

Nutritional Ecology, Movement Patterns & Herd Dynamics of Nilgai (*Boselaphus tragocamelus*) in Kuno National Park, Madhya Pradesh

By

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In

Wildlife Sciences

Under the Supervision of

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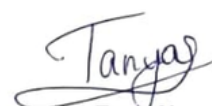
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DECLARATION

I hereby declare that the work conducted under the thesis entitled '**Nutritional Ecology, Movement Patterns & Herd Dynamics of Nilgai (*Boselaphus tragocamelus*) in Kuno National Park, Madhya Pradesh**', is a record of original and independent research work done by me and subsequently submitted for the award of the degree of Master's in Wildlife Science at the Academy of Scientific and Innovative Research. This research work has been carried out under the guidance and supervision of Dr. Vishnupriya, Scientist- E, and co-supervision of Dr. Bilal Habib, Scientist- F and C.M. Bipin, Project Scientist of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge. No AI has been used for any aspect of the work therein.



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Certificate

This is to certify that the thesis by **Tanya Vyas** titled '**Nutritional Ecology, Movement Patterns & Herd Dynamics of Nilgai (*Boselaphus tragocamelus*) in Kuno National Park, Madhya Pradesh**' submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science** of Wildlife Institute of India

Tanya Vyas has put one semester of research work under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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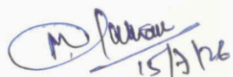
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Executive Summary

Despite the various types of research done before on the nilgai, very little focus was given to what actually propelled forth their propensity to raid crops. This study was meant to delve into the factors that could possibly lead to crop raiding by nilgai. In context of the semi-arid zone, nutrition played a factor for nilgai that lived in places overrun by invasives, but did not provide any advantage to nilgai with access to natural vegetation. Through Manley's selection ratios, it was found that nilgai select for savannah, especially at night, proving a negative association with forests. Models run for finer structural cues showed a negative selection for elevations, slope, hills and mixed forests. Avoidance of predators was seen despite lack of actual attack. Herd dynamics showed changes daily and across the breeding season. And finally, many novel behaviours of nilgai were noted; there is potential for further research on their social structure.

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CHAPTER ONE:

1.1] INTRODUCTION



Fig. 1.1.1 Male adult nilgai in Kuno

The nilgai is a striking and widespread mammal that is frequently associated with agricultural conflict in India. Their population was estimated to be roughly 1,00,000 at the turn of the millennium (Rahmani 2001) and has been rapidly growing since then- buoyed by the advent of stricter animal protection laws and an increasing lack of their natural predators. Their distribution presently extends from Northeast Pakistan to West Bengal and Nepal to Andhra Pradesh (Prater 1980). They were also found in Bangladesh before their extirpation a century ago (Rahman 2024) and skeletal remains and anecdotes of their presence have been found as far South as Mysore (McMaster 1871), Nilgiri Hills (Davidar 2019) and Attirampakkam (Murugan, Paranthaman & Saravanakumar 2020), although this is also speculated to be from captive nilgai and not a natural extension of their range.

This type of widespread distribution ensures an adaptation to a broad range of vegetation across varying climates and topographies; in literature they are often referred to as mixed feeders, with a broad preference for rangelands- scrub and savannah (Chandel et. al. 2025). Yet this is often then contended by their sighting in forested landscapes, capable of living off browse as well. It has been noted that in comparison to other ungulates, they often show high plasticity in diet, switching between graze, browse, dry dung and dead vegetation depending on availability (Sheffield 1983).

But this same versatility has also exacerbated their status as agricultural pests across the country. (Chauhan 2011). Human-Nilgai conflict is a fast-growing problem in

Northern India, with a variety of mitigation measures and technologies cropping up to tackle the issue. (Jain et. al. 2022) But a critical part of invasion ecology is understanding the proximate behind the ultimate, the mechanisms and ecology of conflict animals that drives their decisions, with more research tending to focus on removal rather than cure (Richardson & Pyšek 2008). Similarly in crop raiders, lack of attention given to the drivers behind their behaviour has resulted in nothing more than an 'arms race' between farmers and wildlife. And with shifting perceptions with regards to money & economy, the tolerance to such herbivore crop raiders is also lessening in India (Chandel et. al. 2026).

The most common assumption made in this line of study is that crop-raiding occurs due to nutritional richness or ease of digestibility that is present in crops cultivated by man. Herbivores naturally select for the best forage while grazing or browsing (Dorgeloh et. al. 1998)- with high protein and low fibre- which is a feature of all crops grown by humans as well, making them attractive forage (Saini et. al. 2020). In studies of other mammalian crop-raiders, it has been also found that certain crops help make up a mineral deficiency (Rode et. al. 2006, Chama, Siachoono & Phiri 2025). But antelopes have been found to be not as dependent on high-quality plants (Jarman 1974, Abaturov Subbotin 2011), as they often reside in semi-arid and nutrient-low regions. Then if natural vegetation was available, would it truly be a necessity to raid? This brought us to the first question.

Further, habitat structure has long been considered an important factor that dictates movement & dispersal of animals (James & Shugart 1980). The vast monoculture plains that are formed by agricultural fields are also commonly found to act as familiar structures for grassland mammals (Benedek & Sirbu 2018). If nilgai were 'edge'-sensitive species (Reis & Sisk 2010, Khanal 2016) as previously considered in most anecdotal literature, could the system formed by the sharp shift of semi-degraded buffer forest into vast swathes of grasses possibly resemble their preferred open habitat and attracted them to crop fields, independent of nutrition? This was the second question.

Following these explanations, consideration was given to any possible indirect factors that could cause this movement.

While nilgai have been widely considered overabundant based on fragmented population estimations, it is still a contestable number. Still, it is speculated in theory that a species reaching carrying capacity within a protected area will move out of the human-established borders to find new territory in human-dominated lands (Chauhan & Singh 1990). Therefore, establishing their density would be useful in determining this.

It is also well known that nilgai have a lack of natural predators in today's world, with the fragmentation of the populations of India's carnivores (Bayani & Watve 2016), with them forming varying proportions of prey diets. While it is thought that humans

are perceived as predators in certain regions (Roy, Dash & Sathyakumar 2022, Skogen et. al. 2019)- where they are usually driven off swiftly with the aid of sticks, dogs or loud noises (Chopra & Rai 2009)- many communities in India are known for their tolerance of the species despite the monetary loss. Thus, there is a confusion in the nilgai's perception of predators both in terms of humans and carnivores, which could be valuable information if teased apart, to help understand their navigation in a landscape of fear.

Finally, there has been a curious dearth of detailed study on the nilgai alone in its native range. Little literature is available on their behaviour, species biology & herd structure (Sliwa et. al. 2023). Even the significance of its most known behaviour-daily midden site usage- has not been explored. This research gap is troubling in its lack; ecological knowledge is the basis of any research, solution or mitigation, and the sparse information on nilgai ecology will only make it harder to reach a balance. Thus, an effort was made throughout to understand the natural history of the nilgai.

Whatever the underlying reason, conflict has been increasing linearly in the past decade, as both sides continuously adapt to the struggle, with nilgai displaying impressive adaptability to most mitigation measures within short amounts of time (Jain et. al. 2022). Nilgai have been reported from various sources to be capable of jumping across walls above eight feet, making most barriers completely unsuccessful (Gautam & Bissa 2014) and various anti-crop raiding devices such as the use of nylon rope, garden net, nylon net, bio-acoustic device, reflective ribbon, scarecrow, chemical repellents and animal faecal solution have been implemented, yet in most places these have largely proved to be ineffective.

Unfortunately, when these do not work, it has led to policy measures such as culling to keep up with the fast-growing nilgai population that inevitably affect small farmers disproportionately (Srivastava & Singh 2024). Bihar- a state reported to have one of the lowest forest covers of the country- has already killed over 4,000 nilgai over two years- a method criticized as unscientific and unhelpful. Nilgai have also expanded their habitat west with the greening of inter-dune spaces in Rajasthan due to the leakage of the Indira Gandhi canal (Sivaperuman & Baqri 2009), where farmers have historically not needed to contend with this problem. There have been calls near Ranthambore to push them into the forests, behind brick walls where they can be a part of natural ecosystems- but is that where they really belong, when it is often claimed that they are not forest species? In fact, the Protected Areas where translocation of problem nilgai is usually proposed are majorly forested, which could possibly shift the location of the problem rather than solve it (Osborn & Hill 2005).

Kuno National Park encompasses a vast area and contains open and mixed forests, scrubland, grasslands and surrounding croplands in a management-sensitive landscape that will help in understanding selection in this aspect. It is an accurate representation of the Central Indian Highlands and the relocation of the Kuno villages, first for lion then cheetah reintroduction (Parihar & Singh 2022), have left

behind many minor grassland patches in a mosaic representative of ancient ecosystems (Meinzen-Dick & Singh 2026) through which natural nilgai movement patterns can be studied.

To understand the reasons for the nilgai's dependency on cropfields could help us circumvent the problems in a much more effective and ethical manner. Furthermore, it can help decrease the need for culling, which will improve tolerance of local people who have to let go of more and more of their sentiments and beliefs in order to face the economic losses being created by these animals (Hill 2018), and their increasing frustration with government officials and forest departments. To allow it to continue unchecked in any capacity will only cause more strife in an increasingly barren world.

1.2] OBJECTIVES

➤ Objective 1: What attracts nilgai to agricultural fields?

- To investigate the nutritional dependence that nilgai have upon crops.
 - Hypothesis 1:- Concentrations of nutritional elements present in pellets will be higher in nilgai raiding human-selected crops.
 - Prediction :- Nilgai will disproportionately consume crop when available to them, resulting in a visible change in their nutritional output.
- To assess the features and structure of an ideal nilgai habitat.
 - Hypothesis 2:- Nilgai select grassland and flat scrubland as suitable habitat over forest areas.
 - Prediction :- Despite available forested areas with good nilgai forage, their presence will be seen higher in the savannah compared to the forest.

➤ Objective 2: Does species biology play a factor in their movement?

- To understand the influence of predator avoidance and risks involved with crop-raiding.
 - Hypothesis 3:- Nilgai will show avoidance to predators in Kuno regardless of predation.
 - Prediction :- There is a spatial or temporal avoidance shown with respect to presence of leopard, hyena and cheetah.
- To monitor the changes in nilgai herds and behaviours with changing seasons to explain movement.
 - Hypothesis 4:- Changes in natural herd dynamics causes incidental movement into cropfields.
 - Prediction :- Fission-Fusion of nilgai herds will provide some unknown alternate explanation for nilgai movement.

CHAPTER TWO:

2.1] STUDY SPECIES

The nilgai (Scientific Name: *Boselaphus tragocamelus*; Vernacular Name: Rojh/Nilghor/Banbakri/Blue bull) is a unique animal endemic to the Indian Peninsula, and is considered the largest antelope in Asia, despite not being a true bovine or true antelope. Debate on its taxonomic status had formerly placed it in several different genera- *Antilopa*, *Camaa*, *Damalis*- until the *Boselaphus* genus was finalized by Sclater in 1883, of which the nilgai is the only extant member (Leslie 2008).

The lineage is theorized to have originated from early bovids around 6.54–9.64 million years ago (Solounias 1990, Hassanin and Ropiquet 2004, Bibi 2007), during the rapid speciation of Family Bovidae in India during the Miocene (Pilgrim 1939). Six ancestral sister genera have been identified that resemble Boselaphines, and recent remains from one other species from the genus have been discovered in Sardhok, Pakistan, dating to the Pleistocene, called *B. nomadicus* (Siddiq et. al. 2017). Related smaller genera include Elachistoceras and Eotragus; the medium-sized genera include Miotragocerus, Tetracerus and Tragoptax; the larger genera include Selenoptax, Pachyoptax and Sivapoptax (Khan et al., 2014), the last of which gave rise to the *Boselaphus* genus. Now only the nilgai and four-horned antelope (*Tetracerus quadricornis*) from the Boselaphini tribe remain.

The nilgai stands at an average of 120-150cm at the shoulder (Sankar & Goyal, 2004), with a long neck, a distinct humped back and sloping hindquarters. They also have a characteristic barrel chest and thin legs that enable them to accelerate rapidly from a standstill, clear heights of 1.5m (Sekhar 1998) and sustain kilometre-long runs. In terms of coat coloration, they have a sandy-brown pelage at birth, which persists in females as they get older; along with specific white markings: two spots on cheek, on spot of forebrow, supra-lip extending to a gular patch, striped fetlocks just above the hoof and mid-undercarriage extending to tail (Leslie 2008). They also have black markings: the ends of the mane, stripes on the inside of the ears, black knees and striped fetlocks. (Jain 2022)

For males, the coat darkens around four years of age (Sheffield 1983) to a steel grey/roan blue; combined with other secondary sexual developments like black legs, longer manes, a more pronounced pendant of hair at the base of the gular patch, and smooth horns that vary from 15-30cm; although occasionally females with shorter horns are also sighted. (Leslie 2008). Males also are distinctly bigger than the females, with clear sexual dimorphism as is characteristic of antelopes (Jarman 1974). Both sexes have striped black ears and white patches on cheeks, forebrows and chests, as well as stripes of white and black above the hooves; although the males variability in this latter marking.

With regards to social structure, nilgai are considered herd animals, although solitary males are also reported often, as well as the occasional solitary female. There are three types of nilgai groups reported: Male-only herds, Female herds with calves, and Mixed herds during the breeding season (Johnsingh & Manjrekar, 2016). These herds can vary in number from the usual average of 2.9 to 120, and have been reported to be larger in summers compared to winters (Khan & Khan 2016), with merging of multiple smaller herds into a large group.

But nilgai herds are often unstable and dynamic, with some literature reporting a daily flux in their numbers- which brings into question the usual methods of estimation that have been used to predict their population today. Pellet estimation makes assumptions about defecation rate with movement that would be biased by latrine-using behaviour (Guerrero-Casado et. al. 2020). Line transects also would give skewed results due to the species being naturally wary and cautious, with reports of them fleeing before vehicles catch sight of them (Sheffield 1973). Perception of a single herd as a number of smaller herds may also skew rough estimates by locals.

Behavioural knowledge of wild nilgai is lacking- some descriptions exist of their unique behaviours, such as their daily visitation of the same latrine, neck fighting in males, mating rituals & dynamic nature of herds (Johnsingh 2001), but none of these aspects have been properly researched. No time-activity budgets of wild nilgai are available, and no understanding of their broad social structure exists (Zoromski et. al. 2022). This is possibly due to their low tolerance to approach and flight distance as compared to other species (Sheffield 1973), making unbiased conclusions of their social structure difficult.

They also are prolific breeders, with an extended breeding period (Lochmiller & Sheffield 1989), with births speculated to majorly occur in the late summers and early monsoon (Goldman & Stevens 1980). Yet the specifics of this vary with location, with some literature also claiming no specific season for breeding in nilgai, with calving happening throughout the year. Moreover, female nilgai are sexually active for almost their entire lifespan (1-12 years), and 50% of all births have resulted in twins (Granger et. al. 2024) or even triplets; which has in part been what has led to their astounding, exponential growth in Northern India over the past decade.

2.2] CROP RAIDING

Nilgai is one of the top mammalian species causing crop damage in India today. They have a highly variable diet, with the capability to consume both graze and browse (Prater, 1971, Sankar & Vijayan, 1992, Prasad et al. 2021) across a wide range of forest types. This ability to consume a majority of forage results in nearly all major agricultural crops of the country being available to them as food.

They also are capable of eating vegetation with a large amount of structural defence in the form of thorns and lignified leaves through rumination, with the help of the dental pad on their upper jaw. They also have a high tolerance to as well

phytochemicals such as tannins characteristic of the dry deciduous forest type vegetation. This is seen in their preference for *Zizyphus mauritiana*, *Acacia catechu*, etc. as well as a variety of other plants- *Azadirachta indica*, *Butea monosperma*- that are unpalatable to most herbivores. According to literature, fallen flowers and fruits of *Butea monosperma* and fallen leaves of *Anogeissus pendula* and *Dalbergia sissoo* *Capparis sepiaria*, *Acacia nilotica* and *Z. nummularia* also form a part of their diet in this region (Kale & Tayade 2025, Bhat et. al. 2015). Many populations of nilgai also live entirely off agricultural fields & roadside vegetation.



Fig 2.2.1 A female nilgai browsing upon Acacia catechu

There has also been literature of Nilgai consuming invasive plants- they eat *Acacia nilotica* and *Prosopis juliflora*, and the pods of *Cleome viscosa* and *Cassia tora* (Mehta, Soni & Sankar 2013). Their ability to adapt to Texan vegetation, supported by familiar genera- *Acacia*, *Prosopis*, *Cynodon*- as well as novel vegetation in an entirely different continent also proves their dietary range and fodder consumption capabilities (Picquet 2018). Despite the challenges of an entirely new system, they have reached a population of over 30,000 free-ranging individuals at the present date.

Crop damage quantification is done through a variety of methods- satellite imagery, monitoring yield, observing physical damage (consumption & trampling alike), and detailed questioning (Gentle, Finn & Speed 2011, Skotak & Kamler 2021, Naughton-Treves 1988)- but all of these contain their own flaws and biases. Yet constant observation also is a difficult venture due to nocturnal movement, the multiple points of entry and vast amount of agricultural land to cover.

Regardless, nilgai across India have been documented raiding a large number of crops; wheat, maize, rice, pigeon pea, soybean, oat, cotton, gram, lentils, potato & mustard are all targeted. Vegetables are the most heavily targeted (32%), followed by pulses (22%), cereals (20%) and oil (7.6%) (Chandel et. al. 2024). This is a vast array

of items with different nutritional benefits, and most are often eaten at all stages of their life cycle. Nilgai also have a secondary problem of trampling on growing harvests during rest or travel, which is capable of killing the crop entire instead of stunting their growth if just the leaves were eaten. 10-30% of national crop damage has been attributed to them (AINP-VPM 2024).

For an agricultural-dependent society like India, crop losses are a steadily growing economic problem, with government agencies, engineering and education institutions, non-profits and farmers alike trying to come up with more and more convoluted workarounds to control the destruction caused by animals while trying to keep reactions in line with public viewpoints, religious sentiment and wildlife protection laws (Iqbal 2018). Depreciation caused by insects, birds and mammals take their toll annually, with poorer farmers disproportionately affected.

Mammalian pests are a more complex issue due to their heightened protection and higher support from sympathetic public, causing reluctance from both government and individuals to take harsh measures against them. Yet, their larger size and limited movement make their impacts greater and their presence more visible. Historically, of course, this was always a conflict in India, but with the increasing necessity for currency, the tolerance for these raids are slowly decreasing (Kumar et. al. 2022), and with the low populations of mammals outside protected areas (Karanth et. al 2010), they are easier to accidentally eradicate if reactionary killings are left unchecked, which is a huge loss to the gene pool of the species (Sukumar 2019).

They also run into conflict with India's rapidly shrinking grasslands- since 2007, permanent pastures have shrunk by 1.1 million hectares (Edusoft 2026, Roy & Kaushal 2018, Singh et. al. 2023, Malaviya). The colonial mindset of claiming scrubland as wastelands persists in government today, and the official figures are rife with misclassification and underreporting (Lahiri & Reddy 2025), and then sometimes considered as sites for forced reforestation drives, harming the native wildlife (Kan et. al. 2026).

This, combined with the mass conversion of 45% of India's land cover to agricultural fields (Nayka et. al. 2026), specifically and majorly in their Northern strongholds, has led to major shrinkage in available habitat across their range, with roughly five lakh nilgai residing outside protected areas (Prasad et. al. 2026). Grasslands in India have yet to come under legal protection despite the petitioning for the same by naturalists, and more recently the States (Nandi 2026). Thus, the grassland species of our country have been disproportionately affected by habitat loss, even though the need for spaces for cattle to graze has kept some patches clinging on the edge. And often, the very grassland species left without a home are also the same ones raiding crops.

2.3] STUDY AREA

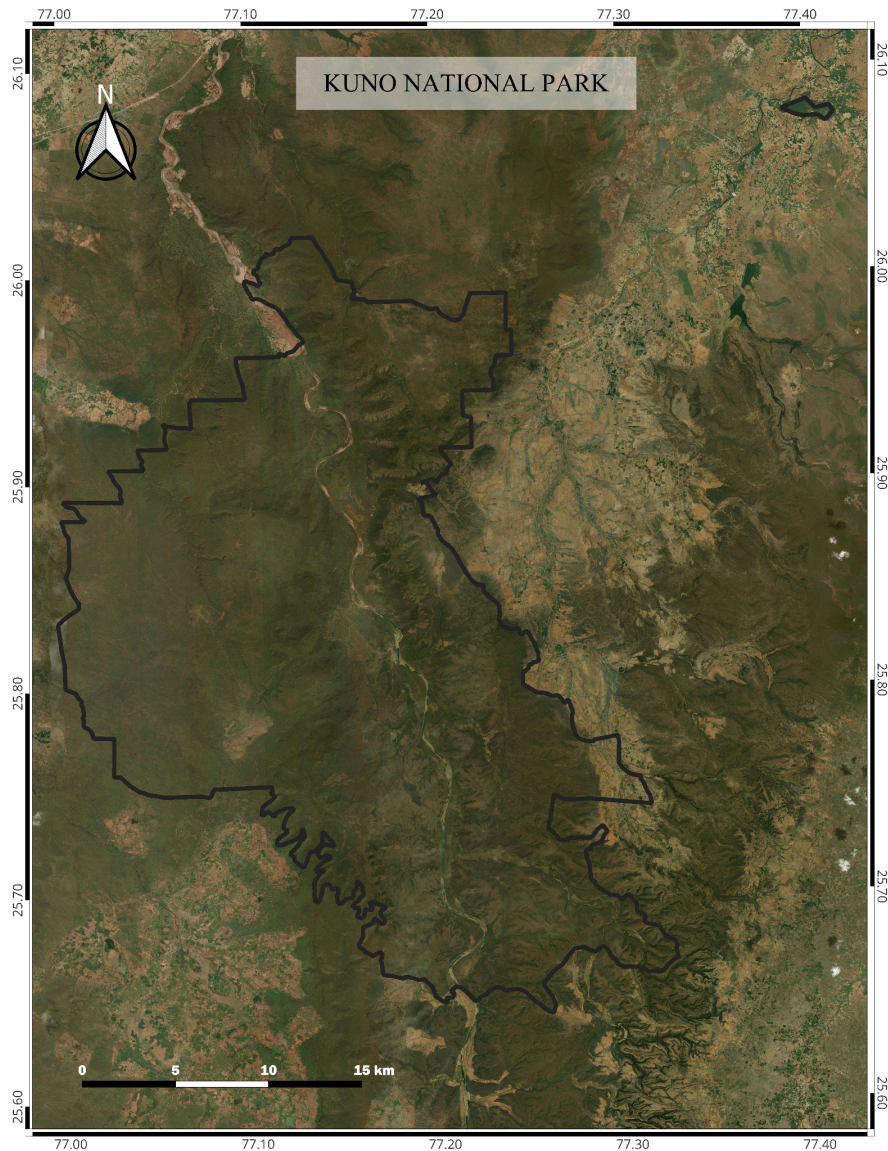


Fig 2.3.1. Map of Kuno National Park & secondary study area, Gohta Protected Forest.

Kuno National Park is located in the Sheopur district of northwestern Madhya Pradesh. The erstwhile Wildlife Sanctuary formed in 1981 initially consisted of the 344 km² that now constitutes the core zone, but the upgraded status of National Park in 2002 extended its borders to cover 750 km² of the landscape. Geographically, it lies between latitudes 25° 30' - 25° 53' E & longitudes 77° 07' - 77°26' N and comes under the category of Northern Tropical Dry Deciduous Forest in the Semi-Arid Biogeographical Zone of India (Rogers & Panwar 1988).

It is a part of the Aravalli-Vindhya junction and is majorly undulating, with the average elevation of the sanctuary from mean sea level ranging from 238 m - 498 m. These hills are also interspersed with some grasslands and woodlands- a feature of

the village relocation programmes- which forms a natural mosaic model that would be useful in deciding the actual preferred habitat for nilgai due to its propensity for equal opportunity browsing and grazing (Johnsingh, Goyal & Qureshi 2007).

The Kuno River bisects the centre of the park, a semi-perennial tributary of the Chambal River that marks the border between MP and Rajasthan. The vegetation is accordingly seasonal- with the forests mainly consisting of *Acacia catechu*, *Terminalia pendula*, *Acacia leucophlora*, *Boswellia serrata* and *Beautea monosperma*. The grasslands are largely *Enteropogon*, *Districhum* and *Cenchrus* (Verma & Lakshmanudu 2022).

Grass cover declined steadily post-winter, with all open areas set on fire around January as part of managemental practices of the National Park (Jhala et. al. 2022). This is a debated but widely practiced grassland conservation strategy used across India in order to prevent encroachment of trees and bring in the next flush of grass (Senthilkumar et. al. 1998). The buffer regions of the park also declined in vegetation, and the water bodies all dried up in April.

The study period lasted from December 2025-March 2026, with temperatures ranging from -1°C at night to 50°C in the afternoon over the changes in season. The average annual rainfall is 760 mm and erratic thunderstorms occurred through the study- a feature of climate change that was not reported ten years ago, and this repeatedly replenished the Kuno River that cuts through the centre of the National Park. Most vegetation declined in the dry season, with water sources reduced to pockets of the Kuno river. The cropping was mainly of mustard (lasting November-February) and wheat (lasting December-March) and both were reported to be raided by nilgai from a total of 21 villages visited.

Nilgai density according to the 2024 report was 0.66 per square kilometre (Qureshi et. al. 2024) and crop raiding was reported from nearly all surrounding villages. A four-day recce was also conducted in September; where grass height limited sighting, but midden sites as a proxy for presence supported a high number of nilgai in the National Park.

The area targeted during study was majorly the ranges Palpur East and Palpur West due to their easier accessibility and road network. The villages of Umri, Magardeh, Ahera and Tiktoli were scouted for high crop-raiding after an initial round of surveys that provided a rough idea of the more affected villages. All collaring occurred in the East Palpur range, in the beats of Jankhyapur, Basantpura North and Basantpura South.

A secondary study area was located around 80km from the Agara gate of the National Park. Located between the villages of Gohta and Khurdrwara, it is a small patch of forest majorly consisting of the invasive *Prosopis juliflora* and other herbs and shrubs, with a minor perennial river flowing through it. While it is only roughly

13 km², it houses a herd of nilgai, and is connected to a larger forest system through a nearby corridor for ensuring constant population influx.

CHAPTER THREE:

3.1] METHODOLOGY

1] Analysis of Pellets for Nutrition:

Nilgai pellets were collected for nutritional analysis over the course of the study, resulting in a total of 240 samples [10 units per location x 3 seasons x 8 locations]. To account for seasonal change and availability of crops/forage, three rounds of collection were conducted- Winter, Transition & Summer. Fresh pellets were collected to minimize back-dating inaccuracies, with 12-18 pellets collected per sample.

Habitat	Pellets Collected in Summer	Pellets Collected in Transition	Pellets Collected in Winter	Total
Forest	30	30	30	90
Fringe	30	30	30	90
Refuge	15	15	15	30

Efforts were made to keep demography of collected pellets equal, but was not wholly successful due to difficulty in locating pellets of females. Pellets were never collected from the same latrine twice in a season, and a minimum distance of 700m was taken between latrines to assume independence in individuals. No more than three samples were collected per day. Three habitats were considered for collection of pellets:

- *Forest: Jakodha, Basantpura and Manak Chowk were considered as core regions, with all three having a minimum distance of 7km from the nearest agricultural field to assure that corresponding nilgai fed only on forest vegetation.*
- *Fringe: Ahera, Tiktoli, Umri and Magardeh were considered as regions where the crop-raiding nilgai were thought to reside, with corresponding villages reporting constant visits through the cropping season.*
- *Refuge: Gohta was a patch of forested land around 80km from the National Park. It mainly consisted of the invasive Prosopis juliflora, and had a permanent tributary running through it. Nilgai were said to use the patch as shelter and raid crops from the villages all around.*

These were sun-dried for one week and stored in a steel trunk in ziplock bags, transported to the WII analytical lab at the end of the study. Out of 240, only 105 random samples were processed due to time constraints for the following:

- Crude Protein: The samples were analyzed via the Kjeldahl's protocol (Goyal et. al. 2022).
 1. The sample was digested at 400°C for 4 hours in the digester.
 2. This was followed by nitrogen analysis in the FOSS Kjeltec™ 8400 analyzer.
 3. Results were multiplied by conversion factor 6.25 to obtain protein values.
- Crude Fibre: The samples were analyzed via the Van Soest's Acid Detergent Fibre method (Van Soest et. al. 1991).
 1. The sample was refluxed with Acid-Detergent Liquid for one hour followed by vacuum filtration and incubation at 100°C.
 2. After 24 hours of incubation, it was made to stand for 3 hours with 70% H₂SO₄ draining.
 3. The sample was once again placed in an incubator after treatment.
 4. After 24 hours of incubation, it was placed in a muffle furnace for 4 hours at 550°C.
 5. Lignin was calculated by the formula:

$$\text{Final Weight/Original Sample} \times 100$$

- Acid-Insoluble Ash: Ash was used as a proxy for inorganic silica content. The sample was burned in a muffle furnace at 500°C for four hours. Silica was calculated by the formula:

$$\text{Final Weight/Original Sample} \times 100$$

Results were compiled in Microsoft Excel. The significance of both differences in habitat and seasonal changes were tested by T-Test, one-way ANOVA and Tukey's HSD.

Body condition scoring was done via visual sighting (Ashraf 1992). Visible pelvic bone, vertebrae and ribs were the parameters used to score 0-1-2 (0 being lowest, 2 being best).

2] Home Range & Resource Selection:

Data from Iridium Satellite Collars from African Wildlife Telemetry was used for this study. Three females and one male were successfully collared in the last week of January. Unfortunately, due to territorial fighting that occurred between the collared male and a subadult male, the collar was broken. Male showed increased skittishness to human presence after, whereas females soon acclimatised to the vehicle as time went on.

The details of the collared nilgai are as follows:

- ❖ Pipli (Nilgai_01)
 - Sex: Female
 - Age: Adult, Estimated 6 years (Lactating mother)
 - Body Condition score: 2
 - Morphometrics: Nose to Tail- 63 inch, Neck- 29 cm, Limb- 30 inch, Chest- 53 inch
 - Captured: 3:16pm, Peepal-Baodi. Darted through forest cover after the herd resumed browsing, estimated distance 20m.
 - Remarks: Post-darting, the individual fled and was located roughly 50m from the original location, with two females of her herd nearby. Ticks were found on the inner ear and udder.
- ❖ Kajal (Nilgai_02)
 - Sex: Female
 - Age: Adult, Estimated 9 years (discolored coat)
 - Body Condition score: 2
 - Morphometrics: Nose to Tail- 51 inch, Neck- 19 cm, Limb- 24 inch, Chest- 60 inch
 - Captured: 12:01pm, Basantpura. Darted by the side of the road post rainshower, estimated distance 8m.
 - Remarks: Post-darting, the individual trotted a short distance and fell around 5 minutes after darting, 70 from the original location, with her entire herd standing nearby. Ticks were found on the inner ear.
- ❖ Aadhasingha (Nilgai_03)
 - Sex: Male
 - Age: Adult, Estimated 7 years (based on size)
 - Body Condition score: 2
 - Morphometrics: Nose to Tail- 59 inch, Neck- 17cm, Limb- 28 inch
 - Captured: 9:30am, Peepal-Baodi. Darted through forest cover after the herd resumed browsing, estimated distance 20m.

- Remarks: Post-darting, the individual fled a short distance and resumed courtship behaviour of the nearby female herd. He fell after roughly three minutes, causing the female herd to flee. Ticks were found on the inner ear.
- ❖ Nimmari (Nilgai_04)
 - Sex: Female
 - Age: Subadult, Estimated 4 years (based on size)
 - Body Condition score: 2
 - Morphometrics: Nose to Tail- 52 inch, Neck- 19 cm, Limb- 20 inch
 - Captured: 3:41pm, Pokinimmari. Darted through forest cover after the herd resumed browsing, estimated distance 20m.
 - Remarks: Post-darting, the individual fled and was located roughly 250m from the original location, with no other nilgai around. Ticks were found on the inner ear.

Out of the three remaining females, only Kajal was sighted with regularity due to her home range largely intersecting with the roads of the park, as was Aadha, who was still recognizable due to his broken horn. When possible, behavioural observations were taken, as well as their herd placement, herd composition and body condition over time.

The collars were Iridium Satellite ones, and animal locations were tracked remotely. Fixes were set to once every hour for fine-scale data, and data from January 26th-June 9th was used for analysis in this study. Visuals were taken on regular intervals to ensure health and assess demography, and deteriorating health was observed over time, as well as disproportionate disrepair of the collar. Difficulty was faced in trying to track the animals down for sightings using receiver equipment, as they would flee before we could come within visual sighting distance.

The home ranges of all three nilgai were calculated, along with daily path lengths, and dial path lengths. Maps were intersected with the LULC map of Project Cheetah for Kuno National Park to gain use-availability ratio. The softwares used were R Studio, ArcMap, Google Earth and Excel.

3] Density Estimation and Spatio-Temporal Overlap of Nilgai with Predators:

Nilgai are not individually identifiable, move in herds & are prone to flight (Sheffield 1983). Nocturnal activity of nilgai also leads to further gaps in data (Singh et. al. 2017). Therefore, to try and correct for all these biases, a form of abundance estimation known as Camera Trap Distance Sampling (Howe et. al. 2017) was used to try and calculate their population within a known area, trying to decrease bias caused

by detection, nighttime activity being missed and better coverage of the undulating landscape.

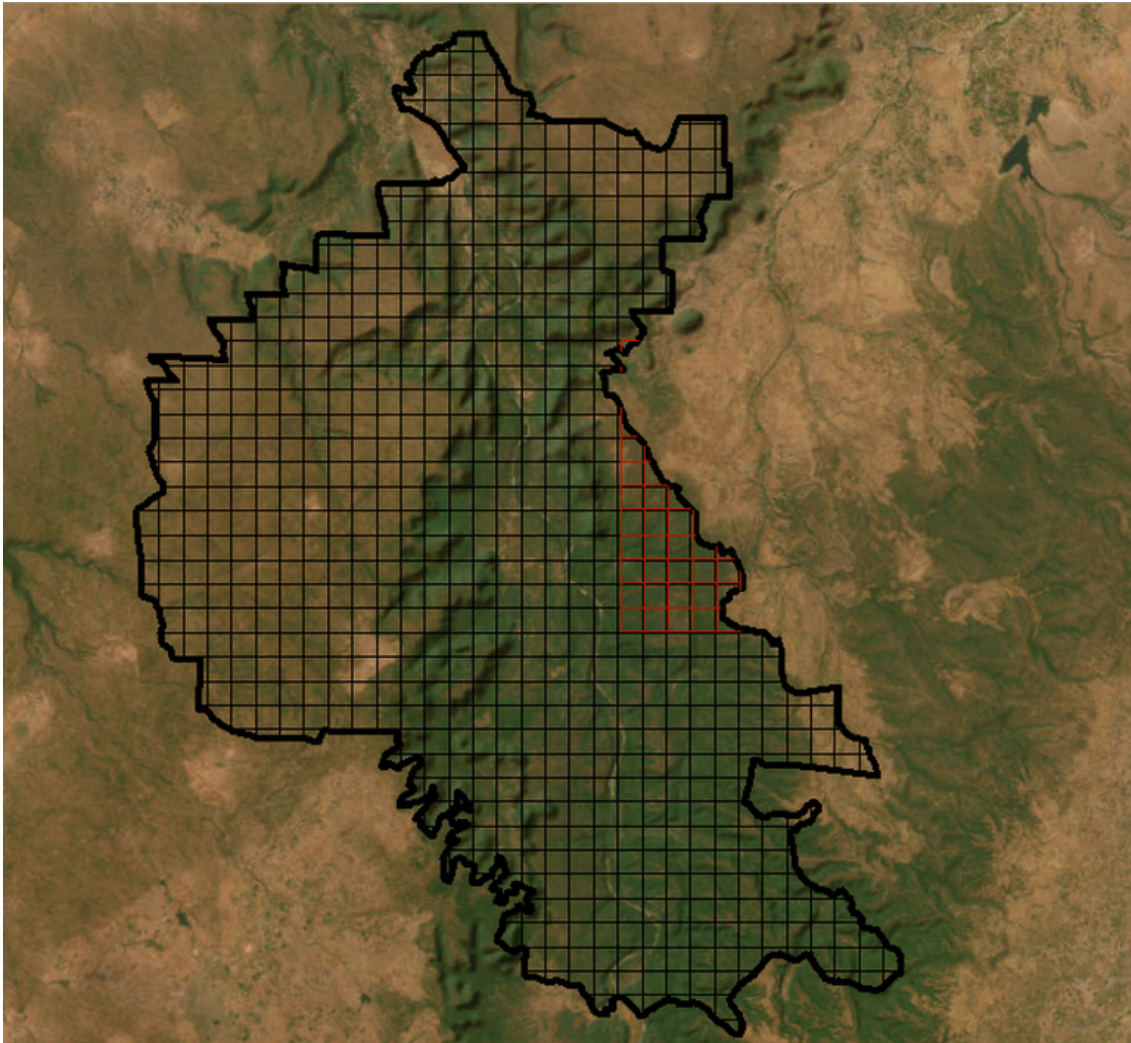


Fig. 3.2.1 Map of CTDS grids laid on fringe of KNP

The camera traps used were Cuddeback C1 models with Infrared Flashes installed, set to 3 photos per capture, with Zone and Aspect Ratio set to Wide. They were placed approximately 60cm high from the ground, and tied tightly with wire to ensure lack of movement. A grid of 1km² was laid along the buffer zone, deemed sufficient based on literature of nilgai seasonal home ranges being roughly 2.6 km²,

Cameras were placed in the centroids of these grids. The habitat was variably plain and undulating, so in the latter, effort was made to turn the cameras facing any nearby animal trails, under 5m. This was done to ensure capture rates while preventing cameras from being stolen, although the drawback of overestimation is thereby still present, affecting inference results. The session lasted 30 days (Feb 11th-March 27th) and cameras were monitored once at the 15-day mark. Points were calibrated by laying out measuring tape in the centre of the capture area and marking each point by holding up whiteboards with the corresponding distance up to 14m,

beyond which detections were truncated. These reference objects were kept constant through the study.

At each deployment site, habitat variables were collected under a radius of 15m from the camera trap. These included:

- Distance to Water
- Terrain
- Human Presence
- Elevation
- Grass Height
- Grass Cover
- Canopy Cover
- Vegetation Species
- Forest Type

Data was then analyzed via Timm-Haucke Distance Estimation software, which includes the advantage of the angle measurement not being needed in the field. The interval of 3 photos was taken to declare a detection independent. The first site had 40 detections, while the second had 20. Cluster size was taken into account. Unfortunately due to time constraints and software issues, the density estimation was not able to run successfully.

To understand the interactions between predators and prey, the Relative Abundance Index of leopards, hyena, cheetah and nilgai were calculated from the detections from 23 cameras (one stolen and one removed).

$$RAI = \text{Number of Detections} / \text{Effort (Trap Nights)} \times 100$$

The RAI values for nilgai, male nilgai & female nilgai were modelled against the habitat variables collected above to obtain fine-scale habitat selection. Spatio-Temporal overlaps were calculated in R Studio.

4] Herd Dynamics:

All direct sightings of nilgai throughout the course of the study was noted in the Epicollect software. Rough estimate of total effort is 100 days, 7 hours a day (7am to 12pm, 3pm to 6pm), not counting chance sightings when not working. Other variables collected were:

- Date
- Time
- Location
- Terrain (Forest, Grassland, Edge)

- Body Condition Score (0/1/2)
- Herd composition
- Remarks

The criteria for classifying adult males was the presence of the blue coat that is said to come in at four years, whereas brown-coated individuals with horns and leaner males with an in-between pelage were assumed to be subadult males. For females, personal opinion on size was used to classify a female as a subadult or adult based on the height, leaner build and presence of barrel chest. Any individuals within 300m of each other were considered a single group.

Visibility conditions were majorly clear while surveying, though the occasional winter fog and rainshower caused minor data gaps. Broad terrain was mainly used as a habitat marker. Composition of the herds of identifiable individuals was tracked over the course of the study. The form was also distributed to the researchers of Project Cheetah for better accuracy.

Overall 312 observations of nilgai herds or individuals were made over four months. The results were analyzed in R studio packages *ggplot2*, *dplyr* & *tidyverse* to understand age-class changes over time. This data was also used for a preliminary understanding of use of habitats by this species, as well as a track record for identifiable individuals to give us a preliminary understanding of home range.

5] Behavioural Analysis:

Surveys were conducted by vehicle across the National Park and certain locations were finalized as more productive to visit due to the ease of sightings and the distance to basecamp: the beats of Tiktoli, Manak Chowk, Jakodha, Peepal-Baodi, Basantpura and Pokinimmari. These places were visited at random, at different times of the day, to minimise bias. The locations covered a variety of different habitats-grasslands, *Acacia catechu* forests, *Zizyphus maritima* forests, *Terminalia pendula* forests, mixed forests and varying levels of flat and undulating terrain. Study times lasted from December 10th-March 28th.

As soon as an individual or herd was sighted, the vehicle (a closed white Bolero jeep) was stopped gently either before or after the animal, and then slowly brought to a better vantage point after the nilgai had relaxed and returned to foraging or looking in other directions. Individuals were sometimes followed at a distance above 30m, and many were habituated to our vehicle within a month. When the animals went out of sight, the search for the next herd was resumed.

The following protocol was observed:

1. Collection of demographic data on Epicollect (Date, Time, Location...)
2. Recording the names of any consumed forage species if possible.
3. Instantaneous scan sample of the visible herd members.

4. Focal scan sample of random individual herd member for a duration of five minutes. Once this time had elapsed, the individual was switched, usually to a different age-sex class than the current focal animal.

Group Composition	Name	Type	Mechansim	Description
All	Browsing	State	Foraging	Consuming parts of dicot plants; from trees, shrubs or herbs.
All	Grazing	State	Foraging	Consuming parts of monocot plants; usually grass.
All	Ruminati ng	State	Foraging	Chewing the cud; usually sitting but also can occur standing. No food is eaten for 15 seconds before chewing motion occurs.
All	Vigilance	State	Prey	Standing with ears unmoving and body tense, usually looking in a particular direction. Scanning for threats was also included in this definition.
All	Alarm Call	Event	Prey	A deep, quick call made upon sighting a threat. Seen in the case of leopards, hyenas and humans on foot.
All	Standing	State	Locomotion	Standing without foraging, ruminating or vigilance. Ears and tail constantly moving, head occasionally moved.
All	Sitting	State	Resting	Sitting sternally, usually in a circular formation
All	Walking	State	Locomotion /Fleeing	Moving forward slowly, often with the neck stretched forward.
Males	Stotting	Event	Fleeing	A slow trot, not very fast but with the intent to get away.
All	Cantering	Event	Fleeing	Moving at a quicker speed, in the traditional cantering sense.
All	Galloping	Event	Fleeing	Running at full speed to flee from something.
All	Spooking	Event	Prey	Startling due to a disturbance and running a short distance before halting.
Males	Chasing/ Being Chased	Event	Courtship	Being run off a herd of females by another courting male across a large distance. Can also occur after neck-fighting.
Males	Following	State	Courtship	A solitary male follows a female around with his tail held upwards, sniffing nether regions and nuzzling.
Females	Being Followed	State	Courtship	Female walks around, letting the courting male march behind her. Can spook or allow mating.
All	Mating	Event	Courtship	Mounting of male upon female after successful courtship.

Male	Nuzzling	Event	Courtship	Courting male reaching out to rub chin on back, neck or face.
All	Grooming	Event	Cleanliness	Licking of body, scratching of ear via leg. No allogrooming observed.
Calf/ Female	Suckling	Event	Rearing	Drinking or providing milk
Males	Posturing	Event	Courtship	Neck stretched out, tail sometimes upright, walking slowly forward with an arched back and stiff legs.
Females	Hitting	Event	Rearing	Seen in older females, using head to smack another individual out of the way.
Males	Neck-Fighting	Event	Courtship	Getting down on knees and wrestling by placing necks against each other. Horns are also utilized. The winner chases off the loser.
All	Drinking	Event	Drinking	Bending down to have water. Different from standing in a water body.

Table 1. Ethogram for Nilgai (Boselaphus tragocamelus)

The final data came up to about 51 scan samples and 226 focal scans that resulted in twenty hours of data. The need for five-minute scans was mainly due to the constant movement of the nilgai, usually resulting in them going beyond visual range before the five minutes had finished, unless the terrain enabled visuals for a further distance. Weather remained largely clear, and while a few excursions were made during fog and rain, not many individuals were sighted on these outings and so the effort was dropped. The timing of searches increased with the increase in sunlight time as winter ended, and conscious effort was made to keep afternoon surveys as constant as possible.

There were a few individuals recognizable on sight- the three collared nilgai, a female with a bent ear and her calf, a male nilgai with one horn and the ex-collared male nilgai with half a horn. These individuals were all noted by name whenever sighted and used for behaviour sampling. The most seen was Kajal (Nilgai_03) and her sampling was the highest.

Subadult males were the least common to see because of their only distinguishing characteristic being their horns, which were difficult to spot from the distances being observed. Some behaviors were seasonal and dependent on availability of resources.

Analysis included time-activity budgets, grazing-browsing ratios and fleeing strategies for different age-sex classes through R Studio packages *dplyr* and *ggplot2*. Detailed descriptions of the courtship behaviours have also been included below. All information about sighted herds were recorded in Epicollect. Pictures related to each behaviour are included in Appendix.

CHAPTER FOUR:

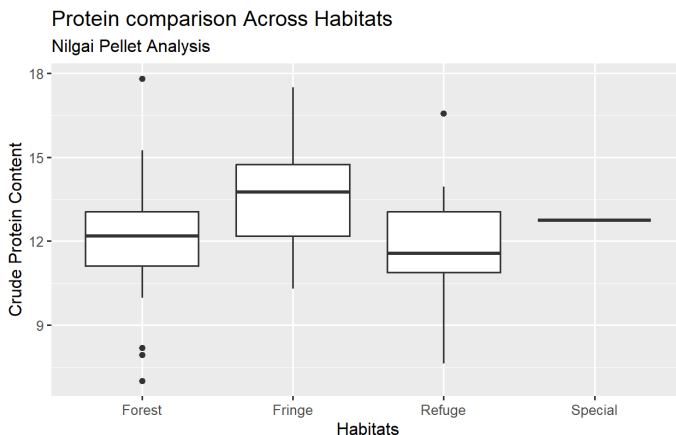
4.1] RESULTS

Objective One: What attracts nilgai to agricultural fields?

- *H1: Concentrations of nutritional elements present in pellets will be higher in nilgai raiding cultivated crops.*

The following assumptions of the three treatments for pellet analysis are as follows:

1. Forest: Nilgai that did not raid crops of any kind, because of the distance to the core zone.
2. Fringe: Nilgai that did raid crops, because they lived at the edge of the national park.
3. Refuge: Nilgai that resided in a patch of Prosopis during the day and raiding crops at night.
4. Special: Pellets from the herd of collared nilgai that had been raiding crops continuously for a week, whose results act as a measure of accuracy against the results of forest and fringe.



Category	Estimate	Standard Error	p-value
Intercept	12.01	0.26	< 2e-16 *
Fringe	-1.52	0.36	7.0e-05 *
Refuge	0.02	0.51	0.96
Special	0.73	1.75	0.67

Fig 4.1.1. Boxplot of protein variation across treatments
Table 2a. Descriptive statistics of protein analysis modelling

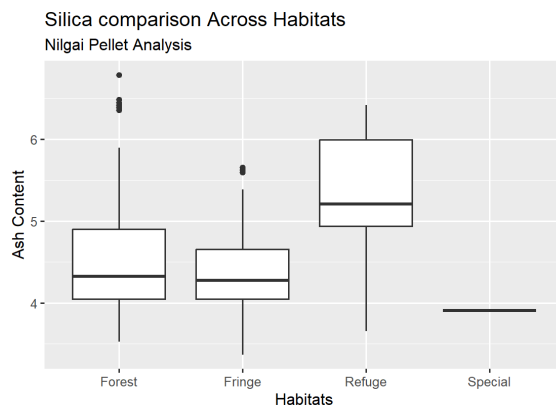
Linear models under the package *stats* were used to model the results of protein against habitat type, with an AIC of 419.443 and df of 101. The means were tested via one-way ANOVA (with a significance of 0.000442) and then further compared by the Tukey-Kramer's HSD test, revealing the following results:

Fringe-Forest	0.002	Significant
Refuge-Forest	0.997	Not Significant

Special-Forest	0.987	Not Significant
Refuge-Fringe	0.032	Significant
Special-Fringe	0.973	Not Significant
Special-Refuge	0.980	Not Significant

Table 2b. Tukey-Kramer's HSD test results for protein

Protein content is highest in the fringe area (buffer area with crop-raiding nilgai), lower in the forest area (core zone with nilgai wholly dependent on wild vegetation) and lowest in the refuge (a *Prosopis juliflora* patch where nilgai took shelter and then raided crops from surrounding villages at night).



Category	Estimate	Standard Error	p-value
Intercept	22.18	1.16	< 2e-16 *
Fringe	-2.47	1.63	0.13
Refuge	6.89	2.30	0.003 *
Special	-6.90	7.78	0.37

Fig 4.1.2. Boxplot of silica variation across treatments

Table 3b. Descriptive statistics of silica analysis modelling

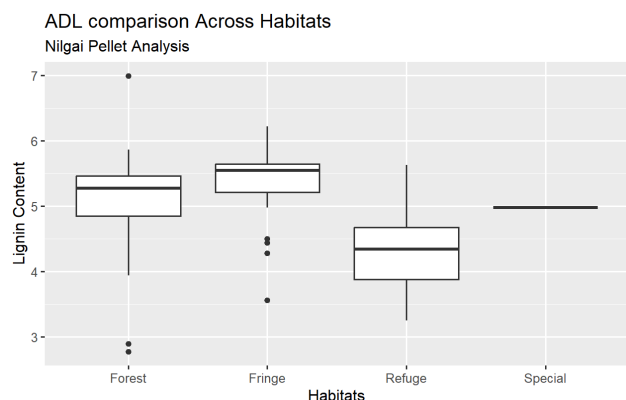
Linear models under the package *stats* were used to model the results of protein against habitat type, with an AIC of 732.432. The means were tested via one-way ANOVA (with a significance of 0.000442) and then compared by Tukey-Kramer's HSD test, revealing the following results:

Fringe-Forest	0.402	Not Significant
Refuge-Forest	0.018	Significant
Special-Forest	0.805	Not Significant
Refuge-Fringe	0.0004	Significant
Special-Fringe	0.940	Not Significant
Special-Refuge	0.307	Not Significant

Table 3b. Tukey-Kramer's HSD test results for silica

The silica content of the refuge patch is much higher, which is in line with the exotic *P. juliflora* being the most abundant vegetation within the patch itself. These nilgai in particular therefore will have major benefits in consuming crops with less silica.

Pipli's analysis shows consistency with this, although even less silica than counterparts. There might be some minor nutritional benefit for fringe nilgai to crop raiding for lack of silica, but not significant for this analysis.



Category	Estimate	Standard Error	p-value
Intercept	26.99	0.86	< 2e-16 *
Fringe	2.45	1.21	0.045 *
Refuge	-7.46	1.70	2.97e-05 *
Special	-2.23	5.76	0.69

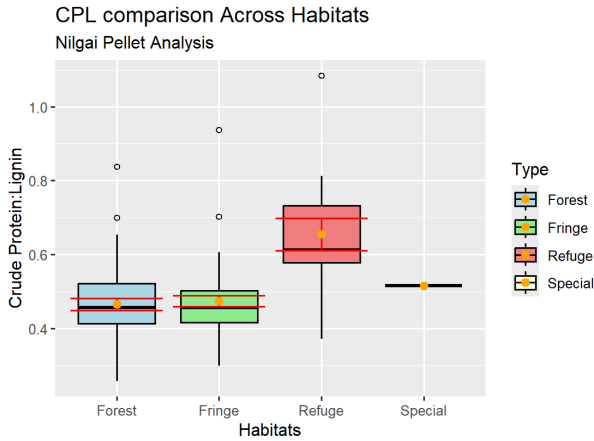
Fig 4.1.3. Boxplot of ADL variation across treatments
Table 4a. Descriptive statistics of ADL analysis modelling

Linear models under the package *stats* were used to model the results of protein against habitat type, with an AIC of 669.575. The means were tested via one-way ANOVA (with a significance of $1.718e-06$) and then compared by Tukey-Kramer's HSD test, revealing the following results:

Fringe-Forest	0.114	Not Significant
Refuge-Forest	0.0005	Significant
Special-Forest	0.989	Not Significant
Refuge-Fringe	0.0000008	Significant
Special-Fringe	0.861	Not Significant
Special-Refuge	0.821	Not Significant

Table 4b. Tukey-Kramer's HSD test results for silica

The lignin content of the nilgai living in refuge is decidedly lower than the ones living in the forest and fringe.



Category	Estimate	Standard Error	df	p-value
Intercept	0.46	0.017	101	< 2e-16 **
Fringe	0.008	0.024	101	0.72
Refuge	0.18	0.03	101	2.65e-07 **
Special	0.05	0.11	101	0.66

Fig 4.1.4. Boxplot of CP:L variation across treatments
Table 5a. Descriptive statistics of CP:L analysis modelling

Linear models under the package *stats* were used to model the results of protein against habitat type, with an AIC of 469.45.

The consumption of lignified plants is more in forested areas than it is in the exotic patch, meaning refuge nilgai are almost completely dependent on crops despite the lack of protein it affords them.

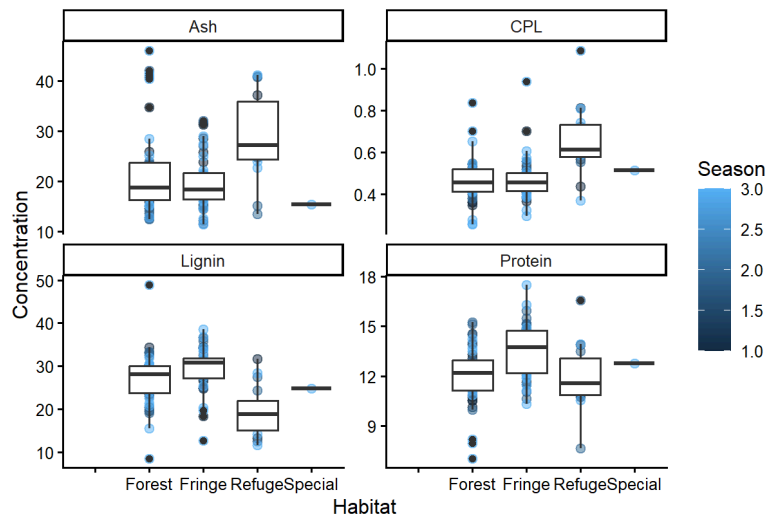


Fig 4.1.5. Summary of all analyses run together through package facetwrap.

Due to the small effect size of collection of pellets upon the data (5 units per 8 locations per season) further analysis was not possible.

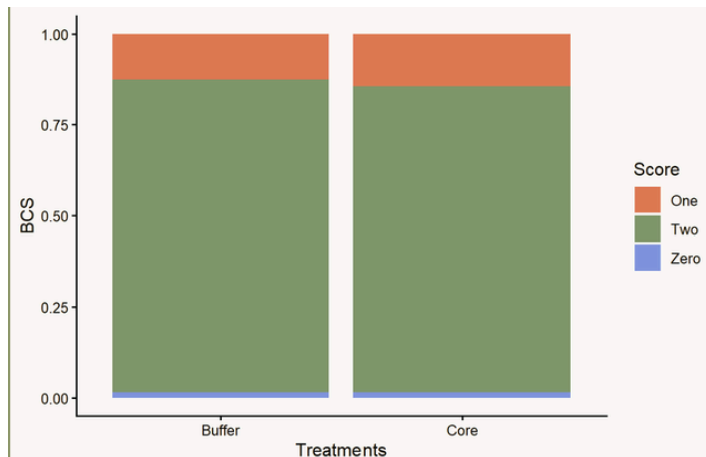


Fig 4.1.6. Body Condition across sites.

Fig 4.1.7 Lowest body condition scoring on a nilgai

Body Condition Scores were collected as a measure of lacking nutritional conditions across habitats. However, due to the higher number of lactating mothers, which are already prone to being in lower health, during the course of this study (as the evidence of breeding season will provide later), the usage of this scoring is not viable. When analyzed regardless, BCS did not have any relation to date, habitat type or sex.

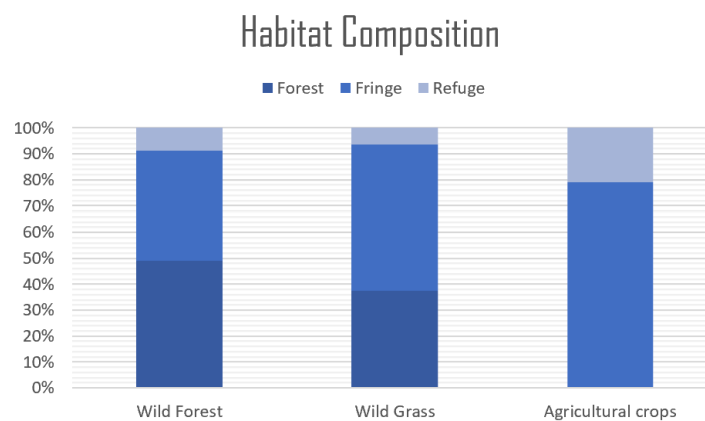


Fig4.1.8. Habitat Composition across treatments

The bounds of the various locations were mapped and laid on ArcMap and the area was calculated by pixel value. The composition of the forest cover, grassland cover and crop cover present in the various treatments are represented in the graph alongside. This displays the amount of available vegetation for the nilgai of each treatment across locations.

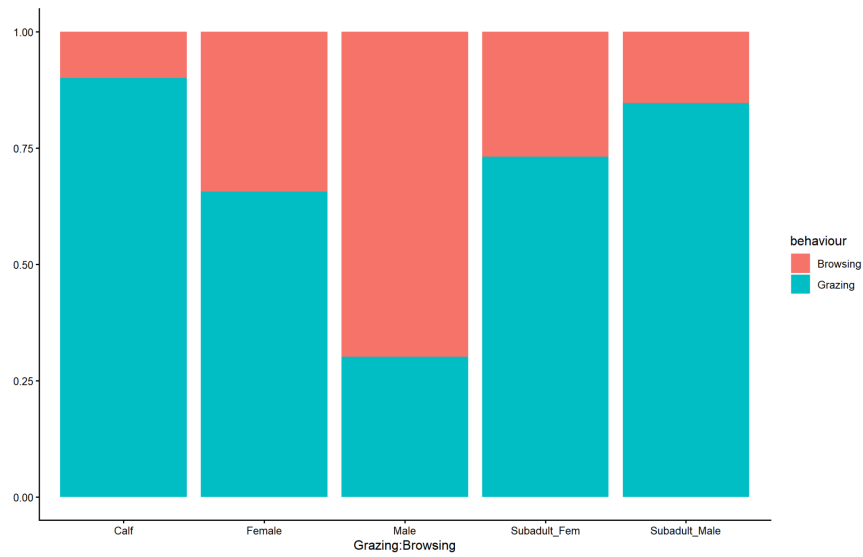


Fig 4.1.9. Grazing to Browsing Ratios across Age-Sex Classes

Behavioural observations across the study season showed a clear preference to graze over browse. There was no significance of age-sex classes for one feeding style over the other, barring calves, who could not reach the trees.

- *H2: Nilgai select grassland and flat scrubland as suitable habitat over forested and hilly areas.*

The movement patterns of nilgai through collar were analyzed in ArcMap, Google Earth and R Studio through the packages *move*, *adeHabitatHR*, *adeHabitatHS*, *spa* and *mapview*.

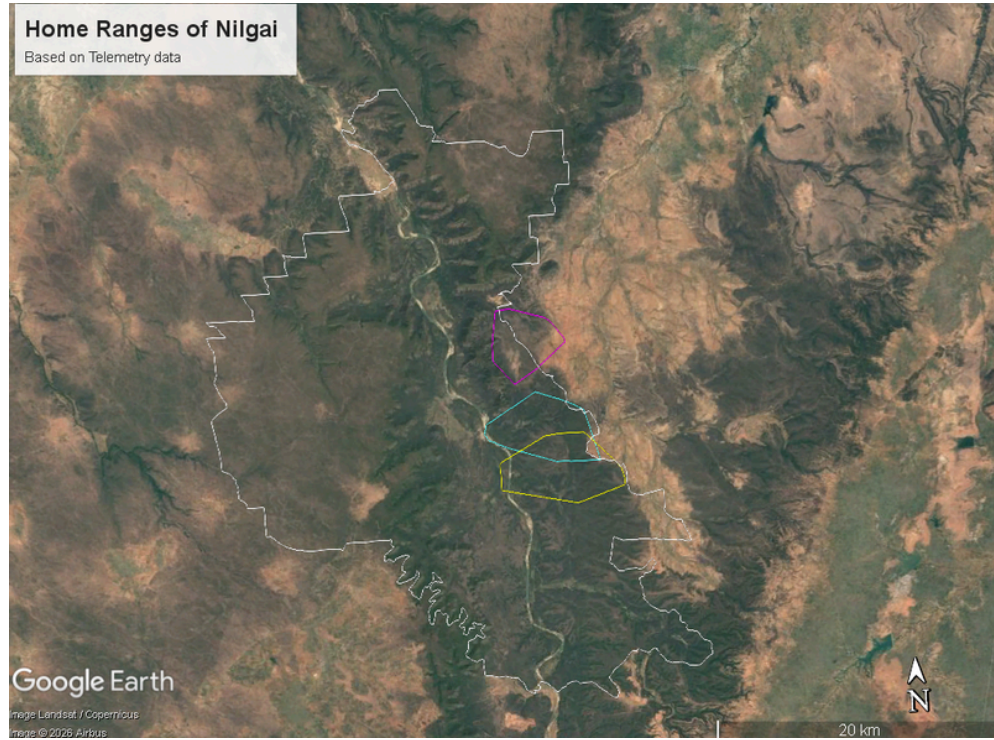
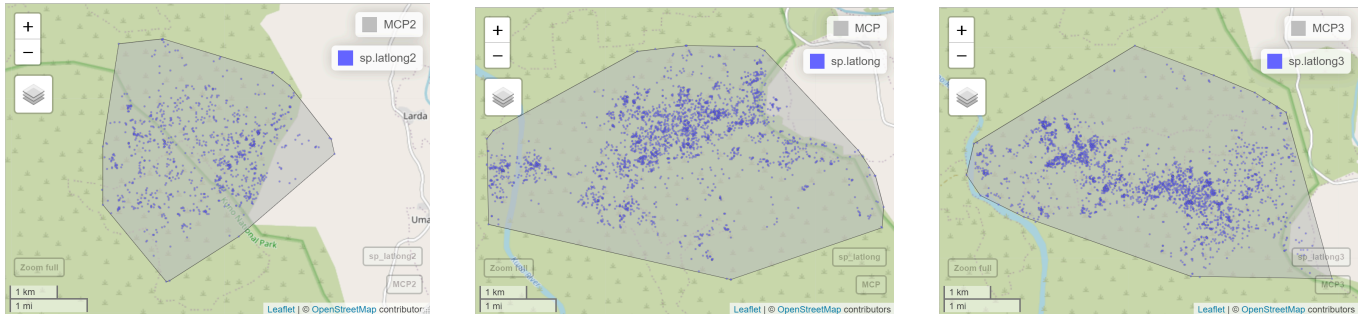


Fig. 4.2.0. Map of all three home ranges, calculated via minimum convex polygon.

Nilgai	MCP	KDE	KLSCV
Pipli	15.68311	-50%: 3.971345 -95%: 13.535667 -99%: 18.716467	-50%: 1.092120 -95%: 4.925069 -99%: 6.682089
Kajal	24.04266	-50%: 3.826071 -95%: 17.001563 -99%: 25.272205	-50%: 1.229808 -95%: 6.918572 -99%: 9.450107
Nimmari	29.00746	-50%: 4.484887 -95%: 21.058737 -99%: 29.708163	-50%: 1.728199 -95%: 7.983436 -99%: 10.807567

Table 7. Areas of home ranges calculated through different methods.

The home ranges were calculated on the basis of three different methods- Minimum Convex Polygon, Kernel Density Estimation & Kernel Least-Square Cross Validation. Through the latter, the used areas can further be narrowed down to the above patches of highly used regions. All three home range estimations are used in 50-90-95% ratios.



Figs. 4.2.1 a: Home range of Pipli through Minimum Convex Polygon. Fig. b: Home Range of Kajal through MCP. c: Home Range of Nimmari through MCP.

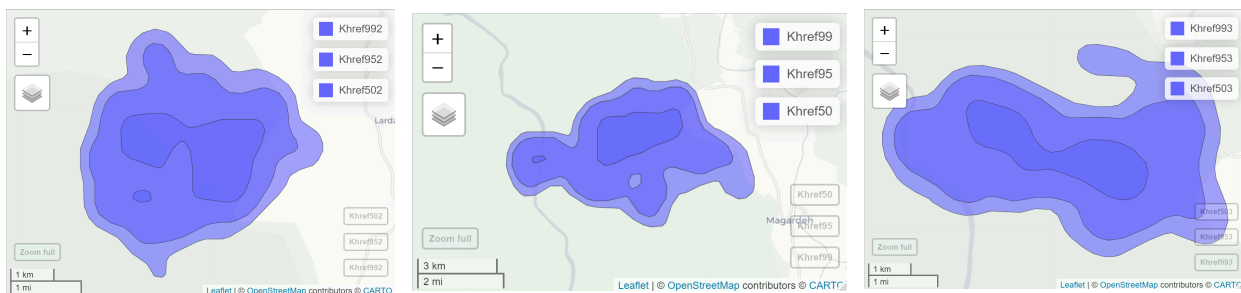


Fig. 4.2.2 a: Home range of Pipli through Kernel Density Estimation. b: Home Range of Kajal through KDE. c: Home Range of Nimmari through KDE.

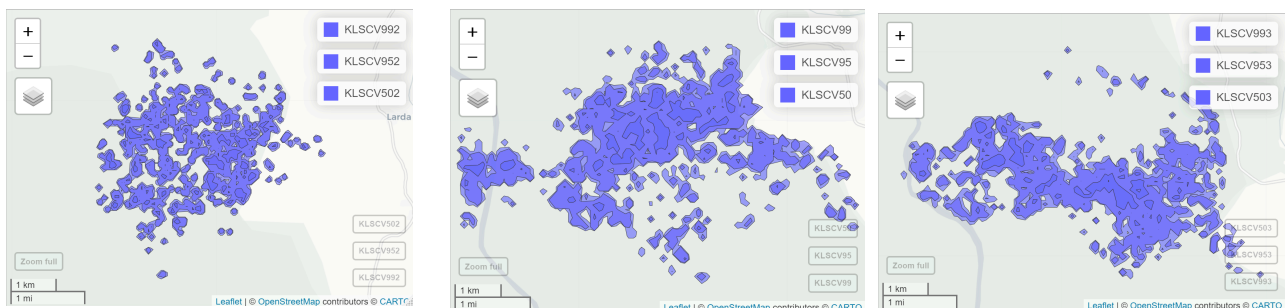


Fig. 4.2.3 a: Home range of Pipli through Kernel Least Square Count Value. b: Home Range of Kajal through KLSCV. c: Home Range of Nimmari through KLSCV.

The three nilgai belonged to age-sex classes and had different herd sizes over time. This perhaps explains the differences in home range area, with the newly formed subadult herd of Nimmari roaming across a wider range of habitats than the established older herds of Pipli and Kajal.

The home range size increased with shrinkage of water bodies over time. Movement of nilgai was constant through 24-hour location data, with very few periods to be classified as rest. This is in line with field observations, where the maximum period of rest was found to be 1 hour and 7 minutes in the afternoon.

Unfortunately, due to the delay in collaring, the data began only a few weeks before the harvest season of the mustard crops, and the presence of tractors in the fields limited the amount of collar data that could have been used to understand decision-making in crop raids by nilgai.

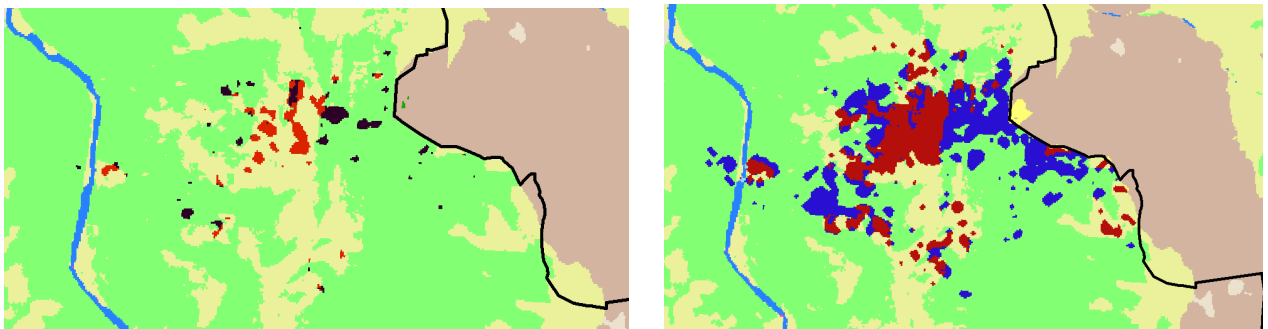


Fig 4.2.4. Habitat selection via KLSC50 and KLSCV90 laid upon the LULC map.

The locations were then overlaid upon the LULC map (30x30m) provided by Project Cheetah and analyzed for habitat selection. The concept of Manley's availability and use ratios was selected for this analysis, and calculated through ArcMap and package adeHabitatHS. Design 3 was selected for the classification of differential habitat selection by different individuals.

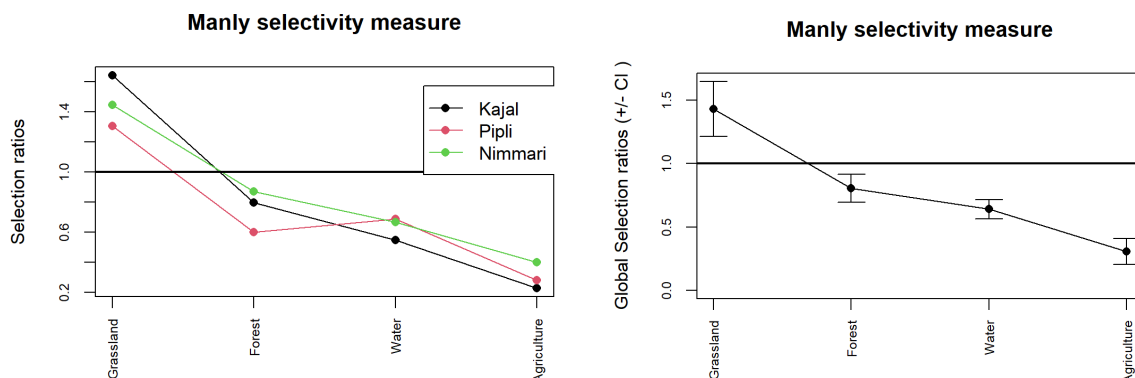


Fig. 4.2.5 Manley's Use-Available ratio for habitat (Design 3)

In this graph, it is visible how grasslands are highly selected and forest is negatively selected for all three individuals, despite the high availability of their preferred browse plants within their forests. The lack of selection of water can be explained by the minor ponds through the park in winter that were not visible from satellite during the making the LULC map, which would have sustained them enough to not need the major water bodies of the region. The lack of selection for agriculture can be partially explained by the crops being harvested fully by March.

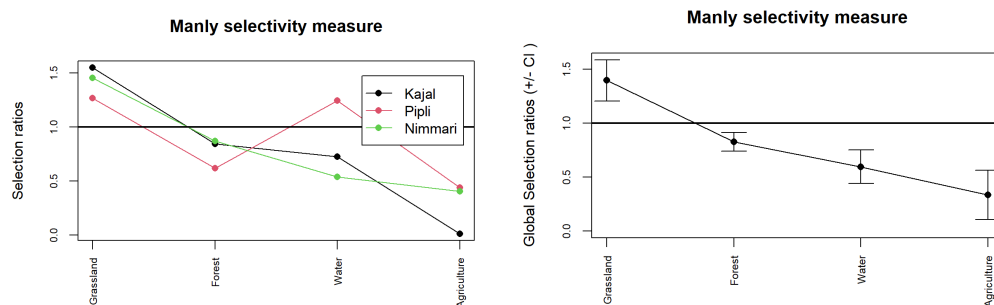


Fig. 4.2.6 Manley's Use-Available ratio for habitat at night (Design 3)

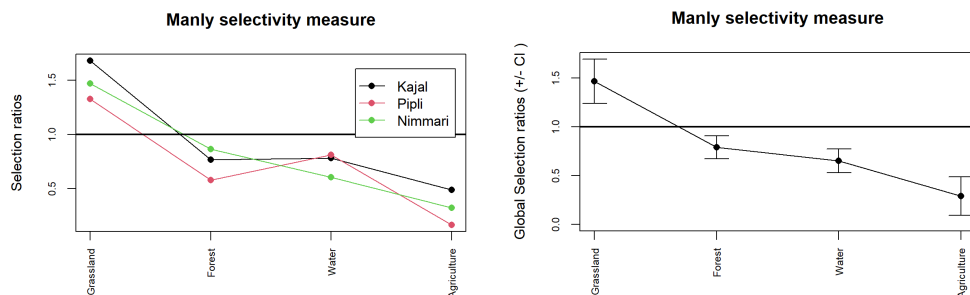


Fig. 4.2.7 Manley's Use-Available ratio for habitat for day (Design 3)

The data was further segregated into day and night based on the sunrise-sunset times of package *suncalc* and analyzed once more. Nimhari and Pipili both increased their times in agriculture at night, and Kajal increased her times in grassland at night. Pipili showed increased fixes at the waterbody, which is an open space in the grassland itself.

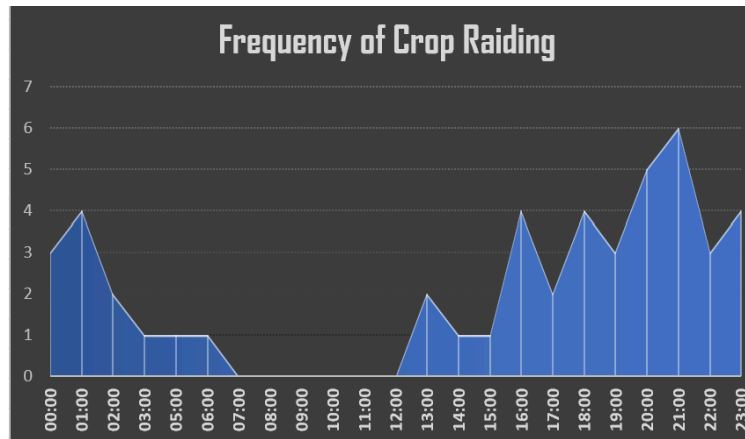


Fig 4.4.1. Frequency of crop raiding across a 24-hour period, taken from collar data of Pipili and Nimmari.

From the telemetry data of Pipili and Nimmari, actual crop raiding timings were taken from the frequency of fixes present in locations that currently were occupied for agriculture. The timing can be cautiously said to be between 4pm-2am, with a peak at 9pm. This also corroborates with the findings above.

Apart from the telemetry, the data from the camera trapping was analyzed to better understand the selection based on the structure and vegetation at a finer scale. Nilgai RAI was analyzed as a species as well as divided into male and female, against the habitat variables collected during deployment of camera traps.

	Nilgai			Male Nilgai			Female Nilgai		
Variable	Estimate	Standard Error	p-value (df)	Estimate	Standard Error	p-value (df)	Estimate	Standard Error	p-value (df)
Elevation	-0.3	0.16	0.08*(21)	-0.32	0.14	0.03*(20)	-0.2	0.19	0.30 (21)
Canopy Cover	-38.684	9.988	0.0009*	-22.7	10.28	0.03 **	-36.24	11.7	0.005 **
Slope	-19.394	7.97	0.03*	-14.11	7.163	0.06*	-14.82	9.07	0.11

Mixed Forest	-3	13.32	0.82	21.33	14.11	0.15	-28.33	14.18	0.006*
Dhok Forest	11.67	12.16	0.35	1.66	11.79	0.89	35	12.95	0.01*

Table 8. Nilgai RAI modelled against variables of habitat structure.

Nilgai were also modelled against other variables collected during camera deployment. They were found not to be positively or negatively related to:

- Grass height
- Grass Cover
- Structure: Open Forest, Dhok Forest, Salai Forest
- Extended Terrain: Plateau
- Animal Trails
- Human Presence in the forest

Objective Two: What effect does species biology have on movement?

- *H3: Human-dominated landscapes provide an area free of natural predators for nilgai to move into.*

The camera traps were placed across an area of 25sqkm, over a variety of topography and vegetation. Infrared flashes being equipped enabled the capture of nocturnal movement without disturbing the wildlife and affecting detections. Cameras were placed on animal trails in case the positioning at the centroid was unfavorable to capture the movement of a nilgai in front of the camera due to various factors (space, grass, human presence).

The temporal activity of various predators and nilgai at individual cameras were contrasted and overlapped using the R package overlap. Nilgai were separated into male and female nilgai due to their segregated living styles (no mixed herds were captured on cameras during the study).

Nilgai were temporally segregated from hyenas, but not leopards. Still, they were observed giving alarm calls in the face of a leopard on field, and it is possible male leopards occasionally succeed in hunting younger nilgai.

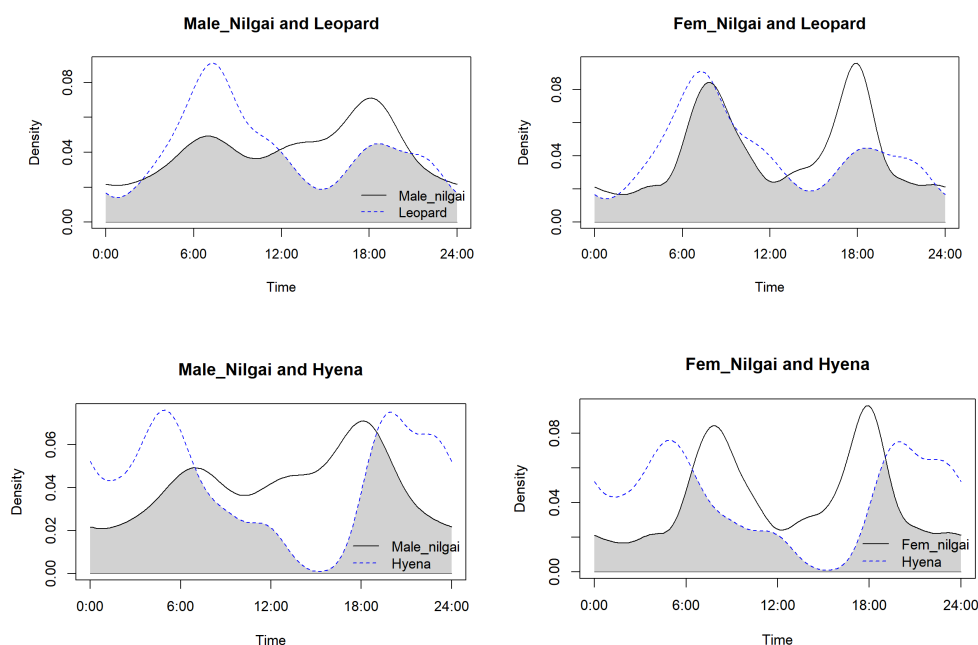


Fig 4.3.2. Temporal overlap of male & female nilgai, leopard & hyena.

The niche overlap of the nilgai with other captured individuals (barring chital, sambar and wild pig due to their commonality) was as follows:

	<i>Fem_nilgai</i>	<i>Male_Nilgai</i>	<i>Leopard</i>	<i>Hyena</i>	<i>Chousingha</i>	<i>Cheetah</i>
Fem_nilgai						
Male_Nilgai	0.61					
Leopard	0.44	0.36				
Hyena	0.50	0.47	0.79			
Chousingha	0.26	0.079	0.012	0.000000		
Cheetah	0.42	0.39	0.44	0.65	0.000000	
Nilgai	0.93	0.79	0.48	0.60	0.22	0.56

Table 9. Pianka's Matrix of niche overlap for various predators & nilgai

Combining both, it seems as if nilgai show no temporal avoidance and have no niche overlap with leopards entirely. Cheetah and hyenas however, have a higher niche overlap and nilgai show temporal avoidance to both, even if the cheetah captures in the camera are very low at present moment of study.

The original plan for CTDS analysis was not able to come to fruition due to lack of time for the software analysis. Instead, the Relative Abundance of each animal was calculated via the following formula:

$$\text{Number of Detections/Effort (Trap Nights)} \times 100$$

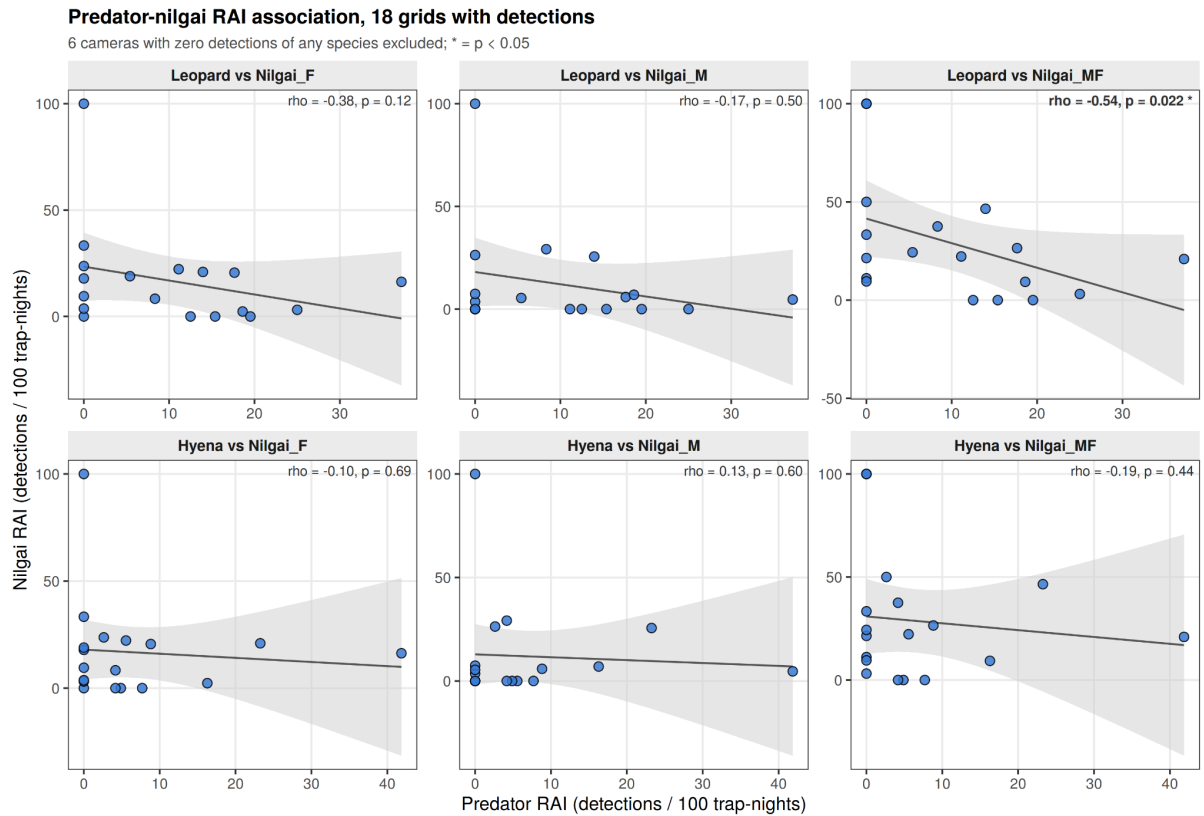
RAI for each individual camera was also captured and presence was measured against each other. Independent captures were defined as more than 4 frames before the next animal. Nilgai presence was found significant against the presence of cheetahs and hyenas and not against leopards, indicating similar use of habitat as in the matrix above.

Cheetah	Chousingha	Fem_Nilgai	Hyena	Leopard	Male_Nilgai	Nilgai
0.002778	0.013889	0.093056	0.065278	0.093056	0.056944	0.15

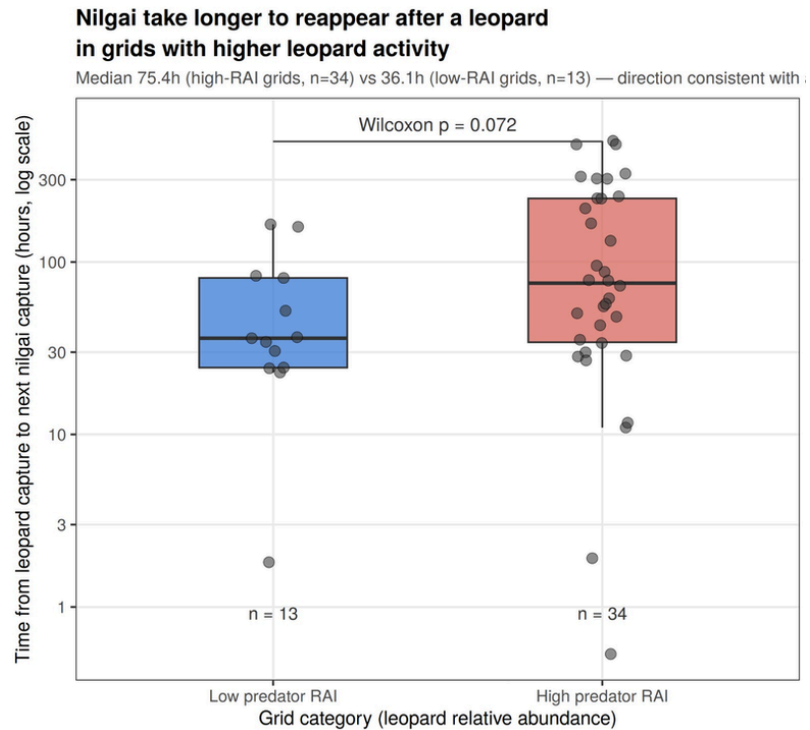
Table 10. RAI of various species

Predator	Estimate	Standard Error	df	t-value	p-value	AIC
Leopard	0.1766	0.2898	21	0.609	0.014*	197.3
Hyena	0.5664	0.2479	20	2.285	0.03336*	193.2
Cheetah	10.00	3.861	21	2.590	0.01749*	191.9

Table 11. Nilgai RAI modelled against predator RAI



Using this, the spatio-temporal associations of nilgai RAI against predator RAI were modelled, and it was seen that nilgai showed significant avoidance behaviour in presence of a leopard.



This implies an influence of predators on their movement.

➤ *H4: Changes in herd dynamics causes incidental movement into cropfields*

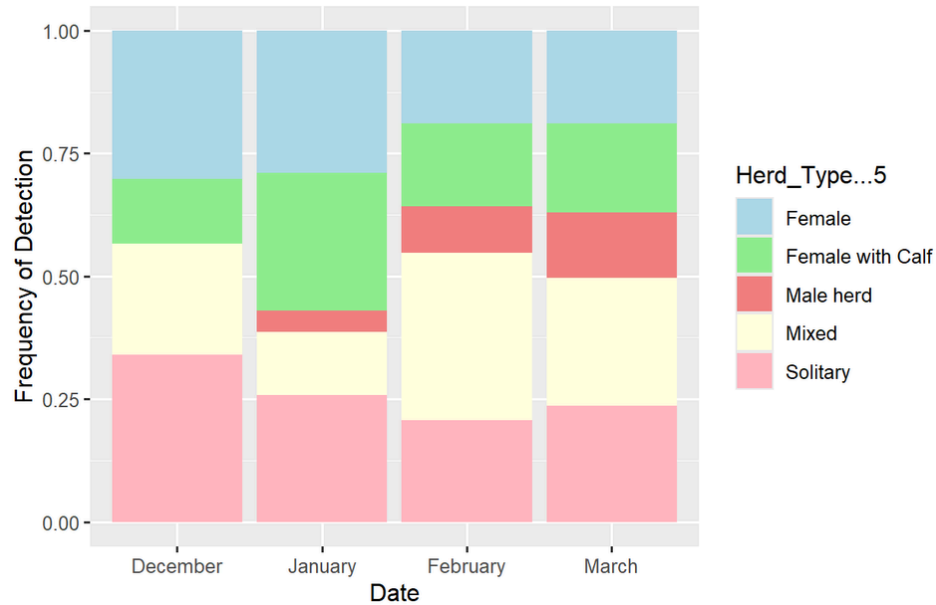


Fig 4.4.2. The change in herd composition over season

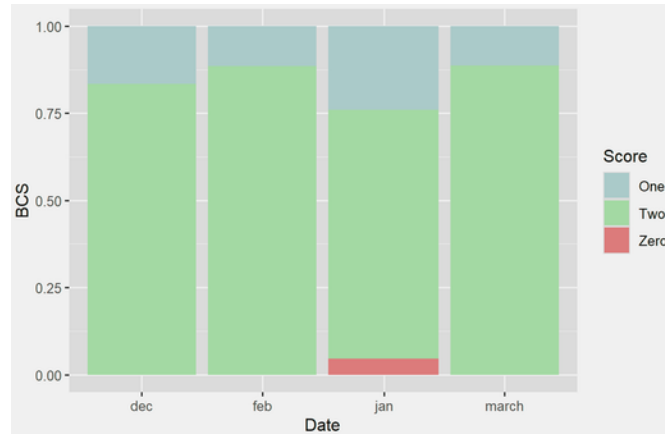


Fig 4.4.3. Low body condition was used as a proxy for lactating females.

Over the course of the study, a clear pattern of changing demography was seen. In late December and Early January, female herds with calves and solitary males peaked in visibility, while subadult sightings were low, and then Late January onwards the bachelor herds started being sighted.

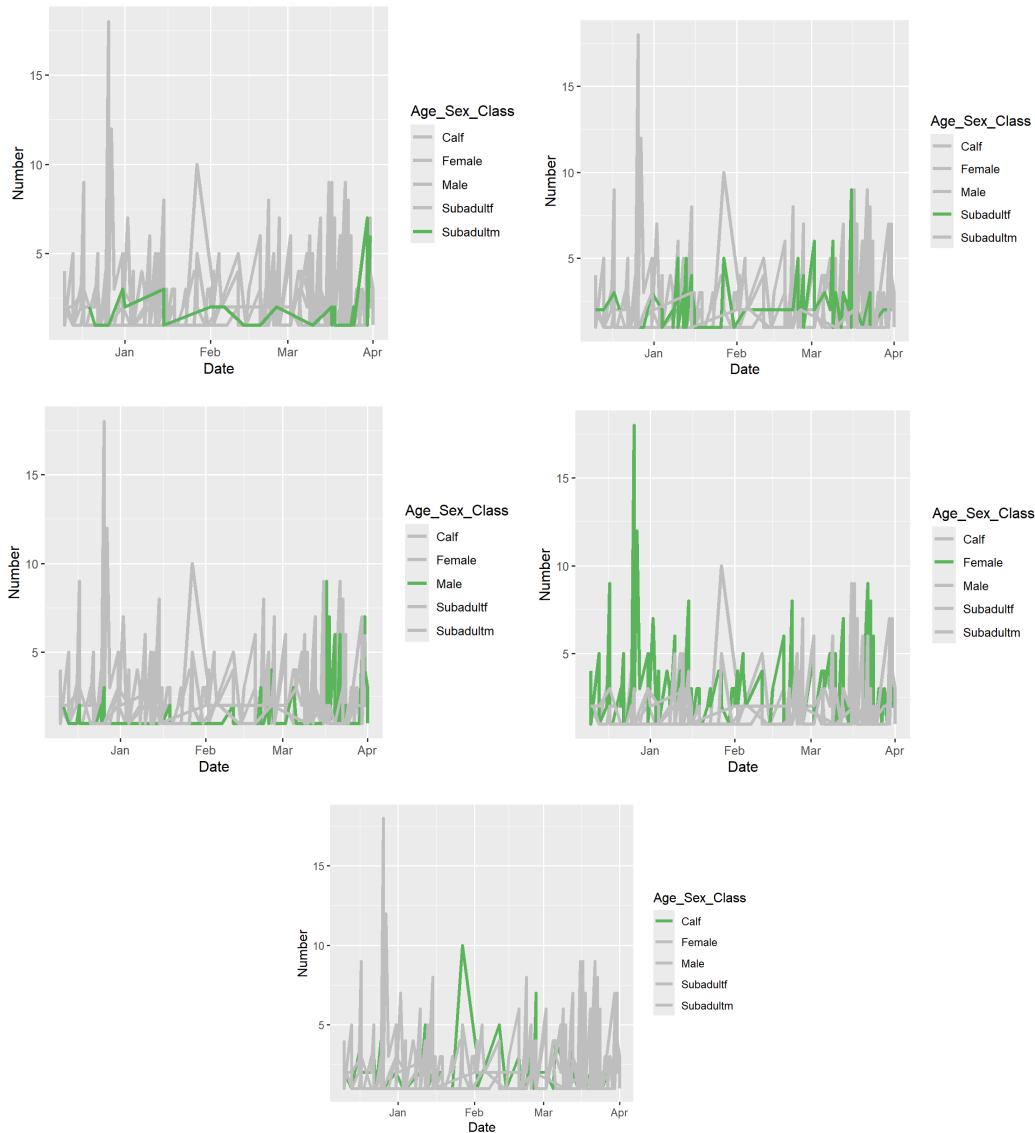


Fig 4.4.4. Graphs depicting when sightings peaked for each age-sex class.

And then February onwards male herds became visible once more, comprising both adults and subadults. Courtship occurred sparsely in mixed herds, with solitary males still visible until early February. Mixed herds still occurred in March, but solitary males lessened in number and male herds were more prominent, marking an end to the breeding season.

Shortly after, the appearance of creches in both females and males separately became notable. Two-three adults accompanied by roughly seven subadults and a couple of juveniles (in between calf and subadult) were seen in each herd. All creches were mainly seen in open habitats, with the male adults initiating play-fights and sparring, and the female adults moving through different foraging habitats to the water.

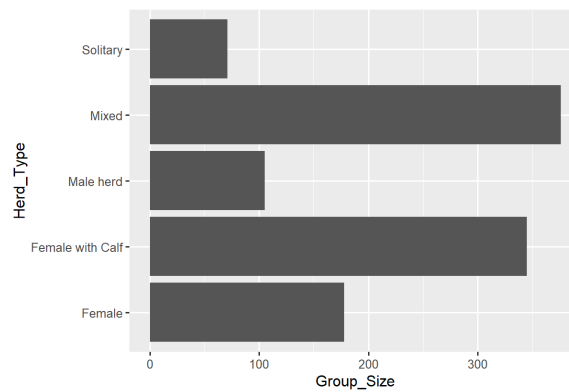


Fig 4.4.5. The variations in group sizes of the different herd types.

Group sizes did change with time, with it being significantly notable due to the formation of mixed herds. There was also an occurrence of a super-herd due to work being done on grassland maintenance in the park, where a total of twenty-one nilgai-females, calves, subadults and males- were all seen grouped together in an open grassland.

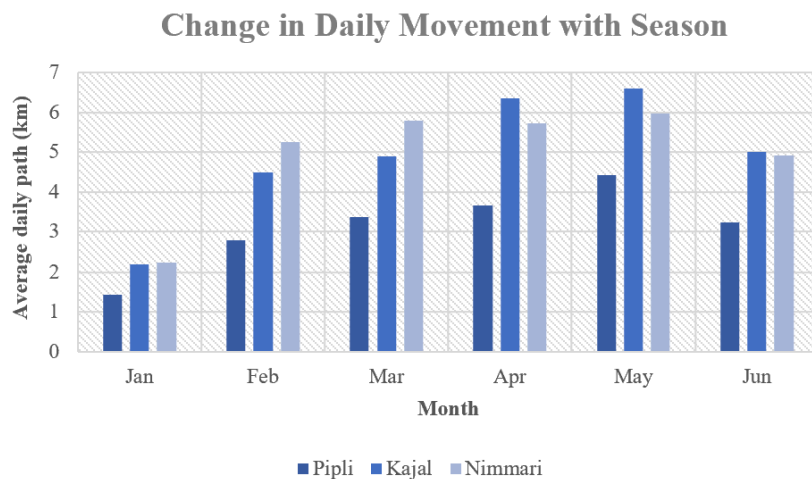


Fig 4.4.6. Daily movement of collared nilgai with progressing rise in temperatures

The collared nilgai fixes were analyzed and compared for the daily movement, which increased overall as summer progressed. This could again indicate Pipli's grassland home range being a more ideal habitat or be a function of water bodies being active in Pipli's range longer versus Kajal and Nimmari having to walk to the river for water as summer progressed.

Step selection analysis was also initially planned for, but due to lack of time, it was not possible.

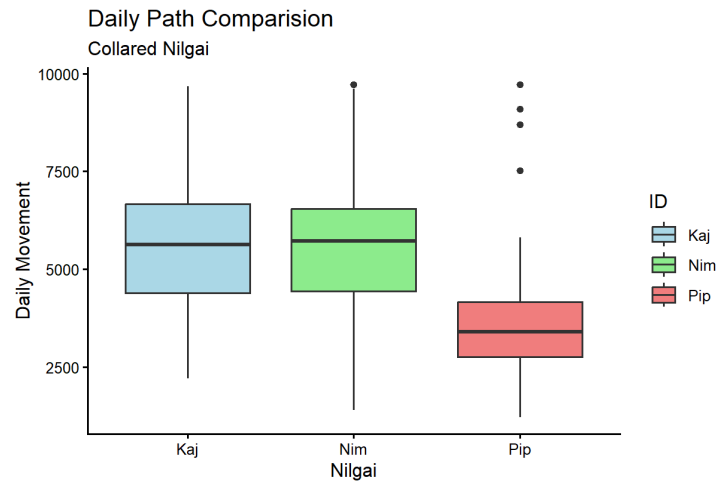


Fig 4.4.7 Daily path comparison of collared nilgai steps

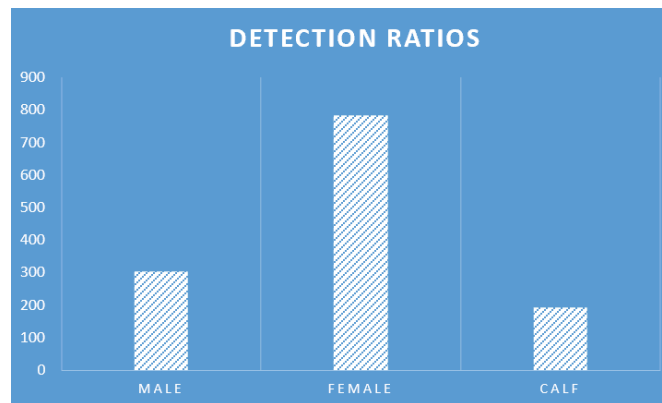


Fig 4.4.8. Detection ratios of different sexes of nilgai through the study

Due to constant herd fluidity and inability to identify individual animals, the possibility of collecting only independent sightings for analysis was impossible. Still, the total sightings during the behaviour observations were pooled for analysis. The Male:Female ratio of sighted individuals was 3:8, and the Calf:Adult Female ratio was 1:3. These ratios could be skewed by a number of factors during collection, but are generally consistent with antelope sex ratios across the globe.

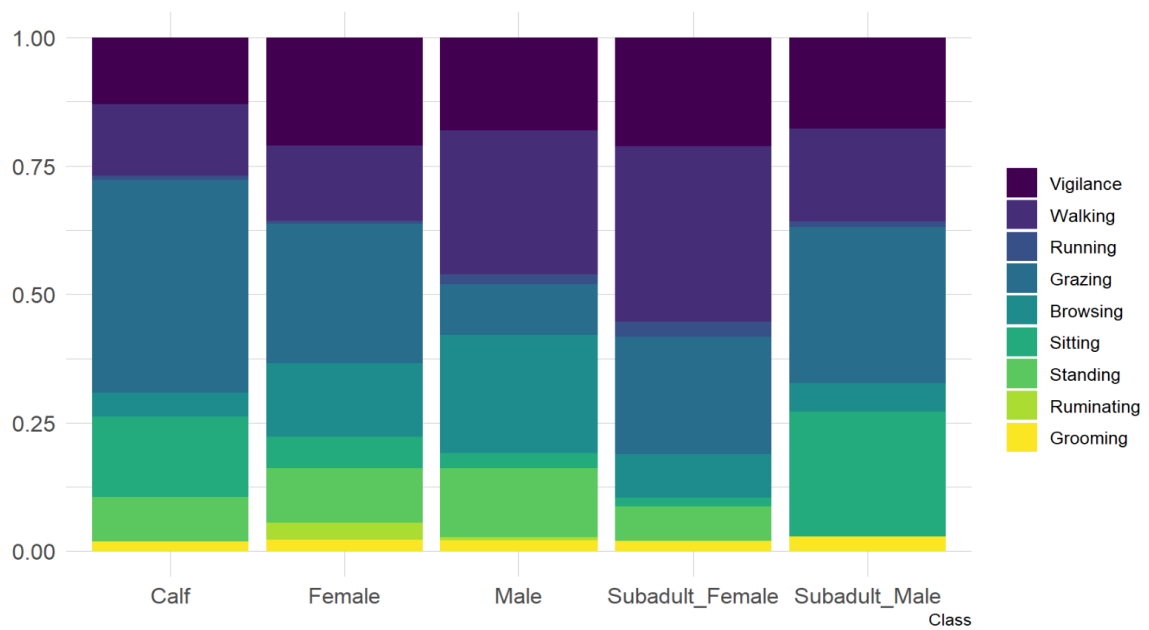


Fig 4.4.9. Time - activity budget of Nilgai

Age-Sex	Top Behaviour	Possible Explanation	Top Behaviour 2	Possible Explanation
Adult Male	Walking	Searching for Mates	Browsing	Building up Body Condition for Courting
Adult Female	Grazing	Building up Body Condition after Calving	Vigilance	Constant lookout during grazing
Subadult Male	Walking	Exploration due to not being part of a herd	Grazing	Building up Body Condition for Growth
Subadult Female	Grazing	Building up Body Condition for Growth	Sitting	Able to take longer rest in presence of a herd
Calf	Grazing	Building up Body Condition for Growth	Walking	Constant walking to graze

Table 13. Top two behaviours of different age-sex classes of Nilgai

The reasoning for the top behaviours of the different age-sex groups are in line with the predicted breeding season, calving season & grass availability after the monsoon flush.

No type of behaviour was found to change significantly with forest type, visibility or location.

Grooming increased with the advent of summer- perhaps due to shedding of winter coat or due to increase of flies and ticks. Tail flicking and ear flapping also increased.

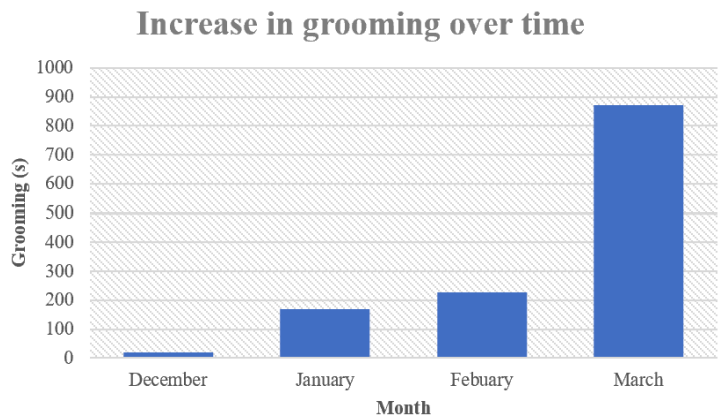


Fig. 4.4.11. Grooming rates as seasons progressed

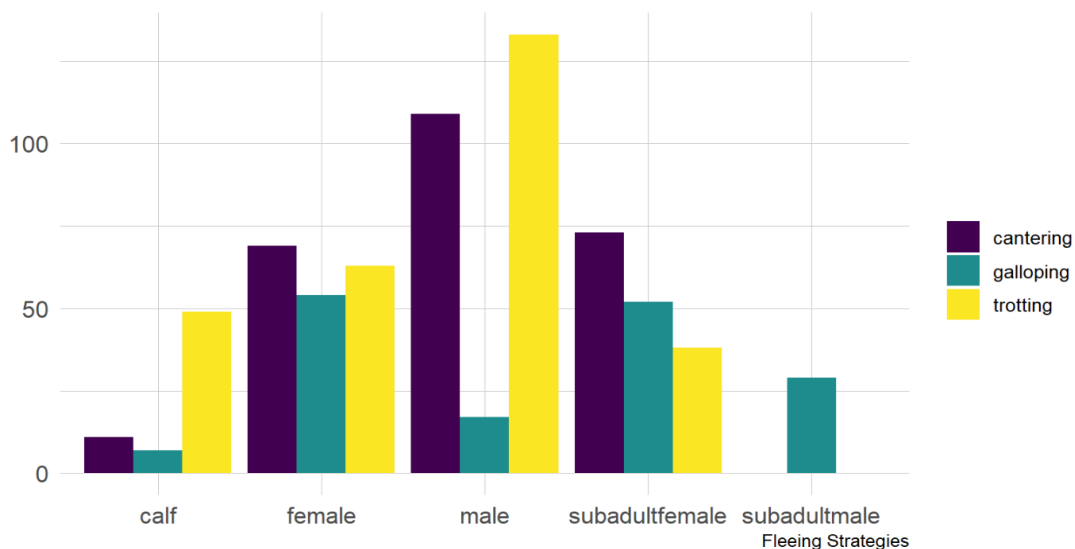


Fig 4.4.12. Bar graph of various styles of fleeing amongst age-sex classes

Fleeing strategies also differ vastly amongst sexes- adult males preferred to walk, stott or canter away but rarely fled at full speed; adult females fled at an even but quick pace; calves and subadults were prone to quick fleeing, whether they were part of a herd or not. Skittishness in nilgai decreases with age and size, but even a calf fleeing was seen to trigger an entire herd into stampeding.

Other behaviours have been covered in the section on natural history observation.

4.2] DISCUSSION

For an antelope, the value of a plant depends upon it having high protein, digestible carbohydrates and low fibre (Arman & Hopcraft 1975, Klaus-Hügi et. al. 1999). Nilgai specifically have been found to be exemplary foragers through various studies, from the ruminal microflora that has superior fibre digestive capabilities (Paul et. al. 2004) to the numerous studies of their plasticity in diet (Meena & Choudhary 2019), to the consumption of near-unpalatable plants for most other species. Their body mass, averaging around, 220kg, requires only an 8% protein intake at minimum. (Sankar et al., 2004). This reflects in their near-continuous intake of food through the day, adaptability to scrubland habitat and their widespread distribution.

The protein analysis suggests some minor benefit seen in fringe nilgai that raid crops. Yet the protein intake of forest and refuge nilgai are similar, despite the differences in available nutrition, suggesting no benefit to crop-raiding if natural vegetation is absent.

The analysis for crude fibre shows the concentration to be much higher in forest and fringe than refuge. As crops are known to have lesser lignin, this could imply a very high dependence on mustard & wheat for the nilgai in Gohta. Nilgai have also been noted to have higher lignin digestibility compared to other herbivores (Paul et. al. 2004), which means both their tolerance and requirement for fibre is perhaps more. This is in line with observation of feeding nilgai- on many occasions they were seen eating lignified thorns and stems instead of just the leaves.

In the Crude Protein: Crude Fibre calculation, refuge nilgai are ranked the highest despite having the least protein intake, because their lignin scores are even lower. They consume much less lignin content despite their capability to eat *P. juliflora* (28% lignin: Pereira et. al. 2025) when required, which means they are heavily dependent on the crops through the season instead, which lack the high lignin and other phytochemicals of invasive plants. But this still does not mean that they are healthy individuals, as the body condition of the nilgai captured on the camera trap in Gohta was found to be very low.

So we can cautiously infer that there is barely any nutritional benefit at all to crop raiding for the nilgai that have access to both mustard and forest, since the protein gain is minimal and the presence of excess lignin in natural forage is not as problematic a factor for them as it would be for other ungulates. Yet, for the nilgai living in a patch of land overrun by exotics poor in protein (during the course of the study, when the pods of *P. juliflora* are not available) and high in lignin, there might be no choice but to at the very least supplement the diet with crops nearby instead, if not outright depend on them.

This result may vary with location, with different crops possibly can provide more nutrition than mustard, or may possess some micronutrient that increases its attractiveness. And despite the claim of them being coarse feeders in multiple pieces

of literature, if they were able to tolerate food with protein values as low as 8% dry weight as suggested, then almost the entire plant would be available to it as food, and no selection between parts of the plant need be made. However, nilgai did show selectivity for the apical tips of forage in field- young leaves with softer thorns and the leaves of grass as in other antelopes (Otieno 2019)- which means they do choose for nutritionally rich food, and they simply do not require the mustard.

Therefore, there is sufficient evidence to suggest the nilgai of Kuno- desert antelopes living in a semi-arid region- do not favour eating crops if a good amount of alternative natural habitat is present. In fact, the collared individual Nimmari only went out of the borders of the park once the crops had already been harvested and the lands remained empty aside from the husks left behind. However, if commons are left to be invaded by exotics, it is possible that there will be a higher dependency on crops. Further study on the linkage between availability of natural habitats, invasives and crop raiding can also be pursued to better answer this question.

According to the principles of habitat ecology, under the conditions of Ideal Free Distribution, animals choose the best habitat available to them (Kacelnik 1992). With the assumption that nilgai are sufficiently protected in Kuno and are free to explore and choose habitat, it is predicted that they will follow a dispersal-settlement-establishment framework, where certain key environmental factors are noted during the exploration phase and then home range is established in the smallest and best area available.

When comparing the different home range sizes, it is clear that the subadult Nimmari- only seen alongside other subadults- is the one with the highest range of movement, almost double the size of Pipli's established herd. While this could be a function of the habitat itself also since the water bodies were scattered through her range, the level of daily movement that she undertook also suggests exploration rather than established knowledge. This is a trend common to subadults in other species as well.

The habitat-cue hypothesis states that structural habitat cues are the proximate factor determining territory size (Veech 2021). Once selection on the first scale is made- i.e. the availability of resources like food and water- the second largest factor that dictates animal movement is the structure of the habitat itself. Certain features of the landscape inscrutable to the human eye will be given much importance to the animal that has evolved in that habitat (Smith and Shugart 1987), influencing the decision on whether to settle or disperse further.

Some of these structural cues- forest type, slope, canopy cover, grass cover, etc.- were tested for, and mixed forest, elevation, slope and hills were found to not be preferred by the nilgai. This does not mean they did not occur and live in these habitats because field observations themselves saw otherwise, but it also speaks to these places not being their ideal habitat.

From the results of both telemetry and camera trapping, it is clear that nilgai disproportionately select for open, flat grasslands even when the forest in question is highly suited to their diet- dominated by *Zizyphus mauritania*, *Acacia catechu*, *Acacia leucophloea* & *Terminalia pendula*- and is in season for flowers, fruits & leaves.

Often, public outcry while dealing with nilgai overabundance results in calls for mass translocations of the antelopes to protected areas (Kritika et. al. 2023); which are more often than not forested areas with sparse grassland patches, surrounded by the much more suitable cropfields. Protected areas also are often on elevations, due to human encroachment occurring more rapidly on fertile plains than the inaccessible hills, further narrowing down the availability of good nilgai habitat, which may be the reason they try to leave the borders.

An example may be seen in the case of Kuno itself; although nilgai were released on the Khair Kaccha plateau in September, the slopes and hills surrounding this region and the utter lack of sightings in this region throughout surveys conducted means that we can safely assume the majority of them have emmigrated to more suitable areas. It makes ecological sense for the hilly core zone to consist of lesser nilgai than the more gradual buffer, and despite the abundant resources in browse, it does not entice enough to keep them there. While many studies claim a preference for browse over graze in nilgai from other regions, there is no literature to give support to a nilgai that only browses.

Structurally and functionally, they are grasslands in themselves, kept free of encroaching trees and tended to. To a certain extent, it can be claimed that the need for grasslands plays a major role in the nilgai's consistent and unrelenting move into the fields across Northern India.

But when humans have introduced so many measures to keep them out, when the stray dogs and harried farmers with their livelihoods to lose hunt nilgai down constantly, do these animals still select for this high-stress location over the relatively stress-free forest?

When nilgai are discussed, it is a common narrative for them to be using protected forests as shelter, and cunningly raid the farmer's hard-grown crops at night, circumventing all mitigations and high walls to reach the reward at the other end. Putting it in ecological terms, it could be a result of the decisions made for optimal foraging with greater reward for greater risk- assumed in this scenario to not be the case- or them showing temporal avoidance of humans, whom they see as predators (Otieno et. al. 2019). This latter statement is highly plausible, considering how well known they are for fleeing at the sight of a human approaching from even a far distance (Sheffield 1973).

When I followed the hoofprints and collar locations of Pipli through the fields, I found that there were calves, subadults and adults that had moved through the crops.

Similar instances have been reported (Jain 2022) where females move in first, followed by their calves and occasionally males. They learn at a young age from their herd that the crops are a resource, and the various strategies to bypass human interventions to get to it, and carry this knowledge if and when they disperse from their natal range. They may already know how to navigate this landscape of fear, and treat it as any predator-rich area.

Yet through the analysis of collar data it is also seen that nilgai may have a natural preference for utilizing grasslands at night- as seen in Kajal favouring the wild savannahs at the same time range Pipili and Nimmari enter the human-created ones. This could be an alternative explanation to their proclivity for 'raiding'; their thievery may be a natural extension of what has been their ecological behaviour for all these hundreds of thousands of years- it is just that no one ever was there to see it and their habitat had never shrunk to this extent for it to matter.

One explanation for their nocturnal use could be temperature; nilgai were often observed resting during the midday heat, and their sightings also decreased around this time as they supposedly used the forest cover for shade and associated thermoregulation; but conversely, there were occasions where they would be grazing in extreme heat and sun where all other animals had disappeared.

Another explanation could be that the cropfields provide shelter to them from predators. But nilgai are notorious for having no natural predators in the current landscape (Binadi 2017), often used to bolster prey-availability studies without taking into much consideration the actual animals that will control their numbers; tigers and leopards hunt them at almost negligible rates, dholes and wolves (and in present times stray dogs) usually require an entire pack just to take down a subadult, and they are too big even as juveniles for most carnivores.

Still, we find that despite this, they show avoidance to leopards in Kuno; possibly due to their extremely high leopard density resulting in predation out of pressure. While this behavioural plasticity has not extended to overall temporal avoidance, the presence of a leopard still results in nilgai absence. Moreover, with the introduction of cheetahs in this habitat, which provide a better fit for nilgai in terms of niche overlap, recorded predation events and habitat preference (Mills 2004), there might be mounting advantages for nilgai to move into the cropfields to avoid these predators.

There is another driver not considered when planning this dissertation; the constant movement of the nilgai. From the telemetry data, it was found that nilgai never stopped to rest above one hour, moving through nearly all hours of night and day. This need for movement can also shape the result of walking through fields in spite of the risk, although further studies are required on the subject.

Connected to this last point, and the first argument I have for the understanding of species biology being relevant to helping inform mitigation, is their ever-shifting

herd dynamics. Nilgai show a daily fission-fusion of established herds and have high tolerance to conspecifics. In field, I observed a male nilgai halting to let a calf sniff at him curiously, and a courting nilgai was allowed to graze alongside a female herd in between mating charges. On one occasion, a herd of twenty nilgai was seen to have formed due to distress from the loud construction work within their home range, and no overt in-fighting was seen.

But this instinctual behaviour of splitting up into dyad or solitary groups could also be the reason for their constant sightings, which are considered to be different individuals each time. Calving season also occurs in October, with juveniles seen in the herd around this time, signifying growth. Although there are only 12 nilgai in the area, watching different group sizes come out each day might make it feel as if there were 30, causing overestimations by officials and locals in how many are actually causing damage. This affects both their reputation and their population estimates.

Another problem with population counts of this animal is also their unique usage of latrines (Zoromski 2022). While I was not able to quantify or analyse patterns of latrine site visitation due to lack of time and subsequent abandonment of latrine sites if I placed a camera trap nearby, there is an entire social system built around these sites. There were three main types observed: large-scale latrines visited by all, large latrines visited by multiple males & what is perhaps territory marking by smaller, single-male latrines. But if this is the case, where a latrine can mark the presence of one or multiple males, combined with the constant movement of females throughout their territory daily, then pellet count estimations of nilgai will be heavily skewed to overabundance as compared to other herbivores, when in actuality they are much less in number.

In summer, daily movement and group size of nilgai increases, with them moving through the vacant croplands as harvest season ends (Khanal 2016) in front of the people who live there. This presence clearly makes an impression, as from the survey we can see the reports of people who have seen huge herds walking through their fields, and understandably assume that they are the same invisible raiders who have been tormenting them through the nights of the harvest season.

Another downside of the lack of knowledge in nilgai ecology is the possible future effect of male-biased removal.

As seen in the camera trap data, males showed more preference to flat open landscapes than females. Moreover, as seen from the changing herd compositions in Fig. 4.4.2, males in the breeding season split from a single bachelor herd to several solitary individuals, dispersing out in different directions to find the constantly moving female herds, becoming territorial.

While it is said to differ nationwide, the peak breeding season for nilgai in Kuno is indisputably December-March, which almost totally overlaps with the cropping season. This means that the males dispersing to find mates, pushed out due to the

formation of individual breeding territories, will find themselves in the cropfields, causing damage through both grazing and trampling. And they bear the cost of being so visible- easy to identify with their dark coat and large size- and are often the ones being blamed for the loss.

And with the first response for male nilgai being freezing or walking instead of a gallop, I speculate it all accumulates in fatal consequences.

There was even an occasion in field where a villager also referred to male and female nilgai as separate animals entirely- 'Nilgai' & 'Rojh'- and the name blue bull bears the implication that it is the males to be targeted, which could lead to a heavily skewed sex ratio in a species that already has a tendency for a fewer number of males (Khan & Khan 2016).

In studies on other species with same-sex herds, this has been found to be disastrous. Subadult males that were to be hormonally and physically suppressed by older males in bachelor herds now lose that structure when the older bulls are culled, and the lack of stability that this results in causes them to be erratic, aggressive and unstructured (Doughty 2014). Generational knowledge flowing down the male line is interrupted with respect to habitat usage, teachings of where to find water and forage, and more damage is caused rather than less when these younger males now have to explore the landscape to find these places themselves, causing them to be more likely to physically attack threats.

The effects of this imbalance is also seen in the females. In white-tailed deer populations, also prone to overabundance and subjected to a culling management practice in the last few decades (Adams 2012), it has been speculated that it causes a hydra effect (Sieber 2012)- unruly subadult males approach females at a higher rate, resulting in imbalanced breeding seasons and an increase in calving.

If this trend is consistent with the bachelor herds of nilgai as well, the likelihood of the same issues being present is high. And in a species like nilgai, with its high twinning rate and year-round births, it will take barely any time for the numbers to restore themselves once more- perhaps even above the carrying capacity it would have automatically reached to before- amplifying the problem instead of solving it.

Moreover, the scale at which culling is occurring, unchecked and by the aggrieved farmers themselves, is another type of ecological disaster waiting to happen; it is very easy to drive an overabundant species to extinction (Bucher 1992)- and easier still when the decade-old population estimations have such a high likelihood of being entirely wrong.

4.3] Natural History Observations



Fig 4.6.1 Female nilgai who was identified by her 'bent ear' in Basantpura. She was often accompanied by her calf and an older nilgai, and sometimes seen with Kajal's extended herd.

Nilgai are quite fascinating animals. They are highly adaptable to changes that would drive away most other species, tolerant to extreme conditions and capable of living in ones unsuitable to them as well. Herds remained constantly on the move with very little rest. Drinking was observed occasionally, where the nilgai would stand in the water for a few minutes and drink for up to a minute on average. Licking of tree sap was observed on one occasion.

One observation not found in my literature review was their formation of creches. Both male and female herds consisting of a few adults, half a dozen subadults and many calves were seen. These adults also possibly change with time, as Pipli was originally one of the adults in the female creche, but after a week was not seen with this herd again.

Male creches were mainly seen near the open bank near the water pond, with adult males sitting around in a circle and subadults being taught how to spar by a single adult. Neck fights were relatively tame, with the adult pushing against the subadult's neck until they began wrestling, occasionally going to their knees; but often the subadult would tire and the adult would back off. Other subadults also practiced amongst themselves, showing mounting behaviour and posturing. This type of behaviour was highly guarded, and there were multiple occasions where this fighting dissolved as soon as our vehicle arrived.



Fig.4.6.2 a: Subadult males sparring b: Adult male posturing

An actual male-male fight was witnessed only once and recorded by a fellow researcher; it was this very video that later allowed us to identify that it was indeed Aadhasingha in this fight when his collar was found bloodied and torn nearby a few days later.



Fig 4.6.3 Stills from nilgai subadult and Aadhasingha fighting. Above: Photo of 'Aadhasingha'

The fight itself involved the pressing of horns into the front of the neck to throw the other off balance, as well pressing the necks side by side while on their front knees. The former action is what caused the collar to get sliced off; and is possibly why Aadha lost the fight to a subadult; the half-horn that he was named for could not sufficiently cause injury to the extent it was being done to him. Aadhasingha ran away at a gallop from the fight, and was chased away further by the subadult with his tail raised.



Fig. 4.6.4 Nilgai male courting female with tail raised, sniffing.

Tail-raising behaviour was also seen during courtship. The courtship ritual involved a male or two approaching a female herd. A slow mating march would occur, with the male keeping his tail raised and sniffing after her for above forty minutes. After a while, the male would switch females and continue. Sometimes licking of female genitals was observed during this march, along with one occasion of consumption of female urine.

Mounting was observed only once through the whole study. This mating march would often last for forty minutes, and then often another male would approach.

The male that arrived would be approached by the courting male. First, he would posture, moving forward with head held low, neck stretched and back arched. Then, on some occasions he would charge and chase off the newcomer, usually around 800m. But on some occasions, even if the approacher was a subadult, the courting male would simply walk away and let the next male start courting without any fight. Once in the span of an hour, three such changeovers were observed.

This could have two explanations- one, that the posturing is sufficient to decide approach without a fight or two, the males recognize each other as being from the same herd in the non-breeding season, and have a pre-established hierarchy. This may allow younger adults to court the females for altruistic reasons, if they happen to be related.

To support this, a majority of the time the nilgai driven off (or fought) were the two males with broken horns, who were never once seen with a bachelor herd. Perhaps their lack of this important secondary sexual character also deems them unfit for being in the herd.



Fig. 4.6.5 Nilgai 'Eksingha' who only had one horn

The grooming increase in summer seems to be a function of coat shedding. Black patches started forming on their body as hair decreased after February. Tail flicking and ear flapping was near constant by March- either due to flies or increased temperature.



Fig. 4.6.6 Female nilgai with shedding coat

Due to the herd composition, the ability to tell whose calf belonged to whom was limited, but there was an occasion where a solitary female was observed with twins in hiding.



Fig 4.6.7 Nilgai female with twins

Alarm calls of nilgai are short, sharp and deep. They were observed giving them for a leopard that had come between a subadult and the herd, but no attack occurred. The adults would also sit in circles, with each animal facing a different direction, to maximise vigilance.



Fig. 4.6.8 Adult nilgai sitting in a circle with vigilance in all directions



Fig 4.6.9 Kajal hitting her calf to direct them off the road

Kajal also showed instances of herding the fellow members of her herd through head-butting and slapping, driving them forward in short bursts. She also was commonly at the front of the herd and was the only nilgai for whom the entire herd stopped for when darting was occurring. This could possibly mean she fulfils a matriarch position within the herd, or at least functions as an elder to guide them through the forest.



Fig 4.6.10 Male nilgai looking towards cameras

Nilgai also showed quick learning behaviour; out of all the animals that noticed the camera traps, nilgai were not only the quickest to notice the most intricately hidden cameras, but also very rarely stopped to investigate. Especially if placed on latrines, but also for covered IR cameras, nilgai often would turn tail and run before coming close.

There was also one incident of wall jumping that was caught on camera; this wall is roughly six and a half feet tall and the nilgai is either a female or juvenile male.



Fig. 4.6. 11 Nilgai jumping a wall leading to cropfield during the night



Fig 4.6.12 The nilgai 'pipli' at a large latrine near the water body

Fig 4.6.13 An active large latrine in Magardeh

One of the most underresearched parts of nilgai species biology is the use of latrines. While they were not the focus of this study, note was made of large, frequently used, mixed-sex latrines in some locations. These were different from the smaller

male-only latrines, and the single-use piles theorized to be used for territory marking. Still, this information and social significance of these latrines remains unknown.

CHAPTER FIVE:

CONCLUSION

5.1] Management Implications

This study has major implications on current management for nilgai populations.

The assumption of nutritional benefits driving crop-raiding has been pervasive in scientific literature for many years. This has not been contested despite no recent data supporting it- and all the technology developed for mitigation, inventions made to deter wildlife & declaration of them as vermin has been based on this fact. Further, in these systems, the status of invasion in the forest patches they are said to take refuge in has not been noted, with no quantification of how much native vegetation is available to nilgai that heavily depend on crops.

As stated, this study may differ with change in location, but if the nutritional findings remain constant, then it can be concluded that it is the second set of results driving them into the fields rather than the first: that they select for open grasslands naturally because of structural cues such as flat land, lack of canopy cover, etc. that inform them that agricultural fields are their ideal habitat. Nighttime ‘raiding’ can possibly be a pre-established inclination to use grasslands at night.

Structural attractiveness to cropfields is entirely different from a nutritional dependency; if the perceived habitat itself is the croplands, then no amount of mitigations will suppress their evolutionary need to be in the fields. The actual strategy will then become the expansion of grasslands and scrubland in Protected Areas or establishing new ones that conserve spaces with these habitats, providing the correct ecosystem for the nilgai with its preferred native vegetation.

Predator influence upon nilgai presence in high leopard regions implies that nilgai view them as threats. While no solid conclusions can be drawn, more work into predation rates can help understand the actual predators that will help control nilgai populations- bolstering the entire trophic chain in the correct ecosystem rather than trying to fit an unwilling species into the wrong location.

It may not be possible to prevent movement of solitary males or subadults during the harvest season, but through more behavioural research and social structure studies across different landscapes, we can better understand their species biology and learn something to circumvent this problem. Perhaps if they are in the habit of abandoning latrines where humans have clearly interfered, as seen during the camera trapping procedures, removal of these latrines from the vicinity may provide some change in

behaviour. If they are dependent on grasslands at night, plans can be made to allow them to access their natural ones with less disturbance.

Adjusted methods for density calculations would also benefit a more robust population estimate. Carrying capacities of nilgai in Protected Areas being expanded through savannah management would also be useful, benefiting other scrubland species as well as dependence of the local cattle, goats and sheep upon these same places.

Another thing of note- the collared male with the broken left horn was possibly an unfit male by conspecific standards. This was proven when he lost the neck-fight with a subadult of a size class smaller than him, and his refusal to flee from courting a female herd after being darted. This example of sexual selection perhaps gives us a clue to ethical culling- if unhorned males are not preferred by females, perhaps large-scale dehorning can help control their numbers far more efficiently.

Labelling an animal as vermin has grave implications under the Wildlife Protection Act. It has no protections from farmers it has wronged, whether the guilty party was a single outlier or a representative of the species, whether the act has occurred yet or not. Even if the sentiments of a majority of Indians today falls towards the sympathetic and religious significance holds a large-scale mass slaughter in check, the intolerance increases every day. The governments who have provided licences to kill have set a dangerous precedent- the same one that the British government set out all those years ago when a similar narrative was put in place about pests of the jungle, and we almost lost all our leopards, dholes, wolves, elephants, rhinos & tigers.

5.2] Limitations

The most prominent limitation of the study was the lack of time. This study was conducted over a short winter-to-summer transition of five months, which lacks the influence of the summer and monsoon upon the system, therefore not giving the full picture. The delay due to logistics, mistakes made in the application of methods and small collar samples all hindered forming more accurate conclusions.

Forage samples collected in the field caught fungus during the transport to WII, and only pellet analysis was possible. The assumption behind pellet chemistry analysis is that intake is equivalent to outtake, which does not take into account rumination or disproportionate absorption. The finer diet composition is not known.

Since the quantities of neither protein nor lignin are not varying in any significant degree between forest and fringe, it would be more informative to study the quantity of crop present in the pellets through microhistology (Hinnant 1988) to properly understand the actual effect of crops upon their diet. A monocot-dicot ratio would also help inform actual proportions of graze and browse.

A lack of crop-damage quantification due to spaced out raiding, fear of bandits and lack of time is another blow to the study. Due to the labwork time crunch, I also had to leave field in March, so the seasonal change data was slightly lacking.

The behavioural data was opportunistic and limited to the areas closest to basecamp. Although each sampling event only began post habituation of the animal, the results still were possibly affected by my presence. Misclassification of age-sex status, especially for subadult males, is highly likely. The division of vigilance behaviour into vigilance and scanning would also have been more informative.

Camera placement also greatly affects the rate and frequency of detections, even though linear models run on the detection success between trail and non-trail cameras did not show significance. Nilgai are also highly sensitive to smell; many cameras showcased nilgai spotting the hidden cameras where very few other animals turned to look, and did not approach, with some cases of them running away also seen. This perhaps would have affected RAI, and requires further in-field or analytical fixes.

5.3] Final Thoughts

The original purpose of this dissertation was to understand the drivers behind crop-raiding in hopes to better inform the strategies taken to mitigate their influence. I had hoped to unearth some information that could explain their decision-making process, that would assist in finding more useful and science-based actions, rather than the on-demand culling processes that are in play today.

Based on the results, it is my personal opinion that crop-raiding is more a function of habitat and not so much nutrition. No matter how many times you remove the nilgai from the system, no matter how many mitigations and solutions are crafted, within a few years they will find a way to return and resume the conflict once more.

Instead, these findings should be used as another argument for the establishment of Protected Areas that include savannah and rangeland. More studies on established protected grasslands and comparative nilgai raiding there would be useful in furthering this claim.

Yet despite the interesting findings, there still must be a healthy skepticism for the results of only one trial period. Therefore, the findings should be interpreted as strong evidences for plausible mechanisms rather than the definitive proof of nutritional dependence, predator avoidance, or biological drivers of crop-raiding. It can largely be considered as a preliminary assessment for a topic of research that has a lot of potential left to explore

Still, this line of thinking opens the door to new strategies for mitigation as well as a change in the public narrative of animal ‘thievery’. Animals are not inherently malicious or cunning; it is our anthropogenic view of their actions that deems them

so, which often clouds the actual reasons behind their actions. And if coexistence is the goal we aspire to reach, we must start understanding the world from their point of view instead.



Fig 5.3.1. A nilgai bull looking towards the cropfields in the distance

CHAPTER SIX:

6.1] References

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114. R studio ver. 4.4.2

6.2] Appendix

Village	Who raids crops?	When do they raid?	Why do they raid?	Where can we find them?	Do you see them often?
Hetedi	Nilgai, Boar	7pm-8am	1. The crops are 'sweeter' and less thorny than the forest plants. 2. There is not enough to eat in the jungle	In the mornings.	Yes, very often.
Tiktoli	Claimed to not ; uncomfortable with questioning.	-	-	-	-
Agara	Wild Boar, Nilgai rarely	In the mornings, but mainly at night.	Unsure	Not sure but offered to call us when they came to the fields.	Not in the past six years (electric wires set up)
Shahpura	Claimed to not know; uncomfortable with questioning.	-	-	-	-
Umri	Nilgai, Wild Boar, Rabbit	12am-2am	They are hungry	It will be hard to find them.	No, but we know they come from footprints, pellets
Iklaud	Nilgai, Jackal, Wild Boar	7am-9am; 9pm-12am	Do not know	Yes, come in the mornings.	We see them.
Vijaypur	Nilgai, Wild Boar	Morning	To eat crops, to stand in shade,	No, they come occasionally.	We see them.
Magardeh	Nilgai, Wild Boar	Throughout the night	To eat crops	If you stay up at night, you will see them.	We only find hoofprints, pellets.
Gohta	Nilgai	6pm-3am	To eat crops	If you stay till evening, you will see them.	They walk by the side of the road.
Khurdwara	Nilgai, herds of 20	When we are not there	To eat crops	If you come early in the morning, you might see them.	We only find hoofprints, pellets.

Table 12. Summary of informal questioning of villages around Kuno

Above is a summary of answers from various villages surrounding Kuno about crop raiding. The explanation for our questions and my study was explained to them by our local field assistants before beginning, due to the implications of our presence. It was an informal, unstructured survey, with things only written down after we had left their sight. Often our questioning would gather crowds who would present a few different points and answers.

Khair (Acacia catechu)	Remjha (Accacia leucocephala)	Ber (Zizyphus mauritanica)	Dhok (Anogeissus pendula)	Mustard (leaves)	Wheat	Desmostachya bipinnata	Apluda mutica	Cenchrus ciliaris
15%	26.5%	13.3%	17.7%	4.11%	13.1%	7%	4.2%	3.6%

Table 6a. Crude Protein content in various common vegetation of Kuno.

Khair (Acacia catechu)	Remjha (Accacia leucocephala)	Ber (Zizyphus mauritanica)	Dhok (Anogeissus pendula)	Mustard (leaves)	Wheat	Desmostachya bipinnata	Apluda mutica	Cenchrus ciliaris
1.8%	4.12%	13.3%	17.7%	4.11%	13.1%	-%	3.2%	3.6%

Table 6b. Silica content in various common vegetation of Kuno.

Khair (Acacia catechu)	Remjha (Accacia leucocephala)	Ber (Zizyphus mauritanica)	Dhok (Anogeissus pendula)	Mustard (leaves)	Wheat	Desmostachya bipinnata	Apluda mutica	Cenchrus ciliaris
37%	6.78%	13.3%	17.7%	4.11%	13.1%	7%	4.2%	3.6%

Table 6c. Lignin content in various common vegetation of Kuno.