well-being and increases food security (Kremen & Miles 2012, Kremen 2015). Much of the understanding about the capacity of agriculture landscapes to support biodiversity has focused on agroecosystem landscapes with plantation crops such as coffee, cocoa etc. in the tropical rainforest biome. For example, shaded cocoa plantations can constitute long-term permanent habitats for black howler monkeys (Zarate et al 2014), whereas oil-palm plantations are not wildlife-friendly (Yue et al 2016). Mellink et al (2016) found that nopal fruit orchards were important habitats for birds in the dryland agroecosystem.

Dryland ecosystems cover 41% of the earth’s surface and despite being areas of low productivity (Scherr & McNeely 2008), they are important for global food security. Around two billion people and 50% of the global livestock population (Safriel et al 2005) are supported by dryland ecosystems. The arid and semi-arid habitats are home to fauna adapted to living in these climatically harsh conditions, which are declining at alarming rates (Durant et al 2014). Protected areas only cover 4-5% of the dryland biome (Davies et al 2012) and it is critical to understand if dryland agriculture and farming systems are wildlife-friendly for
large mammals, where the exact nature of wildlife friendliness is likely to vary depending on species traits (Gangadharan et al 2016).

The objective of this study was to investigate the degree to which agricultural areas in dryland systems are friendly for large wild mammals. To address this question, I chose a densely-populated/human-dominated, semi-arid landscape in India and studied the extent of use of agricultural habitats by the blackbuck (*Antilope cervicapra*), a Near Threatened antelope endemic to the Indian subcontinent. The present blackbuck distribution is highly fragmented and restricted to small protected and unprotected grassland patches in dryland agriculture-dominated landscapes. Blackbuck are prime candidates to examine the capacity of dryland agriculture habitats to support large mammalian herbivores as throughout their current range, blackbuck have been often reported to use agricultural fields (Figure 3.1) in Andhra Pradesh (Prasad & Ramana Rao 1990, Manakandan & Rahmani 1998), Gujarat (Ranjitsinh 1989, Jhala 1993), Haryana (Chauhan & Singh 1990), Madhya Pradesh (Chandra 1997, Rajpurohit & Chauhan 1996), Rajasthan (Prakash 1990, Chauhan & Rajpurohit 1996) and Maharashtra (Rahmani 1991, Bharucha & Asher 1993). In some areas, blackbuck feed on crops and studies have documented that blackbuck cropland use varies spatially with respect to distance from natural habitats and temporally, by season (Bharucha & Asher 1993, Jhala 1993, Manakandan & Rahmani 1998). However details about why this variation occurs and how cropland use patterns can be explained based on characteristics of the fields and the surrounding matrix are largely unknown.
I measured and analyzed patterns of blackbuck cropland use in the human-dominated semi-arid dryland agriculture landscape around the Great Indian Bustard Sanctuary in the state of Maharashtra, India. I utilized a hierarchical sampling strategy in order to develop a framework for understanding the factors
that constitute wildlife friendliness or unfriendliness at the scale of landscape and individual fields. I monitored fields continuously for three years to test hypotheses about factors influencing blackbuck cropland use patterns. The overarching hypothesis I test based on the existing knowledge of blackbuck behavioural ecology is that blackbuck use of agricultural fields is governed by perceptions of risk, rather than resources. Based on this hypothesis, I predict that distance to natural habitat – in this case dry grasslands, rather than type or nutritional value of crops would explain cropland use at the landscape scale, within a cluster of fields and at the scale of a field. I also predicted that, as a consequence, certain agricultural fields would be used more intensely than others. Additionally, as they are behaviourally adapted to open habitats, blackbuck use of fields would reduce once crops grow high enough to potentially provide cover for predators.

3.2 Methods

3.2.1 Study area

The study was undertaken in the Great Indian Bustard Sanctuary in Maharashtra. Prior to rationalization, the extent of the Sanctuary was 8496.44 km², of which 83% was private lands, 11% comprised common grazing land and 6% was under the jurisdiction of the Maharashtra Forest Department with a mere 0.11% under protection (Pande 2005). One such protected area of ~6 km² is located at Nannaj in Solapur district was selected for this study. The 108 km² study area comprised of protected grasslands (located within the Great Indian Bustard Sanctuary), unprotected grasslands (livestock grazing areas), afforested patches and agricultural areas (Figure 3.2). The annual rainfall is less than 750 mm and six villages are present in the study area with a population of ~25000 people (2001 census). The main crops grown in the study area are cereals such as
Jowar - *Sorghum bicolor*, Maize - *Zea mays* and Wheat - *Triticum spp*; pulses like Pigeon pea – *Cajanus cajan* and Chick pea – *Cicer arietinum*; vegetables, oil seed and cash crops. The sanctuary and surrounding areas support breeding populations of the Great Indian Bustard (*Ardeotis nigriceps*), Indian wolf (*Canis lupus pallipes*) and blackbuck. There has been much variation in the blackbuck population, an increase from 150-200 animals in 1981 to 600-800 in 1988 (Rahmani 1991), a small decrease to 600 animals during the 90’s (Kumar & Rahmani 2008, Kavita Isvaran, personal observations) to around 300 animals now (Krishna et al 2016).

### 3.2.2 Blackbuck cropland use patterns

This method was used to test the hypothesis about blackbuck perception of risk in agricultural areas by predicting that fields located closer to refuges or natural habitats in the landscape would be used more intensely by blackbuck than fields further away. From November 2008 to November 2009, cropland use at the landscape scale was evaluated by sampling 91 crop fields across the 108 km² study area. The locations were selected randomly from a land use classification map using the ‘Random Point Generator v 1.3’ extension in ArcView. Each agricultural field was sampled once every eight weeks across the sampling period, such that each field was sampled a total of 7 times. In each sampling session, two observers walked the diagonal of the field and recorded the occurrence signs (tracks and pellets) of blackbuck in a two meter wide strip (dashed lines in Figure 3.2a). The surrounding matrix, that is, areas sharing a side or a corner with the sampled field, were categorized into the four land use types; agricultural field, unprotected grassland, protected grassland, plantation. In order to rule out alternate explanations, I also recorded the following data in each field: presence/absence of crop protection measures and if present, the type
of protection measure, e.g. hedges, wire fences, brambles; crop type and source of irrigation (e.g. bore-well, well).

3.2.3 Blackbuck use of individual fields

I tested the hypothesis by examining whether fields which share more corners and sides with refuges are used more intensely than fields that are surrounded by an agricultural matrix. 36 fields located next to refuges were selected randomly to understand factors influencing cropland use. 66% of fields were sampled thrice (n=96). In each sampling occasion, use was assessed in 12 quadrats (grey boxes in Figure 3.2a). The following data was collected in each quadrat; presence of blackbuck indirect signs (signs and tracks), number of plants present, number of plants grazed. The matrix surrounding the field was also recorded.
3.3 DATA ANALYSIS

3.3.1 Blackbuck cropland use patterns

For analysis at both the landscape and field scale, cropping patterns were explored by calculating number of fallow and cropped fields in each sampling period. Cropped fields were further classified into the main crop types, i.e., cereals, pulses, vegetables and other miscellaneous crops. The probability of blackbuck use of a field with respect to distance of the field from the non-agriculture (plantations, protected and unprotected grasslands) habitat edge was explored using means and confidence intervals.
3.3.2 **Blackbuck use of individual fields**

Cropping patterns were explored by calculating number of fallow and cropped fields in each sampling occasion. Cropped fields were further classified into the main crop types, i.e., cereals, pulses, vegetables and other miscellaneous crops. The effect of non-agricultural sides on cropland use was explored using a linear model. Intensity of use was quantified at each field by averaging across all quadrats in which use was recorded.

3.4 **RESULTS**

3.4.1 **Blackbuck cropland use patterns**

91 fields were sampled on seven occasions resulting in 419 trials which were distributed over a yearlong cropping cycle. The number of fallow and cropped fields varied seasonally with very few fields cropped during the summer and monsoon months. Cereal crops (Jowar – *Sorghum bicolor*, Maize – *Zea mays* and Wheat – *Triticum spp.*) were most abundant followed by pulses (Tur/Pigeon pea – *Cajanus cajan* and Chick pea – *Cicer arietinum*), vegetables and other miscellaneous (oil seed and cash crop) types (Table 3.1). These fields were located at a mean distance of 684.5 meters from non-agricultural habitats (min = 0 meters, max = 2510 meters). Forest department plantations, protected and unprotected grasslands constituted the non-agricultural habitats in the study area.Physical protection measures such as fences etc. were absent in all fields.
Table 3.1  
**Crop types in the study area in each sampling occasion.**

<table>
<thead>
<tr>
<th>Sampling occasion</th>
<th>Month</th>
<th>Sample size</th>
<th>% Cereals</th>
<th>% Pulses</th>
<th>% Vegetables</th>
<th>% Misc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nov 08</td>
<td>43</td>
<td>66.67</td>
<td>3.85</td>
<td>17.95</td>
<td>11.54</td>
</tr>
<tr>
<td>2</td>
<td>Dec 08</td>
<td>70</td>
<td>72.29</td>
<td>9.31</td>
<td>10.44</td>
<td>7.90</td>
</tr>
<tr>
<td>3</td>
<td>Feb 09</td>
<td>76</td>
<td>72.96</td>
<td>1.84</td>
<td>18.51</td>
<td>6.67</td>
</tr>
<tr>
<td>4</td>
<td>Apr 09</td>
<td>85</td>
<td>5.56</td>
<td>0.00</td>
<td>38.89</td>
<td>55.56</td>
</tr>
<tr>
<td>5</td>
<td>Jun 09</td>
<td>67</td>
<td>33.33</td>
<td>0.00</td>
<td>0.00</td>
<td>66.67</td>
</tr>
<tr>
<td>6</td>
<td>Sep 09</td>
<td>26</td>
<td>33.33</td>
<td>33.33</td>
<td>25.00</td>
<td>8.33</td>
</tr>
<tr>
<td>7</td>
<td>Nov 09</td>
<td>52</td>
<td>53.75</td>
<td>18.75</td>
<td>17.50</td>
<td>10.00</td>
</tr>
</tbody>
</table>

Out of 419 trials, blackbuck signs in crop fields were detected only on 20 occasions and 30% of these detections were in fallow fields. The mean distance of fields where blackbuck signs were detected was 150 meters from non-agricultural habitats (min = 0 meters, max = 1398 meters) (Figure 3.3).

**Figure 3.3**  
Distance of fields without (0) and with (1) blackbuck signs from non-agricultural habitats. The line represents the median; the box represents the interquartile range and the whiskers represent the data extremes.
3.4.2  *Blackbuck use of individual fields*

The number of cropped fields varied widely with season, all fields (n=36) had crops in the first sampling occasion and only two fields had crops in the second sampling occasion. Blackbuck use ~50% of the agricultural fields irrespective of whether they are cropped or fallow (Table 2). 25% of the fields had some kind of crop protection measures, as crop use by blackbuck was recorded. In the first sampling occasion, 60% of the fields had cereals (Jowar) while the remaining were pulses (Tur). Both Jowar and Tur fields were used by blackbuck and there seemed to be no selectivity with respect to crop type as ratio of cereals:pulses fields used (64%) was the same as cereals:pulses fields in the landscape (62%). Crop use averaged 42% of individual plants that were present in the sampled quadrats (range: 17-100%) with the number of non-agricultural sides influencing the intensity of crop use in a field (Figure 3.4, R²=0.57).

**Figure 3.4**  *Correlation between agricultural crop use and number of non-agricultural sides and corners around a field.*

\[ y = 0.0694x + 1.2272 \]

\[ R^2 = 0.5709 \]
Table 3.2  Blackbuck use of agricultural fields and crops.

<table>
<thead>
<tr>
<th>Sampling occasion</th>
<th>Cropped fields</th>
<th>Fallow Fields with blackbuck signs (%)</th>
<th>Fields with crop use by blackbuck (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 2010</td>
<td>36</td>
<td>0</td>
<td>21 (58.33)</td>
</tr>
<tr>
<td>March 2011</td>
<td>2</td>
<td>34</td>
<td>17 (47.22)</td>
</tr>
</tbody>
</table>

3.5 DISCUSSION

The cropping cycle at Nannaj is largely monsoon driven resulting in seasonal variation in number of cropped and fallow fields with cereals being the most common crops grown. Jowar and Tur were the main crops and crop protection measures were largely absent in the study area. Blackbuck use of agricultural habitats is restricted to fields adjoining natural habitats and not extending beyond 150 meters from the non-agricultural habitat edge. Interestingly, in Rollapadu, blackbuck use of croplands was restricted to within 200 meters from protected area (Manakadan & Rahmani 1998). The localized nature of agricultural habitat use suggests that crop fields further away from non-agricultural habitats are perceived to be more risky by blackbuck than croplands located at the edge. The greater use of agricultural areas at the agricultural-grassland edge results in blackbuck feeding on crops.

At the scale of individual fields situated at this edge, crop use was observed in 50% of sampled fields and damage to crops varied considerably, ranging from 17-100% (mean = 42%), with the matrix playing an important role. The intensity of crop use increased with the number of natural habitat sides and corners around a field. Cereals (Jowar) and pulses (Tur) were damaged in the same ratio as their availability in the landscape, suggesting that blackbuck were using crops based on crop abundance in the landscape. Therefore, the most important
predictors of blackbuck presence in agricultural habitats are the distance from
non-agricultural habitats followed by number of non-agricultural sides and
corners around a field. In Rollapadu Wildlife Sanctuary in Andhra Pradesh,
Manakadan & Rahmani (1998) reported that blackbuck use agricultural fields
and feed on 7 of the 20 crops cultivated in the area – sorghum (*Sorghum bicolor*),
foxtail millet (*Setaria italica*), groundnut (*Arachis hypogea*), greengram (*Vigna
radiata*), redgram (*Cajanus indicus*), blackgram (*Vigna mungo*) and cotton
(*Gossypium arboreum*). In the Latuda and Katuda villages in the Surendranagar
district of Gujarat, blackbuck were reported to feed on the sorghum fodder crop
(Jhala 1993).

Detailed examination of agricultural habitat use by blackbuck at the Great Indian
Bustard Sanctuary, Nannaj has revealed that blackbuck primarily use
agricultural fields located at the edges of natural habitats, and the degree of crop
use and the resulting economic losses to farmers during such forays in isolated
fields and fields without protection can be considerable.

I examined one aspect of the ability or capacity of dryland farming systems to
support biodiversity – that is spatial and temporal use of agricultural fields by an
endemic large mammalian herbivore, the blackbuck. I find that agricultural areas
closer to natural habitats are used by blackbuck. Perhaps, the observed patterns
were due to the enhanced perception of risk associated with human-dominated
agriculture fields as blackbuck are poached in the study area. The blackbuck
population is also kept in check by poaching, three poaching attempts were
detected and stopped with protected area staff during fieldwork from 2008-2010.
Hunting of blackbuck in the western regions of Maharashtra by non-pastoral
nomadic communities has been documented as a means to supplement diets
(Malhotra et al. 1983), but information as to the end markets for the poaching that currently occurs in this region is not available.

Interestingly, blackbuck use agricultural areas even after crops have been harvested, suggesting that crop availability may not be the sole reason for blackbuck using agricultural areas. It is likely that the long history of settled monsoon-driven agriculture in the dry plains of the Indian sub-continent has resulted in blackbuck using agricultural areas as and when they are available. The earliest reports of blackbuck crop damage date in Maharashtra back to the 1900s (Anon 1880, Anon 1910a, Anon 1910b), suggesting that blackbuck use of agricultural areas and crops has a long history. Reports of crop use by blackbuck in India resurged almost a century later in the 1990s. In majority of the instances, blackbuck use of agricultural crops was perceived negatively, but there are remarkable instances of tolerance and positive beliefs (Jhala 1993).

The Indian protected area network currently covers 4.7% of India’s geographic area (Rodgers et al. 2002), but some habitats like grasslands are underrepresented in the current network. Less than 1% of all grasslands are currently under protection and only ten small grassland protected areas exist (Rahmani 2006). Given this scenario, blackbuck persistence is dependent on agricultural habitats. In the study area, the dryland farming system is “blackbuck friendly”, but there are limits due to species traits that result in a dynamically changing patchwork of friendly and unfriendly agricultural habitats.

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