Prey selection, ranging pattern and habitat utilization of the reintroduced tigers (*Panthera tigris tigris L.*)in Sariska Tiger Reserve, Rajasthan, western India.

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By

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Dedicated to my Baba (Shri. Jayapada Bhattacharjee),
Maa (Smt. Manju Bhattacharjee)
and
Kakima (Late Smt. Chandra Roy)

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SUBHADEEP BHATTACHARJEE

Executive Summary

In a forest ecosystem, large felids are generally the top predators in almost every food chain influencing the structure and dynamics of the subsequent descending trophic levels. Evaluation of last fifty years' presence and absence status of large felids in Protected Areas (PAs) of Indian subcontinent revealed that local extinction was highest in the dry deciduous habitat. Tiger, among all large felids had already become locally extinct from 70% of semi-arid dry thorn and 35% of dry deciduous forest areas. Tigers in dry semi-arid forests with its global western most limit, survive in small isolated populations. The present study assessed the movements and ranging patterns, prey availability, prey utilization and resource selection of reintroduced tigers in Sariska Tiger Reserve from July 2008 to June 2012.

After the local extermination of the tiger population in Sariska Tiger Reserve (STR), during December, 2005 with the consent of the National Tiger Conservation Authority (NTCA) and the Rajasthan Forest Department a recovery plan for tigers in Sariska was prepared by the Wildlife Institute of India along with a detailed protocol for tiger reintroduction. The recovery plan suggested initial reintroduction of five adult tigers (two male and three female) as the founder population and subsequent supplementation with three individuals (two female and a male) at every two years till next six years period. Therefore with three restocking populations added to the founder would help to sustain a viable tiger population in Sariska till next hundred years.

As per the aforesaid plan six adult tigers (three males – ST1, ST4 and ST6 and three females – ST2, ST3 and ST5) were reintroduced from Ranthambhore Tiger Reserve to Sariska Tiger Reserve between June, 2008 and February 2011. Thereafter, during January 2013, two more female tigers (ST9 and ST10) were reintroduced in Sariska as a part of the supplementary stock. Tigers were first chemically immobilized and then radio-collared in Ranthambhore. Thereafter they were airlifted by helicopter / transported by road and brought to Sariska Tiger Reserve. In Sariska they were released inside a carnivore proof one hectare enclosure, which was enriched with a natural vegetation cover and adequate water holes. This process is known as "soft release" and it helped to monitor their physiological and behavioral response in the new environment. After three to four days of observations from a camouflaged watch tower, the individuals were released into the wild.

All the re-introduced tigers explored large areas initially soon after reintroduction and subsequently established their home ranges in smaller areas in the notified National Park of the

Tiger Reserve, which was the best available habitat in Sariska Tiger Reserve. Sariska was a hunting ground for the royal family of Alwar and functionaries of British Government. After independence, Sariska was declared as a Wildlife Reserve on 7th November, 1955, under the Rajasthan Wild animals and Birds Protection Act, 1951. The Sariska Tiger Reserve lies in the district of Alwar, Rajasthan state between Latitude: N27^{o}04' to N27^{o}45' and Longitude: E76^{o}17' to E76^{o}34' and is located in the hill range of Aravallis. The total area of Sariska Tiger Reserve is 881.11 km^2 which has been notified as critical tiger habitat (CTH). During July 2012 a buffer area of 322.23 km^2 encompassing some part of the Alwar Territorial Forest Division in the north and part of Jamwa Ramgarh Wildlife Sanctuary in the south around CTH has been notified. Therefore, the effective total area of Sariska Tiger Reserve after July 2012 is 1203.63 km^2. The vegetation of Sariska correspond to (1) Northern tropical dry deciduous forests (subgroups 5B; 5/E1 and 5/E2) and Northern Tropical Thorn forest (subgroup 6B). *Anogeissus pendula* is the dominant tree species covering over 35% area of the forest. *Boswellia serreta* and *Lannea coromandelica* grow at rocky patches. *Acacia catechu*, *Butea monosperma* and *Zizyphus mauritiana* are common in the valleys. The large carnivores found in STR include tiger (*Panthera tigris*), leopard (*Panthera pardus*) and hyena (*Hyaena hyaena*). Smaller carnivores include jungle cat (*Felis chaus*), caracal (*Caracal caracal*), golden jackal (*Canis aureus*), ratel (*Mellivora capensis*), palm civet (*Paradoxurus hermaphroditus*), small India civet (*Viverricula indica*), common mongoose (*Herpestes edwardsii*), small Indian mongoose (*H. auropunctatus*) and ruddy mongoose (*H. smithi*). During 2009, desert cat (*Felis silvestris*) was reported from Sariska. At present, there are eight villages located inside the notified National Park area of the Tiger Reserve, which are due for relocation since 1984. The human population is over 1700 in the villages of National Park along with a population 10,000 livestock including buffalo, cow, goat and sheep. There are 19 more revenue villages inside the Tiger Reserve (outside notified National Park). The human population in these villages is around 8,000 and the livestock population is more than 20,000.

The present study was conducted in 400 km^2 area which is the notified National Park area of Sariska Tiger Reserve from July 2008 to June 2012 covering all the three seasons monsoon (July to October), winter (November to February) and summer (March to June) with the following objectives:

a) to evaluate the prey availability for the reintroduced tigers,

b) to assess the prey selection patterns of the reintroduced tigers,

c) to study the movement and ranging patterns of the reintroduced tigers and

d) to assess the habitat utilization patterns, resource selection and response of tiger to various anthropogenic pressure in the study area.

Prey species availability was estimated by line transect method under distance sampling technique. A total of 52 line transects were walked. In total nine potential prey species were recorded on line transects. These were four wild ungulate species (chital, sambar, nilgai and wild pig), one primate (common langur), one small mammal (hare), two livestock (cow and buffalo) and one bird (peafowl). On each sighting of the target species, group size, age and sex composition, radial distance and sighting angle were recorded.

In Sariska, peafowl was observed to be the most abundant prey species throughout the study period. The density (km^{-2} ± SE) of peafowl varied from 73.94±6.69SE km^{-2} to 125.83±9.66SE km^{-2} during the study period. During 2008-09, chital was the most abundant (15.42±2.58SE km^{-2}) amongst the wild prey species followed by common langur (9.13±2.0SE km^{-2}), nilgai (8.39±1.02SE km^{-2}), sambar (7.66±1.16SE km^{-2}) and wild pig (7.60±1.51SE km^{-2}). During 2009-10, chital (15.56±2.83SE km^{-2}) was the most abundant wild ungulate prey species followed by nilgai (12.08±2.24SE km^{-2}), common langur (11.90±2.68SE km^{-2}), sambar (9.04±1.28SE km^{-2}), and wild pig (6.80±2.80 km^{-2}). During 2010-11, nilgai (17.66±1.71SE km^{-2}) was the most abundant wild ungulate prey species followed by common langur (14.30±2.75SE km^{-2}), chital (13.44±2.66SE km^{-2}), wild pig (8.29±1.95 km^{-2}) and sambar (7.87±1.33SE km^{-2}). During 2011-12, nilgai (19.66±1.85SE km^{-2}) was the most abundant wild ungulate prey species followed by chital (16.25±3.00SE km^{-2}), common langur (15.30±2.90SE km^{-2}), wild pig (11.64±2.11SE km^{-2}) and sambar (6.94±1.27SE km^{-2}). Since there were eight villages inside the Sariska notified National Park area and 32 inside the Tiger Reserve area, the estimated abundance of livestock was comparatively high in the study area. The densities of domestic livestock in the study area were recorded as 38.38±6.61SE km^{-2} during 2008-09, 58.0±14.56SE km^{-2} in 2009-10, 56.22±10.19SE km^{-2} in 2010-11 and 69.31±9.92SE km^{-2} during 2011-12.

In the intensive study area, the estimated total ungulate (wild and domestic) densities were 77.45±6.37SE km^{-2}, 99.42±9.37SE km^{-2}, 103.48±9.78SE km^{-2} and 123.8± 9.13SE km^{-2} during the years 2008-09, 2009-10, 2010-11 and 2011-12 respectively. The estimated total wild

ungulate densities were 39.07±3.16SE km^{-2}, 41.42±5.66SE km^{-2}, 47.26±5.86SE km^{-2} and 54.49±6.31SE km^{-2} during the years 2008-09, 2009-10, 2010-11 and 2011-12 respectively. In the intensive study area, the available prey biomasses (wild and domestic) were calculated as 12, 210.99 kg km^{-2} during 2008-09; 17, 425.91 kg km^{-2} in 2009-10; 18, 050.17 kg km^{-2} in 2010-11 and 21, 154.37 kg km^{-2} during 2011-12 respectively.

The prey densities estimated from the present study compared with those from other parts of the country revealed that Sariska Tiger Reserve harbors high densities of nilgai and wild pig.

A total of 103,178, 216 and 158 tiger scat samples were collected respectively in 2008-09, 2009-10, 2010-11 and in 2011-12. After comparing the utilization (from scat analysis) and availability (from distance sampling analysis) of prey species, Ivlev's index of prey preference for each species was estimated. The prey preference order in 2008-09 was sambar> chital> nilgai> livestock> common langur wherein the reintroduced tigers significantly preferred sambar and chital. The prey preference order in 2009-10 was as follows: sambar> nilgai> chital> wild pig> common langur > livestock. The prey preference during in 2010-11 was in the following order: sambar> chital> wild pig> nilgai> livestock> common langur. The prey preference in 2011-12 was in the following order: sambar> chital> nilgai>wild pig>livestock. During 2011-12, sambar and chital were significantly preferred by the tigers. A total of 115, 129, 127 and 95 kills of the reintroduced tigers were recorded in the study area during 2008-09, 2009-10, 2010-11 and 2011-12 respectively. Sambar and chital were the most preferred prey species by reintroduced tigers throughout the study period and these two deer species contributed more than 50% in tiger's diet.

Due to the presence of 28 villages in the Tiger Reserve with large domestic livestock population and their free grazing practice, there was high livestock predation by the re-introduced tigers (n=167) from the forested habitat inside STR during the study period. The increasing trend of livestock predation (>20%) by tigers is a matter of concern.

Three adult male and three adult female radio-collared tigers were periodically monitored in Sariska Tiger Reserve to study their daily movements and seasonal – annual ranging patterns. A total of 1218, 2818, 3169, 2181, 2087 and 1889 radio locations were recorded for the ST1 to ST6 tigers respectively during the period of July 2008 to June 2012. Each reintroduced tigers was observed to move at an average rate of 10-20 km per day till 40-50 days of their reintroduction during the initial exploration of habitats. Thereafter, these rates were subsequently reduced as they started settling down in smaller areas. During courtship and successful predation events, movements of

the tigers were reduced to 0.2 to 0.3 km per day while the maximum movement by an individual recorded in a day was 40.81 km. The mean daily movement of the male tigers (7.06±0.11SE km) was greater than that of the females (5.78±0.08SE km). During monsoon and winter, the estimated mean daily movement of each tiger was greater as compared to summer. The home ranges of the reintroduced tigers were estimated using 100% and 95% Minimum Convex Polygon estimators along with fixed kernel estimators (95% and 50%) and adaptive kernel estimators (95% and 50%) as these techniques were universally accepted for comparing with other available studies on tiger home ranges.

The estimated mean monsoon and winter home ranges of the male tigers using 100% MCP method were 155.25±8.1SE km^2 and 151.80±22.27SE km^2 respectively, which were larger than the summer range i.e. 138.10±18.20SE km^2. The ranging analysis of the tigresses with 95% fixed kernel estimator revealed that the mean monsoon (90.78±20.75SE km^2) and winter (76.71±5.76SE km^2) home ranges of the females were larger than their mean summer (70.31±7.96SE km^2) ranges. The range overlap between the male and female tigers ranged from 41% to 56% in each season and annually, whereas the female-female and male-male range overlaps varied from 10% to 30% and 10% to 18% respectively, season wise and annually. No range overlap between the tigers ST5 (female) and ST6 (male) was observed during the study period. The overlap between the core areas of activity amongst the female tigers was observed much less (zero to two percent season wise and annually), whereas the male-female mean range overlap of the core areas was found much larger (10% to 55%) in each season as well as annually. On an average, zero to three percent of overlap between the core areas of activity of the male tigers was estimated season wise and annually during the study period.

The mean home range estimates (100% MCP and 95% fixed kernel) of male and female reintroduced tigers from the present study were compared with other available studies in Indian subcontinent, Russian Far East and South-east Asia. It was observed that both male and female tiger home ranges estimated in Sariska Tiger Reserve were much larger as compared to other areas of Indian subcontinent except from the forests of Sumatra and Russian Far East.

Habitat utilization patterns of six reintroduced tigers (ST1, ST4 and ST6-male; ST2, ST3 and ST5-female) were studied in Sariska Tiger Reserve from July 2008 to June 2012. The radio-collared tigers were monitored periodically through satellite-GPS and VHF telemetry (ground tracking) using ‘triangulation’ and ‘homing in’ techniques. On each radio location of tigers, the

GPS location, habitat type used as well as microhabitat and terrain types were recorded. The vegetation type for each tiger location was extracted from a multispectral (Landsat 7 ETM+) high resolution (28.5m) classified satellite imagery (1:50,000) from the Global Land Cover Facility, NASA for better representation. The information on proportion of different categories of habitat availability was also extracted from the same classified satellite imagery incorporating the entire area of Sariska Tiger Reserve. Habitat preference by the tigers was assessed using Bonferroni confidence interval method and Ivlev's index (Ivelev 1961; Neu *et al*., 1974). Similarly, on each radio location of tigers, the topography related parameters such as altitude, aspect and slope were analyzed from a high resolution (10m) Digital Elevation Map (DEM) prepared from the contour map. Density of human disturbance (lopping and wood cutting) were estimated from 15 m radius circular plots on every 200 m distance of 52 line transect (n = 520), 112 radial line transect of length 2 km each around each of 28 villages (n = 1148) and also from kill, scat and homing in locations of tiger (n = 1470). The following parameters were recorded from these above-mentioned 3138 habitat sampling plots -

1. Major vegetation type
2. Major terrain type.
3. Wood cutting and lopping density (15 m radius) (total no. of tree cut down and branch lopped per ha)
4. Distance to the nearest
    - Waterhole
    - Road
    - Temple
    - Village

The tigers largely used *Anogeissus* forests (47.4%) followed by *Zizyphus* (15.7%), *Boswellia* (12.1%), *Butea* (10.6%), scrubland (8.6%), *Acacia* (4.5%) and Riverine forests (1.0%). The overall habitat preference of tigers was in the following order: Riverine >*Zizyphus* >*Butea* >*Anogeissus* >*Boswellia* >*Acacia* >scrubland. In monsoon similar habitat preference was observed where as in summer and winter tigers preferred *Zizyphus* forest over Riverine forest.

Tigers largely utilized gentle slope of 400 m to 550 m elevation (52.5%) as compared to areas with steep slope of more than 550 m altitude (30.3%) and flat terrain of less than 400 m MSL

(17.2%). The mean elevation utilized was 441.4±6.8SE m. Except the scrubland, the reintroduced tigers utilized all other vegetation types such as *Anogeissus* forest, *Zizyphus* forest, *Boswellia* forest, *Acacia* forest, *Butea* forest and riverine forest more than their availability.

In Sariska, riverine habitat is found only 0.03% of the total available vegetation types where as the riverine habitat utilization by the tigers was estimated as 1%. This difference between utilization and availability made riverine forest as most preferred habitat type by the tigers. Among the terrain types, only medium elevation range of 400 m to 550 m was utilized more than their availability by the tigers where as the steep terrain of more than 550 m elevation and gentle flat terrain of less than 400 m was utilized less than their availability.

The mean Euclidean distance of all the tiger locations (during 2008-2012) from the nearest waterhole was estimated as 684.1±3.8SE m which was found less as compared to their mean Euclidean distances from roads 2000.1±15.8SE m and the nearest village 2309.3±10.1SE m. In summer the mean distance to nearest waterhole was estimated as 646±5.5SE m which was found less than that in winter (673±6.1SE m) and monsoon (722±7.9SE m). This signified that water is a limiting factor for the habitat utilization pattern of the re-introduced tigers in Sariska.

The mean density of the human disturbance activities were estimated as 4.63 ± 0.19SE tree cut ha^{-1} and 132.61 ± 21.33SE tree lopped ha. The five worst affected tree species by human disturbances were recorded as *Anogeissus pendula, Acacia catechu, Acacia lucophloea, Butea monosperma* and *Zizyphus mauritiana*. At each of the village centre or the 0 m locations, almost no evidence of human disturbance could be recorded as the areas were completely devoid of tree species. Evidences of wood cutting and lopping were observed maximum within the distance of 1000 m to 1400 m from each village center and both of these activities were recorded till 2000 m distance from each village.

The resource selection patterns of reintroduced tigers were evaluated at their population level (1st order resource selection) as well as gender based selection of resources at the similar geographic level (2nd order resource selection). For this, boundary map of Sariska Tiger Reserve was divided into four square km (2km x 2km) grids. The values of kernel utilization distribution (UD – the probability of utilization of any area) of the reintroduced tigers and other habitat parameters were extracted grid wise to carry out further analysis of resource selection function. Therefore, a total of 30 habitat variables were estimated in each grid of the Sariska Tiger Reserve. Collinearity and correlation test was carried out in between these 30 variables to select

the non-collinear variables. A total of ten resource selection models were tested for the model significance and finally a mixed model with ten habitat variables such as north east aspect, percentage availability of *Anogeissus* and *Zizyphus* forests, encounter rates of sambar, chital and livestock, Euclidean distance to nearest waterhole and village and encounter rates of anthropogenic disturbance such as wood cutting and lopping was assessed as the best fitted model with lowest AIC and ΔAIC values along with model significance to the resource selection patterns of the tigers.

Results of Generalized linear model (GLM) showed that north east aspect, *Anogeissus* and *Zizyphus* forests, encounter rates of sambar, chital and livestock and distance to village had positive ß value w.r.t. tigers' utilization distribution pattern, whereas the distance to nearest waterhole and encounter rates of the anthropogenic disturbance such as wood cutting and lopping had negative ß value. A similar trend was found in male and female tigers' resource selection as well as in the seasonal variation of the resource selection by them. This signifies that the tigers avoided human presence where as locations of waterholes were important in their habitat utilization patterns.

Ecologically, the *Zizyphus* forest always plays a key role in the ecosystem of a tropical dry deciduous forest. The *Zizyphus* patches allow a number of palatable grasses to grow under it, such as *Chloris dolichostachya*, *Heteropogon contortus* and *Cynodon dactylon*. These grass species along with fallen *Zizyphus mauritiana* leaves and fruits which contain high protein, influenced assemblage of a number of prey species of tiger (ungulates and primates) in the study area. Similarly *Anogeissus pendula* forest along with palatable shrub species such as *Grewia flavescence* and *Capparis sepiaria* provided suitable habitat for sambar. Hence, tigers utilized this forest type significantly and this forest type positively influenced the utilization distribution (UD) of the reintroduced tigers.

The Euclidean distance of the tigers to the nearest waterhole negatively affected the tigers' UD which meant that more was the distance from any waterhole less was the UD by the tigers. Therefore, it can be concluded that tigers preferred to stay near waterholes. It was found that 32 prominent waterholes are located adjacent to the State High-way in prime habitat of notified National Park area of Sariska. Since, the tigers had preference close to water locations, the vehicular traffic (>20 vehicles/ hour) in the State Highway needs to be regulated to avoid any further conflict issue with the tigers as well as other wild prey species. The Euclidean distance of

the tigers to the nearest village showed positive control on the UD of the tigers. This signified that tigers avoided the village and human-habitation areas and kept an average distance of more than two kilometer during the study period. No incidence of tiger venturing into the villages and attacking livestock or human was reported during the study period.

Amongst the prey species of tiger, abundance (encounter rates) of sambar, chital and domestic livestock positively influenced the resource selection of all the tigers including male and female individuals. Sambar and chital both being the preferred prey species of tigers found in high abundance in *Zizyphus* and *Anogeissus* forests in the prime habitats of STR. Therefore, both of them positively affected the UD of the tigers in Sariska. Since there are 29 villages currently present in the Tiger Reserve and eight in the notified National Park area, the population of domestic livestock was found high and their density was estimated as 30 – 70 individuals km^{-2} during 2008 to 2012. The predation of domestic livestock by tigers was also high (>20%). The livestock used to graze freely in the forested habitat without any guidance from their owners and go back to the village by themselves. In retaliation to such predation, the first reintroduced male tiger (ST1) was found dead during November 2010 due to poisoning on a buffalo carcass inside the Tiger Reserve area. Therefore, relocation process of the existing villages and the restricted and supervised grazing practice along with timely compensation schemes are recommended to reduce further retaliatory conflict issues.

Anthropogenic disturbance activities such as lopping and wood cutting showed a significant negative relation with the UD of the reintroduced tigers. There are eight villages yet to be relocated from the prime habitat of the notified National Park area of Sariska. Till these villages are relocated, the anthropogenic activities such as wood cutting, lopping and grazing should be restricted and regulated for the future survival of tigers in Sariska.

Since the tiger population in the wild is dwindling drastically in its entire distribution range, and since Sariska, which had the western-most distribution of tigers, has seen their complete extinction once, it has grown even more necessary to monitor and study the relevant ecological aspects such as ranging pattern with regard to anthropogenic pressure, food habits, and prey selection of the reintroduced tigers. Therefore the outcome of long-term monitoring studies on tigers will be helpful for the park administration to manage this top-most predator and it habitats, and as a whole the complete ecosystem, more effectively.

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

In the lineage of feline evolution, genus *Panthera* is considered the oldest while the genus *Felis* is more recent. Phylogenetic studies have brought members of the subfamily *Pantherinae*, such as *Panthera*, *Uncia* and *Neofelis* together into one lineage (Eisenberg, 1986). The family *Felidae* is classified into two sub-families i.e. *Pantherinae* and *Felinae*, 14 genera and 40 species worldwide. Fifteen among these including five species of large felids are distributed in the Indian subcontinent. In a forest ecosystem, felids are generally the top predators in almost every food chain influencing the structure and dynamics of the subsequent descending trophic levels (Eisenberg, 1986). Evaluation of last fifty years' presence and absence status of large felids in Protected Areas (PAs) of Indian subcontinent revealed that local extinction was highest in the dry deciduous habitat. Tiger, among all large felids had already become locally extinct from 70% of semi-arid dry thorn and 35% of dry deciduous forest areas (Chundawat and Gogate, 2001). Tigers in dry semi-arid forests with its global western most limit, survive in small isolated populations (Sankar *et al*., 2010).

Studies indicated that a demographically viable tiger population could be efficiently managed within such smaller PAs provided their prey base and adjoining habitats are managed intensively (Karanth and Stith, 1999; Sankar *et al*., 2005). For this comprehensive management, scientific understanding of the site specific ecosystem, human interference in the concerned habitats and predator-prey relationship should be prioritized. Adverse environment featured with degraded habitat, moderate to high anthropogenic influence and depleted prey base may obligate the carnivore species to depend more or solely on the domestic livestock available in and around the forested areas which may result in to human-wildlife conflict issues. The forest degradation may eventually compel the predator to expand its home range augmenting human-carnivore conflict issues further (Karanth, 1991; Vanak, 1997; Chundawat and Gogate, 2001).

Under these circumstances, importance of landscape level conservation planning surrounding the PAs becomes very critical for conservation of large carnivores such as tiger and other co-predators. The conventional way of conservation of PAs is to focus the conservation strategy for

focal or surrogate species. In ecology, such surrogate species are classified in three major groups such as flagship species, umbrella species and species known as biological indicators for an ecosystem (Mills *et al*., 1993; Andelman and Fagan, 2000). Tiger, the charismatic top predator of forest ecosystem, acts simultaneously as the "Umbrella species" and "Flagship species" and provides a "coattail effect" i.e. attracting intrinsic conservation measure (Soule, 1985) for all other species associated in the concerned ecosystem. Hence it is necessary to understand the patterns of territoriality, habitat utilization, predation pattern, food habits and resource selection by this top predator for the landscape level conservation.

Therefore, in the present study, the movement and ranging patterns along with the prey selection, habitat utilization and resource selection of the tigers with respect to anthropogenic interference were envisaged for Sariska Tiger Reserve, Rajasthan, western India in order to suggest effective management strategies for the conservation of this endangered felid.

1.2. REINTRODUCTION: A CONSERVATION TOOL

The last resort of conservation measure of any species is reintroduction of the same in the concerned habitat where it became locally exterminated. It has much public attraction and may be portrayed in the media as a glorious accomplishment of hands-on conservation, overcoming all the practical and political constraints. But it also symbolizes a failure, a mismanagement of our environment, which failed to protect previous surviving populations (Kruuk, 2009). In deteriorating ecological circumstances, reintroductions have proved to be a valuable tool for the recovery of the species that have become either globally or locally extinct in the wild (Woodroffe, 1999).

Reintroductions can also give us an insight into the reasons of disappearance of a species from the areas where they formerly occurred. But the whole process is reasonably expensive, experimental and should properly be monitored (Sutherland, 2004). Reintroduction of a species is thus addressed after all other conservation actions at a region have been tried, tested and subsequently not succeeded. Reintroduction of large predators have had a poor success rate in the past (Panwar and Rodgers, 1986; Wemmer and Sunquist, 1988; Breitenmoser *et al.,* 2001) and the overall conservation benefits in the long-term management are questionable (Hunter *et al.,* 2006; Haywards *et al.,* 2007a). Although top-order mammalian predators have declined globally (Weber & Rabinowitz, 1996), they are still amongst the most frequently reintroduced

group of organisms (Seddon *et al.*, 2005). There were multiple reasons for this, including assisting with a species' conservation (Hayward *et al.*, 2007b), the degree of knowledge about these charismatic species, the restoration of ecosystem functioning (Terborgh *et al.*, 1999; Sinclair *et al.*, 2003) and also the financial benefits of their presence in ecotourism ventures (Lindsey *et al.*, 2005).

This overview of the various threats to top predators may ultimately benefit their conservation. If scientists can successfully identify the root of the extinction threats to a species and agree upon them, they can proceed towards removing those threats. But disparity of opinion with conservation practitioners might be the reason behind in some countries where numerous reintroduction programmes were implemented while other countries have not taken any initiative so far. Generally due the elusive and cryptic nature, the mammalian top predators are more difficult to study which has resulted in insufficient ecological understanding to develop confidence in conservation management actions.

Therefore, a great deal of behavioral understanding of such species to the change in habitat and prey species dynamics along with human interference or disturbance is required before establishing any protocol for the reintroduction of these top-predators. Post-reintroduction monitoring of the individuals is thus very important towards achieving the success in the reintroduction projects. In any such attempts, success of the reintroduction programme of any species can be possibly delineated by the breeding of the reintroduced individuals with the birth of the wild-born generation or a three year breeding population with natural recruitment exceeding mortality (Griffith *et al*., 1989), particularly in small, isolated reserves (Hayward *et al*., 2007c).

The re-introduction and recovery of the Eurasian lynx (*Lynx lynx*) in 1970's, Florida Panther (*Puma concolor coryi*) in Florida, USA during 1981, African wild dog (*Lycaon pictus*), in Africa in late 1990's, wolves in Yellowstone National Park during 1995-96 (Smith and Bangs, 2009), are a few among such instances that enriched our knowledge about the science and management of carnivore reintroductions. Reintroduction of bear has also been accomplished worldwide with varying extent of success (Clark *et al*., 2002). But 'Homing effect' is a significant issue for American black bears (*Ursus americanus*) where the success of reintroduction for all bear species tend to be positively correlated with translocation distance and choice of proper age and sex of the target individuals (preferably sub-adults and females).

Poor public approval, management understanding and improper habitat selection for the release of the animals were the most significant causes for failures of some of the bear reintroduction programmes (Clark *et al*., 2002). With the rapid decline of global wild population and range of snow leopards (*Uncia uncia*) and growing ex-situ population, reintroduction programmes of snow leopards are also in the plans of the policy makers and wildlife biologists (Jackson and Ale, 2009). But selection of suitable stock for reintroduction and release site with minimum conflict probabilities are the major concern for such programmes. Generally, in most of the reintroduction studies, the post-translocation monitoring was not investigated and the results do not suggest a high success rate of the re-introduction programme and the reasons for the failures were poorly investigated and reported (Hunter, 1998; Haywards *et al*., 2007b).

The wider distribution of Eurasian lynx (*Lynx lynx*) in Europe in present days than the past centuries has been contemplated to both natural recovery processes and reintroduction programmes (Linnell *et al*., 2009). Out of four remnant lynx populations, three (Scandinavia, eastern Baltic and Carpathian Mountains) had shown significant recoveries where as the fourth (southern Balkan) population had not been revitalized which might be due to its small size and habitat isolation. Since 1971, there were 15 different reintroduction attempts throughout Europe using both wild and captive animals. Out of these, six were futile, four were of uncertain status and the rest five were successful.

Most of these reintroduction projects dealt with relatively few animals, have had little post-reintroduction monitoring and did not maintain present-day IUCN (International Union for the Conservation of Nature and Natural Resources) guidelines. Despite this ad hoc approach, the distribution of lynx in Central Europe at present is much wider and sustainable which would have not been possible to accomplish by mere natural expansion. The experience of lynx recovery would surely help in formulating strategies for carnivore conservation at very large spatial and temporal scales with a systematic conservation-planning approach, where reintroduction and natural recovery can be adopted as complementary tools (Linnell *et al*., 2009).

The Florida panther (*Puma concolor coryi*) is one of the most iconic animals in the United States, having been federally scheduled as endangered since 1967 by Endangered Species Preservation Act of 1967 and Endangered Species Act of 1973 (Thatcher *et al*., 2006). Habitat loss and fragmentation were the most severe threats to the panther in Florida (Kautz, 1994),

resulting in limited potential for natural population expansion leading to a small isolated population of only 20 individuals during 1970's.

Thereafter, the Florida Panther Recovery Plan was carried out to re-establish two additional panther populations within the regions of the historic range as a major objective (U.S.F.W.S., 1995). This collaborative effort among the scientists and management resulted in a revitalized population of 160 individuals in 2011 (Florida Fish and Wildlife Conservation Commission, 2013). Although there were arguments about the introduction of eight female cougars (*Puma concolor*) from a closely related Texas population to avoid the genetic inbreeding problems but due to these recovery attempts the habitat conditions in the south-eastern United States had considerably changed.

The panther reintroduction and recovery programme had also improved several other conservation scenarios such as an increase in the purchase and protection of large tracts of public lands, the large-scale recovery of forest habitats with an increase in populations of prey species such as white-tailed deer (*Odocoileus virginianus*) as well as changes in human attitudes towards wildlife conservation with the legal protection afforded by the Endangered Species Act (Thatcher *et al*., 2006).

In South Africa, Kruger National Park was the only source of viable population of African wild dogs (*Lycaon pictus* Temminck, 1820). In 1997, as a conservation priority, establishment of a second viable population was suggested. However, in the absence of suitable large conservation areas, a series of small, isolated sub-populations known as managed metapopulation were developed with intensive management actions of successive translocation of wild dogs between different protected areas. During 1998 to 2006, 66 founder animals were used to establish nine such sub-populations. In June 2005, these managed metapopulation were observed to grow to a population of 264 animals in 17 packs with a considerable high survival rate of pup (64%) and yearling (71%) (Davies-Mostert *et al*., 2009).

Although the managed metapopulation strategy was successful in terms of enriching species assemblages and motivating ecotourism initiatives, a number of management challenges such as wild dog-human conflict issues, maintenance of wild prey population for the wild dogs and the necessity of overcoming stochastic processes affecting small populations were also reported. These long-term initiatives of wild-dog translocation and conservation strategies might also be successfully applied to other large mammal species occupying in fragmented habitats as an

indispensable last resort to fend off their local extinction. In addition to the approaches of human-induced management, priority should always be given to conservation strategies which would support natural dispersal and self-regulation of the population (Davies-Mostert *et al*., 2009).

Wolves (*Canis lupus*), were completely eradicated from Yellowstone National Park (YNP) during 1926 because of a Congressionally-mandated policy. Thereafter, wolves were planned to be reintroduced from Canada as the Endangered Species Act (ESA) of 1973 proposed their restoration and US National Park Service policy also suggested restoring them in natural conditions. After nearly 20 years of unrelenting public debate, wolves captured in Canada were reintroduced to central Idaho and YNP during 1995 and 1996 (Smith and Bangs, 2009). By the end of 2007, there was an estimated population of 1500 wolves distributed across the states of Montana, Idaho and Wyoming with a population of 171 individuals in YNP (Smith and Bangs, 2009). The reintroduced population grew rapidly (17% per year) with a high pup survival and low human-caused mortality. Despite high genetic relatedness among the packs, the overall genetic diversity of the population was still observed quite high and equivalent to other wild North American wolf populations (Smith and Bangs, 2009).

Wolves primarily preyed on elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*) in summer and bison (*Bison bison*) in winter. It was observed that predation strategy of the wolves was highly selective to the elk calves in early winter and to older females throughout the year. But frequency of bull elk had been increased in the wolf kill in recent time, possibly due to the declined habitat condition by multi year drought (Smith and Bangs, 2009). Interactions of the wolves with the other large carnivores were also significant as the population of coyote (*Canis latrans*) was reduced and their social structure was found altered due to the presence of reintroduced wolves. In contrast, population of grizzly bear (*Ursus arctos*) was aided by the wolves with probable provision of ungulate carcasses as bear feed. Except a few incidences of inter-specific killing, wolves supposed to have little effect on cougars (*Felis concolor*). But, wolves might be a factor in a trophic cascade involving the control of wolves–elk–willow food chain, as the height of willow (*Salix spp*.) being suppressed for decades by elk browsing was observed to be increased after three years of wolf reintroduction. Population augmentation of beavers (*Castor Canadensis*) and songbirds were also associated with the willow revival. In

general, wolf reintroduction was considered a success but political opposition with continuing controversy among federal and state wildlife managers still prevailed.

Along with these worldwide accounts of reintroduction of different large mammalian predators, attempts were also made in the past to translocate problem tigers in India (Seidensticker, 1976; Panwar and Rodgers, 1986) as well as in Russian Far East (Miquelle *et al*., 2001; Goodrich and Miquelle, 2005) to the farthest possible habitats. But due to completely nil or very less post-translocation monitoring activities, the fate of the translocated tigers was not documented. Sometimes, deaths of such translocated individuals were also reported in conflicts with human (Goodrich and Miquelle, 2005).

1.3. BACKGROUND OF THE STUDY

After the local extermination of the tiger population in Sariska Tiger Reserve, Rajasthan, western India, a report was prepared by the Wildlife Institute of India (Sankar *et al*., 2005) wherein a blue print for tiger re-introduction was prepared. It was suggested that reintroduction should establish self-sustaining populations with high reproductive fitness in the wild environment and ample genetic diversity (Frankham *et al*., 2002). In December, 2005 with the consent of the National Tiger Conservation Authority (NTCA) and the Rajasthan Forest Department a recovery plan for tigers in Sariska was prepared by the Wildlife Institute of India along with a detailed protocol for tiger reintroduction. The recovery plan suggested initial reintroduction of five adult tigers (two male and three female) as the founder population and subsequent supplementation with three individuals (two female and a male) at every two years till next six years period (Sankar *et al*., 2005). Therefore with three restocking populations added to the founder would help to sustain a viable tiger population in Sariska till next hundred years.

Therefore, according to the aforesaid plan six adult tigers (three males – ST1, ST4 & ST6 and three females – ST2, ST3 & ST5) were reintroduced from Ranthambhore Tiger Reserve to Sariska Tiger Reserve between June, 2008 and February 2011. Tigers were first chemically immobilized and then radio-collared in Ranthambhore. Thereafter they were airlifted in the Indian Air force MI-17 helicopters / transported by road and released in Sariska Tiger Reserve. In Sariska they were released inside a carnivore proof one hectare enclosure, which was enriched with a natural vegetation cover and adequate water holes. This process is known as “soft release” and it helped to monitor their physiological and behavioral response in the new environment.

After three to four days of critical observations from a camouflaged watch tower, the individuals were released into the wild.

Continuous monitoring was carried out from the very moment the tigers were released into the wild. The first reintroduced male tiger (ST1) was found poisoned on 14th November 2010 at a place named Kalakhet inside the Tiger Reserve area. The first reintroduced tigress (ST2) was photographed with two cubs (ST7 and ST8) in August 2012 signified the success of the tiger reintroduction project in Sariska. Two more tigresses (ST9 & ST10) were also reintroduced to Sariska from Ranthambhore Tiger Reserve during January 2013 as the supplement to the initial stock following the tiger reintroduction protocol. Therefore, the present population of tigers in Sariska has been increased to nine individuals with seven adults and two sub-adults. The details of the reintroduction of the tigers in Sariska Tiger Reserve along with the features of their radio-collars deployed with the events of collaring and re-collaring are given in the table 1.1.

Table 1.1. Details of tiger reintroduction in Sariska Tiger Reserve.

Sl. No.	Tiger ID	Sex	Date of release in enclosure	Mode of reintroduction	Date of release into the wild	Type of collar deployed	Date of collar ceased functioning	Date of re-collaring	Collar type used	Remarks
1	ST1	Male	28.06.2008	Air	06.07.2008	Satellite GPS VHF	April 2009	June 2009	VHF	Died on 14th November 2010
2	ST2	Female	4.07.2008	Air	08.07.2008	Satellite GPS VHF	November 2011	Not done	n.a.	Littered two cubs in May 2012 (ST7 & ST8)
3	ST3	Female	25.02.2009	Air	27.02.2009	VHF	December 2012	February 2014	n.a.	-
4	ST4	Male	20.07.2010	Road	27.07.2010	Satellite GPS VHF	April 2011	April 2011	VHF	-
5	ST5	Female	28.07.2010	Air	01.08.2010	Satellite GPS VHF	July 2012	August 2012	VHF	-
6	ST6	Male	23.02.2011	Road	27.02.2011	Satellite GPS VHF	October 2012	December 2012	VHF	Tiger that moved out from Ranthambhore and settled in Keoladeo National Park, Bharatpur was translocated to Sariska.
7	ST9	Female	22.01.2013	Road	28.01.2013	Satellite GPS VHF	n.a.	n.a.	n.a.	Reintroduced tigress as supplement to the initial stock
8	ST10	Female	23.01.2013	Road	28.01.2013	Satellite GPS VHF	n.a.	n.a.	n.a.	Reintroduced tigress as supplement to the initial stock

n.a. – Not applicable; GPS – Global positioning system; VHF – Very high frequency

1. 4. OBJECTIVES

The present study on reintroduced tigers in Sariska Tiger Reserve, Rajasthan, was carried out chiefly to understand how these tigers would settle in the new environment in order to address the following objectives:

i. to evaluate the prey availability for the reintroduced tigers,
ii. to assess the prey selection patterns of the reintroduced tigers,
iii. to study the movement and ranging patterns of the reintroduced tigers and
iv. to assess the habitat utilization patterns, resource selection and response of tiger to various anthropogenic pressure in the study area.

1. 5. STUDY PERIOD

The study was conducted from July 2008 to June 2012 (four years) covering all the three distinct seasons such as monsoon (July to October), winter (November to February) and summer (March to June).

1.6. STUDY SPECIES: TIGER (*Panthera tigris tigris*)

Tiger and all other carnivores have been evolved from miacids (*Miacidae*), primitive carnivoramorphans that lived during the Paleocene and Eocene epochs, about 62–33 million years ago (Morlo *et al.,* 2004; Polly *et al.,* 2006). The oldest known felids including tigers were evolved over one million years ago in south Asia. From there the tiger spread north to the Amur region of eastern Russia, south to the islands of Indonesia, and southwest to Indochina and the Indian subcontinent, eastern Turkey, and the Caspian Sea (Hemmer, 1979; Mazak, 1981; Herrington, 1987: Luo *et al.,* 2004).

There are eight generally accepted tiger subspecies found worldwide in accordance with their geographic distribution (Figure 1.1). Bali (*Panthera tigris balica* Schwarz, 1912), Caspian (*Panthera tigris virgata* Illiger, 1815), and Javan (*Panthera tigris sondaica* Temminck, 1844) tiger subspecies were extinct by the 1940s, 1970s, and 1980s respectively (Nowell and Jackson, 1996).

Among the five surviving sub-species, the Royal Bengal tigers (*Panthera tigris tigris* Linnaeus, 1758) exist in India, Bangladesh, Bhutan, western China, western Myanmar and Nepal

(Seidensticker *et al.*, 1999). The Amur or Siberian tigers (*Panthera tigris altaica* Temminck, 1844) are surviving in eastern Russia, northeastern China, and Korea (Matyushkin *et al.*, 1999; Miquelle and Pikunov, 2003) while the Amoy or South Chinese tigers (*Panthera tigris amoyensis* Hilzheimer, 1905) now found only in captivity (Tilson *et al.*, 2004). The Sumatran tigers (*Panthera tigris sumatrae* Pocock, 1929) occur in Sumatra (Seidensticker *et al.*, 1999; Shepherd and Magnus, 2004) where as the Indochinese tigers (*Panthera tigris corbetti* Mazak, 1968) are distributed across Cambodia, China, Laos, Malaysia, east Myanmar, Thailand, and Vietnam (Seidensticker *et al.*, 1999). The average body and skull length along with weight of all the eight sub-species of tiger is given in table 1.2.

Figure 1.1. Past and present worldwide distribution range of tiger (Source: PANTHERA**).**

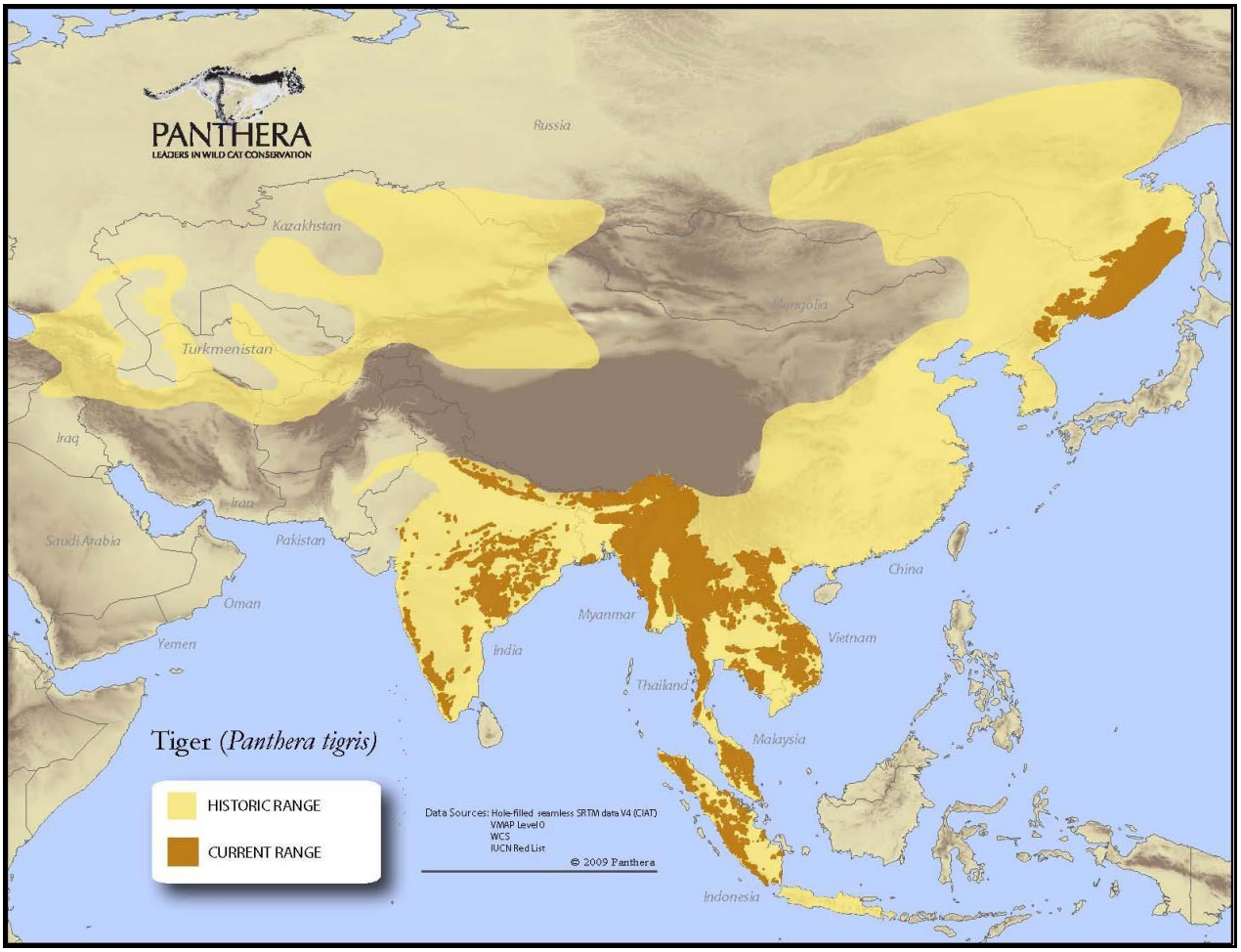


Table 1.2. Size Variation in Tiger Subspecies (source: IUCN)

Living Tiger Subspecies						
Subspecies	**Average Length (M) ("between pegs")**		**Weight (kg)**		**Greatest length of skull (mm)**	
	Male	Female	Male	Female	Male	Female
Bengal	2.70-3.10	2.40-2.65	180-258	100-160	329-378	275-311
Indochinese	2.55-2.85	2.30-2.55	150-195	100-130	319-365	279-302
Siberian	2.70-3.30	2.40-2.75	180-306	100-167	341-383	279-318
South China	2.30-2.65	2.20-2.40	130-175	100-115	318-343	273-301
Sumatran	2.20-2.55	2.15-2.30	100-140	75-110	295-335	263-294
Extinct Tiger Subspecies						
Subspecies	**Average Length (M) ("between pegs")**		**Weight (kg)**		**Greatest length of Skull (mm)**	
	Male	Female	Male	Female	Male	Female
Bali	2.20-2.30	1.90-2.10	90-100	65-80	295-298	263-269
Caspian	2.70-2.95	2.40-2.60	170-240	85-135	316-369	268-305
Javan	2.48	---	100-141	75-115	306-349	270-292

Tiger, the largest wild felid in Indian subcontinent, occupies a wide range of habitats from moist and dry deciduous to dry thorn forest; evergreen forests to the mangroves and grasslands to tropical montane forests (Wikramanayake *et al*, 1999; Sunquist and Karanth, 1999; Miquelle, *et al*, 1999; Chundawat, 2001). Tiger is a habitat specialist and its response varied according to the habitat it occupies (Sunquist and Sunquist, 1989). The breeding success, social organization and occupancy patterns of tigers were influenced by the availability, composition and distribution (both temporal and spatial) of suitable prey species whereas tigers showed significant tolerance to variation in altitude, temperature and rainfall regimes (Sunquist, 1981; Karanth, 1991).

Tiger is also the most discussed species among all the wild felids in both scientific and non-scientific communities as well as among the policy makers all over the world (Andelman and Fagan, 2000). As the largest predator in Asia, the tiger has always been revered as a cultural and social icon throughout of its former and present range from ages. In spite of such extensive concern about conservation issues, in the last few decades populations of tiger along with other 22 large carnivore species (Fuller, 1995) had significantly been reduced worldwide over their former geographical range due to incessant habitat destruction and fragmentation (Seidensticker, 1986; Johnsingh *et al.*, 1991), loss of connectivity between suitable habitats (Ceballos and Ehrlich,2002), over hunting and depletion of the wild prey (Karanth, 1991; Karanth *et al.,* 2004; Hayward *et al.,* 2007c), poaching for commercial reasons (Jackson, 1993; Rabinowitz, 1993) combined with slackening protection for socio-political reasons (Ghosh, 1993). Despite their endangered status, detailed long-term ecological studies on tigers in their entire distributional range are lacking. Increasing the scientific understanding of tiger ecology is the most urgent conservation challenge for management of tiger population in the Indian subcontinent (Chundawat and Malik, 2010).

In Indian subcontinent, tiger ecology was studied mostly in moist deciduous forests of gangetic plains, terai arc and western ghat landscapes (Schaller, 1967; Sunquist, 1981; Tamang, 1982; Smith; 1984; Karanth and Sunquist, 1995; 2000; Harihar and Pandav, 2012), whereas in dry deciduous habitats studies are lacking (Chundawat, 2001). Tiger is territorial and wide ranging, but the effective size of the home range is the function of density and biomass of larger prey species in its specific habitat (Sunquist, 1981; Karanth, 1991; Karanth *et al*., 2004). These innate biological traits had always made the species susceptible to local extinctions due to negative alterations in the habitat and prey density by the ever expanding human population pressure (Karanth, 1991; Griffiths and Van Schaik, 1993; Crooks, 2002; Fisher *et al*., 2003; Cardillo *et al*., 2004; Cardillo *et al*., 2005).

1. 7. ORGANIZATION OF THESIS

The thesis is corroborated with six chapters.

Chapter I gives introduction to the study which includes the background of carnivore conservation, process of reintroduction as a conservation tool and brief account on the origin of the study. This chapter also describes the ecological aspects of study species and the objectives of the study.

Chapter II deals in descriptive account of the study area including the topography and vegetation, available fauna and the human settlements.

Chapter III deals with prey species abundance, density estimates and trend in population in consecutive four years from 2008-09 to 2011-12.

Chapter IV describes prey selection and food habits of the reintroduced tigers, which includes the percentage occurrence of each prey species in tiger's diet, proportion of their biomass consumption and prey selection.

Chapter V describes the movement and ranging patterns of the reintroduced tigers in the study area, which includes estimation of their seasonal and annual home ranges using different home range estimators.

Chapter VI deals with habitat use and resource selection of tiger and its prey species with respect to vegetation and terrain types and anthropogenic influence in the study area.

CHAPTER TWO

2. STUDY AREA

2.1. INTRODUCTION

Sariska Tiger Reserve (STR) is a notified National Park located in the semi arid tract. It once served as hunting ground for the royal family of Alwar and functionaries of British Government. Shooting was permitted till 1955. After independence, Sariska was declared as a Wildlife Reserve on 7th November, 1955, under the Rajasthan Wild animals and Birds Protection Act, 1951. Sariska was included in the list of Tiger Reserves by Government of India in 1978 as the 11th Tiger Reserve. The total area of the Sariska Tiger Reserve was then 881 km^2. In 1982, an area of 273.8 km^2 was declared as Sariska National Park vide Preliminary Notification No. F11 (22) Raj-8/78 Jaipur Dated 27 August 1982 under Wildlife Protection Act 1972 (Central Act No. 53) section 35 (1). Within STR, there are several places of historical interest.

The Pandupole temple which is a major attraction for tourists and pilgrims lies in the National Park area of the Reserve. The temple and the surroundings are associated to the Hanuman the Monkey God and the Pandavas when they were in exile in the Mahabharata epic. The Neelkanth temple and ruins of several other temples found inside STR are now protected by the Archaeological Survey of India (ASI). Evidences of Mughal invasion are retained in the forts located in and around the Sariska. The Kankwadi fort, originally built by Maharaja Jai Singh II of Jaipur, located inside the National Park area of the Reserve, where in the Mughal Emperor Aurangzeb had imprisoned his eldest brother Darashikoh for a duration of 7-8 years during the struggle for succession of the throne.

2.2. LOCATION AND AREA

The Sariska Tiger Reserve lies in the district of Alwar, Rajasthan state between Latitude: N27^{o}04’ to N27^{o}45’ and Longitude: E76^{o}17’ to E76^{o}34’ and is located in the hill range of Aravallis spreading over the tract starting from Mount Abu and culminating on Delhi ridge (Figure 2.1). The Tiger Reserve falls in Gujarat-Rajputana Biogeographic zone (Rodgers and Panwar, 1988). The Reserve lies on Delhi-Jaipur State Highway via Alwar,

at a distance of 200 km from Delhi, 37 km from Alwar and 110 km from Jaipur. The total area of Sariska Tiger Reserve is 881.11 km^2 which has been notified as critical tiger habitat (CTH) in the official gazette of the state vide Notification No. F3 (34) Forest/ 2007 Dated December 28, 2007. Of these, Reserved Forest occupied 604.97 km^2 of area and the Protected Area is 276.13 km^2. During July 2012 a buffer area of 322.23 km^2 encompassing some part of the Alwar Territorial Forest Division in the north and part of Jamwa Ramgarh Wildlife Sanctuary in the south around CTH has been notified. Therefore, the effective total area of Sariska Tiger Reserve after July 2012 is 1203.63 km^2.

2.3. TOPOGRAPHY, DRAINAGE AND GEOLOGY

Sariska Tiger Reserve is characterized by rugged terrain, valleys and plateau with the altitudinal variation from 240 m to 777 m (Figure 2.3). The two main plateaus are Kankwadi (524 m) and Kiraska (592 m). The most remarkable characteristics of the hills are their homogenetic regularity of height, level summits and uniform appearance, stretching out from northeast to south-west (Soni, 2000).

The Ruparel River runs through the middle of the Tiger Reserve in North South direction. The drainage from most areas of the northern portion of the Tiger Reserve including Bandipool stream flows into the Ruparel River, while the drainage of the southern part of the Tiger Reserve flows into the Mansarovar Lake.

Major part of the area is occupied by rocks of Delhi system and Aravalli system comprising of quartzites, conglomerates, grits, Limestone, phyllite, granites and schist (Pascoe, 1950). Most of the high ridges are comprised of quartzites, conglomerates and grits. Evidences of lava conglomerates are also occasionally seen. These ancient crystalline and metamorphic rocks with gneiss and schist etc. are generally covered by red sandy soils. Red soils are poor in nitrogen, phosphorus and humus contents and alkaline in nature. There are comparatively rich, fertile and dark colored soils in plains and river valleys. The depth of soil layer is more than 1 m in valleys, whereas it is only a few centimeters deep on the hill slopes. The soil is sandy loam and alkaline with pH varying from 7.25 to 8.00 (Yadav and Gupta, 2006).

2.4. CLIMATE

Sariska Tiger Reserve is characterized by sub-tropical dry climate with distinct winter (November-February), summer (March-June), monsoon (July-August- September) and post-monsoon (October). The highest temperature (~ 48^{o}C) is recorded in May-June and the lowest (up to 1^{o}C) in December-January. The bulk of the precipitation is from South West monsoon and occurs during the months of July to September. Average annual rainfall recorded is 650 mm (Sankar, 1994). The rainfall during the period from June-September constitutes about 92% of the annual rainfall. The relative humidity is generally low in most parts of the year; it becomes as low as 5 to 15 percent during summer months. However during the rainy days the relative humidity goes over 60%. During the study period (2008-2012), record rainfall of more than 1400 mm was observed in 2011.

2.5. VEGETATION

The vegetation of Sariska correspond to (1) Northern tropical dry deciduous forests (subgroups 5B; 5/E1 and 5/E2) and Northern Tropical Thorn forest (subgroup 6B) (Champion and Seth, 1986). *Anogeissus pendula* is the dominant tree species covering over 35% area of the forest. *Boswellia serreta* and *Lannea coromandelica* grow at rocky patches. *Acacia catechu*, *Butea monosperma* and *Zizyphus mauritiana* are common in the valleys. *Dendrocalamus strictus* is extremely limited in distribution and is found along well drained reaches of the streams and moist and cooler parts of the hills. *Albizia lebbeck*, *Diospyros melanoxylon*, *Holoptelia integrifolia* and *Ficus sp* are found in moist localities. (Sankar, 1994). A number of exotic invasive species have become common in the heavily grazed areas of the Reserve, such as the annual herb *Cassia tora* and the short-statured tree *Prosopis juliflora*. *Adhatoda vasica*, though a native under storey species, has become very common in disturbed and over-grazed areas, and appears to suppress grass and other native herbaceous species. Parmar (1985) and Rodgers (1985) classified vegetation of Sariska as follows: i. *Anogeissus pendula* forest, ii. *Boswellia serrata* forest, iii. *Acacia catechu* forest and iv. Miscellaneous forest, which is further sub-divided into three categories viz. a. *Butea monosperma* forest, b. Riverine forest along nallas and c. Scrub land. Nine different vegetation and land cover categories were

identified in STR (Sankar *et al*., 2009) (Figure 2.2). They are *Anogeissus* dominated forest, *Boswellia* dominated forest, *Butea* dominated forest, *Acacia* mixed forest, *Zizyphus* mixed forest, Scrubland, Agricultural land, riparian forest and Barren land. The percentage proportion of above mentioned vegetation and land cover categories are given in Table 2.1.

Table 2.1. Vegetation and land cover classes in Sariska Tiger Reserve.

Vegetation / Land cover type	**Area (sq. km.)**	**Percentage**
Anogeissus dominated forest	283.3	35.4
Scrubland	152.5	19.1
Boswellia dominated forest	123.5	15.5
Agriculture/Habitation	74.7	9.3
Butea dominated forest	63.6	7.9
Zizyphus mixed forest	47.5	5.9
Acacia mixed forest	32.2	4.1
Barren land	20.6	2.6
Riparian forest	1.6	0.2
Total	799.5	100

Source: Sankar *et al*., (2009)

***Anogeissus* dominated forest**: The *Anogeissus pendula* that occupies 35.4% of the overall vegetation types is the dominant vegetation type in the entire STR distributed largely in gentle slopes. This species is found in association with *Acacia catechu* and *Lanea coromandelica*. The under storey is formed by *Adathoda vasica, Grewia flavescens, Capparis sepiaria* and *Nycatanthus sp*. Ground cover mainly comprises of *Aristida sp., Setaria sp*., and *Chloris sp*.

***Boswellia* dominated forest**: *Boswellia serrata* that occupies 15.4% of the overall vegetation types is found largely in steep slopes and plateaus. This species is found in association with *Anogeissus pendula, Diospyros melanoxylon, Acacia catechu, Wrightia*

tinctoria, *Bauhinia racemosa*, and *Ehretia laevis*. The under storey comprises of *Eurphobia nerifolia, Grewia flavescens*, *G. tenax* and *Capparis sepiaria*. Grass cover is sparse and is formed by *Apluda sp* and *Chloris sp*.

***Butea* dominated forest**: Butea dominat forest occupies 7.9% of the Tiger Reserve. This species is found in association with *Zizyphus mauritiana, Cordia myxa*, *Phoenix Sylvesteris* (along the streams), *Holoptelia integrifolia* and *Cassia fistula*. The *Capparis sepiaria*, *Grewia flavescence*, and *Rhus mysorensis* are the common under storey. Ground layer comprises of *Heteropogon sp* and *Chloris dolichostachya*.

***Acacia* mixed forest**: The *Acacia* mixed forest occupies 4.1% of the total vegetation types in STR. The *Acacia leucophloea* is the dominant vegetation type is found in association with *Prosopis juliflora*, *Acacia senegal*, *Dicrostachys cinerea* and *Maytenus emerginata*. The under storey is formed by *Capparis sepiaria*, *D. cinerea* and *M. emerginata*, Grasses found are *Apluda mutica*, *Cynodon dactylon* and *Desmostachya bipinnata*.

***Zizyphus* mixed forest**: This vegetation community that occupies 5.9% of the total vegetation type in STR is dominated by *Zizyphus mauritiana* in combination with *Acacia catechu, A. leucophloea* and *B. monosperma*. The under storey is formed by *Adathoda vasica, Cassia tora*, *Capparis sepiaria* and *Zizyphus nummularia*. *Cynodon sp.*, *Eragrostis sp.*, and *Chloris sp.* are typical grasses found along with this type of vegetation type.

Scrubland: This vegetation type occupies 19.1% of the forest cover in which the tree species such as *Prosopis juliflora, Acacia leucophloea, Acacia nilotica, Acacia senegal*, *Maytenus senegalensis* and *Balanites aegyptiaca* are sparsely distributed. The under storey is formed by *Capparis decidua, C. sepiaria, Rhus mysorensis, Grewia favescens*, *G. tenax*, *Zizyphus nummularia*, *Adathoda vasica* and *Dicrostachys cinerea*. Grass cover is sparse and is mainly formed by *Cynaodon sp, Chloris sp, Sporobolus sp*, and *Synchrus sp*.

Riverine forest: In sariska, forests along the nallahs is more of wet conditions and have patches of trees like *Anthocephalus cadamba, Ficus* species, *Phoenix sylvestris* and *Syzygium cumini* trees which are the typical trees species in those areas.

Figure 2.1. Location and administrative boundary of Sariska Tiger Reserve

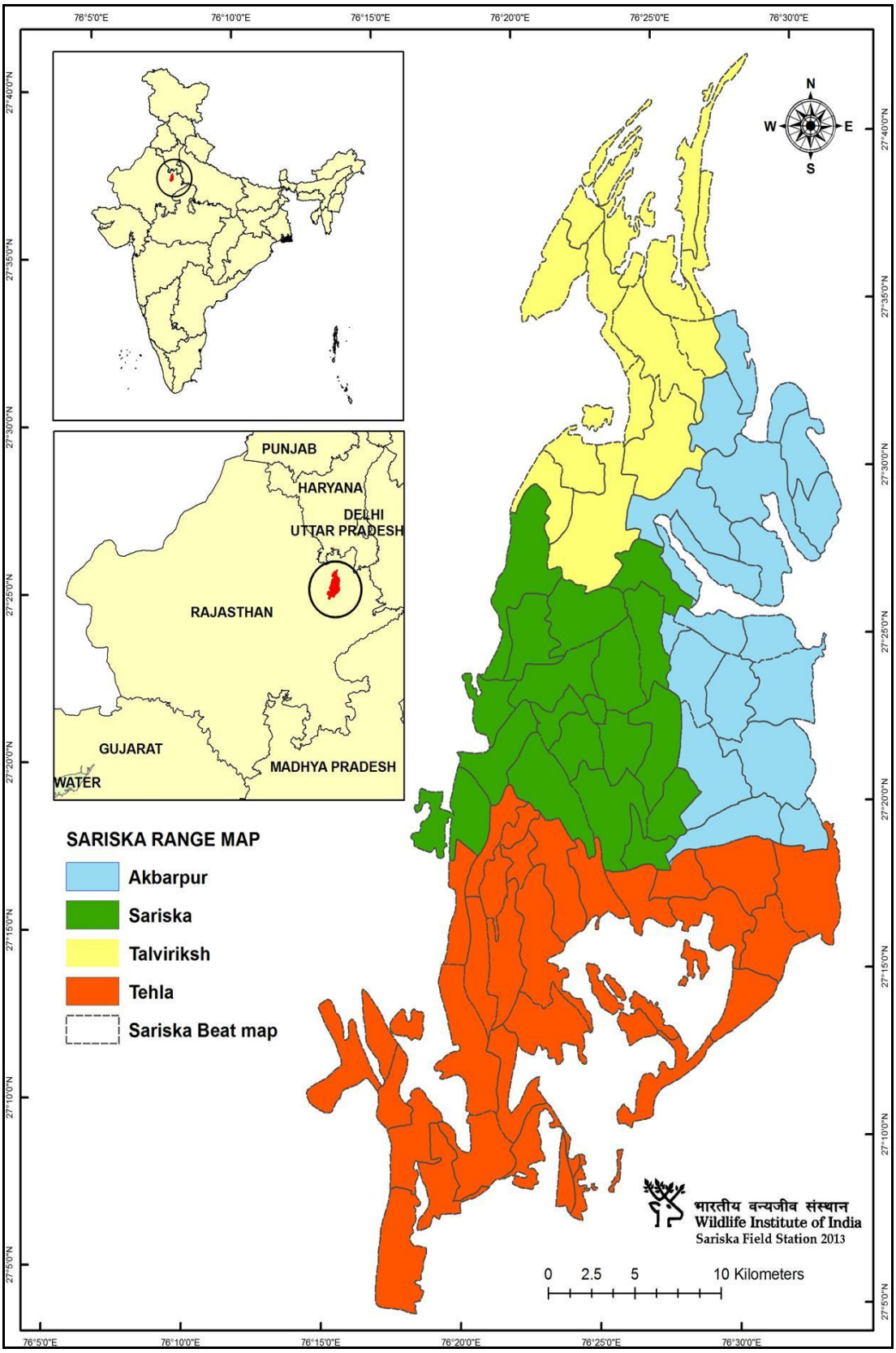


Figure 2.2. Vegetation and land cover map of Sariska Tiger Reserve.

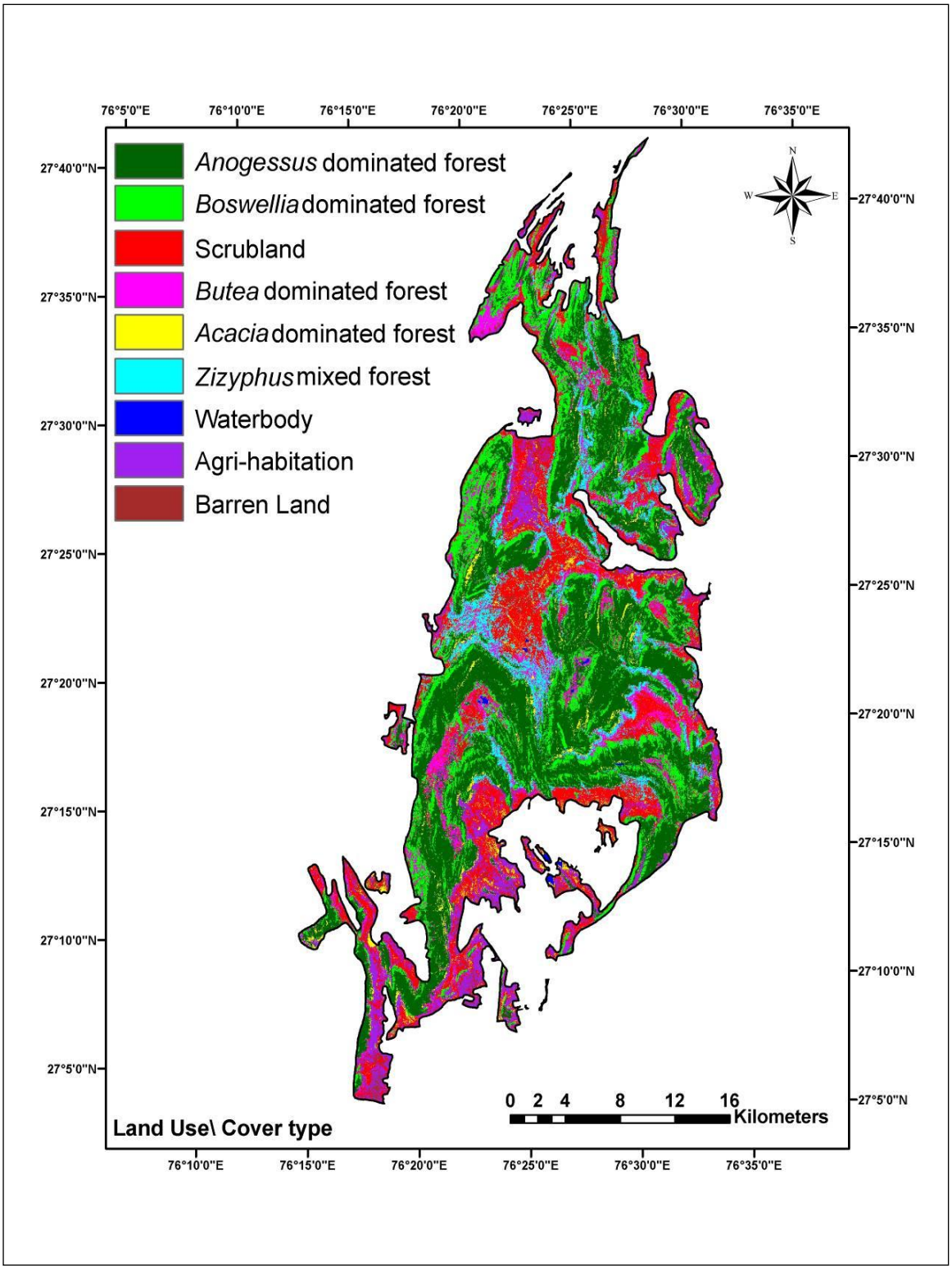


Figure 2.3. Digital Elevation map (DEM) of Sariska Tiger Reserve.

2.6. FAUNA

The large carnivores found in STR include tiger (*Panthera tigris*), leopard (*Panthera pardus*) and hyena (*Hyaena hyaena*). Smaller carnivores include jungle cat (*Felis chaus*), caracal (*Caracal caracal*), golden jackal (*Canis aureus*), ratel (*Mellivora capensis*), palm civet (*Paradoxurus hermaphroditus*), small India civet (*Viverricula indica*), common mongoose (*Herpestes edwardsii*), small Indian mongoose (*H. auropunctatus*) and ruddy mongoose (*H. smithi*). In 2009, desert cat (*Felis silvestris*) was reported from Sariska (Gupta *et al.*, 2009).

Till 2004, tigers survived in most parts of the Tiger Reserve but, unfortunately, poaching exterminated this species from STR in 2005. Wildlife Institute of India, Rajasthan State forest Department and National Tiger Conservation Authority, New Delhi in their joint effort reintroduced eight Tigers (three males & five females) from Ranthambhore Tiger Reserve to STR during June 2008 to January 2013. The wild ungulates of the park are chital or spotted deer (*Axis axis*), sambar deer (*Rusa unicolor*), nilgai (*Boselephous tragocamelus*) and wild pig (*Sus scrofa*). Common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*) are the two primate species found. The other smaller mammals found are rufous tailed hare (*Lepus nigricollis ruficaudatus*), pangolin (*Manis crassicaudata*) and porcupine (*Hystrix indica*). Due to presence of villages inside and on the periphery a large variety of domesticated animals also occurs within the park. These include buffalo (*Bubalus bubalis*), cow (*Bos indicus*), goat (*Capra hircus*), sheep (*Ovis aries*), camel (*Camelus dromedarius*), dog (*Canis Familiaris*) and domestic cat (*Felis domesticus*).

Eleven species of small rodents were captured during the present study. Indian gerbil (*Tatera indica*), Indian bush rat (*Golunda ellioti*), spiny tailed mouse (*Mus platythrix*), house mice (*Mus musculus*), little Indian field mice (*Mus booduga*) long tailed tree mouse (*Vandeleuria oleracea*), sand coloured Rat (*Millardia gleadowi*), soft fur field rat (*Millardia meltada*), brown rat (*Rattus norwegicus*), house rat (*Rattus rattus*) and pygmy gerbil (*Gerbillus nanus*) are the potential prey for small carnivores found in Sariska.

Sariska also holds a variety of bird species including some winter migrants. Sankar *et al*., (1993) recorded 211 species of birds, of which 120 resident, 73 were migrant visitors and

18 considered as vagrants. It has very high density of peafowl as well as grey francolin (Kidwai *et al*., 2011).

Banded krait (*Bungarus fasciatus*), common krait (*Bungarus caeruleus*), cobra (*Naja naja*), fresh water crocodile (*Crocodylus palustris*), Indian rock python (*Python molurus*), desert monitor lizard (*Varanus griseus*), Indian monitor lizard (*Varanus bengalensis*), Indian roofed turtle (*Pangshura tecta*), soft-shell turtle (*Aspideretes gangeticus*), Indian star tortoise (*Geochelone elegans*) are some major reptiles found in Sariska Tiger Reserve.

Though there is no perennial river or water stream (Kumar and Sankar, 1993), there are a number of ephemeral streams and pools found in STR. Except for a few natural springs, water in these locations dries up in summer (Sankar, 1994). The common fish species found in water bodies in this park are *Noemachilus botia*, *Labio boggut*, *Puntius sarana*, *Garra gotyla* and *Rasbora daniconius*.

2.7. HUMAN SETTLEMENTS

Presently, there are eight villages located inside the notified National Park area of the Tiger Reserve, which are due for relocation since 1984 (Figure 2.4). Three villages till January 2013 were completely relocated from Sariska. The village Bhagani was successfully relocated in November 2007 while the village Umri was relocated in March 2012 and the village Rotkyala was relocated in March 2013. People living in these villages mostly belong to the Gujjar community, traditionally dependent on livestock (animal husbandry) for milk-production economy along with the Meenas inhabiting some villages. The human population is over 1700 in the villages of National Park along with a population 10000 livestock including buffalo, cow, goat and sheep (Sankar *et al*., 2009). There are 19 more revenue villages inside the Tiger Reserve (outside National Park) (Figure 2.4). The human population in these villages is around 8,000 and the livestock population is more than 20,000 (Sankar *et al*., 2009).

These villagers depend totally on forests for their livelihood. The people inhabiting these villages are traditionally pastoralist and their main source of income is selling milk and its products like "Mawa and Ghee". The economy of villagers of Kankwadi, Umri, Kiraska, Lilunda and Kundalkha is dependent on animal husbandry, while villagers of

Dabli, Sukola and Haripura also work as daily wage labourers in adjoining areas. The villages like Dabli, Deori and Rekhamala (located on the boundary of the Tiger Reserve), have some agricultural land in core area (Sankar *et al*., 2009). The land holdings in these villages are small and the quality of cattle is also poor which results in poor economy of the people in general.

2.8. TOURISM

Tourism is not regulated and most of the visitors visit Pandupole temple especially on Tuesdays and Saturdays when entry to the reserve is free. During September, large number of tourist and pilgrims come to visit the Pandupole temple which causes heavy traffic inside the National Park even during night hours. However on the other days only day time tourism is allowed and the Reserve remains closed after dusk.

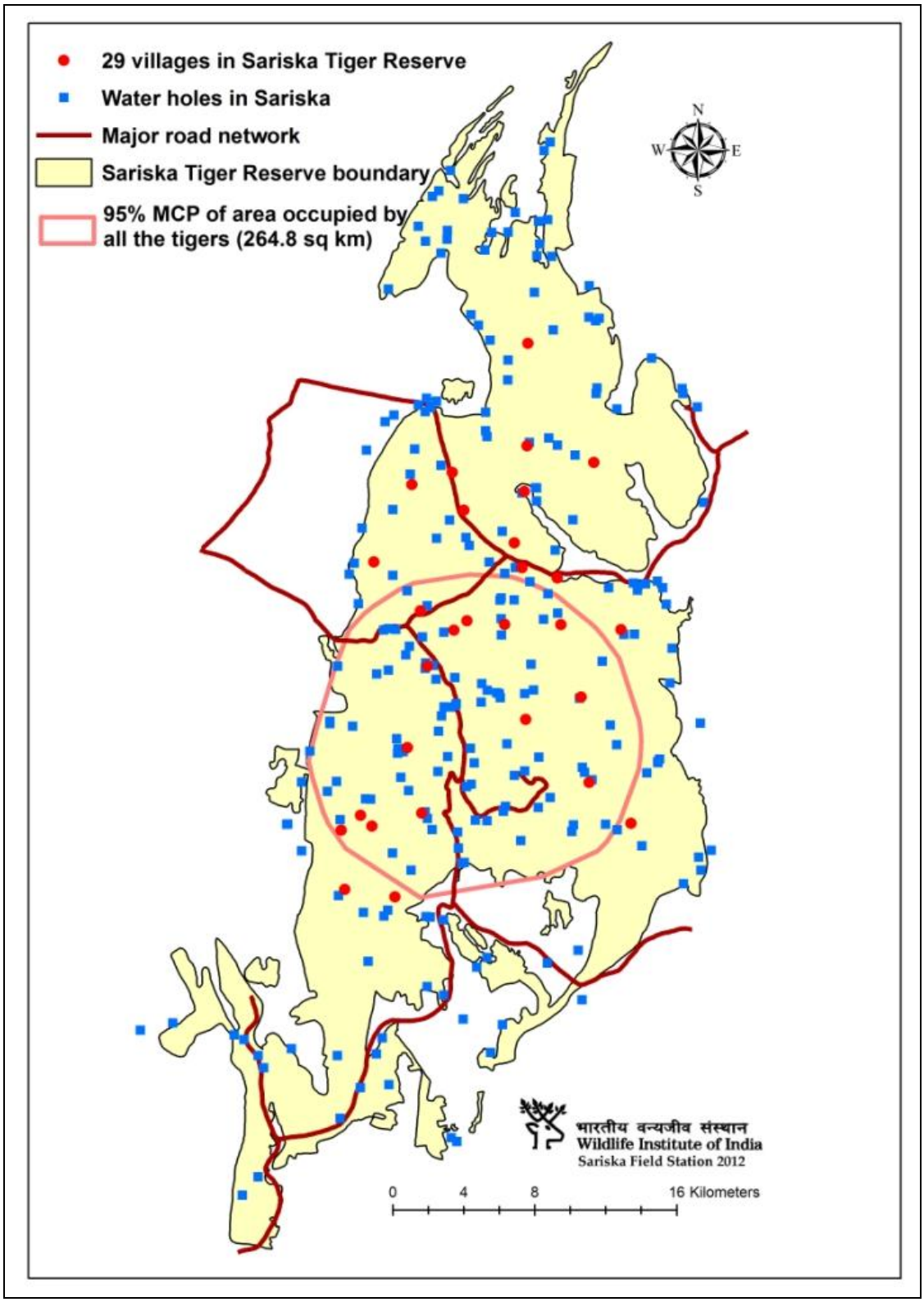
2.9. ADMINISTRATIVE UNITS

Sariska Tiger Reserve comes under Sariska Circle and Sariska Division (Figure 2.1). STR has four territorial ranges: Sariska, Akbarpur, Tehla and Talvriksh. Sariska range constituted of 22 beats, Akbarpur 17 beats, Tehla 25 beats and Talvriksh 14 beats.

2.10. INTENSIVE STUDY AREA

The present study was conducted in around 400 km^2 of area which is the notified National Park area of Sariska Tiger Reserve for four consecutive years from July 2008 to June 2012 covering all the three seasons, monsoon (July to October), winter (November to February) and summer (March to June). The intensive tiger occupied area was estimated as 265 km^2 (Figure 2.4).

Figure 2.4. Intensive tiger occupied area in Sariska Tiger Reserve (265 km^2) with locations of villages, water holes and major road network.



CHAPTER THREE

3. ESTIMATION OF PREY AVAILABILITY FOR REINTRODUCED TIGERS

3.1. INTRODUCTION

Studies of mammalian prey species (generally ungulates and primates) availability estimation had direct and significant contribution to the wildlife management. These augmented the relatively scarce reliable quantitative knowledge and information repository of any protected or un-protected area where any management intervention is required. Such long term studies in any specified area finally helped to develop database regarding the distribution, abundance and habitat requirements of these species. Tigers (*Panthera tigris*) are obligate carnivores that occur sympatrically with leopards (*Panthera pardus*) and sometimes with dholes (Indian wild dogs - *Cuon alpinus*) in most of their range. These wide ranging congeneric mammalian carnivores differing in size (tiger: 160-270 kg, leopard: 30-90 kg, dhole: 12-18 kg) largely prey on ungulates such as cervids, bovids and suids (Schaller, 1967; Seidensticker, 1976; Johnsingh, 1983; Karanth and Sunquist, 1995, 2000; Bagchi *et al*., 2003; Andheria *et al*., 2007).

Despite facing the same threats of local extermination, leopards were more successful than tigers, largely because of their ability to live in different environments and the flexibility in their diet (Bailey, 1993). Previous studies on the food habits of sympatric leopards and tigers had shown that their diets were quite analogous when prey was abundant (Schaller, 1967; Johnsingh, 1983; Karanth and Sunquist, 1995; Bagchi *et al*., 2003; Andheria *et al*., 2007). However, under deteriorating habitat conditions leopards might not be as adversely affected as tigers due to their ability to shift towards smaller prey (Ramakrishnan *et al*., 1999). Therefore, studies assessing the prey species availability and the food habits of sympatric carnivores not only aid in our understanding of factors influencing their ecological segregation but may also serve as an indicator of change in habitat quality (Ramakrishnan *et al*., 1999).

Isolated and patchy populations of mammalian prey species (generally ungulates and primates) are however much difficult to conserve due to their unique habitat and forage requirements. However, the greatest relevance of prey population estimation studies was found in management strategies focused to resource based conservation of any species. Large mammalian carnivore populations were mainly resource limited (Slobodkin *et al*., 1967), with the condition of a predator population depending on the availability of its prey (Sunquist and Sunquist, 1989). The

evolution and radiation of the *Panthera* stock in fact showed close correlation to that of the *Cervid* and *Bovid* species (Sunquist *et al*., 1999). Karanth *et al*., (2004a) developed simple mechanistic models for predicting large carnivore densities as a function of prey species density and found results reasonably consistent with model predictions which eventually re-emphasized the importance of prey species as a limiting factor for large carnivore conservation at the macro-ecological scale. Thus, estimating the prey population size or density in an area is elemental for understanding the status of the predators and for the future plans and strategies for its management and conservation (Varman & Sukumar, 1995).

In the present study, densities of the prey species was estimated using the distance sampling based line transect method (Anderson *et al*., 1979; Burnham *et al*., 1980; Buckland *et al*., 1993). Since estimating animal densities using Distance Sampling method used to overrule the bias of non-detection, this method was preferred over others (Karanth and Nichols, 1998). Line transects had been found to be very effective and reliable in estimating densities of ungulates in the Indian Subcontinent (Karanth *et al*., 2004). With studies indicating that wild herbivores in particular were adversely affected by populations of livestock (Mishra and Rawat, 1998) and given that wild prey populations were a determinant of the viability of tiger populations (Karanth and Stith, 1999), the recovery of even small populations of tigers would depend on prey species population structure as well as minimizing anthropogenic pressures (Cardillo *et al*., 2004; Sankar *et al*., 2010). Considering this great importance of the prey species for tiger conservation (Karanth and Stith, 1999; Miquelle *et al*., 2010), it is critical to study the availability and demography of the prey base to understand tiger predation ecology for its further survival.

3.2. LITERATURE REVIEW

Estimation of availability of different mammalian prey species (generally ungulates and primates) could be carried out using both direct and indirect methods. Direct count method involved counting individuals of particular group(s) of animals in any given area. This might be carried out in the form of aerial survey and waterhole count. This method was usually practiced in African Savannah (Koster and Hart, 1988) to estimate mammalian prey species. Although prey species of various carnivores were large bodied but direct or total counts in larger areas were subjected to the limitations of vegetation cover and also high logistic costs. Population of herbivores could also be estimated by indirect sampling, in which animal signs, such as dung or

tracks, were encountered (Eberhardt, 1978). Significant information such as a distribution, population size and diet for elusive species which were difficult to record, could be retrieved from pellets or dung counts and analysis (Putman, 1984). However, these methods did not reliably consider the factors such as probabilities of detecting animals and their non-random spatial distribution.

As a result, advanced population estimation techniques using sample survey methods such as line transects to estimate mean densities and their associated variance in a quantitative model based framework was therefore found to be more reliable and had been in regular practice during the last three-four decades in all forest types. Line transect sampling was one of the abundance estimating approaches collectively known as distance sampling methods (Thomas and Karanth, 2002). This method actually helped in estimating the abundance of some biological population in an area of known size and boundaries. It was first incorporated in early 1930's to obtain estimates of wildlife abundance. In 1949, Hayne gave the first estimator which was based only on sighting distances. After this no significant theoretical advances took place until 1968 when Gates *et al.,* (1968) suggested that probability density function f(x) be taken as a negative exponential form , $f(x) = a \exp^{(-ax)}$ where 'a' was an unknown parameter to be estimated. Gates *et al*., (1968) derived an estimator based on radial distance. Anderson and Pospahala (1970), studied waterfowl nesting by line transects. Seber (1973) developed a general model structure for line transects sampling and presented an approach based on effective strip width. Thereafter, Robinette *et al.,* (1974) presented a series of field evaluations of various line transect methods while at the same time Sen *et al*., (1974) discussed the estimation of wildlife densities using both right angle and radial distances.

Burnham and Anderson (1976) formulated a general mathematical theory of line transect to support a framework of either parametric or non parametric density estimation based on either right angle or sighting distances. Pollock (1978) also considered a principle of density estimators for line transects sampling. Anderson *et al*., (1979) provided guidelines for field sampling including practical considerations. A log linear approach for estimation of population size using the line transects method was also given by Anderson *et al*., (1979). These authors emphasized that it was essential to record observations allowing straight lines and obtain accurate measurements of distance and sighting angles. Utmost care must be taken so that objects present on the line transects were seen with highest probability i.e. 100% or one. Eberhardt (1978)

addressed the general question of determining sample size for population studies. Line transect based on right angled distances were discussed by Eberhardt (1978). Some parametric models for line transect sampling had been introduced by Ramsey (1979) and Quinn and Gallucci (1980).

A parametric generalization of the Hayne estimator for line transects sampling and robust estimation from the line transects data was deduced by Burnham (1979). Alldredge and Gates (1985) interpreted line transect estimators such as exponential or half normal for left truncated distributions. The Fourier series model for analyzing perpendicular distance data from the line transect sampling was proposed by Crain *et al*., (1979). Burnham *et al*., (1980) published a monograph on line transect sampling theory and application. Their extensive work provided a review of previous methods and presented guidelines for field activities and identified a small class of estimators that seemed generally useful. Usefulness was based on four criteria: Model robustness, Pooling robustness, Shape criterion and Estimator efficiency.

Lately, Buckland (1985) proposed perpendicular models for line transect sampling and found the hazard rate model to be the most promising and Routledge and Fyfe (1992) offered confidence limits for line transect estimates based on shape restrictions, while fitting density functions with polynomials was tried by Buckland (1992). At the same time, an extensive review of statistical methodology involved in estimating animal abundance was given by Seber (1992). He had discussed the use of plots, strips, lines and points for estimating population density or for providing an index of density based on indirect signs. Buckland and Turnock (1992) later on also discussed effects of responsive movement on abundance estimation using line transect sampling.

Drummer and McDonald (1987) introduced first the cluster size variable as a covariate in the detection functions. Drummer (1991) programmed a computer software package called *SIZETRAN* to furnish the needs of computations. Another program *NPARTRAN* for line transect data analysis, giving confidence limits for line transect estimates based on shape restrictions was reported by Quang (1991). A computer program *DISTANCE* (Laake *et al.*, 1993) was developed to allow all-inclusive analyses of the type of distance data. The program was written in *FORTRAN* and ran only on any IBM PC compatible micro computer with 640 KB of RAM (Buckland *et al.*, 1993). The program *DISTANCE* allowed more attentiveness on the results and elucidation of biology of population. The present study used a superior version of this program *DISTANCE 6.0* (Thomas *et al*., 2009) for estimation of prey species availability.

Recent studies in predator ecology had documented that the predator abundances could be well explained by gradients in prey biomass and abundances (Carbone and Gittleman, 2002; Karanth *et al.*, 2004). In the Indian sub-continent Karanth and Sunquist (1992) employed line transect sampling to estimate the herbivore populations in the tropical forests of Nagarhole, southern India favoring Fourier Series Estimator. In another study of line transect method for estimating densities of large mammals in a tropical deciduous forest was carried out by Varman and Sukumar (1995). Further studies on animal abundance across the Indian sub-continent revealed that ecological densities of ungulate species ranged from a total of 10 individuals / km^2 (Jathanna, 2001) to 90.3 individuals / km^2 (Biswas and Sankar, 2002; Harihar *et al.*, 2009; Sankar *et al.*, 2010). This wide range of values represented the habitat types across the Indian subcontinent which had supported varied densities of ungulate species (Karanth *et al.*, 2004).

The simplified protocol which was followed in the present study was adopted by National Tiger Conservation Authority (NTCA) and Wildlife Institute of India (WII) for the line transect based sampling in tiger occupied landscapes in India (Jhala and Qureshi, 2004). A number of studies had been conducted in Sariska on predators and their prey base. Mathur (1991) studied ungulate population and their habitat interaction. Sankar (1994) studied ecology of sympatric herbivores and the densities of prey species of tiger and leopard. Sankar and Johnsingh (2002) studied food habits of tiger and leopard and Avinandan *et al.*, (2008) studied prey selection by native population of tigers in Sariska. Avinandan *et al.*, (2008) also estimated the abundance of prey species in Sariska-Kalighati-Pandupole valley. Sankar *et al.*, (2009) and (2010) also studied the prey species availability in the 274 km^2 of Sariska notified national park area.

3.3. METHODOLOGY

Prey species availability in the present study was estimated by line transect method under distance sampling technique (Burnham *et al.*, 1980). This method had been widely applied to estimate densities of prey species in different forests in Indian subcontinent (Karanth and Sunquist, 1995; Khan *et al.*, 1996; Stoen and Wegge, 1996; Biswas and Sankar, 2002; Bagchi *et al.*, 2003; Harihar *et al.*, 2009). The line transects (32) monitored in the present study was laid during 2006-07 (Sankar *et al.*, 2009) and 20 new line transects were laid during the study period (during 2008-09). A total of 52 line transects of length of 2 km. each were walked five to nine times each year (three times in three seasons) (Figure 3.1). The total transects length in the

intensive study area was 104.0 km. For each transect the beginning and end point coordinates (Latitude and Longitude) were recorded by a handheld GARMIN-72 Global Positioning System. The bearings of each of the line transect were measured using a hand held see through magnetic compass (Suunto *KB 20*). The broad forest types and terrain types in which each transect was laid, were also recorded. Record was kept for all ungulates, primates, livestock, hare and peafowl that were seen during the walk. On every walk the followings were noted:

Species identity: Data on each potential prey species was collected separately on each transect walk.

Group size: An individual animal or more than one animal of the same species within 20 m to each other were considered to be a single group.

Age and sex composition: Whenever any individual or group was observed the broad age category and gender of the individuals comprising that group were collected.

Radial distance: A laser range finder was used to measure the radial distance of the animal. In case of a herd, distance to the centre of the herd was recorded.

Sighting angle: A Magnetic see through compass was used to record the bearing of the animal seen with respect to the transect line from the initial point of observation. In case of the herd / group, the angle between the point of the observation and the centre of herd / group was recorded.

Program *DISTANCE* 6.0 (Thomas *et al*., 2009) was used to estimate the density of prey species. The data after imported into *DISTANCE* 6.0 was primarily examined by assigning very small intervals to the perpendicular distance interval classes. Next on the basis of the general distribution of the data, suitable cut off points were chosen to optimize the fit of the model. The best model was selected on the basis of the lowest Akaike Information Criterion (AIC) (Burnham *et al*., 1980; Buckland *et al*., 1993). Global pooled estimate and detection function were used for each particular species across the years during 2008-09 to 2011-12 since the detection probability patterns were assumed consistent for the similar transects in the study area. This pooled estimation of the species detection was considered to be more robust since the variance in the cluster size could be taken care as an ecological parameter.

The number of individuals in each species per unit area multiplied by the average weight for the species gives an estimate of the biomass for the area (Schaller, 1967). In the present study, the biomass estimation was done by multiplying the density (density/km2) of each prey species in

the intensive study area by their average body weight (Sankar and Johnsingh, 2002; Avinandan *et al*., 2008).

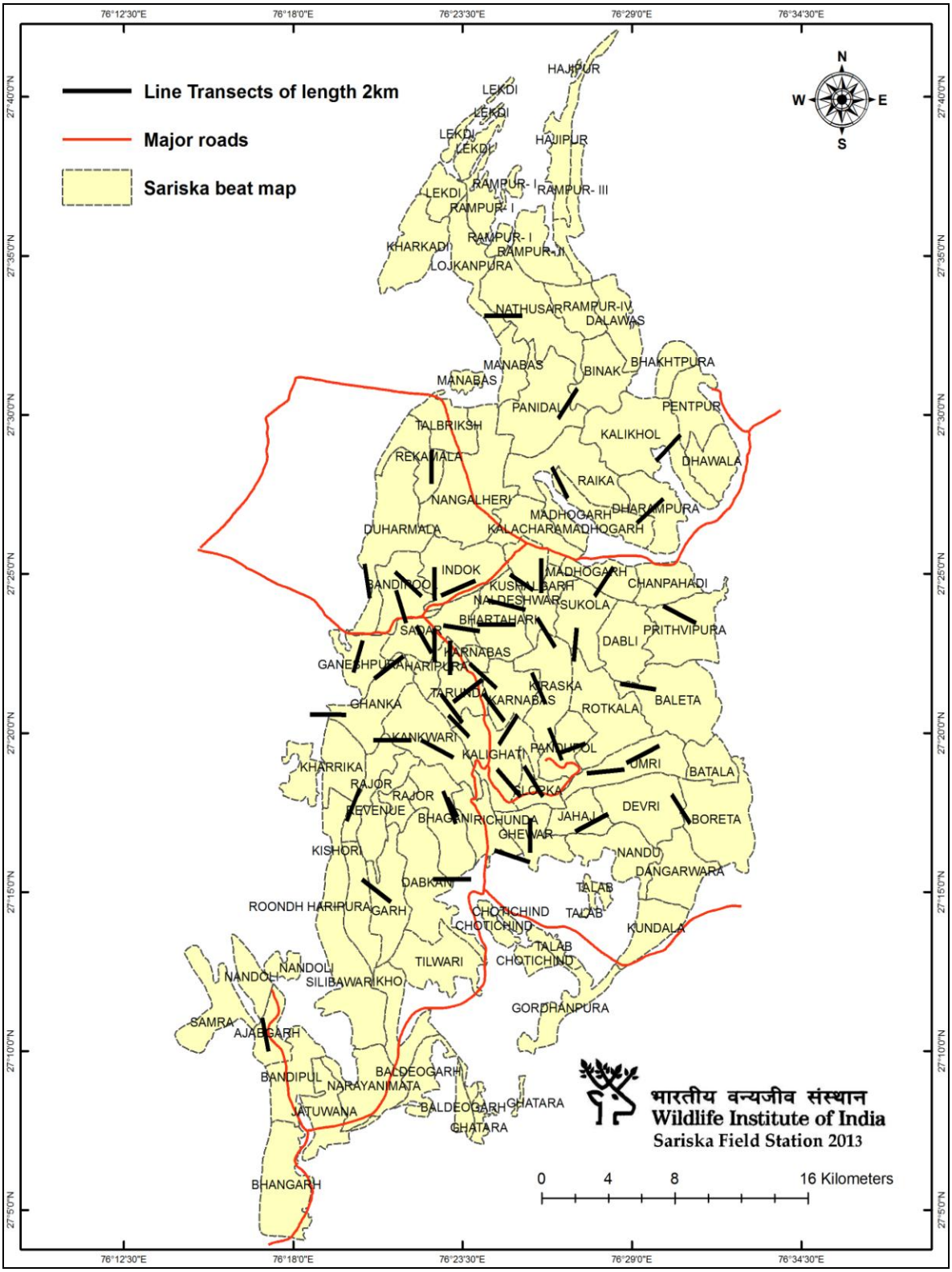
The following assumptions were made for the line transect sampling in the present study:

1. The animals were randomly and independently distributed in the study area
2. The sighting of one animal was independent of the sighting of another.
3. No animal was counted more than once.
4. Animals were fixed at the initial sighting position and did not move before being counted and distance to them from the transect being measured.
5. The response behaviors of the prey population as a whole did not substantially change in the course of walking a line transect.
6. The individuals were homogeneous with regard to their responsive behavior, regardless of sex, age etc.
7. The probability of an animal being seen , given that it was a right angle distance y from the line transect path (irrespective of which side of path it is on) , was a simple function g(y) , say of y , such that g(0) =1(i.e. probability 1 of seeing an animal on the path).
8. Animals directly on the line were never being missed.
9. Distances and angles were always measured accurately.

(After Burnham, 1980; Seber, 1982; Buckland *et al*., 2001)

In Sariska, distribution of prey species could not be treated as random especially in summer when the animals tend to concentrate around water sources (Sankar, 1994). However by placing the line transects randomly in every representative forest and terrain types in the intensive study area the first assumption was not violated. There was very little chance of violating the other four assumptions in Sariska where substantially open habitat conditions permit easy detection and accurate measurement of data. These transects were walked three times in early morning in each season (summer, monsoon and winter) for four successive years from 2008 to 2012.

Figure 3.1. The locations of 52 line Transects in Sariska Tiger Reserve.



3.4. RESULTS

In total, nine potential prey species were recorded on line transects. These were four ungulate species (chital, sambar, nilgai and wild pig), one primate (common langur), one small mammal (hare), two domestic livestock (cow and buffalo) and one bird (peafowl).

In the intensive study area, the recorded total number of observations, estimated cluster size, group encounter rate and density of different prey species are given in tables 3.1 to 3.4 for consecutive four years between 2008 and 2012. The best model selected for all prey species was half normal with cosine adjustment 2, 3 (P = 0.69, Chi-square = 0.1507 and degree of freedom = 1) based on minimum Akaike Information Criterion (AIC) in the year of 2008-09 (Figure 3.3), while in 2009-10, the best chosen model was half normal with cosine adjustment 2 (P = 0.45, Chi-square = 1.5749 and degree of freedom = 2) (Figure 3.4), in 2010-11, the most preferred model was half normal with cosine adjustment 2 (P = 0.41, Chi-square = 1.8600 and degree of freedom = 2) (Figure 3.5) and in 2011-12, the best fitted model was half normal with cosine adjustment 2, 3 (P = 0.61, Chi-square = 1.0208 and degree of freedom = 1) (Figure 3.6). The total number of walks were 285 (total effort = 570 km) during 2008-09. The total temporal replicates were 244 (total effort = 488 km), 294 (total effort = 588 km) and 288 (total effort = 576 km) during the years 2009-10, 2010-11 and 2011-12 respectively. The effective strip widths for all species estimated in the intensive study area was 27.43 m, 25.18 m, 31.28 m and 20.01 m during the years 2008-09, 2009-10, 2010-11 and 2011-12 respectively (Figure 3.3 to 3.6).

In the study area, peafowl was the most abundant prey species throughout the study period. The density (km^{-2} ± SE) of peafowl varied from 73.94±6.69SE km^{-2} in 2009-10 to 125.83±9.66SE km^{-2} in 2010-11. During 2008-09, chital was the most abundant (15.42±2.58SE km^{-2}) amongst the wild prey species followed by common langur (9.13±2.0SE km^{-2}), nilgai (8.39±1.02SE km^{-2}), sambar (7.66±1.16SE km^{-2}) and wild pig (7.60±1.51SE km^{-2}) (Table 3.1). During 2009-10, chital (15.56±2.83SE km^{-2}) was the most abundant wild ungulate prey species followed by nilgai (12.08±2.24SE km^{-2}), common langur (11.90±2.68SE km^{-2}), sambar (9.04±1.28SE km^{-2}), and wild pig (6.80±2.80 km^{-2}) (Table 3.2). During 2010-11, nilgai (17.66±1.71SE km^{-2}) was the most abundant wild ungulate prey species followed by common langur (14.30±2.75SE km^{-2}), chital (13.44±2.66SE km^{-2}), wild pig (8.29±1.95 km^{-2}) and sambar (7.87±1.33SE km^{-2}) (Table 3.3). During 2011-12, nilgai (19.66±1.85SE km^{-2}) was the most abundant wild ungulate prey species followed by chital (16.25±3.00SE km^{-2}), common langur (15.30±2.90SE km^{-2}), wild pig

(11.64±2.11SE km^{-2}) and sambar (6.94±1.27SE km^{-2}), (Table 3.4). Since there were eight villages inside the Sariska notified National Park area and 32 inside the Tiger Reserve area, the estimated abundance of livestock was comparatively high in the study area. The densities of domestic livestock in the study area were recorded as 38.38±6.61SE km^{-2} during 2008-09, 58.0±14.56SE km^{-2} in 2009-10, 56.22±10.19SE km^{-2} in 2010-11 and 69.31±9.92SE km^{-2} during 2011-12.

In the intensive study area, the estimated total ungulate (wild and domestic) densities were 77.45±6.37SE km^{-2}, 99.42±9.37SE km^{-2}, 103.48±9.78SE km^{-2} and 123.8± 9.13SE km^{-2} during the years 2008-09, 2009-10, 2010-11 and 2011-12 respectively. Similarly the estimated total wild ungulate densities were 39.07±3.16SE km^{-2}, 41.42±5.66SE km^{-2}, 47.26±5.86SE km^{-2} and 54.49±6.31SE km^{-2} during the years 2008-09, 2009-10, 2010-11 and 2011-12 respectively. In the intensive study area, the available prey biomass (wild and domestic) was calculated as 12, 210.99 kg km^{-2} during 2008-09; 17, 425.91 kg km^{-2} in 2009-10; 18, 050.17 kg km^{-2} in 2010-11 and 21, 154.37 kg km^{-2} during 2011-12 (Table 3.1 to 3.4). Figure 3.2 shows detail of estimated densities of all the major mammalian prey species during the period 2008-09 to 2011-12. The estimated detection probability pattern curves for all the species considered together as well as the individual prey species during the study period (2008-09 to 2011-12) were given in figure 3.3 to figure 3.16.

Table 3.1. Estimated density, biomass, cluster size and other statistical parameters of different prey species in Sariska Tiger Reserve during 2008-09.

Category / Prey species	Wild prey species							Domestic Livestock	
	Chital	Sambar	Nilgai	Wild pig	Common langur	Hare	Peafowl	Buffalo	Cattle
No. of spatial replicates (Line Transect)	52	52	52	52	52	52	52	52	52
Total no of walk	285	285	285	285	285	285	285	285	285
Effort (L) km	570	570	570	570	570	570	570	570	570
Total no of observation	94	94	105	37	29	34	481	81	94
Individual Density (D_i) / km^2	15.42	7.66	8.39	7.60	9.13	3.45	91.92	18.38	20.0
D_i Standard Error (± SE)	2.58	1.16	1.02	1.51	2.0	0.92	11.48	4.09	5.4
Biomass (kg / km^2)	693.9	957.5	1510.2	288.8	73.04	12.42	312.53	4962.6	3400
D_i Coefficient of variation (% CV)	16.74	15.10	12.13	19.9	21.8	26.67	12.5	22.17	29.28
D_i - 95% Confidence Interval	11.06 – 21.49	5.68 – 10.34	6.59 – 10.68	5.13 – 11.26	5.94 – 14.04	2.53 – 4.37	71.73 – 117.77	14.31 – 22.47	14.6 – 25.5
Group Density (Ds) / km^2	3.38	3.43	3.22	1.98	1.10	2.76	18.57	3.26	3.28
Ds Standard Error (± SE)	0.55	0.51	0.38	0.38	0.23	0.18	2.15	0.27	0.31
Ds Coefficient of variation (% CV)	16.35	14.8	11.89	19.0	21.42	6.4	11.6	17.24	17.20
Cluster Size (Mean)	4.94	2.24	2.61	3.84	8.36	1.11	4.95	5.63	9.78
Standard Error (± SE)	0.19	0.06	0.06	0.22	0.36	0.04	0.24	0.98	1.6
Detection probability (p)	0.42	0.43	0.33	0.26	0.33	0.24	0.33	0.33	0.29
Goodness of fit (chi^2 - p)	0.41	0.56	0.41	0.89	0.73	0.97	0.50	0.86	0.9
Effective Strip Width (ESW) (m)	33.61	38.90	33.26	21.13	32.92	21.84	26.35	40.9	32.9
Group encounter rate	0.23	0.27	0.21	0.08	0.07	0.15	0.98	0.22	0.26
Model	Uniform	Uniform	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal
Model adjustment term	cosine, order -1, 2	cosine, order -1, 2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2

Table 3.2. Estimated density, biomass, cluster size and other statistical parameters of different prey species in Sariska Tiger Reserve during 2009-10.

Category / Prey species	Wild prey species							Domestic Livestock	
	Chital	Sambar	Nilgai	Wild pig	Common langur	Hare	Peafowl	Buffalo	Cattle
No. of spatial replicates (Line Transect)	52	52	52	52	52	52	52	52	52
Total no of walk	244	244	244	244	244	244	244	244	244
Effort (L) km	488	488	488	488	488	488	488	488	488
Total no of observation	103	141	86	31	38	43	318	86	102
Individual Density (Di) / km^2	15.56	9.04	12.08	4.74	11.90	1.83	73.94	27.20	30.80
D_i Standard Error (± SE)	2.83	1.28	2.24	1.81	2.68	0.66	6.69	4.33	5.1
Biomass (kg / km^2)	700.2	1130	2174.4	180.12	95.2	6.59	251.40	7344.0	5544.0
D_i Coefficient of variation (% CV)	18.22	14.20	18.53	38.2	22.5	33.62	9.1	16.1	16.5
D_i - 95% Confidence Interval	10.84 – 22.33	6.82 – 11.98	8.36 – 17.46	2.26 – 9.94	7.64 – 18.54	1.17 – 2.49	61.82 – 88.43	22.87 – 31.53	25.70 – 35.90
Group Density (Ds) / km^2	3.41	4.04	4.64	1.24	1.42	1.51	14.94	4.83	4.74
Ds Standard Error (± SE)	0.61	0.56	0.85	0.47	0.32	0.15	1.15	0.67	0.75
Ds Coefficient of variation (% CV)	17.86	13.9	18.38	37.7	22.1	9.9	7.70	14.7	18.2
Cluster Size (Mean)	4.94	2.24	2.61	3.84	8.36	1.11	4.95	5.63	6.5
Standard Error (± SE)	0.19	0.06	0.06	0.22	0.36	0.04	0.24	0.98	0.92
Detection probability (p)	0.42	0.43	0.33	0.26	0.33	0.24	0.33	0.33	0.34
Goodness of fit (chi^2 - p)	0.41	0.56	0.41	0.89	0.73	0.97	0.50	0.86	0.61
Effective Strip Width (ESW) (m)	33.61	38.90	33.26	21.13	32.92	21.84	26.35	40.9	39.01
Group encounter rate	0.23	0.32	0.31	0.05	0.09	0.07	0.79	0.30	0.42
Model	Uniform	Uniform	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal
Model adjustment term	cosine, order -1, 2	cosine, order -1, 2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2

Table 3.3. Estimated density, biomass, cluster size and other statistical parameters of different prey species in Sariska Tiger Reserve during 2010-11.

Category / Prey species	Wild prey species							Domestic Livestock	
	Chital	Sambar	Nilgai	Wild pig	Common langur	Hare	Peafowl	Buffalo	Cattle
No. of spatial replicates (Line Transect)	52	52	52	52	52	52	52	52	52
Total no of walk	294	294	294	294	294	294	294	294	294
Effort (L) km	588	588	588	588	588	588	588	588	588
Total no of observation	84	116	172	44	56	46	506	108	113
Individual Density (D_i) / km^2	13.44	7.87	17.66	8.29	14.3	1.82	125.83	25.55	30.67
D_i Standard Error (± SE)	2.83	1.33	1.71	1.95	2.75	0.4	9.66	3.13	5.65
Biomass (kg / km^2)	604.8	983.75	3178.8	315.02	114.4	6.48	427.82	6898.5	5520.6
D_i Coefficient of variation (% CV)	19.77	16.9	9.67	23.50	19.6	22.22	7.7	12.20	18.4o
D_i - 95% Confidence Interval	9.08 – 19.89	5.63 – 11.0	14.58 – 21.40	5.22 – 13.18	9.53 – 20.65	1.4 – 2.2	108.15 - 146.4	22.17 – 29.03	25.15 – 36.45
Group Density (Ds) / km^2	2.95	3.52	6.78	2.16	1.68	1.58	25.43	4.53	4.72
Ds Standard Error (± SE)	0.57	0.59	0.64	0.49	0.32	0.21	1.53	0.48	0.51
Ds Coefficient of variation (% CV)	19.44	16.6	9.37	22.80	19.1	13.12	6.03	12.1	13.6
Cluster Size (Mean)	4.94	2.24	2.61	3.84	8.36	1.11	4.95	5.63	6.5
Standard Error (± SE)	0.19	0.06	0.06	0.22	0.36	0.04	0.24	0.98	0.92
Detection probability (p)	0.42	0.43	0.33	0.26	0.33	0.24	0.33	0.33	0.34
Goodness of fit (chi^2 - p)	0.41	0.56	0.41	0.89	0.73	0.97	0.50	0.86	0.61
Effective Strip Width (ESW) (m)	33.61	38.90	33.26	21.13	32.92	21.84	26.35	40.9	39.01
Group encounter rate	0.20	0.27	0.45	0.09	0.11	0.1	1.34	0.30	0.40
Model	Uniform	Uniform	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal
Model adjustment term	cosine, order -1, 2	cosine, order -1, 2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2

Table 3.4. Estimated density, biomass, cluster size and other statistical parameters of different prey species in Sariska Tiger Reserve during 2011-12.

Category / Prey species	Wild prey species							Domestic Livestock	
	Chital	Sambar	Nilgai	Wild pig	Common langur	Hare	Peafowl	Buffalo	Cattle
No. of spatial replicates (Line Transect)	52	52	52	52	52	52	52	52	52
Total no of walk	288	288	288	288	288	288	288	288	288
Effort (L) km	576	576	576	576	576	576	576	576	576
Total no of observation	119	162	266	54	67	66	798	97	113
Individual Density (D_i) / km^2	16.25	6.94	19.66	11.64	15.30	1.92	124.36	28.3	41.01
D_i Standard Error (± SE)	3.00	1.27	1.85	2.11	2.90	0.4	8.85	4.68	6.58
Biomass (kg / km^2)	731.25	867.5	3538.8	442.32	122.4	6.48	422.82	7641.0	7381.8
D_i Coefficient of variation (% CV)	18.49	178.3	9.40	18.1	18.9	22.22	7.1	16.5	16.0
D_i - 95% Confidence Interval	11.26 - 23.44	4.82 – 9.98	16.32 – 23.70	8.14 – 16.64	10.53 – 22.23	1.4 – 2.2	108.09 – 143.07	23.82 – 33.18	33.94 – 47.6
Group Density (Ds) / km^2	3.56	3.10	7.54	3.03	1.83	1.62	25.13	5.03	6.31
Ds Standard Error (± SE)	0.65	0.56	0.69	0.52	0.34	0.32	1.33	0.42	0.57
Ds Coefficient of variation (% CV)	18.13	18.1	9.10	17.14	18.5	19.74	5.3	8.35	9.03
Cluster Size (Mean)	4.94	2.24	2.61	3.84	8.36	1.11	4.95	5.63	6.5
Standard Error (± SE)	0.19	0.06	0.06	0.22	0.36	0.04	0.24	0.98	0.92
Detection probability (p)	0.42	0.43	0.33	0.26	0.33	0.24	0.33	0.33	0.34
Goodness of fit (chi^2 - p)	0.41	0.56	0.41	0.89	0.73	0.97	0.50	0.86	0.61
Effective Strip Width (ESW) (m)	33.61	38.90	33.26	21.13	32.92	21.84	26.35	40.9	39.01
Group encounter rate	0.24	0.24	0.50	0.13	0.12	0.18	1.33	0.37	0.49
Model	Uniform	Uniform	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal	Half normal
Model adjustment term	cosine, order -1, 2	cosine, order -1, 2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2	cosine, order -2

Figure 3.2. Estimated densities of all the major prey species (mammals) of tiger in Sariska. Tiger Reserve from 2008-09 to 2011-12.

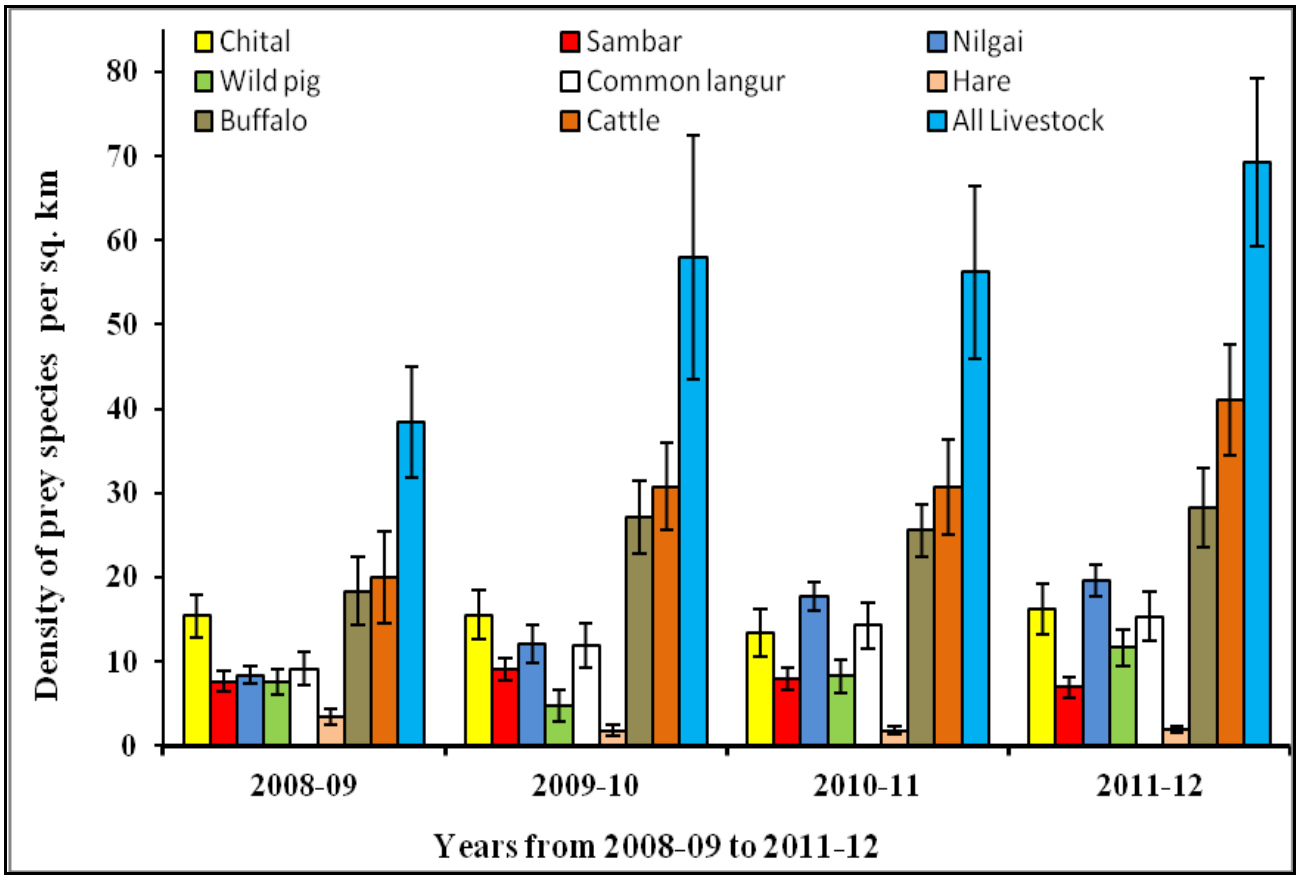


Figure 3.3. Detection probability curve generated by *DISTANCE* 6.0 software for all prey species in the intensive study area in Sariska Tiger Reserve during 2008-09.

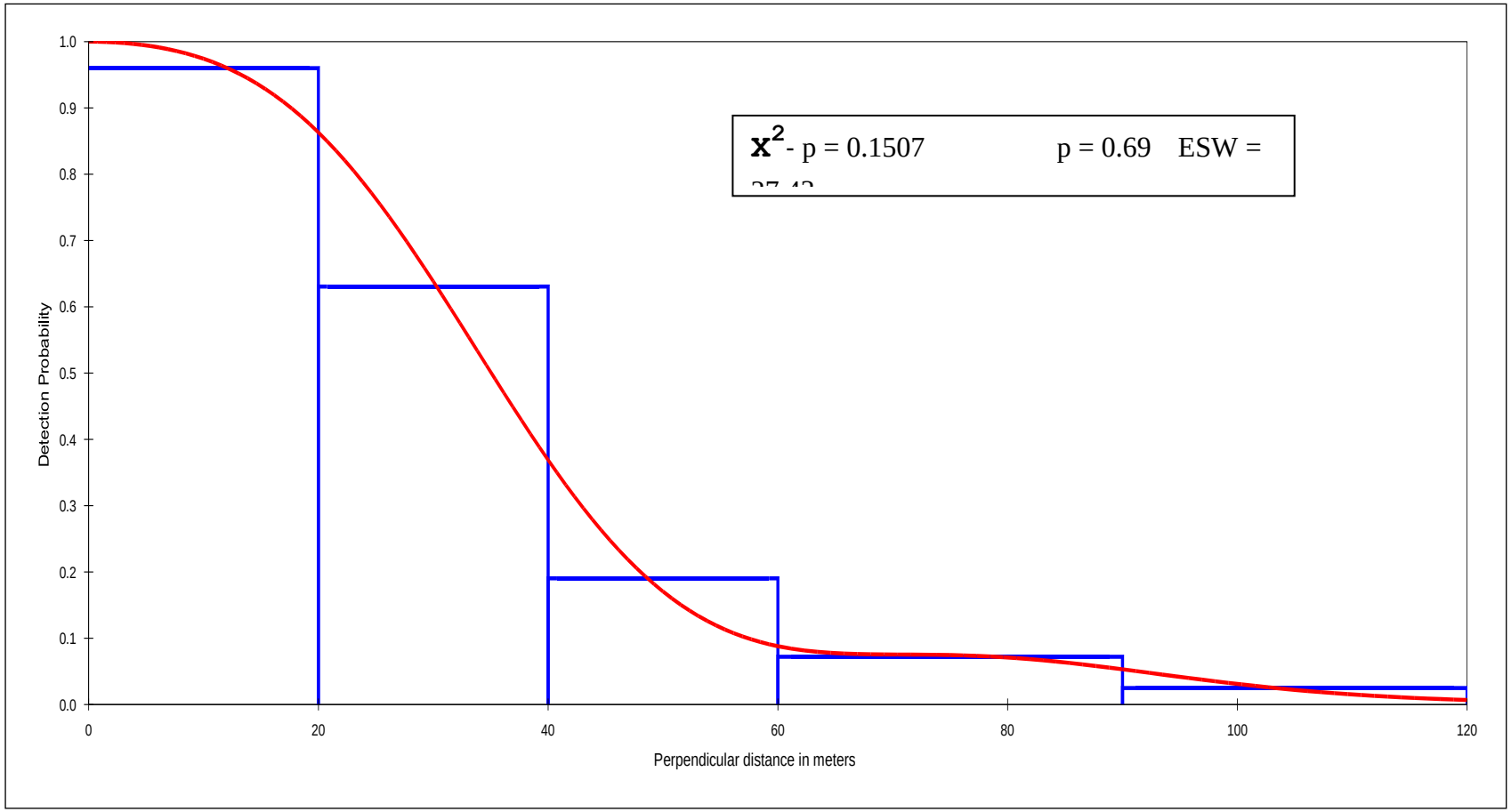


Figure 3.4. Detection probability curve generated by *DISTANCE* 6.0 software for all prey species in the intensive study area in Sariska Tiger Reserve during 2009-10.

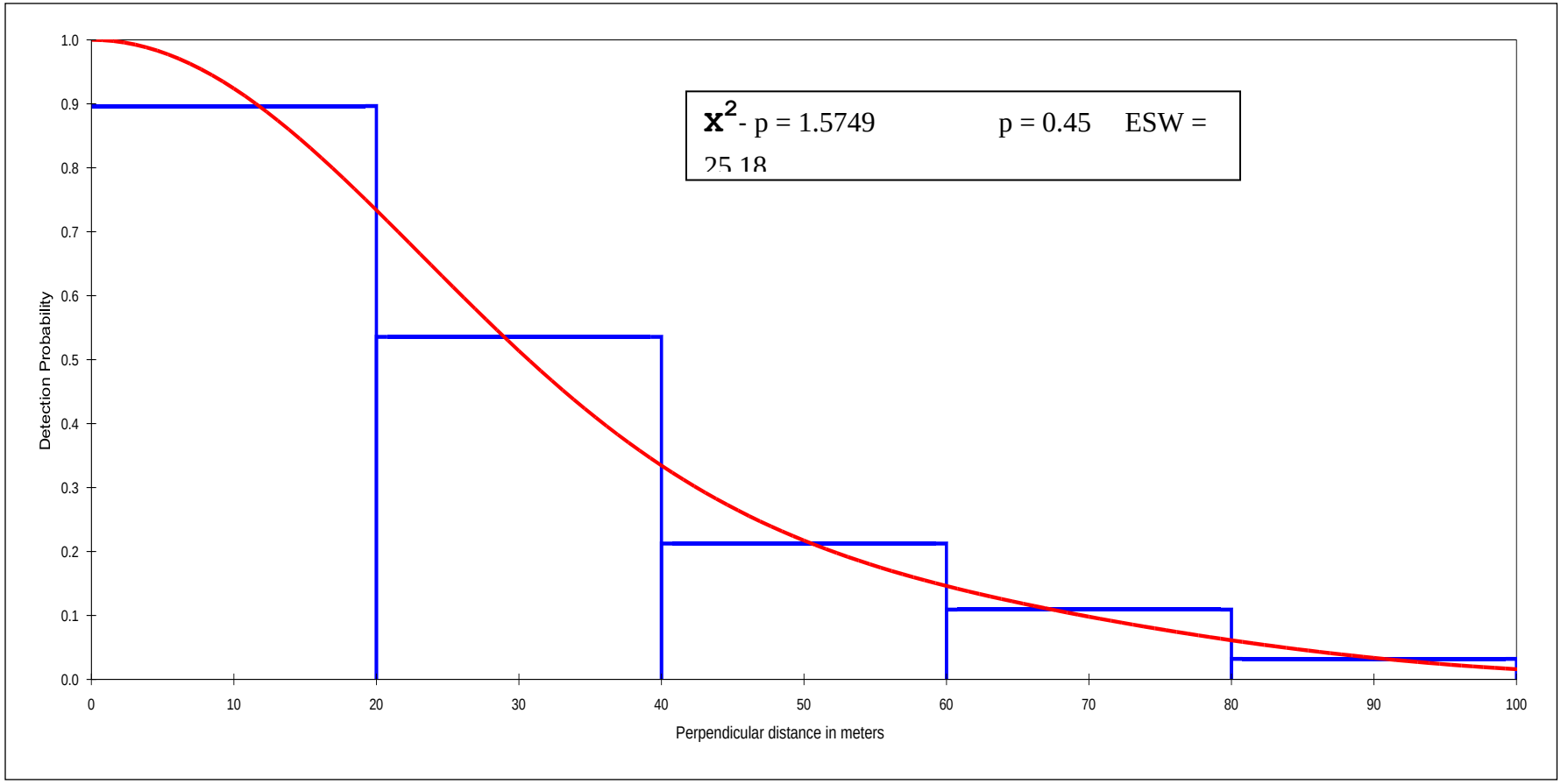


Figure 3.5. Detection probability curve generated by *DISTANCE* 6.0 software for all prey species in the intensive study area in Sariska Tiger Reserve during 2010-11.

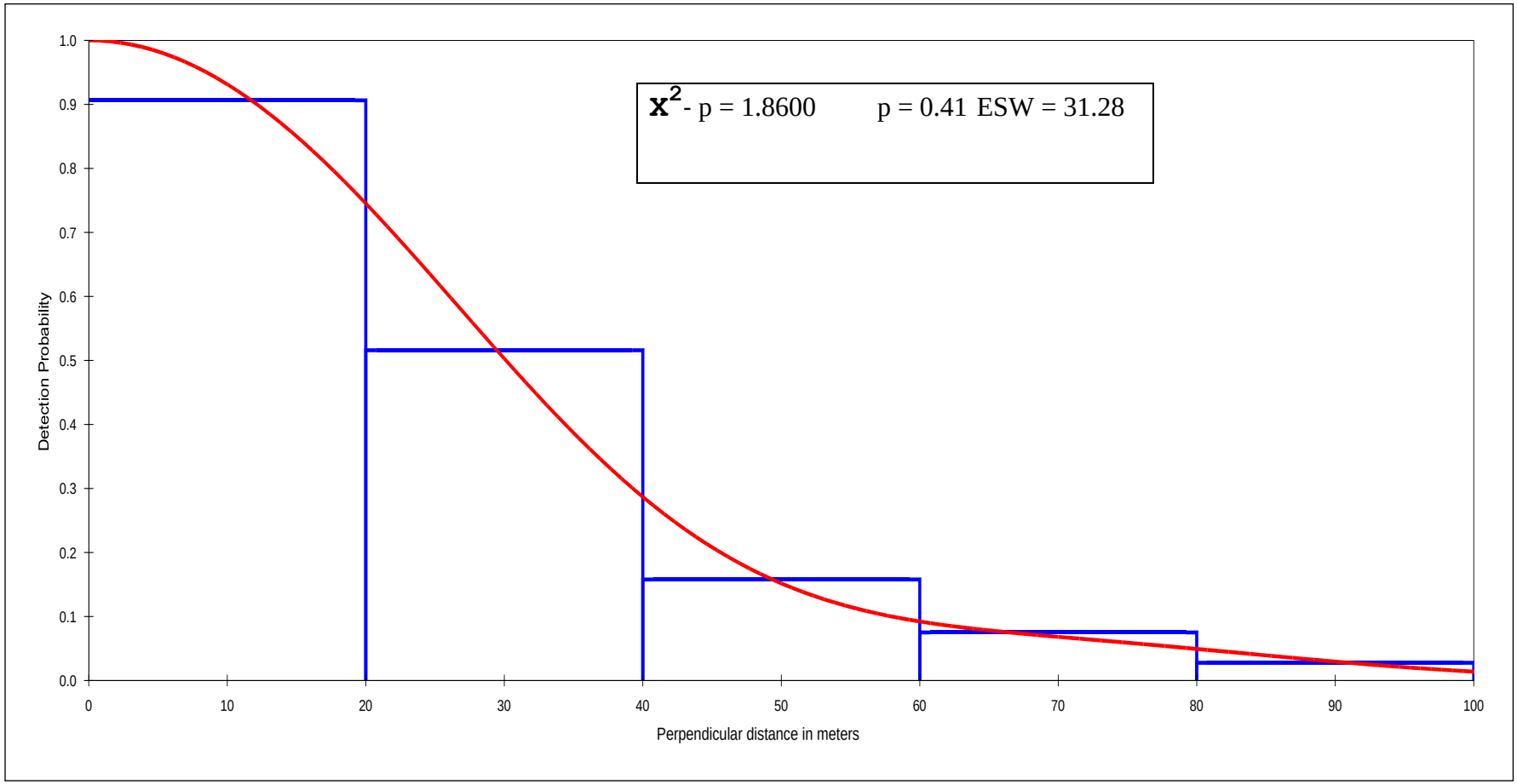


Figure 3.6. Detection probability curve generated by *DISTANCE* 6.0 software for all prey species in the intensive study area in Sariska Tiger Reserve during 2011-12.

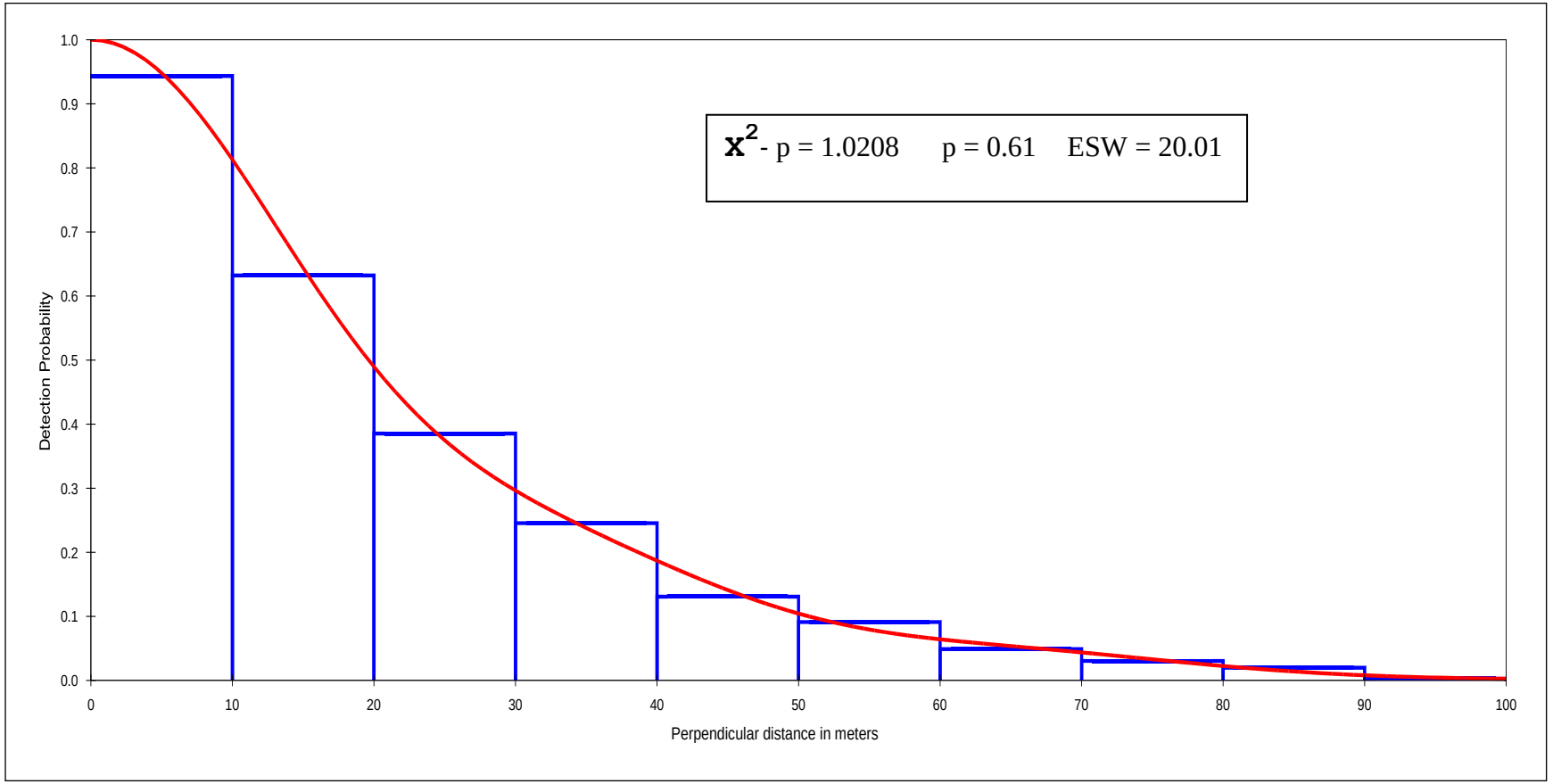


Figure 3.7. Detection probability curve for chital during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Uniform with cosine adjustment term order- 1, 2 ($\mathbf{X^2}$- p = 0.41, df – 5; p = 0.42; ESW = 33.61 m).

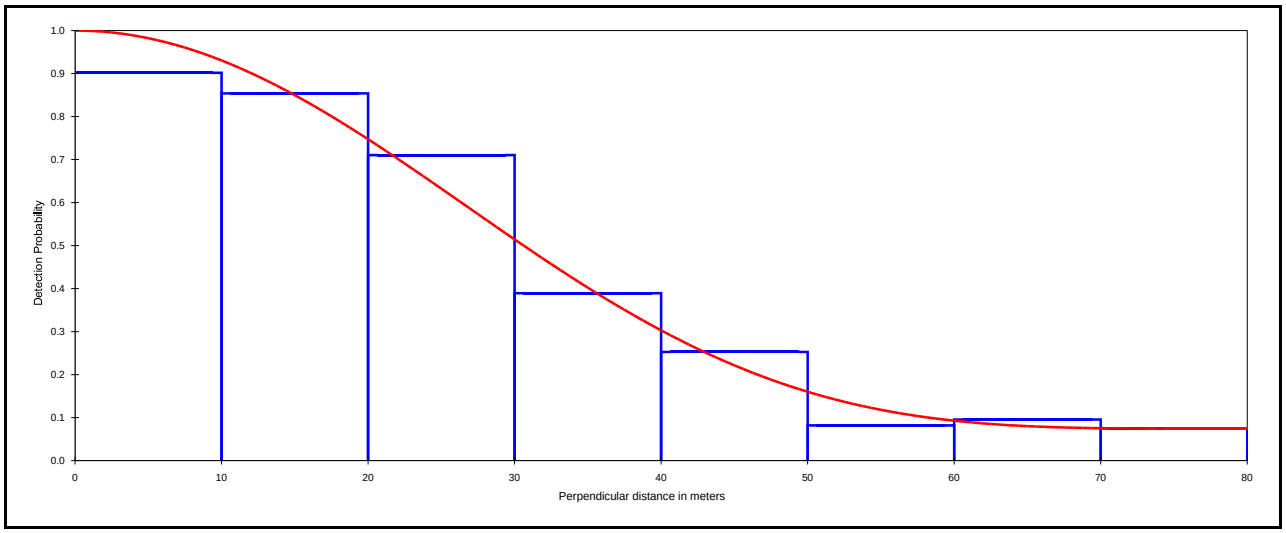


Figure 3.8. Detection probability curve for sambar during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Uniform with cosine adjustment term order- 1, 2 ($\mathbf{X^2}$- p = 0.56, df – 6; p = 0.43; ESW = 38.90 m).

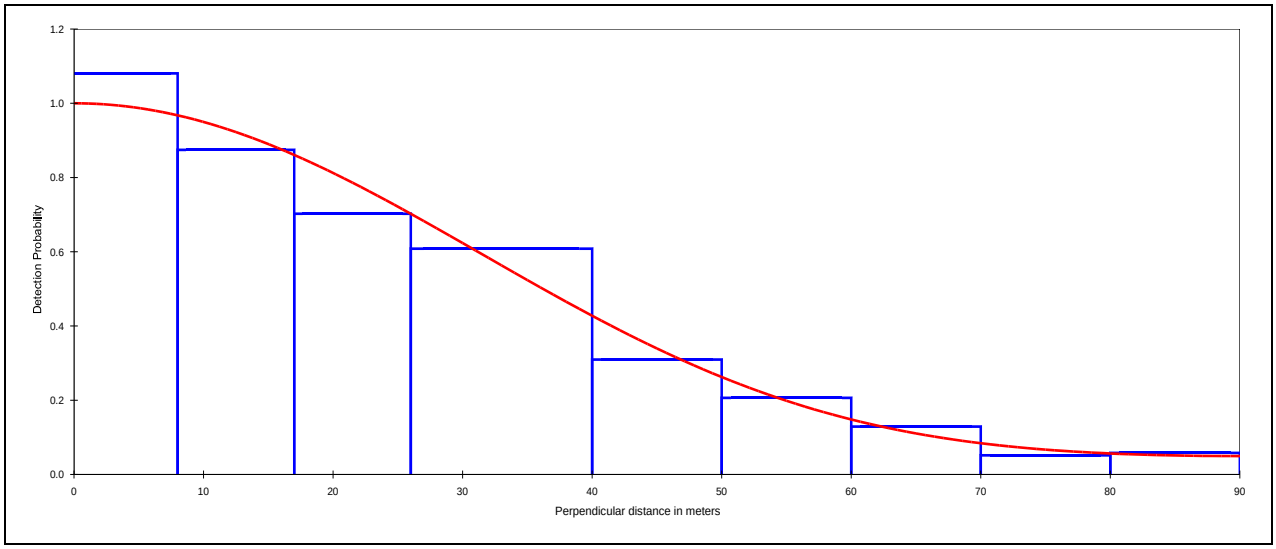


Figure 3.9. Detection probability curve for nilgai during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 (χ^2- p = 0.41, df – 7; p = 0.33; ESW = 33.26 m).

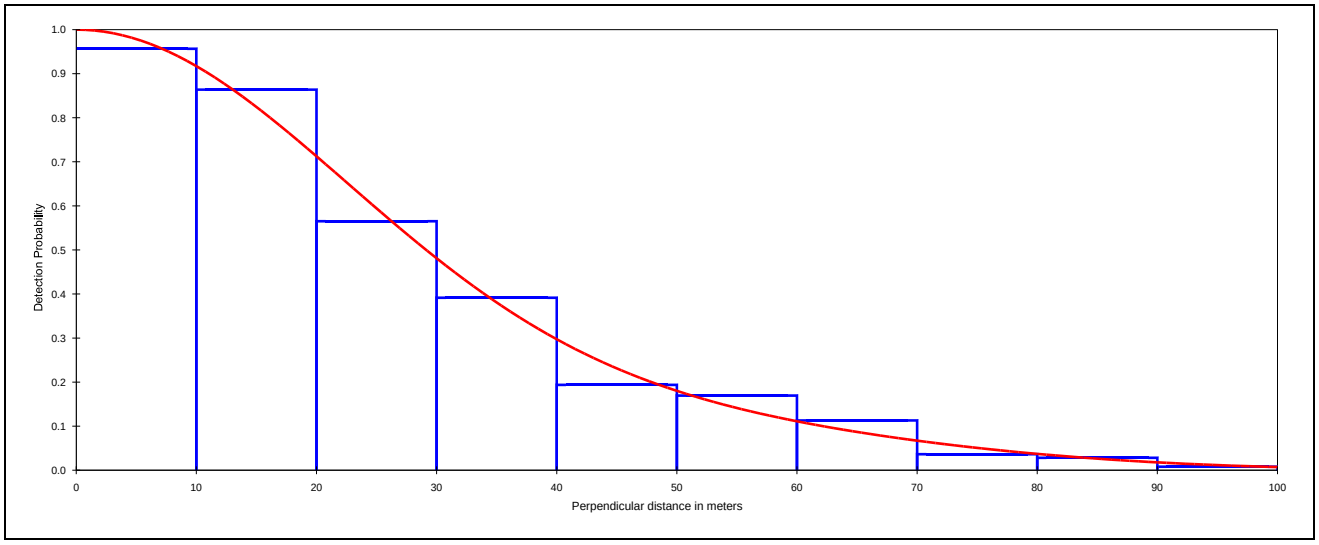


Figure 3.10. Detection probability curve for wild pig during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 (χ^2- p = 0.89, df – 5; p = 0.26; ESW = 21.13 m)

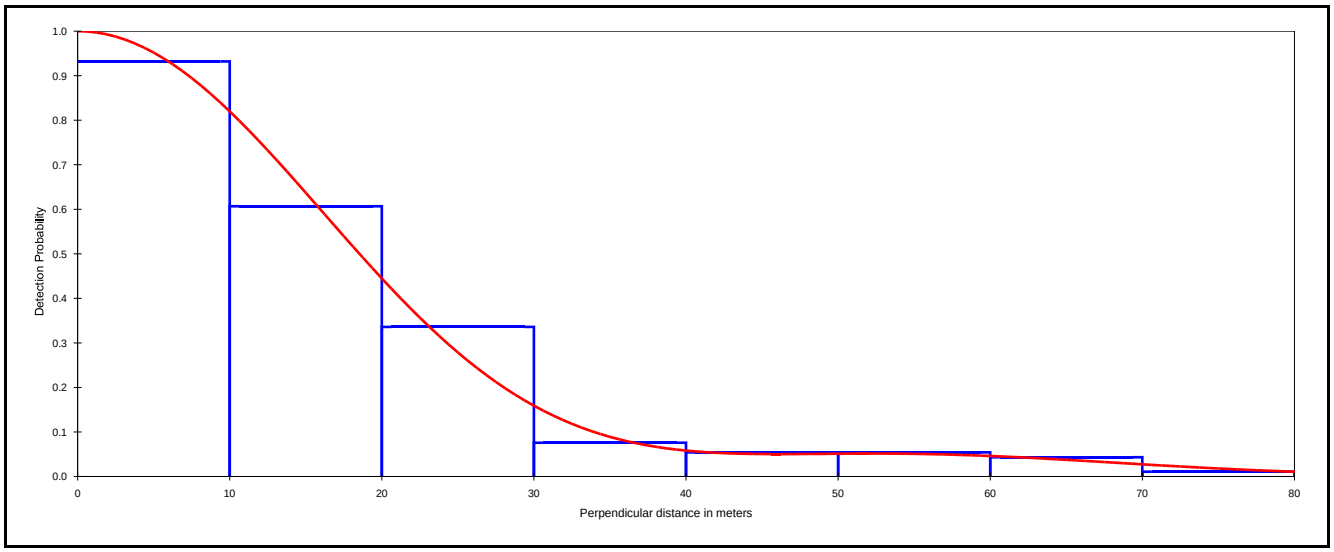


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Figure 3.11. Detection probability curve for common langur during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 ($\mathbf{X^2}$- p = 0.73, df- 7; p = 0.33; ESW = 32.92 m).

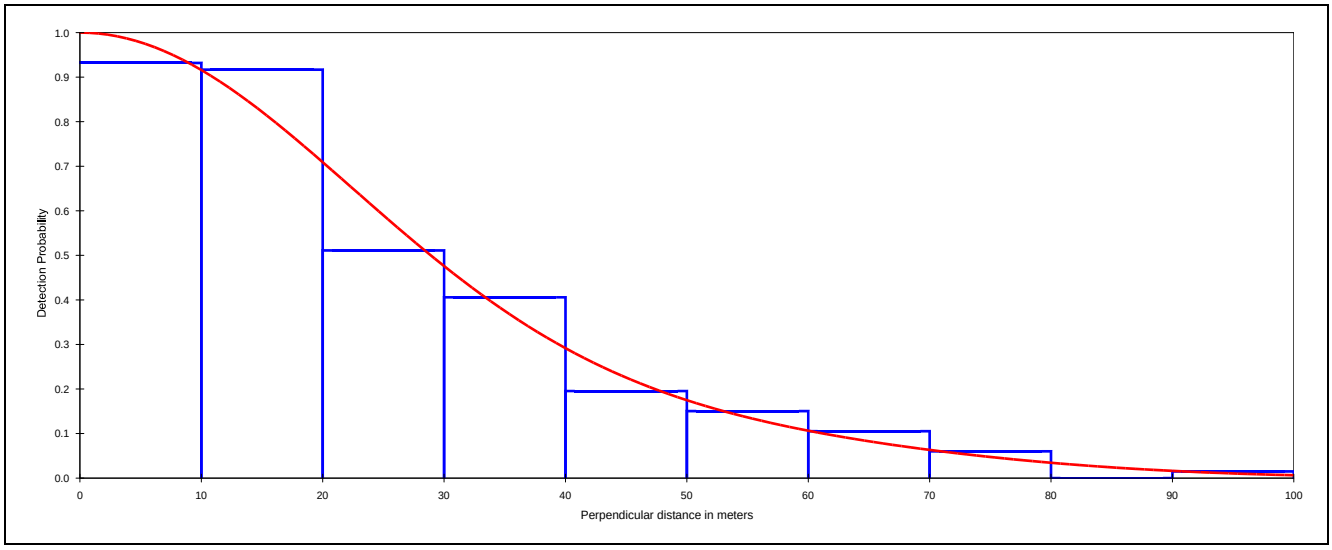


Figure 3.12. Detection probability curve for hare during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 ($\mathbf{X^2}$- p = 0.97, df -5; p = 0.24; ESW = 21.84 m).

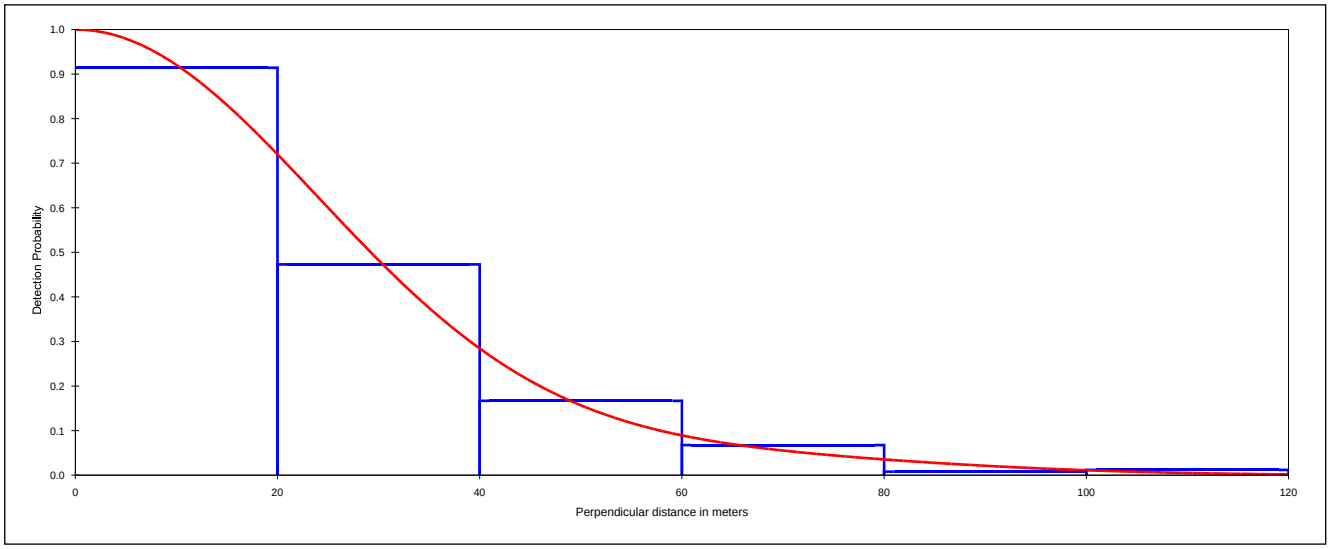


Figure 3.13. Detection probability curve for peafowl during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 (χ^2- p = 0.50, df – 6; p = 0.33; ESW = 26.35 m).

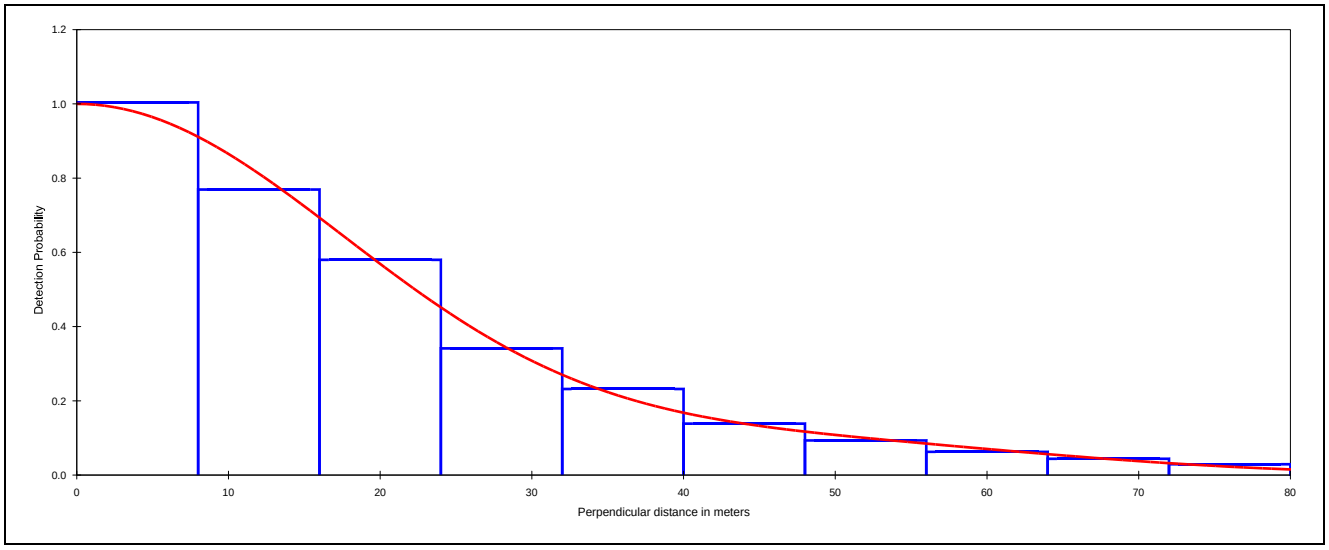


Figure 3.14. Detection probability curve for buffalo during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 (χ^2- p = 0.86, df- 6; p = 0.33; ESW = 40.9).

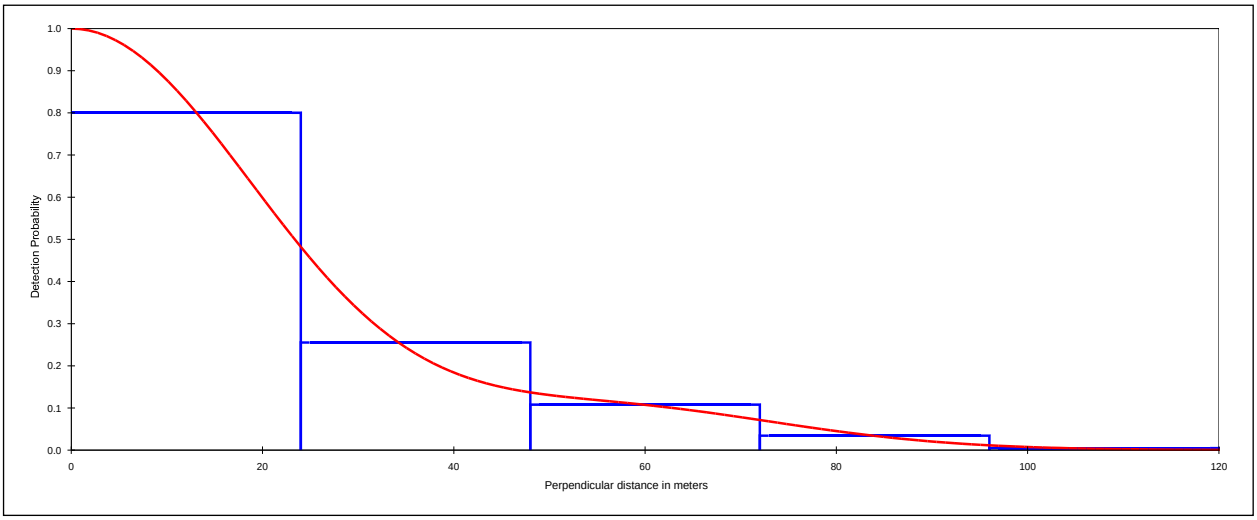


Figure 3.15. Detection probability curve for cattle during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 ($\mathbf{X^2}$- p = 0.61, df- 6; p = 0.34; ESW = 39.01 m).

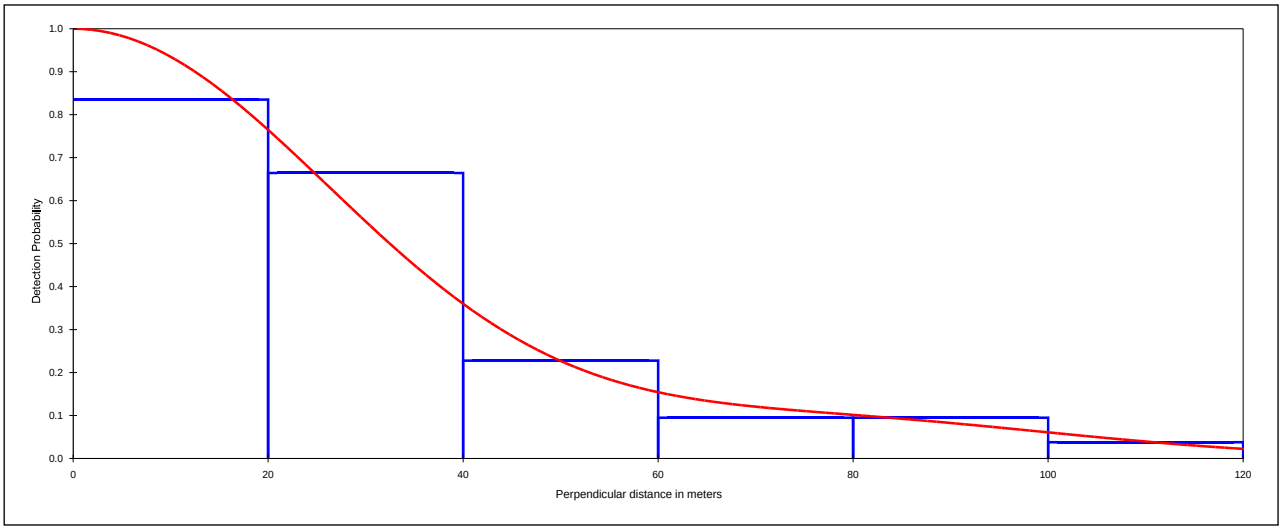
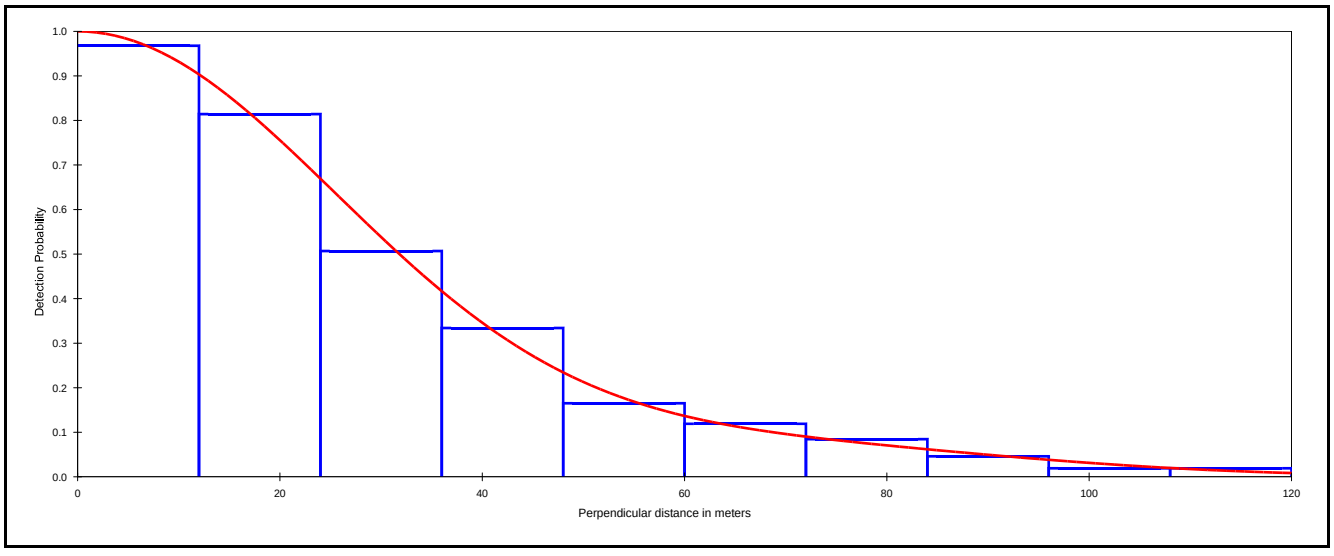


Figure 3.16. Detection probability curve for all livestock (buffalo and cattle) during 2008-09 to 2011-12 in Sariska Tiger Reserve.

Model: Half normal with cosine adjustment term order- 2 ($\mathbf{X^2}$- p = 0.88, df- 7; p = 0.31; ESW = 36.91 m).



3.5. DISCUSSION

The estimated overall densities of wild ungulate species were high (54.49±6.31SE km^{-2}) due to availability of variety of vegetation types ranging from dry-thorn forests to riparian forests, availability of food, water and better protection in the intensive study area. There was a gradual increase in densities of chital, nilgai and wild pig were observed over the years in Sariska during the study period. The availability of grass species like *Chloris dolichostachya, Heteropogon contortus* and *Cynodon dactylon* during monsoon and fallen *Zizyphus* leaves and fruits during winter might have influenced high congregation of chital, sambar, nilgai and wild pig in the valley habitats. Similarly in late winter and early summer, fallen leaves of *Anogeissus pendula* which contains high protein (Sankar, 1994), attracts large assemblage of ungulates in the undulating hills. The density of common langur (15.30±2.90SE km^{-2}) was also found high as compared to similar semi arid habitat of Ranthambhore National Park (Bagchi *et al*., 2003) in the study area because of the availability of food plants such as *Zizyphus mauritiana, Zizyphus nummularia, Diospyros melanoxylon, Acacia catechu, Acacia lucophloea, Butea monosperma, Ficus glomerata,* and *Ficus bengalensis* throughout the year.

The estimated densities of nilgai and wild pig in Sariska Tiger Reserve were the highest as compared to other protected areas of the country (Table 3.5). Since there were eight villages situated inside the intensive study area till the end of the study period, the observed high densities of livestock species might be an artifact of overlap between the grazing time by the villagers and time of line transect walk.

It was observed that the density of chital and sambar reduced slightly during 2010-11. During 2010, Sariska experienced prolonged and severe dry summer. The temperature reached and continued to be around 49^{o}C in the day time for more than two and half months. This led to a number of wild ungulate mortalities in the Tiger Reserve. Quite a few sambar (n = 19) and wild pig (n = 6) died in the study area due to foot and mouth disease (FMD) during summer of 2010. The decline in the density of chital and sambar might further be attributed to the sudden outbreak of *Cassia tora* in the study area in 2010. *Cassia tora* had been reported to show allelopathic potential (Sarkar *et al*., 2012; Vitonde *et al*., 2014) causing growth suppression of native crops and palatable grass species. Reduction in the growth and abundance of palatable grasses might have limited the congregation of chital and sambar in the valley areas and fragmented their group size and density. A total of seventy sambar were trans-located to Kumbhalgarh Wildlife Sanctuary,

Udaipur from Sariska notified National Park during May-June of 2010. Such measures should not be encouraged since sambar was found to be the most preferred prey species of tiger during the study period (See Chapter Four).

Sankar *et al*., (2009) estimated the livestock population in the intensive study area as 9,000 domestic livestock (consisted of brahminy cattle, buffalo, goat, sheep and camel), though no sheep was recorded on the line transects during the present study. The density of domestic livestock (buffalo and brahmini cattle) in the study area showed a steady increase from 38.38±6.61SE km^{-2} to 69.31±9.92SE km^{-2} from 2008-09 to 2011-12, which is a matter of concern.

The density of hare in the study area was low as compered to other potential prey species throughout the study period (Table 3.1 to 3.4). Generally being nocturnal, the sightings of hare were very less during the morning time when the line transects were walked to collect the field data for estimation of density of the prey species. The timing of transect walk therefore might have led to the underestimation of its density.

The estimated wild prey densities obtained from the present study were compared with those from other available studies in the country. It revealed that Sariska notified National Park area harbored moderate densities of chital, sambar, nilgai and wild pig (Table 3.5). The estimated densities of nilgai and wild pig were found higher than any other available studies in the Indian sub-continent (Khan *et al.*, 1995; Karanth and Nichols, 1998; Chundawat *et al*., 1999; Bagchi *et al*., 2003; Ramesh *et al.*, 2008; Harihar *et al*., 2009; Majumder, 2011 and Jhala *et al*., 2012).

Table 3.5. Densities of ungulate species in different protected areas of India.

Locations	Chital	Sambar	Nilgai	Wild pig	Sources
Sariska notified NP	16.25	6.94	19.66	11.64	Present study (2011-12)
Kuno WLS	51.59	3.59	2.32	4.68	Jhala *et al*., 2012
Pench TR, MP	60.5	7.5	2.1	8.6	Majumder, 2011
Rajaji NP	49.9	14.6	2.4	1.9	Harihar *et al*., 2009
Mudumalai NP	55.30	2.80	NA	0.40	Ramesh *et al.*, 2008
Ranthambhore TR	31.00	17.15	11.36	9.77	Bagchi *et al*., 2003
Panna TR	10.80	9.16	6.02	---	Chundawat *et al*., 1999
Kanha NP	49.70	1.50	NA	2.50	Karanth and Nichols, 1998
Gir NP	57.30	3.50	0.58	---	Khan *et al*., 1995
Keoladeo NP	9.79	0.75	7.00	2.24	Haque, 1990

--- Data not available

Several studies documented the available prey base density in the study area since 1991 (table 3.6). It was evident that the density of nilgai rose gradually over the years in last decade which was an indicator of increase in anthropogenic pressure on the available habitat and also represented the health of the natural forests getting converted from dense to open scrubland.

In India, both tropical dry deciduous and tropical moist deciduous forests are equally potential as a wild prey base habitat. The dry deciduous forests in Sariska Tiger Reserve harbored one of the considerable biomass densities of wild ungulates in the country (Table 3.7).

If the current population dynamics of the wild ungulates could be managed with better management strategies such as eradication of weeds (*Cassia tora* and *Adathoda vasica*) from the valley habitats of Sariska and complete relocation of villages (n=8) from the notified National Park area, it would be helpful in maintaining a sustainable population of at least 15 – 20 adult tigers in Sariska (Sankar *et al*., 2005).

Table 3.6. Studies on wild ungulate abundance in the study area (Sariska notified National Park) in different years.

Studies	Chital*	Sambar*	Nilgai*	Wild pig*
Mathur (1991)	10.0	5.2	11.1	---
Sankar (1994)	30.7	15	18.3	---
Avinandan (2003)	27.6	8.4	5.2	17.5
Tiger Task Force (2005)	10.3	13.3	23.3	4.1
Present Study (2008-09)	15.42	7.66	8.39	7.6
Present Study (2009-10)	15.56	9.04	12.08	4.74
Present Study (2010-11)	13.44	7.87	17.66	8.29
Present Study (2011-12)	16.25	6.94	19.66	11.64

--- Data not available; * Density (km^{-2})

Table 3. 7. Biomass density of wild prey species in different dry deciduous forests of India.

Name of the study area	Forest Type	Prey Biomass (Kg km^{-2})
Sariska Tiger Reserve (Present Study – 2011-12)	Tropical dry thorn and dry deciduous	6132.0
Kuno WLS (Jhala *et al*., 2012)	Tropical dry deciduous	3866.516
Pench TR (Majumder, 2011)	Tropical dry deciduous	5780.25
Nagarhole TR (Karanth and Sunquist, 1992)	Tropical dry and moist deciduous	14744
Bandipur TR (Johnsingh, 1983)	Tropical dry and moist deciduous	14520
Gir WLS (Berwick, 1971)	Tropical dry deciduous and thorn	6342.9
Kanha TR (Schaller, 1967)	Tropical moist deciduous	3902.3 ± 4805.7

CHAPTER FOUR

4. FOOD HABITS AND PREY SELECTION OF THE REINTRODUCED TIGERS

4.1. INTRODUCTION

Tigers (*Panthera tigris*) are the largest of the felids with a vast historical distribution that once covered Asia and much of the diverse habitats within the continent (Nowell & Jackson, 1996). During last one hundred years, global population of tigers has been found to plummet with its geographical range getting vastly contracted (IUCN, 2013). This had led the status of the species listed as endangered (IUCN, 2013). Even long-term conservation actions, such as the 40-year-old Project Tiger initiative in India (Panwar, 1987) and intensive research projects in other parts of the tiger range countries were struggling to manage this declining pattern of their population due to several natural and anthropogenic causes. The major reasons of this decline had been revealed as illegal hunting by native communities, poaching for commercial purposes, declining in natural prey base, habitat loss and habitat degradation and fragmentation (Karanth and Stith, 1999; Carroll and Miquelle, 2006; Chapron *et al*., 2008; Wilson and Mittermeier, 2009; Miquelle *et al*., 2010). To understand the impact of prey depletion on tiger subsistence, it is critical to understand the predation pattern of the tiger along with its co-existence pattern with other sympatric carnivores (Karanth and Stith, 1999; Karanth and Sunquist, 2000; Miquelle *et al*., 2010).

Tigers are solitary, ambush hunters (Wilson and Mittermeier, 2009) and require >5 kg of meat daily (Sunquist, 1981). They were found capable of capturing and killing large prey, including adult male gaur (*Bos gaurus*) (Karanth and Sunquist, 1995) whereas they predated on prey as small as hares (Johnsingh, 1983). Tiger diet was found biogeographically diverse based on the local prey availability (Sunquist, 1981; Karanth and Sunquist, 1995; Miquelle *et al*., 1996, 1999). Based on the breadth of their diet across their range, it might be deduced that tigers were non-selective predators; however, it seemed that the morphology and solitary hunting strategy of this species had inflicted limitations on the prey it can capture most efficiently causing minimal risk to its claws and canines.

A global review study on tigers' food habit and prey selection pattern found that wild pig and sambar were largely consumed by tigers, with red deer and barasingha likely to be significantly preferred (Hayward *et al*., 2012). Prey body mass was one of the most important variables that related to tiger prey preference with species weighing between 60 and 250 kg found preferred by tigers yielding a ratio of predator to preferred prey of 1:1 (Hayward *et al*.,

2012). This information could be very significant to predict tiger diet, carrying capacity and movement patterns and other important implications for tiger conservation throughout its distribution. There were several studies that documented the food habits and prey preferences of tigers (Schaller, 1967; Eisenberg and Seidensticker, 1976; McDougal,1977; Rakov, 1979; Dinerstein,1980; Sunquist, 1981; Johnsingh, 1983; 1992; Rice, 1986; Filonov, 1989; Rabinowitz, 1989; Dhungel and O'Gara, 1991; Karanth and Sunquist, 1992; 1995; Seidensticker and McDougal, 1993; Srikosamatara,1993; Støen and Wegge, 1996; Chundawat *et al*., 1999; Biswas and Sankar, 2002; Bagchi *et al*., 2003; Khan, 2004; Reddy *et al*., 2004; Karanth *et al*., 2004; Harihar *et al*., 2006; 2011; Wang & Macdonald, 2006; Wegge *et al*., 2009; Miquelle *et al*., 2010; Sankar *et al*., 2010). These studies provided reliable data to holistically review the diet and prey selection of the tiger.

In Sariska Tiger Reserve all the tigers got exterminated due to poaching in 2004. A total of six tigers (three male and three female) were re-introduced in the study area between 2008 and 2011. Hence, in the dry deciduous forest of Sariska with high density of large-bodied ungulate assemblage (Sankar *et al*., 2009), it was crucial to study the food habits and prey preference of these reintroduced tigers in the presence of other sympatric competitor species.

4.2. LITERATURE REVIEW

The predation ecology studies of tiger and other large carnivores were found greatly significant to design subsequent resource based conservation action plans for these endangered animals. Studies on feeding ecology of carnivores relied on direct observations of incidences of hunting, finding the remains of prey killed, or studying the remains of prey found in scats. Since tigers are generally crepuscular and elusive animals, direct observation on their predation is rarely possible. Most studies therefore relied on the indirect evidence from kills and scats. Tigers had been reported to kill large to medium sized prey, but also fed on a variety of small animals occasionally. In Bandipur Tiger Reserve, southern India, tiger preferred sambar and avoided chital (Johnsingh, 1983). One explanation was that chital "assembled in open areas to spend the night where they were immune to tiger predation" (Johnsingh, 1983). Whereas, "sambar used to spend more time in the dense vegetation where tigers preferred to make kills, lived in smaller groups and did not rest in open areas" (Johnsingh, 1983).

In the tropical forests of Nagarhole National Park, southern India, where ungulate densities were very high, Karanth and Sunquist (1995) observed that tiger usually selected prey species weighing more than 176 kilograms, while leopard and dhole predated on prey species in the

range of 31-175 kg size class. The average weight of the principal prey species killed by tiger found in this study was estimated as 91.5 kg. At Nagarhole, tiger predation was biased towards adult male chital, sambar and wild pig but to young gaur, signifying that the tiger preferentially targeted this age-class of gaur (Karanth and Sunquist, 1995). Tiger, leopard and dhole are not large or strong enough to kill adult elephants and rhinoceroses. However, tigers occasionally preyed upon elephant and rhino calves. In Nagarhole National Park, Karanth and Sunquist (1995) confirmed that one percent of all tiger kills were calves of the Asian elephant (*Elephas maximus*). Dhole and leopard in the same area did not prey upon elephant calves.

In Chitwan National Park, Nepal, Seidensticker (1976) recorded tiger predation on a calf of the Indian rhinoceros (*Rhinoceros unicornis*). However, such predation happened seldom.

Biswas and Sankar (2002) in Pench National Park showed that chital (*Axis axis*) (47.3%), sambar (*Rusa unicolor*) (14.5%) and wild pig (*Sus scrofa*) (10.9%) constituted the major part of the tiger's diet. Tigers seemed to kill medium and large-sized species more often as reported by this study. Wild pig and sambar were preferred and consumed more than their availability, whereas chital were predated in similar proportion to their availability. Gaur (*Bos gaurus*) and nilgai (*Boselaphus tragocamelus*) were not represented in the tiger's diet. Common langur was consumed in lesser proportion by tigers than expected as per their available densities. The average weight of animals consumed by tigers in the intensive study area was 82.1 kg. The study also revealed that tigers were mostly dependent on the wild ungulates rather than on domestic livestock.

Bagchi *et al*., (2003) in Ranthambhore Tiger Reserve documented that chital (31%) and sambar (47%) constituted the bulk of the tigers' diet and both of them were preferred prey. Whereas, nilgai (*Boselaphus tragocamelus*) and chinkara (*Gazella benetti*) contributed minimally (5–7% and < 1%, respectively) to the diet of the tigers. Domestic livestock made up 10% to 12% of the tigers' diet. The average weight of an animal consumed was between 107 and 114 kg reflecting a preference for large prey.

Study on prey selection by tigers in Nagarjunsagar Shrisailam Tiger Reserve (Reddy *et al*., 2004) showed that wild pig (*Sus scrofa*) was the most preferred prey species followed by chital (*Axis axis*) and sambar (*Rusa unicolor*). Domestic livestock comprised only seven percent of the tiger diet. The mean weight of the prey species consumed by tigers showed in this study was 56.3 kg which was much less than other areas. Reddy *et al*., (2004) also suggested that tigers preferred to kill smaller prey and avoided livestock in tropical dry deciduous forests.

Another study in Bandipur Tiger Reserve (Andheria *et al*., 2007) reported that the large ungulates, gaur (*Bos gaurus*) and sambar (*Rusa unicolor*), contributed 73% of biomass consumed by tigers where as the relative percentage of occurrence of chital (*Axis axis*) was 33% in tiger kills.

Sankar and Johnsingh (2002) in Sariska Tiger Reserve reported that chital and sambar were mostly found in tiger scats followed by the common langur. Their study also stated that in terms of biomass, sambar contributed maximum (53.9%) in tiger's diet followed by chital (30.5%) and common langur (5.8%). Contribution of the remaining prey species was less than 10%.

Avinandan *et al*., (2008) documented the prey selection by the tigers in Sariska before their local extermination during 2004. The study showed that sambar was largely preferred by tigers and the order of prey preference was sambar> chital > nilgai> livestock (cattle and buffalo) > common langur> wild pig.

Ramesh *et al*., (2009) studied food habits and prey selection of tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu, Southern India during January to August 2008. A total of 179 tiger scat samples were collected and analyzed. The study revealed that sambar and chital were the principal prey species for both tiger and leopard in the study area. The preferred prey species of tigers found by the study were sambar, common langur, wild pig and cattle. The study showed a significant dietary overlap between tiger and leopard based on percentage frequency (82%) and biomass consumption (72%).

Thereafter, the preliminary study on the reintroduced tigers in Sariska (Sankar *et al*., 2010) reported prey preference in the order of sambar> chital > nilgai> livestock (cattle and buffalo) > common langur.

Hayward *et al*., (2012) reviewed the available worldwide literature on tiger diet based on prey availability and estimated Jacobs's electivity index scores from kill and scat data. The study found that wild pig (*Sus scrofa*) and sambar (*Rusa unicolor*) are preferred by tigers while red deer (*Cervus elaphus*) and barasingha (*Cervus duvauceli*) were much higher in term of preference. Prey body mass was the only variable that related to tiger prey preference with species weighing between 60 and 250 kg were mostly preferred by tigers.

Miller *et al*., (2013) deployed global positioning system (GPS) collars on Amur tigers (*Panthera tigris altaica*) during 2009–2012 to study annual kill rates in the Russian Far East. The study could detect 111 kill sites using GPS telemetry. Logistic regression was used by the authors to model both the probability of a kill site at GPS location clusters and the size of prey species at kill sites according to several spatial and temporal cluster covariates. The best

selected model for predicting kill sites included the duration of the cluster in hours and cluster fidelity components as covariates. The study revealed that Amur tigers made a kill once every 6.5 days and consumed an estimated average of 8.9 kg of prey biomass per day (95% CI 8.8–9.0 kg/day).

Majumder *et al*., (2013) published a study on Predation ecology of three large sympatric carnivores, tiger, leopard and dhole in Pench Tiger Reserve, Madhya Pradesh, Central India. A total of 285 tiger kills were recorded by the authors. They compared the age–sex class distribution of each ungulate species recorded as kill data with the corresponding prey population recorded from line transects and vehicle transects. The study showed that all three large carnivores preferred medium-sized prey species such as chital, whereas significant difference was observed when comparing different health conditions of prey species predated upon. The study suggested that the observed difference in prey choice as per their body size was a strategy adopted by large carnivores to partition prey resources to reduce intra-guild competition.

4.3. METHODOLOGY

4.3.1. ESTIMATION OF FOOD HABITS OF THE REINTRODUCED TIGERS

Scat analysis method was chosen to estimate the proportion of different prey species consumed by tiger, the method being widely used simultaneously cost and time effective (Schaller, 1967; Sunquist, 1981; Johnsingh, 1983; Reynolds and Aebischer, 1991; Bagchi *et al*., 2003). Tiger scats were collected during periodic monitoring in the study area between 2008 and 2012. Tiger scats were differentiated from that of other carnivore species on the basis of diameter and bulk in size and other secondary information such as homing in telemetry locations, pugmarks, and scrape marks.

The scats were collected in paper bags and the quality of scat, date, locality and GPS locations were noted. Fresh scats were air dried before storing in paper bags. All the scats were brought to the research laboratory of Wildlife Institute of India, Dehradun. Each scat were then broken down and washed under running water by using a sieve. The scat contents were then teased apart with forceps and undigested prey remains such as hairs, bones, skin, claws, hooves, mandible, quills and grass material were separated. All the prey remains were examined macroscopically to identify the species (Grobler and Wilson, 1972). At least 20 hairs were picked up randomly from each scat for the preparation of slides (Mukherjee *et al*., 1994). A combination of hair characteristics like color, length, width, medullary structure, ratio of medulla width to hair width, cuticular pattern of the prey hairs of each scat collected

were observed under binocular light microscope and compared with the reference slides available in the laboratory of Wildlife Institute of India, Dehradun. To find out the effective sample size in a year to understand the food habits of reintroduced tigers from scat analysis, 10 tiger scats were chosen at random and their contents analyzed. This was continued until all the scats in the sample of each year had been analyzed once. The cumulative frequency of occurrence of different prey species in the tiger scats over successive random draws was then assessed to infer the required sample size. The identified prey species varied in size and body weight to considerable extent. Hence, the true picture of consumed proportion of different prey species could not be inferred from frequencies of prey remains in scats. Smaller prey species, having more hair per unit body weight produced more scats per unit prey weight consumed, leading to an overestimation of smaller prey species in the carnivore diet (Griffiths, 1975; Ackerman *et al*., 1984; Biswas and Sankar, 2002).

4.3.2. ESTIMATION OF RELATIVE BIOMASS AND PREY SELECTIVITY OF THE REINTRODUCED TIGERS

The correction factor developed by Ackerman *et al*., (1984) from feeding trials on cougar (*Felis concolor concolor* L.) was used to estimate the relative proportion of biomass of different prey species consumed by the reintroduced tigers in the study area. The equation used was as follows: Y= 1.980 + 0.035X, where Y= kg of prey consumed per field collectible scat; X=average weight of an individual of a particular prey species (Ackerman *et al*., 1984). The values of Y from the above equation gave the number of collectible scats produced per kill for each prey species. Hence, the relative biomass consumed for each prey species can be obtained multiplying the Y by the number of scats found with remains of a particular prey species.

The relative number of individual consumed for each species can be obtained dividing the frequency of occurrence of each species by their respective average body weight. These values were used to estimate the percent biomass and number contribution of different prey species to the reintroduced tigers' diet in the study area. Prey selection of tigers was estimated for each species by comparing the proportion of the prey species utilized from scats with the expected number of scats available in the environment for each of the prey species consumed (Ramesh *et al*., 2008). The expected proportion of scats in the environment (i.e. availability) was calculated using the following equation (Karanth and Sunquist, 1995):

$fi = \{(di / \Sigma di\ldots dn) * \lambda i\} / \Sigma \{(di / \Sigma di\ldots dn) * \lambda i\}$, where fi= expected scat proportion in the environment; di= density of 'i' th species; Σ di…dn= sum of the density of all species; λi=

X/Y = the average number of collectible scats produced by tiger from an individual of 'i' th prey species. X = Average Body weight of the species; Y = Ackerman's equation.

The prey selection was measured by using Ivlev's index (Ivlev, 1961) as follows:

E = (U – A) / (U + A), where U = relative frequency occurrence of prey items in predator scats; A = expected scat proportion in the environment. The exact variability of prey items in scats was not known and in order to account for that sensitivity analysis was done by changing coefficient of variance from 10% to 40% (Link and Karanth, 1994; Ramesh *et al*., 2008). The data was bootstrapped 1000 times and analyzed in program *SCATMAN* (Link and Karanth, 1994).

Tiger kills were also recorded as and when encountered during the entire study period from the study area. On each tiger kill, the prey species was identified and its sex and age class were recorded. The date and GPS locations were also recorded on each kill.

The presence of a particular species in tiger scat samples as well as in kill incidents (year wise) was binomially coded to prepare a matrix with 0 and 1. Thereafter, bootstrapping with ten thousand iterations were also carried out for each component to obtain a 95% confidence interval for the mean of each frequency occurrence from the matrix using "boot" function of the software R (R Development Core Team, 2006).

4.3.3. EVALUATION OF STALKING COVER PATTERNS BY THE REINTRODUCED TIGERS FOR PREDATION

During the kill site investigation, most of the time the places at which the prey was initially attacked by the tigers (called the attack site) were identified based on careful examination of the drag-mark, blood trail and disturbed vegetation. For tiger attack sites (or kill sites), the habitat type and distance to the nearest human settlement and water source were recorded. Apart from subjectively categorizing the ground cover density at the kill site as open, moderate or dense, 'visibility' and 'edge' were quantitatively estimated to understand the pattern of stalking cover used by reintroduced tigers.

Visibility was measured at predator eye level whereas the edge was estimated based on the degree of contrast between the most open and densely covered sides of the site. For estimating visibility (which is opposite to stalking cover), a 200-cm tall and 500 cm wide density board (Higgins *et al*., 1994) with 10 equal alternating red and white segments (20 cm height of each colored segment) was used in every kill site. After placing the board at the point of attack, the number segments visible at predator's eye-level (approx. 50±100 cm), at a 15 m distance with 5 m of intervals from all eight directions such as north, north-east, east,

south-east, south, south-west, west and north-west were counted and subsequently recorded in data sheet. For each attack site, the visibility index (V_i) was computed as the average of these eight counts, while the edge index (E_i) was measured as the difference between the highest and the lowest counts.

4.4. RESULTS

A total of 103,178, 216 and 158 tiger scat samples were collected respectively in 2008-09, 2009-10, 2010-11 and in 2011-12. It was observed that, the proportion of different prey species in tiger scats got stabilized once a total of 80 - 90, 120 - 130, 90 - 100 and 90 - 100 scat samples were analyzed respectively in 2008-09, 2009-10, 2010-11 and in 2011-12 (Figure 4.1, 4.2, 4.3 and 4.4). Hence, based on the mean of the upper limit of sampling adequacy for these consecutive four years, it was estimated that a minimum of (105±15SE) scat samples should be analyzed annually to understand the food habits of reintroduced tigers in the study area.

In total, 10 prey species were identified in scat samples of reintroduced tigers during the study period, though only five prey species were identified in 2008-09. All ten prey species were found in tiger scats in 2009-10 and six species were recorded during 2010-11 whereas five species were detected in 2011-12. Frequency of occurrence and percentage frequency of occurrence of prey remains in tiger scats were given in Table 4.1 to 4.4 respectively for four years from 2008-09 to 2011-12. During 2008-09, amongst the prey species, sambar contributed maximum (41.75±0.98SE %) in tiger's diet followed by chital (26.21±0.43SE %), domestic livestock (19.42±0.55SE %), nilgai (10.68±0.40SE %) and common langur (1.94±0.35SE %).

During 2009-10, sambar contributed the most (55.06±1.33SE %) followed by domestic livestock (12.36±0.66SE %), chital (11.24±0.86SE %), nilgai (10.67±0.59SE %), common langur (3.93±0.28SE %), wild pig (2.25±0.30SE %), porcupine (1.12±0.10SE %), rodent (1.12±0.10SE %), mongoose (1.12±0.10SE %) and peafowl (1.12±0.10SE %).

During 2010-11, sambar contributed maximum (43.52±1.19SE %) in tiger's diet followed by domestic livestock (18.98±0.84SE %), chital (18.06±0.79SE %), nilgai (12.50±0.54SE %), wild pig (6.02±0.43SE %) and common langur (0.93±0.30SE %).

During 2011-12, sambar contributed maximum (54.43±1.33SE %) followed by domestic livestock (17.72±0.89SE %), chital (15.19±0.90SE %), nilgai (8.23±0.77SE %) and wild pig (4.43±0.54SE %). The frequency of occurrence of all the detected prey species in the scat samples of the reintroduced tigers are given in figure 4.5.

The number of scat produced for each prey species was calculated dividing the average body weight (B) of each prey species by the weight of prey consumed per field collectible scat (Y) (derived from Ackerman's equation) (Table 4.1 to 4.4.). Biomass contribution of each prey species and proportions of number of individual prey species consumption in the diet of the reintroduced tigers during years 2008-09 to 2011-12 are given in table 4.1 to 4.4.

After comparing the utilization (from scat analysis) and availability (from distance sampling analysis) of prey species, an index of selection of each species was determined (Ivlev, 1961). It was found that, in 2008-09, sambar ($P<0.01$), chital ($P<0.01$) and nilgai were preyed upon more than their availability, while common langur ($P<0.01$) and domestic livestock ($P<0.01$) were preyed less than their availability (Figure 4.6). The prey preference order in 2008-09 was sambar> chital> nilgai> livestock> common langur wherein the reintroduced tigers significantly preferred sambar and chital. During 2009-10, sambar ($P<0.01$) was preyed more than their availability, while nilgai, chital, wild pig and domestic livestock ($P<0.01$) were preyed less than their availability (Figure 4.6). The prey preference order in 2009-10 was as follows: sambar> nilgai> chital> wild pig> common langur > livestock. During 2009-10, sambar was significantly preferred by the reintroduced tigers. During 2010-11, sambar ($P<0.01$) and chital ($P<0.01$) were preyed more than their availability, while common langur ($P<0.01$) and domestic livestock ($P<0.01$) were preyed less than their availability. Nilgai and wild pig were preyed little less in proportion to their availability ($P>0.05$) (Figure 4.6). The prey preference order in 2010-11 was in the following order: sambar> chital> wild pig> nilgai> livestock> common langur. During 2010-11, sambar and chital were significantly preferred by the tigers. During 2011-12, sambar ($P<0.01$) and chital ($P<0.01$) were preyed more than their availability, while nilgai, wild pig ($P<0.01$) and domestic livestock ($P<0.01$) were predated less than their availability (Figure 4.6). The prey preference in 2011-12 was in the following order: sambar> chital> nilgai>wild pig>livestock. During 2011-12, sambar and chital were significantly preferred by the tigers whereas wild pig and livestock were significantly not selected by the tigers.

A total of 115, 129, 127 and 95 kills of the reintroduced tigers were recorded in the study area respectively during 2008-09, 2009-10, 2010-11 and 2011-12. During 2008-09, sambar contributed maximum (42.61±1.44SE %) to the reintroduced tigers' diet as per the kill records followed by chital (20±0.88SE %), nilgai (13.04±0.70SE %), domestic livestock (11.30±0.78SE %), wild pig (8.70±0.56SE %), common langur (2.61±0.10SE %) and porcupine (1.74±0.10SE %) (Figure 4.7).

In 2009-10, sambar again contributed maximum (58.14±2.55SE %) in the kill records followed by domestic livestock (17.83±0.82SE %), nilgai (10.85±0.76SE %), chital (7.75±0.45SE %) and wild pig (5.43±0.45SE %) (Figure 4.7).

During 2010-11, domestic livestock contributed maximum (42.52±2.25SE %) in the kill records of reintroduced tigers followed by sambar (26.77±1.13SE %), chital (15.75±0.68SE %), nilgai (8.66±0.54SE %), wild pig (5.51±0.48SE %) and porcupine (0.79±0.10SE %) (Figure 4.7).

Again during 2011-12, domestic livestock contributed maximum (48.42±2.84SE %) in the kill records of reintroduced tigers followed by sambar (33.68±1.25SE %), chital (8.42±0.52SE %), nilgai (7.37±0.46SE %) and wild pig (2.11±0.22SE %) (Figure 4.7 and Table 4.5).

During 2008-09, adult female sambar were predated maximum (24.35±2.25SE %) among all the sex and age classes of the prey species, followed by adult male sambar (12.17±1.01SE %), chital adult male (9.57±0.60SE %), female adult livestock (buffalo and cattle) (8.70±0.80SE %), adult female nilgai (8.70±0.80SE %), chital adult female (7.83±0.65SE %) and adult female wild pig (6.96±0.60SE %) (Figure 4.8). During 2008-2009, rest of the available sex-age classes of the predated prey species contributed less than five percent individually in the diet of the reintroduced tigers.

Similarly during 2009-10, adult female sambar were again predated maximum (34.88±3.10SE %) followed by adult male sambar (16.28±1.20SE %), adult female livestock (11.63±1.10SE %), adult female nilgai (6.20±0.75SE %) and adult female chital (5.43±0.40SE %), while other sex-age classes of the consumed prey species contributed separately less than five percent to the diet of the tigers (Figure 4.9).

In contrary, in 2010-11 adult female of domestic livestock was predated maximum (32.28±3.10SE %) followed by adult female sambar (18.11±1.20SE %), adult female chital (9.45±0.75SE %), adult male sambar (7.87±0.70SE %), adult male livestock (7.09±0.71SE %), while other age-sex classes of the prey species were predated individually less than five percent by the reintroduced tigers (Figure 4.10).

Similar results were also found during 2011-12 when adult female domestic livestock was killed maximum (34.74±3.20SE %) by the tigers followed by adult female sambar (20±2.00SE %), adult male sambar (12.63±1.01SE %), adult male livestock (7.37±0.70SE %) along with other age-sex classes of the prey species contributed independently less than five percent to the diet of the reintroduced tigers (Figure 4.11).

It was observed that during 2009-10 and 2011-12, the ST2 tigress predated on a male peafowl and the ST6 male tiger killed a domestic camel. But these two unique observations were not incorporated in the analysis due to single value for the species. The details of the percentage frequency of consumption of different age-sex classes of each prey species during 2008-2012 are given in Table 4.6.

The visibility index (opposite to stalking cover) and the edge index were estimated for 466 kill sites during the year 2008-09 to 2011-12. The analysis of the mean visibility index at the kill site or attack site (V_{i0}) showed that the species such as porcupine and wild pig were hunted at least visible sites with visibility index 0.45±0.10SE and 0.52±0.08SE respectively, while domestic livestock and common langur were predated in much open or visible sites with index values as 0.71±0.05SE and 0.74±0.11SE respectively. The mean visibility index for all prey species at the kill or attack site 0.61±0.07SE was found to be reduced much to 0.33±0.06SE at a distance of 15m radially considering all eight directions.

The detail of the visibility index and pattern of stalking cover from kill sites of both individual prey species and all prey together are given in table 4.7 and figure 4.12. For each species there was a decline pattern of visibility observed from the kill sites to the 15m point radially with an interval of 5m. Whereas the mean difference between the open and closed habitats (edge index) were found maximum i.e. 2.40±0.39SE at the 10m point from the kill sites of the reintroduced tigers (Table 4.8).

Table 4.1. Average body weight, frequency of occurrence, proportion of biomass consumed and relative number of individual prey species consumed by reintroduced tigers as estimated by scat analysis (n = 103) in Sariska Tiger Reserve (2008-09).

Species	Prey consumed per field collectible scat (kg) (Y)	(Average Body Weight – X) (kg)	Percentage Frequency occurrence (F)	SE	Relative Biomass (RBM) (kg)	Relative individual consumed (RIC)
Sambar	6.36	125.00	41.75	0.98	273.27	33.40
Chital	3.56	45.00	26.21	0.43	95.99	58.25
Nilgai	8.28	180.00	10.68	0.40	91.08	5.93
Livestock	8.28	180.00	19.42	0.55	165.60	10.79
Langur	2.26	8.00	1.94	0.35	4.52	24.27
Wild pig	3.31	38.00	0.00	0.00	0.00	0.00

Table 4.2. Average body weight, frequency of occurrence, proportion of biomass consumed and relative number of individual prey species consumed by reintroduced tigers as estimated by scat analysis (n = 178) in Sariska Tiger Reserve (2009-10).

Species	Prey consumed per field collectible scat (kg) (Y)	(Average Body Weight – X) (kg)	Percentage Frequency occurrence (F)	SE	Relative Biomass (RBM) (kg)	Relative individual consumed (RIC)
Sambar	6.36	125.00	55.06	1.33	622.79	44.04
Chital	3.56	45.00	11.24	0.86	71.10	24.97
Nilgai	8.28	180.00	10.67	0.59	157.32	5.93
Livestock	8.28	180.00	12.36	0.66	182.16	6.87
Langur	2.26	8.00	3.93	0.28	15.82	49.16
Wild pig	3.31	38.00	2.25	0.30	13.24	5.91
Porcupine	2.47	14.00	1.12	0.10	4.94	8.00
Mongoose	2.0395	1.7	1.12	0.10	4.079	65.88
Rodent	1.987	0.2	1.12	0.10	3.974	560.00
Peafowl	2.099	3.4	1.12	0.10	4.198	32.94

Table 4.3. Average body weight, frequency of occurrence, proportion of biomass consumed and relative number of individual prey species consumed by reintroduced tigers as estimated by scat analysis (n = 216) in Sariska Tiger Reserve (2010-11).

Species	Prey consumed per field collectible scat (kg) (Y)	(Average Body Weight – X) (kg)	Percentage Frequency occurrence (F)	SE	Relative Biomass (RBM) (kg)	Relative individual consumed (RIC)
Sambar	6.36	125.00	43.52	1.19	597.37	34.81
Chital	3.56	45.00	18.06	0.79	138.65	40.12
Nilgai	8.28	180.00	12.50	0.54	223.56	6.94
Livestock	8.28	180.00	18.98	0.84	339.48	10.55
Langur	2.26	8.00	0.93	0.30	4.52	11.57
Wild pig	3.31	38.00	6.02	0.43	43.03	15.84

Table 4.4. Average body weight, frequency of occurrence, proportion of biomass consumed and relative number of individual prey species consumed by reintroduced tigers as estimated by scat analysis (n = 158) in Sariska Tiger Reserve (2011-12).

Species	Prey consumed per field collectible scat (kg) (Y)	(Average Body Weight – X) (kg)	Percentage Frequency occurrence (F)	SE	Relative Biomass (RBM) (kg)	Relative individual consumed (RIC)
Sambar	6.36	125.00	54.43	1.33	546.53	43.54
Chital	3.56	45.00	15.19	0.90	85.32	33.76
Nilgai	8.28	180.00	8.23	0.77	107.64	4.57
Livestock	8.28	180.00	17.72	0.89	231.84	9.85
Langur	2.26	8.00	0.00	0.00	0.00	0.00
Wild pig	3.31	38.00	4.43	0.54	23.17	11.66

Figure 4.1. Relationship between contributions of five major prey species in reintroduced tigers' diet with number of scats studied in Sariska Tiger Reserve during 2008-09.

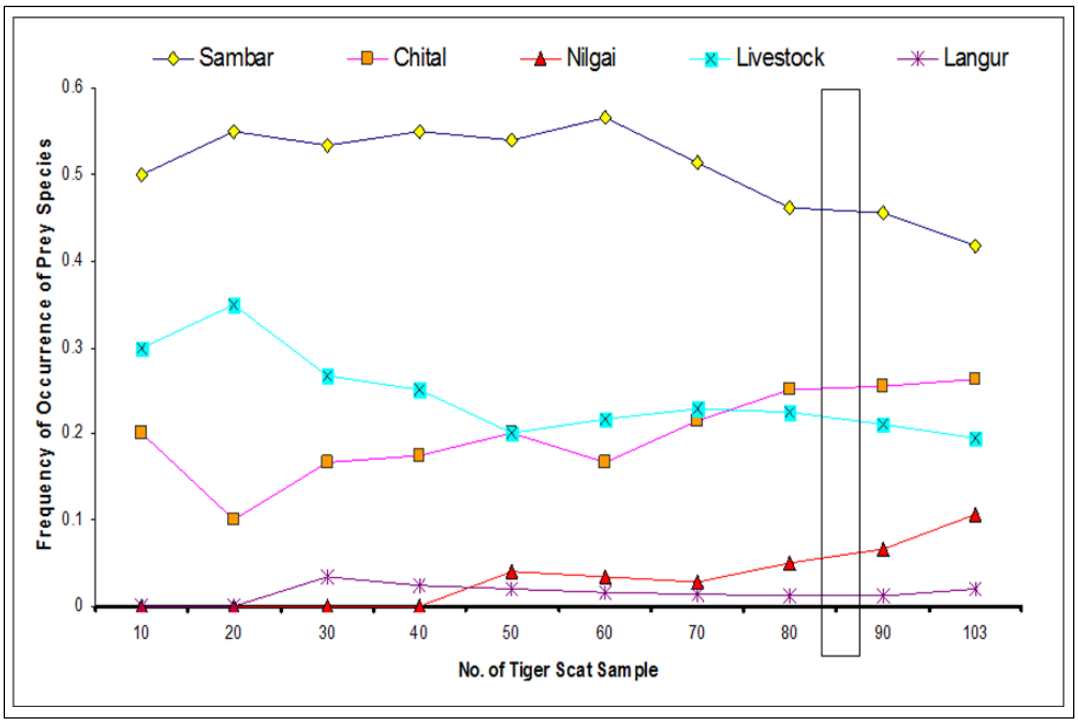


Figure 4.2. Relationship between contributions of ten prey species in reintroduced tigers' diet with number of scats studied in Sariska Tiger Reserve during 2009-10.

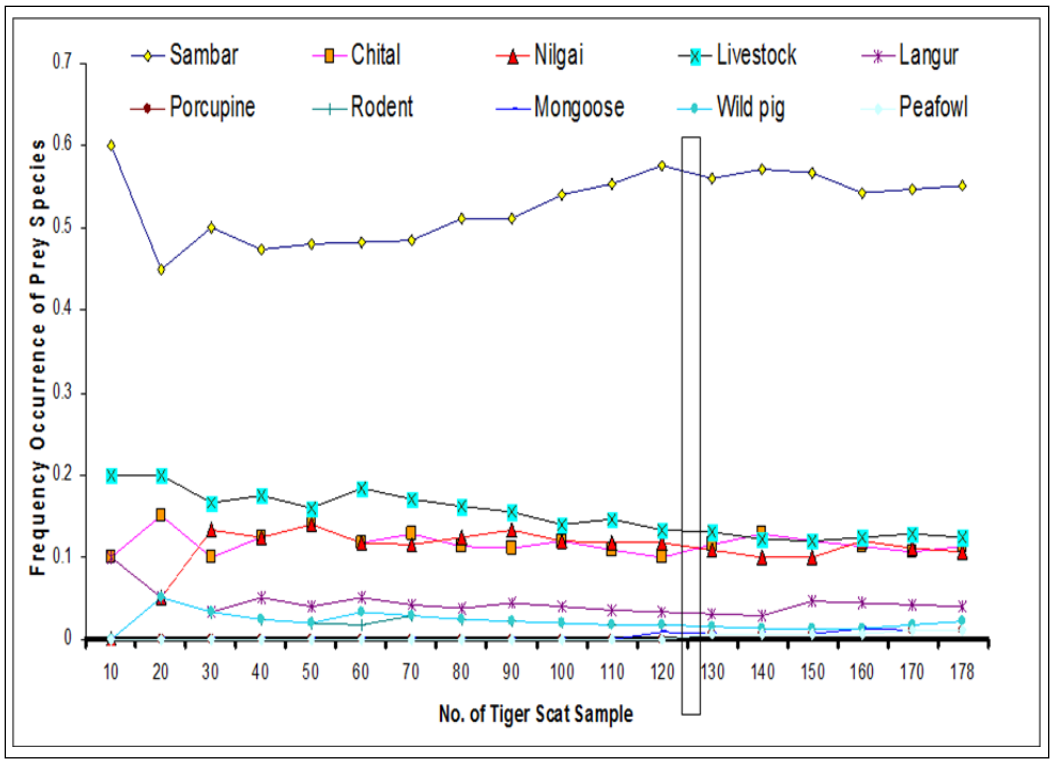


Figure 4.3. Relationship between contributions of six prey species in reintroduced tigers' diet with number of scats studied in Sariska Tiger Reserve during 2010-11.

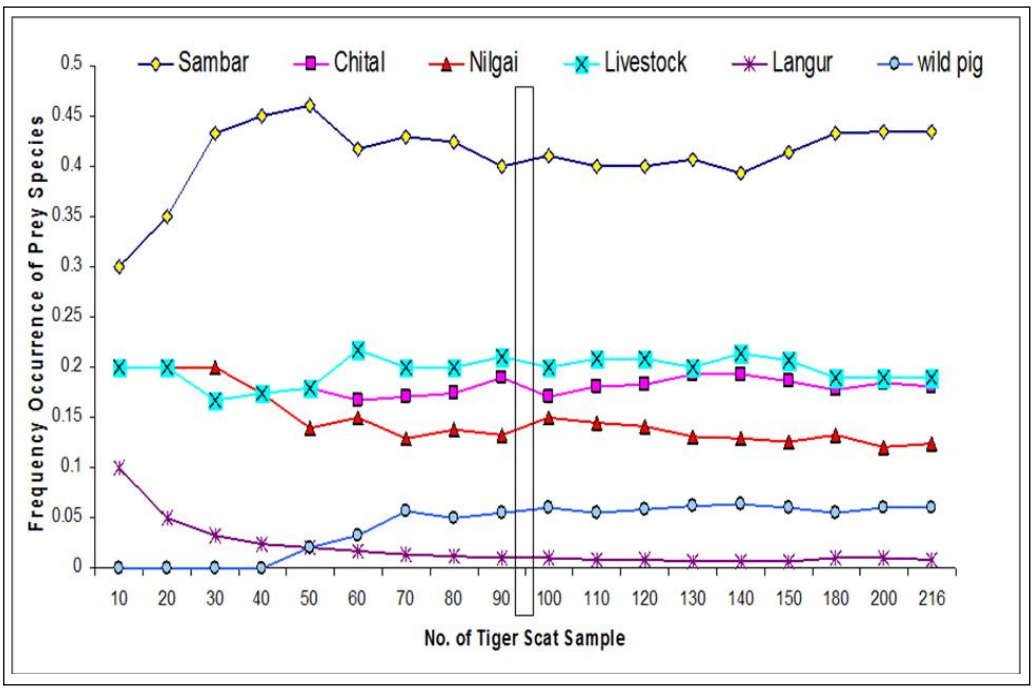


Figure 4.4. Relationship between contributions of five prey species in reintroduced tigers' diet with number of scats studied in Sariska Tiger Reserve during 2011-12.

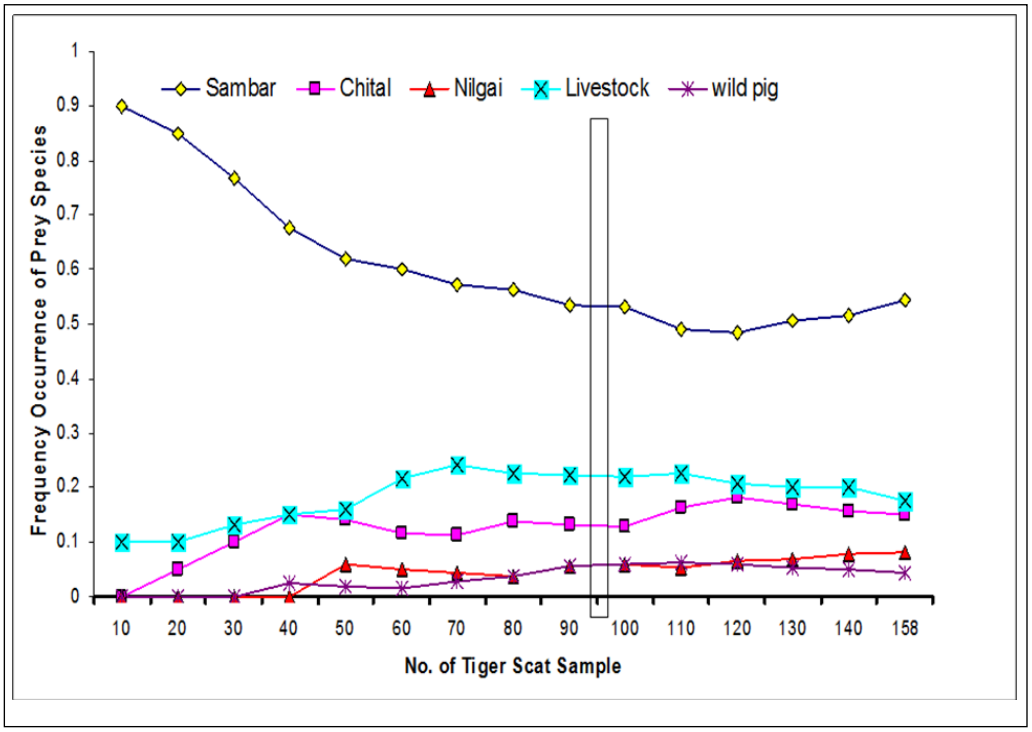


Figure 4.5. Percentage occurrence of prey species found in the scats of reintroduced tigers during July 2008 to June 2012 in Sariska Tiger Reserve.

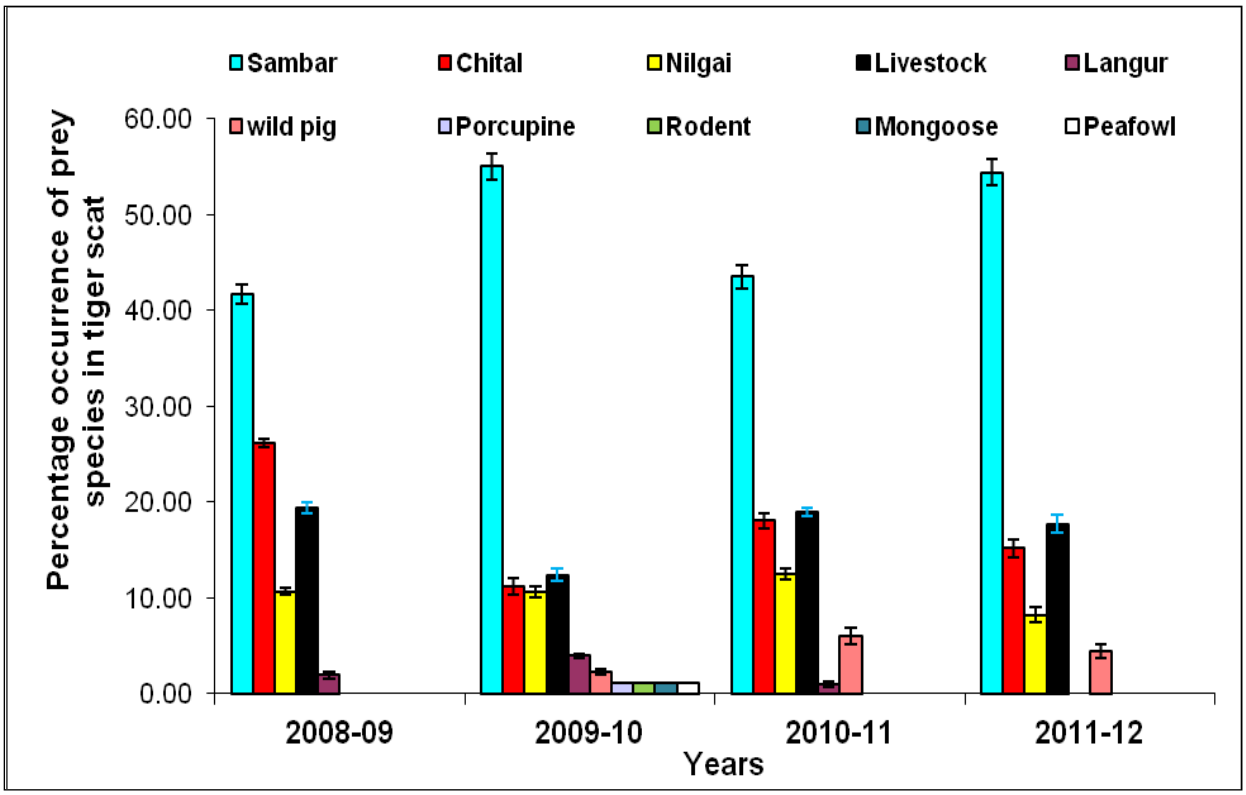


Figure 4.6. Prey preference by reintroduced tigers in Sariska Tiger Reserve based on availability of individuals and utilization through scat analysis from 2008-09 to 2011-12.

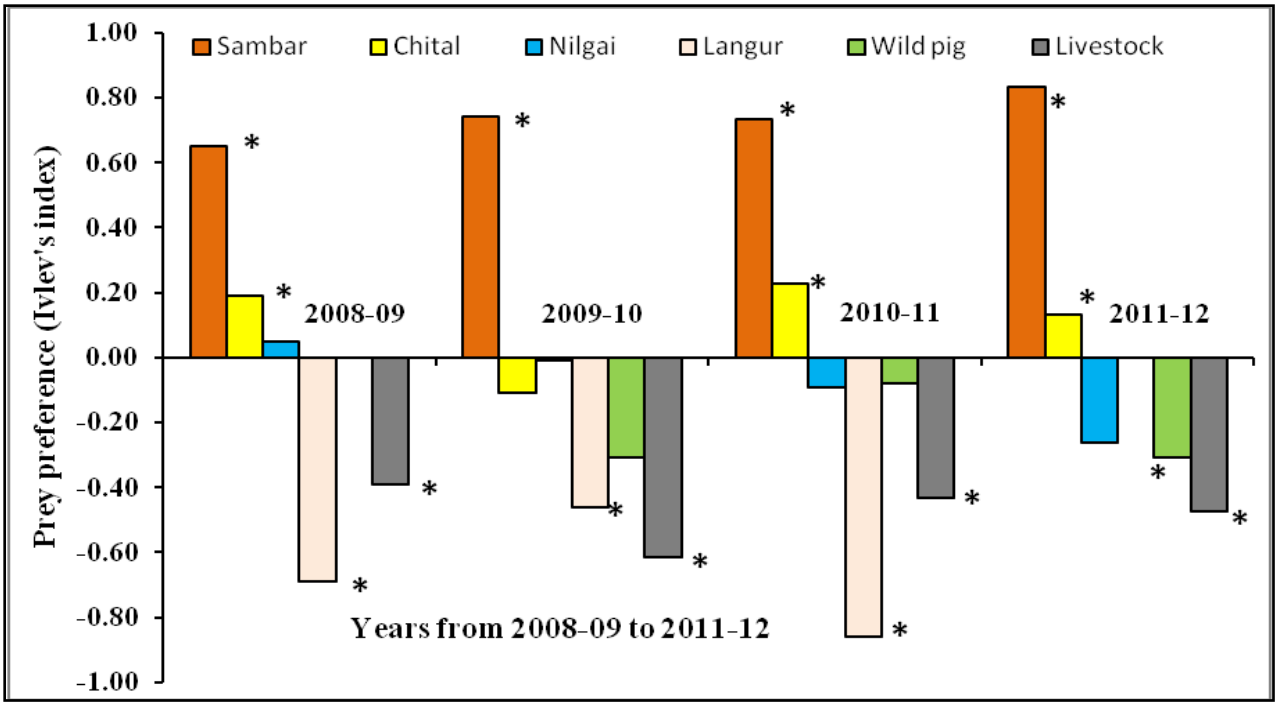


Table 4.5. Percentage frequency of occurrence of individual prey species consumed by reintroduced tigers based on kill data in Sariska Tiger Reserve during 2008 - 2012.

Species	2008-09 (n =115)		2009-10 (n = 129)		2010-11 (n = 127)		2011-12 (n = 95)	
	Percentage Frequency	SE	Percentage Frequency	SE	Percentage Frequency	SE	Percentage Frequency	SE
Chital	20.00	0.88	7.75	0.45	15.75	0.68	8.42	0.52
Nilgai	13.04	0.70	10.85	0.76	8.66	0.54	7.37	0.46
Sambar	42.61	1.44	58.14	2.55	26.77	1.13	33.68	1.25
Wild pig	8.70	0.56	5.43	0.45	5.51	0.48	2.11	0.22
Common langur	2.61	0.24	Not reported	n.a.	Not reported	n.a.	Not reported	n.a.
Porcupine	1.74	0.10	Not reported	n.a.	0.79	0.10	Not reported	n.a.
Domestic livestock	11.30	0.78	17.83	0.82	42.52	2.25	48.42	2.84

n.a. – Not applicable

Figure 4.7. Percentage Frequency of occurrence of prey species killed by reintroduced tigers in Sariska Tiger Reserve from 2008-09 to 2011-12.

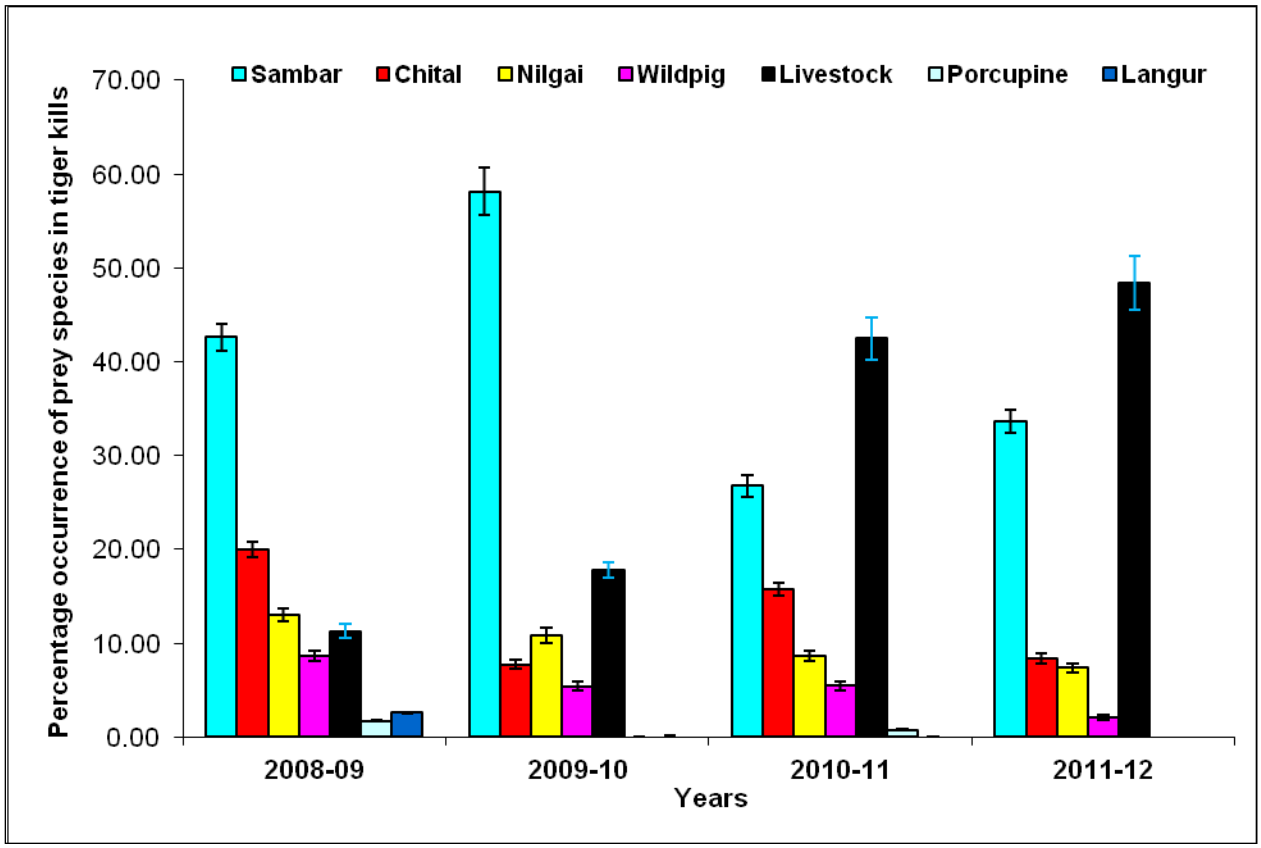


Table 4.6. Percentage frequency of occurrence of each prey species and their age and sex, consumed by reintroduced tigers based on kill data in Sariska Tiger Reserve during 2008 -2012.

Species-sex-age class	2008-09 (n = 115)		2009-10 (n = 129)		2010-11 (n = 127)		2011-12 (n = 95)	
	Percentage Frequency	SE	Percentage Frequency	SE	Percentage Frequency	SE	Percentage Frequency	SE
Common langur adult	2.61	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Chital male sub adult	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
chital male adult	9.57	0.60	1.55	0.10	2.36	0.20	3.16	0.25
Chital female sub adult	2.61	0.20	0.78	0.10	3.94	0.30	1.95	0.10
chital female adult	7.83	0.65	5.43	0.40	9.45	0.75	4.21	0.30
Nilgai male sub adult	0.87	0.10	0.00	0.00	0.79	0.10	0.00	0.00
Nilgai male adult	3.48	0.30	3.88	0.30	0.79	0.10	4.21	0.30
Nilgai female sub adult	0.00	0.00	0.78	0.10	0.79	0.10	0.00	0.00
Nilgai female adult	8.70	0.80	6.20	0.75	6.30	0.76	2.11	0.20
Sambar male sub adult	0.87	0.10	1.55	0.10	0.79	0.10	0.00	0.00
Sambar male adult	12.17	1.01	16.28	1.30	7.87	0.70	12.63	1.01
Sambar female sub adult	5.22	0.40	5.43	0.40	0.00	0.00	1.05	0.10
Sambar female adult	24.35	2.25	34.88	3.10	18.11	1.20	20.00	2.00
Wild pig male sub adult	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wild pig male adult	1.74	0.15	2.33	0.20	2.36	0.20	1.05	0.10
Wild pig female sub adult	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wild pig female adult	6.96	0.60	3.10	0.30	3.15	0.30	1.05	0.10
Porcupine	1.74	0.15	0.00	0.00	0.00	0.00	0.00	0.00
Livestock male sub adult	0.87	0.10	2.33	0.20	1.57	0.12	7.37	0.70
Livestock male adult	1.74	0.12	3.88	0.32	7.09	0.71	1.05	0.10
Livestock female sub adult	0.00	0.00	0.00	0.00	1.57	0.12	5.26	0.45
Livestock female adult	8.70	0.80	11.63	1.10	32.28	3.10	34.74	3.20

Figure 4.8. Percentage Frequency of occurrence of age-sex class of prey species killed by reintroduced tigers in Sariska Tiger Reserve during 2008-09.

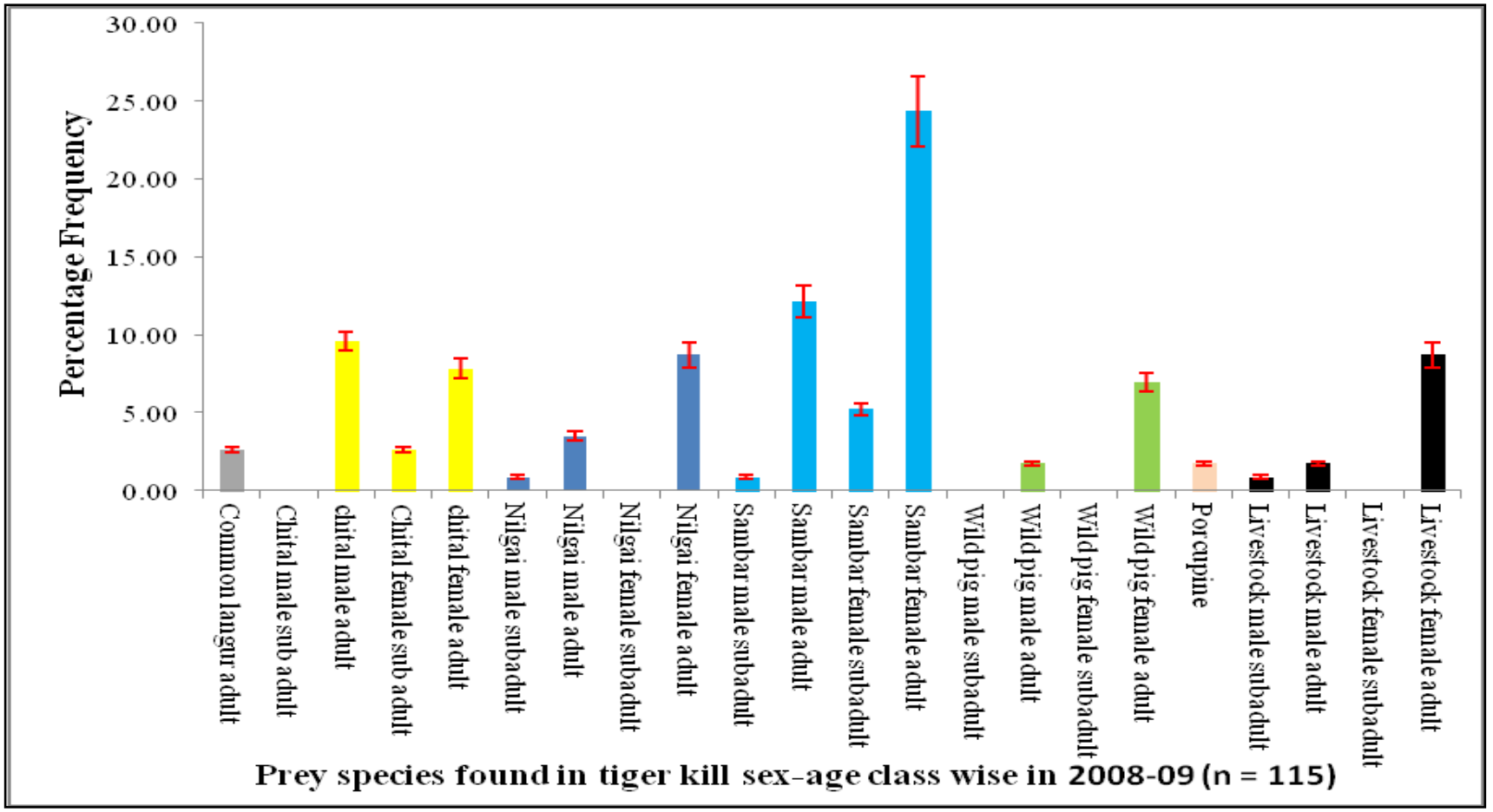


Figure 4.9. Percentage Frequency of occurrence of age-sex class of prey species killed by reintroduced tigers in Sariska Tiger Reserve during 2009-10.

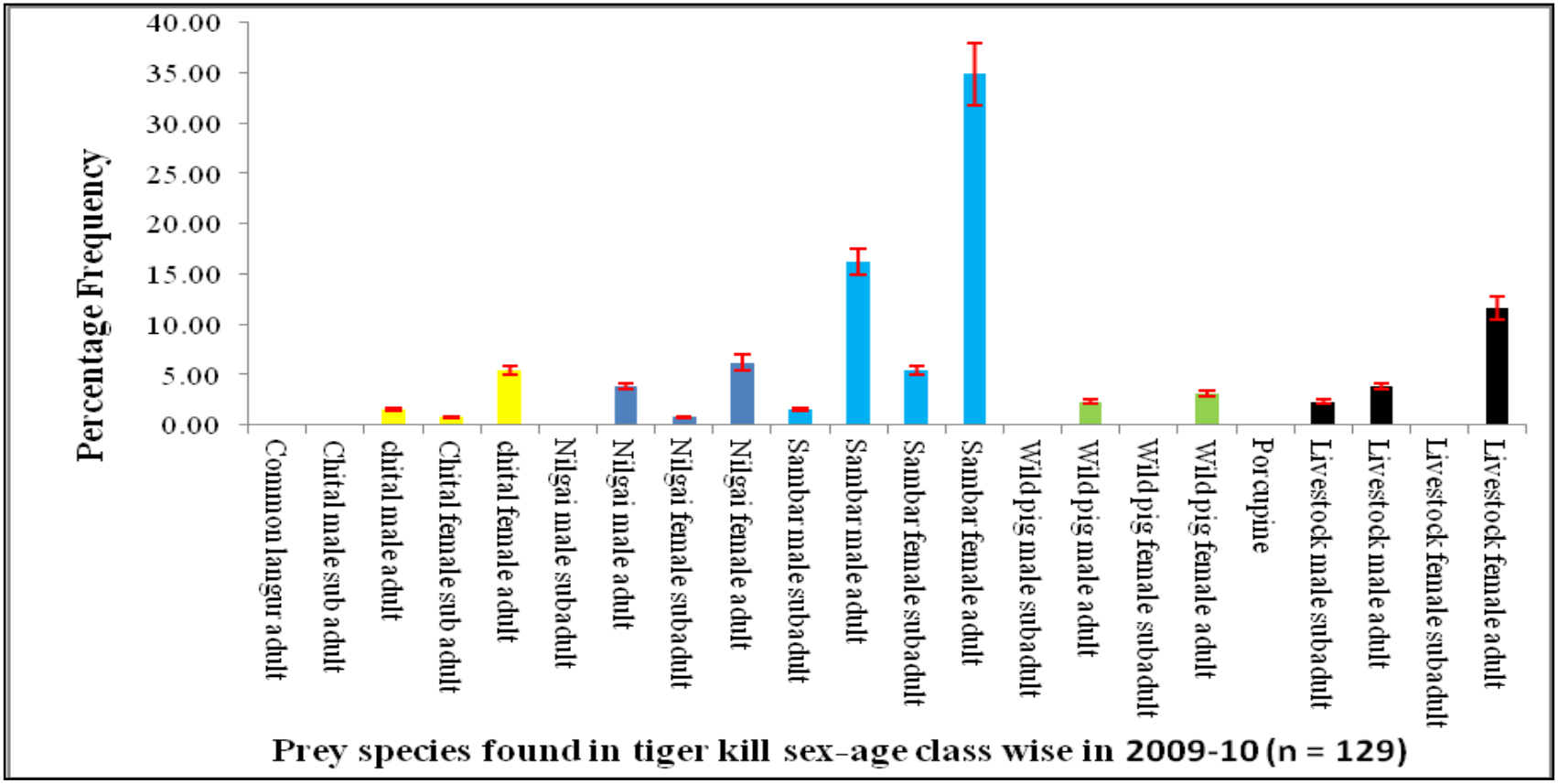


Figure 4.10. Percentage Frequency of occurrence of age-sex class of prey species killed by reintroduced tigers in Sariska Tiger Reserve during 2010-11.

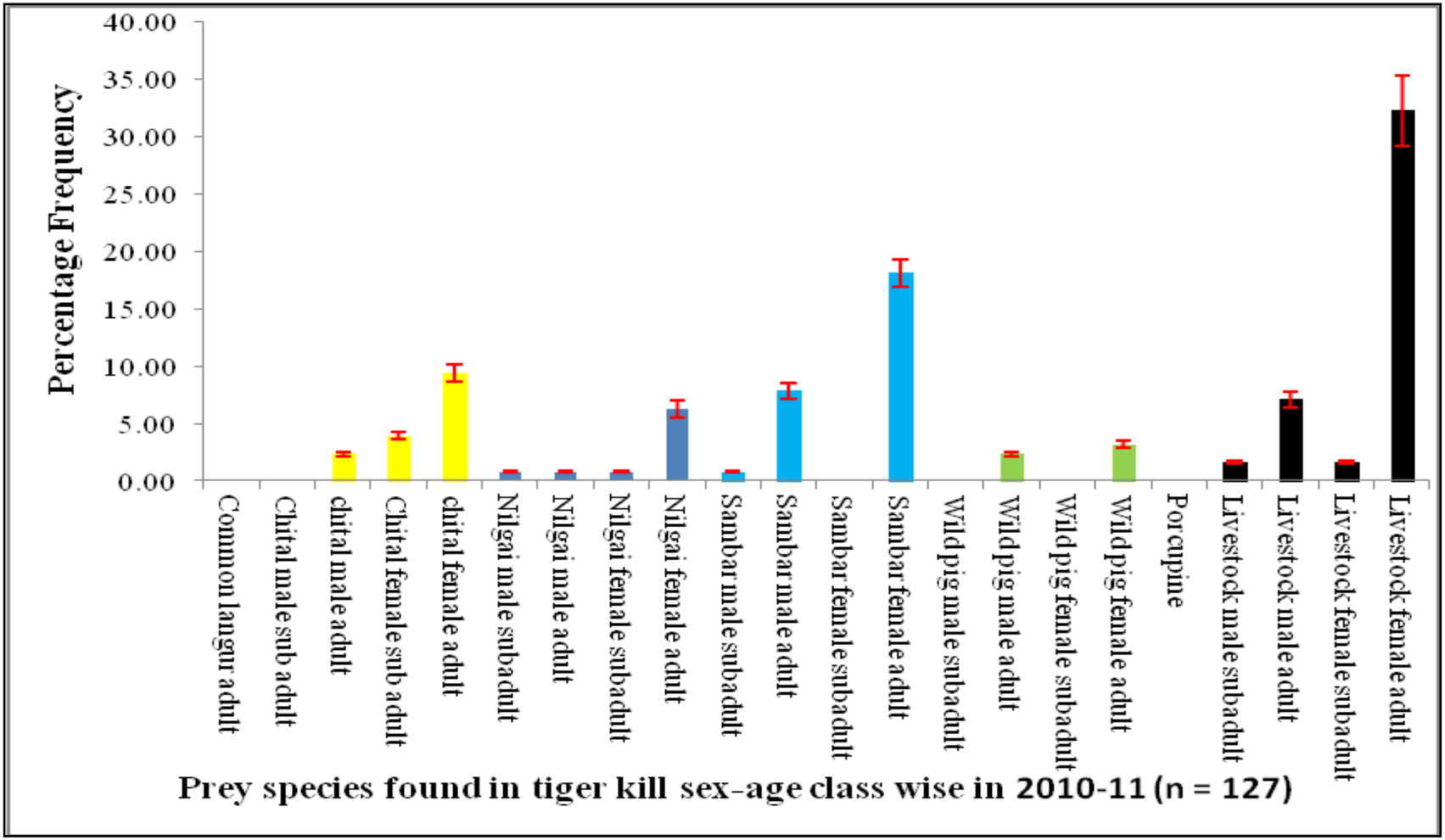


Figure 4.11. Percentage Frequency of occurrence of age-sex class of prey species killed by reintroduced tigers in Sariska Tiger Reserve during 2011-12.

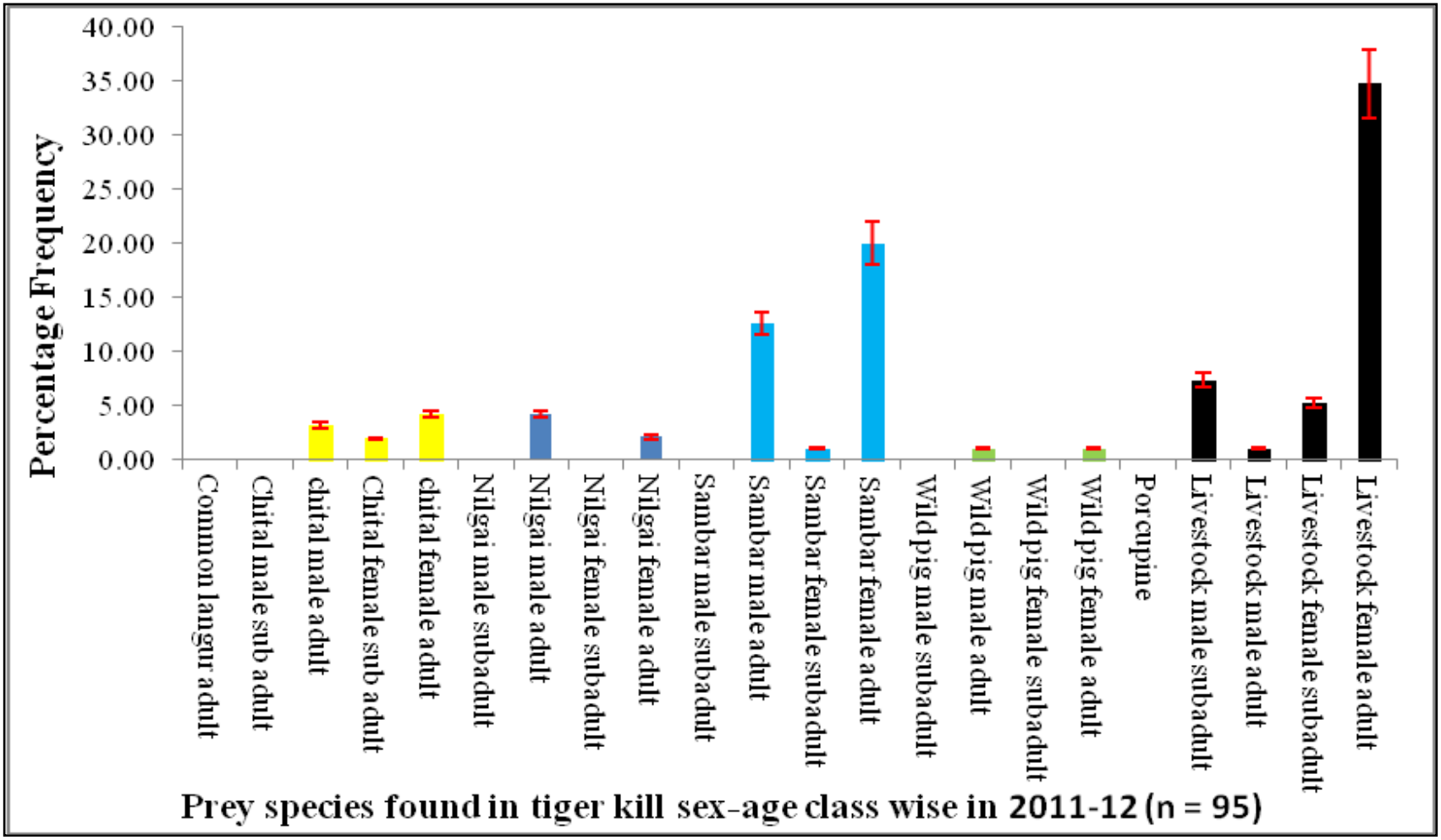


Table 4.7. Indices of visibility to estimate the stalking cover by reintroduced tigers around 15 m radius from the kill site in Sariska Tiger Reserve during 2008 -2012.

Species / Categories	Total sampling points	Vi0 (X)	SE	Vi5 (X)	SE	Vi10 (X)	SE	Vi15 (X)	SE
Sambar	189	0.68	0.05	0.64	0.06	0.55	0.05	0.39	0.04
Chital	61	0.56	0.06	0.51	0.06	0.42	0.07	0.28	0.03
Nilgai	47	0.62	0.06	0.54	0.07	0.48	0.07	0.35	0.04
Wild pig	26	0.52	0.08	0.46	0.08	0.47	0.09	0.27	0.06
Livestock	136	0.71	0.05	0.61	0.05	0.54	0.05	0.39	0.03
Porcupine	3	0.45	0.10	0.40	0.09	0.34	0.10	0.21	0.09
Langur	3	0.74	0.11	0.65	0.10	0.58	0.10	0.43	0.10
All prey	466	0.61	0.07	0.54	0.07	0.48	0.08	0.33	0.06

(Vi0 (X) = Mean visibility at the kill site; Vi5 (X) = Mean visibility at 5 m radius from the kill site; Vi10 (X) = Mean visibility at 10 m radius from the kill site; Vi15 (X) = Mean visibility at 15 m radius from the kill site; SE = Standard Error.)

Figure 4.12. Visibility estimation pattern to understand the stalking cover used by reintroduced tigers around 15 m radius from the kill sites at Sariska Tiger Reserve during 2008 -2012.

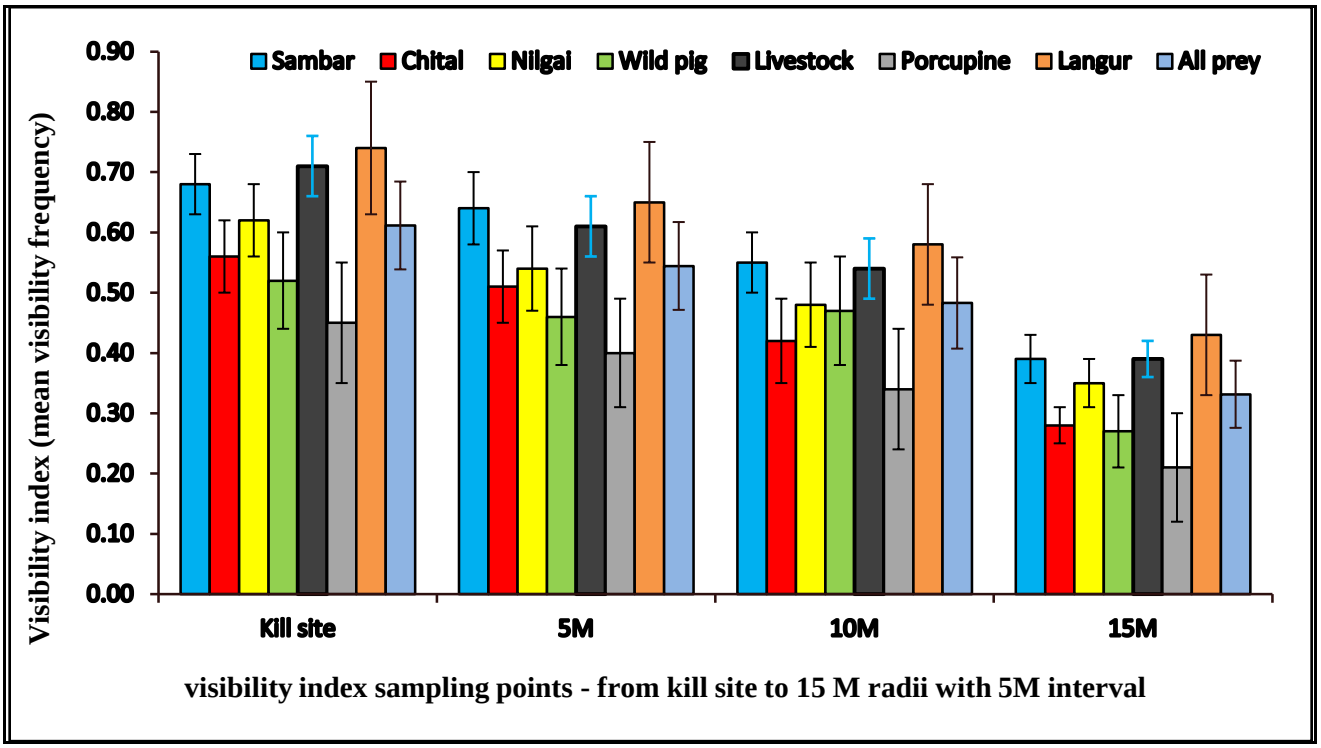


Table 4.8. Indices of edge as the difference of stalking cover utilized by reintroduced tigers around 15 m radius from the kill sites at Sariska Tiger Reserve during 2008 -2012.

Species / Categories	Total sampling points	Ei5 (X)	SE	Ei10 (X)	SE	Ei15 (X)	SE
Sambar	189	2.25	0.45	2.50	0.42	2.50	0.46
Chital	61	2.38	0.51	2.44	0.39	2.13	0.38
Nilgai	47	2.13	0.42	2.25	0.37	2.31	0.35
Wild pig	26	2.06	0.38	2.31	0.36	2.38	0.42
Livestock	136	1.88	0.29	2.38	0.38	2.44	0.46
Porcupine	3	2.38	0.32	2.48	0.42	2.31	0.39
Langur	3	2.38	0.28	2.46	0.40	2.50	0.48
All prey	466	2.21	0.38	2.40	0.39	2.37	0.42

(Ei5 (X) = Mean edge index at 5 m radius from the kill site; Ei10 (X) = Mean edge index at 10 m radius from the kill site; Ei15 (X) = Mean edge index at 15 m radius from the kill site; SE = Standard Error.)

4.5. DISCUSSION

It was evident that sambar and chital were predated more than 50% by the reintroduced tigers during the study period in Sariska Tiger Reserve. In terms of prey biomass consumed, chital and sambar were found to contribute maximum in the diet of large carnivores in India (Biswas and Sankar, 2002; Bagchi *et al*., 2003; Reddy *et al*., 2004; Avinandan *et al*., 2008; Ramesh *et al*., 2008; Sankar *et al*., 2010). The predation rate of sambar by reintroduced tigers in Sariska was more as compared to other studies i.e. Ranthambhore, Pench Madhya Pradesh, Bandipur, Nagarhole and Nagarjunsagar Shrisailam Tiger Reserves (Table 4.9). However, the rate of predation pattern of chital in Sariska was found lower than the above mentioned sites. More sambar predation in the present study may be attributed to the wider distribution of sambar across the study area while distribution of chital was largely restricted in the valley habitats (Avinandan *et al*., 2008).

The study revealed that the domestic livestock was predated by tigers in Sariska in high proportion (overall 17.12% as per the scat data and 30.02% based on kill data) and this may lead to tiger-human conflict issues in future.

Table 4.9. Relative frequency occurrence of the prey species in diet of tiger based on scat analysis from different studies in India.

Author	Chital (%)	Sambar (%)	Nilgai (%)	Wild pig (%)	Common langur (%)	Livestock (%)
Present study (2011-12)	15.19	54.43	8.23	4.43	0.00	17.72
Karanth and Sunquist, 1995	31.20	24.90	NP*	9.40	3.90	-
Biswas and Sankar, 2002	47.27	14.55	-	10.91	3.65	8.18
Bagchi *et al*., 2003	45.67	36.86	3.27	2.89	4.86	5.49
Reddy *et al*., 2004	25.60	9.70	3.60	28.00	1.20	7.31
Andheria *et al*., 2007	32.66	22.30	NP*	9.01	2.25	0.45
Avinandan *et al*., 2008	19.48	51.95	13.79	1.14	5.19	19.58
Ramesh *et al*., 2008	22.75	59.79	NP*	4.23	5.29	3.18

NP*: Not present

Results from a previous study in the study area revealed that sambar and chital were largely predated by tigers when there was an established population of 20-24 tigers (Sankar and Johnsingh 2002; Avinandan *et al*., 2008). However, during 2011-12, reintroduced tigers largely preyed upon sambar and chital while domestic livestock also contributed to a large extent in tiger's diet (Table 4.9). Little more than two percent (2.1%) of buffalo remains was reported in tiger's diet in 2002 (Sankar and Johnsingh 2002) while Avinandan *et al*., (2008) during their study in 2002-03 documented 19% livestock remains in the diet of the tigers. Similarly during 2011-12 (present study), scat analysis revealed that livestock remains were found in 17.72% of the diet of the reintroduced tigers.

Estimation of visibility index or stalking cover also showed that the reintroduced tigers predated domestic livestock in much open or visible habitats (visibility index 0.71±0.05SE) where they got easily detected by the villagers and sometimes disturbed by scavengers such as wild pig, hyena and jackal. The declining pattern of the mean visibility index from the kill or attack site (0.61±0.07SE) to the 15m radial points in all eight directions (0.33±0.06SE) showed that tigers preferred to stalk their prey from a thicker or less visible cover and tried to attack them in relatively more visible areas.

Unlike the studies of Biswas and Sankar (2002), Bagchi *et al*. (2003) and Reddy *et al*. (2004), where tigers were more dependent on wild ungulates, the present study on the reintroduced tigers in Sariska revealed that despite high wild prey abundance in the study area, tigers were still considerably dependent on domestic livestock, posing challenges for the park management

to resolve tiger-human conflicts. After the death of the first reintroduced tiger (ST1) due to poisoning inside the Tiger Reserve on 14th November 2010, the park administration had started paying compensation to livestock owners, for the livestock killed by the tigers and other predators inside the Tiger Reserve. The increase in the detection of domestic livestock kills by the villagers for receiving the compensation since December 2010 might have augmented the proportion of domestic livestock in the kill record during 2010-11 and 2011-12. Complete relocation of the existing villages (n=8) and ban on livestock grazing and other anthropogenic activities in the notified National Park area and restriction on free grazing practices in other areas of the Tiger Reserve are therefore highly necessitated and recommended. It is recommended that the practice of providing compensation should continue till all the villages from the Tiger Reserve are relocated.

CHAPTER FIVE

5. MOVEMENT AND RANGING PATTERNS OF THE REINTRODUCED TIGERS

5.1. INTRODUCTION

Spatial organization or distribution of any population of wild species is one of the most fundamental issues of ecology and evolutionary biology. Spatial distribution has direct influence on the demographic parameters of a population and therefore controls the effective population size within any area (Goodrich *et al*., 2010). The best way to address and understand the natural history of any species is to gather data of its home range and related activities (Burt, 1943). The home range and territory of any individual within a population is regulated usually by the limiting resources in a landscape (Ebersole, 1980; Hixon, 1980; Schoener, 1981; Powers and McKee, 1994; Powell *et al*., 1997; Powell, 2000). The home range of an animal can be defined as the area traversed by the animal in its normal activities of gathering food, caring for young and mating whereas occasional sallies outside the area, perhaps exploratory in nature, should not be considered part of the home range (Burt, 1943). Since "normal" activities are difficult to define, Anderson (1982) and Blundell *et al*., (2001) defined home range as the Probability of locating an animal at a particular place by using a utilization distribution based statistics on relative frequency of location. For any reintroduced animal it is important to know the movement and spatial distribution in the area where they have reintroduced.

A territory is that part of an individual's home range which he / she defends to protect resources (Ostfeld, 1990; Wolff, 1993; Powell *et al*., 1997; Powell, 2000) or offspring (Wolff, 1997). The range must satisfy the energy needs of the animal (Gittleman and Harvey, 1982) and uneven use of the range can provide information about the distribution, importance and accessibility of important resources such as food (Henschel, 1986). The size of home ranges of carnivores appears to be influenced by food availability, body mass and population density (Gittleman and Harvey, 1982; Benson *et al*., 2006). As expected, larger bodied animals need larger home ranges to meet metabolic needs (McNab, 1963). Estimation of home range of an individual or a species is essential for diverse reasons of research and management issues. Information on animals' home ranges provides significant insight into mating patterns and reproduction, social organization and interactions, foraging and food choices of the limiting resources and other

important components of habitat. Quantifying an animal's home range is a procedure of using information about the use of space by the individual to deduce or to gain insight into the cognitive map of its home (Peters, 1978). The utilization distribution maps represent the intensity of use and therefore it can be transformed into a probability density function that describes the probability of an animal being in any part of its home range (Powell, 2000).

The approach using a utility distribution as a probability density function provides one objective way to define an animal's normal activities. A probability level criterion may also be incorporated to eliminate Burt's (1943) occasional sallies. Within an animal's home range the area in which it is estimated to have a 100 percent probability of having spent time would include occasional sallies. The smallest area in which the animal spent 95 percent of its time could exclude occasional sallies. Using a utilization distribution, home range may be operationally defined as the smallest area that accounts for a specified proportion of the total use (Powell, 2000). Most biologists use 0.95 (i.e., 95 percent) as probability level; the smallest area with a probability of use equal to 0.95 is defined as an animal's home range (Powell, 2000). No strong biological logic supports the choice of 0.95 except that exploratory behavior is assumed to be excluded by using this probability level. Eliminating the locations beyond this probability might also eliminate occasional sallies. Statistically the non-independent locations from sequential observations rarely conform to the parametric models of utilization distribution (Powell, 2000). However, lack of independent locations or data may not be a great problem for some analyses (Andersen and Rongstad 1989; Gese *et al*., 1990; Lair 1987; Powell, 1987; Reynolds and Laundrè, 1990). After all, locations that are not statistically auto-correlated are however biologically auto-correlated because animals use cognitive knowledge of their home ranges to plan their future movements.

Herfindal *et al*., (2005) reported a negative correlation between food availability and home range sizes for male and female Eurasian lynx (*Lynx lynx*), which suggests that when food availability increases smaller home ranges are required to obtain sufficient nutrition for survival and reproduction (Benson *et al*., 2006).

Since tiger is a specialized hunter (Sunquist and Sunquist, 1989), it can survive on a wide range of prey species (Hayward *et al*., 2012). Though they are considered habitat generalists (Sunquist, *et al.,* 1999), tigers are still vulnerable to habitat loss and fragmentation since they always prefer a high biomass of large-sized prey (Karanth and Sunquist, 1995) and in the absence of wild prey

populations their ranging pattern and resource selection gets really affected (Karanth, 1991). Their breeding success, social organization and land tenure system are affected by the availability, composition and distribution (temporally and spatially) of suitable prey species. Therefore, emphasis should be given on understanding the predator-prey relationship in any landscape. It is also important to study how the tiger responds to the variable environment. For any reintroduction project, it is important to understand how the reintroduced individuals or population are using and interacting with the new habitat. Home range and habitat utilization studies are the key to assess the reintroduction success of animal.

5.2. LITERATURE REVIEW

One of the basic requirements in the study of animal ecology is the understanding of relationship between the animal and its surrounding environment. At a much simplified consideration, this requirement is sufficed with home range analyses. Home range is a concept that attempts to describe the spatial context of an animal's behavior. From the outset, home range has been measured in terms of the hard boundary defining the edge of polygon containing the area used by an animal (Powell, 2000).

The tiger (*Panthera tigris* L.) is the largest of all felids found in diverse habitat types and show remarkable tolerance to the variation in altitude, temperature and rainfall regimes (Sunquist *et al*., 1999). Being a large and charismatic carnivore, the tiger has attracted considerable attention in the worldwide conservation community (Chundawat *et al*., 2002). In spite of this great attention, the status of this predator has been deteriorating rapidly (Chundawat *et al*., 2002; Jhala *et al*., 2008).

Tigers are territorial and wide-ranging and the effective size of their territory is a function of the density and biomass of prey species in its habitat (Sunquist, 1981). Therefore, studies undertaken to deal with these issues on tiger are important because it can provide a better insight of tiger ecology and behavior. Radio-telemetry studies on tiger have been effectively pursued to address these questions from last 40 years (Seidensticker, 1976; Sunquist, 1981; Smith *et al*., 1987a, 1987b; Smith, 1993; Chundawat *et al*., 1999; Chundawat *et al*., 2002; Goodrich *et al*., 2010). The land tenure system of tigers is broadly similar to that of many other large felids where adult males typically occupy large areas that overlap the home areas of one or more adult females. Female ranges are usually much smaller than those of males. However, the fact those home

ranges can vary widely within a species living in specific landscapes, which makes comparison of the results between study areas difficult (Herfindal *et al*., 2005). It is therefore important to estimate site specific ranging patterns of tigers for better understanding of ecology, conservation and management recommendation.

Smith *et al*., (1983) radio-collared 26 tigers (12 adults and 14 sub-adults) in Royal Chitwan National Park (RCNP), Nepal to study their dispersal patterns, predation and social behavior and interactions with the habitat. Resident female as well as young individuals of age nine to 17 months were radio-collared. The home ranges of the adult females were estimated from 10.6 to 50.4 km^2. Altogether 36 adults and sub-adults tigers were monitored to study their movements and social interaction patterns related to dispersal (Smith, 1993). The Chitwan tigers were reported an isolated remnant of a population once continuous across the lowlands of Nepal. This tiger population was considered as one of the largest isolated tiger populations remaining in the world (Smith, 1993). Isolation and small size threatened these populations with stochastic events that may lead to further reduction in population size.

Five tigers (a male and four female) were radio-collared and subsequently monitored to understand their ranging patterns and interaction with the habitat and prey species in the deciduous forest of Panna Tiger Reserve, Madhya Pradesh (Chundawat, 2001). The study revealed that the home ranges of female tigers are larger than those in other tiger habitats studied. The authors have also reported that the home ranges of all the tigers either extend beyond the Park boundary or touch the periphery, exposing breeding individuals to external anthropogenic pressures and related threats. The study had also found that the tiger distribution had a strong relation to the distributions of chital and sambar and availability of water in the park. All prey species density was reported low (32 animals / km^2) as compared to other similar habitats in the study. The study recommended to integrate the adjoining territorial forest patches where the home ranges of the tigers were extended, to bring them under the management of Panna Tiger Reserve.

Goodrich *et al*., (2010) studied ranging pattern, spatial characteristics and changes in land tenure of radio-collared Amur tigers (*Panthera tigris altaica*) in the Sikhote-Alin Biosphere Zapovednik, Russia, during 1992 to 2006. The authors hypothesized that both male and female would maintain spatially exclusive home ranges and the sub-adult female tigers would show philopatry while males would disperse. Home ranges of resident females (n = 20 home ranges of

14 females) estimated by 95% fixed kernel estimator as 390±136SE km^2 were significantly (P = 0.003) smaller than those of males (n = 6 home ranges of 5 males) i.e. 1,385±539SE km^2 using the same estimator. All radio-collared male cubs dispersed (n = 7) during the study while only two out of six female cubs were found dispersed from their natal home ranges. The study showed that when human-caused mortality was low, adult female tigers survived long enough to share their home range with their daughters, resulting in smaller home ranges forming a higher density of breeding females. All females thereafter reproduced in these smaller territories. However, when human-caused mortality was high, population density was observed apparently much below carrying capacity. The study also suggested that the impacts of poaching appeared to extend beyond the direct loss of individuals, and therefore reserves must be well protected to serve as source populations for adjacent, unprotected areas of tiger habitat.

Barlow *et al*., (2011) communicated a study of two adult female tigers, captured and fitted with global positioning system radio-collars in the south-east of the Sundarbans. Mean home range sizes for these two tigresses were estimated as 12.3 km^2 and 14.2 km^2 with 95% minimum convex polygon (MCP) and fixed kernel (FK) methods respectively. Mean home range size of 14.2 km^2 of a female indicated an approximate density of seven adult females per 100 km^2 in the south-east Sundarbans. The maximum distance moved by a collared individual in one day was 11.3 km. Although the findings were preliminary, yet these home range estimates signified that the Sundarbans of Bangladesh had good quality tiger habitat relative to other tiger landscapes, highlighting the value of this mangrove ecosystem for the survival of this critically endangered species.

Majumder *et al*., (2012) studied ranging patterns of three radio-collared tigers (one adult female, one adult male and one sub-adult male) between March 2008 and December 2011 in Pench Tiger Reserve (PTR), Madhya Pradesh. They estimated the home ranges of adult female, adult male and sub-adult male were 43 km^2, 55.1 km^2 and 52.2 km^2 respectively using 100% minimum convex polygon (MCP). Similar observations for these individuals using 95% fixed kernel (FK) were 32.1 km^2, 64.1 km^2 and 19.1 km^2 respectively. The core area of individual activity for each tiger estimated by 65% FK, were 10.3 km^2, 20.3 km^2 and 6.6 km^2 for the adult female, adult male and the sub-adult male respectively. The radio-collared adult female had recruited three, four and five cubs in her three respective litters. The study showed that minimum 44% of the original natal area was used by the adult female at the time of raising her second litter and 46%

during her third litter. The authors observed a gradual extension of the annual home range of the adult female during the first two years (2008-2010), but the core activity area remained considerably the same over the study period. The study recommended that a minimum of 25 km² to 30 km² inviolate area was required for a breeding female in Pench Tiger Reserve along with high wild prey density (348.2 km^{-2}) and adequate ground cover for the successful raising of cubs up to the dispersal stage.

Priatna *et al*., (2012) rescued and translocated four adult male Sumatran tigers (*Panthera tigris sumatrae*). The tigers were released after 16-225 days of rehabilitation. All of them were fitted with global positioning system radio-collars and subsequently released 74-1,350 km away from their capture site. These tigers were observed to establish their home range in between 6 and 13 weeks. The home range of theses tigers estimated with 100% minimum convex polygon and 95% fixed kernel method varied between 67.1 km^2 to 400 km^2 and 37.5 km^2 to 188.1 km^2 respectively. The maximum distance moved by each tiger in one day was ranged from 8.5 km to 18.9 km.

Athreya *et al*., (2014) studied the movement and activity patterns of a rescued radio-collared tigress in human-dominated landscape in Nagpur district, Maharashtra, western India during December 2011 to March 2012. The total area of usage estimated by 95% MCP estimator was 726 km^2, whereas her home range after moving into the human-dominated forest and agricultural landscape was estimated as 431 km^2 using the similar estimator. Her home range was found to encompass villages, roads and croplands. The authors found her activity as largely nocturnal while she took shelter in dense foliage inside forest patches during the day. Wild pigs (*Sus scrofa*) (n = 12) were mostly predated by this tigress during the study period. Although, she inhabited very close to human dominated areas, yet no conflict incident was reported by the authors.

5.3. METHODOLOGY

5.3.1. ESTIMATION OF MOVEMENT PATTERNS OF REINTRODUCED TIGERS

To study the movement patterns of the reintroduced tigers, the tigers were monitored periodically using radio-telemetry by both 'homing in' and 'triangulation' methods. Each day of monitoring was divided into four cycles of six hours interval (00:01 hours to 06:00 hours; 06:01 hours to 12:00 hours; 12:01 hours to 18:00 hours and 18:01 to 00:00 hours). At least one location of each

individual was tried to record during each of these four cycles and subsequently plotted on a map. For analysis purpose, days when three or more locations from at least three cycles were successfully recorded were considered. Days with less than three locations under three cycles were not incorporated. The distances between these sequential locations of an individual were measured in GIS domain and attributed to that particular day as total movement by the same. The seasonal variations in movement patterns as well as sex-based movement variations of the individuals were also studied during the study period.

5.3.2. ESTIMATION OF RANGING PATTERNS OF REINTRODUCED TIGERS

Home range theory can be used for many conservation and management initiatives. Three things should govern the methods used for doing this: the objective of the study, the potential of the data and the life history of the animal. Unfortunately, there is no perfect home range estimator, and certainly no estimator should be used indiscriminately of the concerns mentioned above. The workmanship of the user rather than the estimator tool would determine the quality of the final assessment and understanding.

Monthly, seasonal and annual home ranges of the reintroduced tigers were estimated by using radio-telemetry. Radio-telemetry technique was adopted to estimate the ranging pattern of the reintroduced tigers as this technique was found to be the most updated and useful to gather information on territoriality, seasonal and annual home ranges and movement patterns of big cats (White and Garrot, 1990; Karanth *et al*., 2010). Radio-locations of each collared tiger were recorded by both satellite and ground tracking through VHF signals based on 'homing in' and 'triangulation' techniques from three to four known reference points (White and Garrot, 1990). Telonics made TR-4 receiver along with 'Yagi' and 'H' antenna were used to track the radio-collared animals. Coordinates of these reference points were recorded with the help of Global Positioning System (GPS).

For estimating home ranges, two to three locations every alternate day per collared animal were recorded. Co-ordinates for the all radio-locations were recorded with the help of Global positioning system (GPS) and later on plotted in Geographical Information System (GIS) domain of appropriate software such as QGIS 2.2.0 Valmiera (http://www.qgis.org) and ArcGIS 9.3 (www.esri.com; 2008-06-26; retrieved 2009-04-16). Two basic methods such as minimum convex polygon (MCP - both 100% and 95%) (Mohr, 1947) and kernel methods (both fixed

kernel and adaptive kernel) (Worton, 1989; Larkin and Halkin, 1994; Lawson and Rogers, 1997; Kernohan *et al*., 1998; Katajisto and Moilanen, 2006; Karanth *et al*., 2010) were used to analyze the home range of the tigers.

Since 100% MCP showed the entire range rather than the ranging pattern therefore, 95% MCP using the fixed arithmetic technique was also used. The MCP method had been observed to be highly sensitive to sample size (number of locations) (Seaman *et al*., 1999) but most studies still cited the use of MCPs for reasons of comparison. Unfortunately this notion only prompted inappropriate comparison because of the sample size issues. Only the most meticulously matched studies should use MCPs as a form of comparison, if the sample sizes were equivalent, along with equal sampling durations and similar treatment of outliers.

In Kernel estimators, the point-to-point evaluation, followed by pixel to point evaluation served the same purpose at each and every pixel. The added benefit of this procedure was that outliers in the dataset are effectively eliminated from the analysis before the time consuming pixel to point analysis begins. So, this was a transformation from deterministic approach to a probabilistic approach of the space use by any animal. 95% Kernel represented the smallest area with a probability of use equal to 0.95 which could further be defined as an animal's home range (Powell, 2000). Anderson (1982) recommended using animals' 50 percent home ranges (the smallest area encompassing a 50 percent probability of use) as their effective home ranges but later on this 50% fixed kernel method was used to find core of the activity and range shifts between seasons. Therefore, within kernel estimators (both in fixed and adaptive kernel) 50% kernel probability was used to find centers of activity of the individuals and range shifts between seasons. Considering the optimum smoothing parameters in kernel, 60% and 40% proportional bands of the reference band widths were selected in fixed and adaptive kernel estimators respectively to estimate the home ranges.

5.4. RESULTS

5.4.1. MOVEMENT PATTERNS OF REINTRODUCED TIGERS

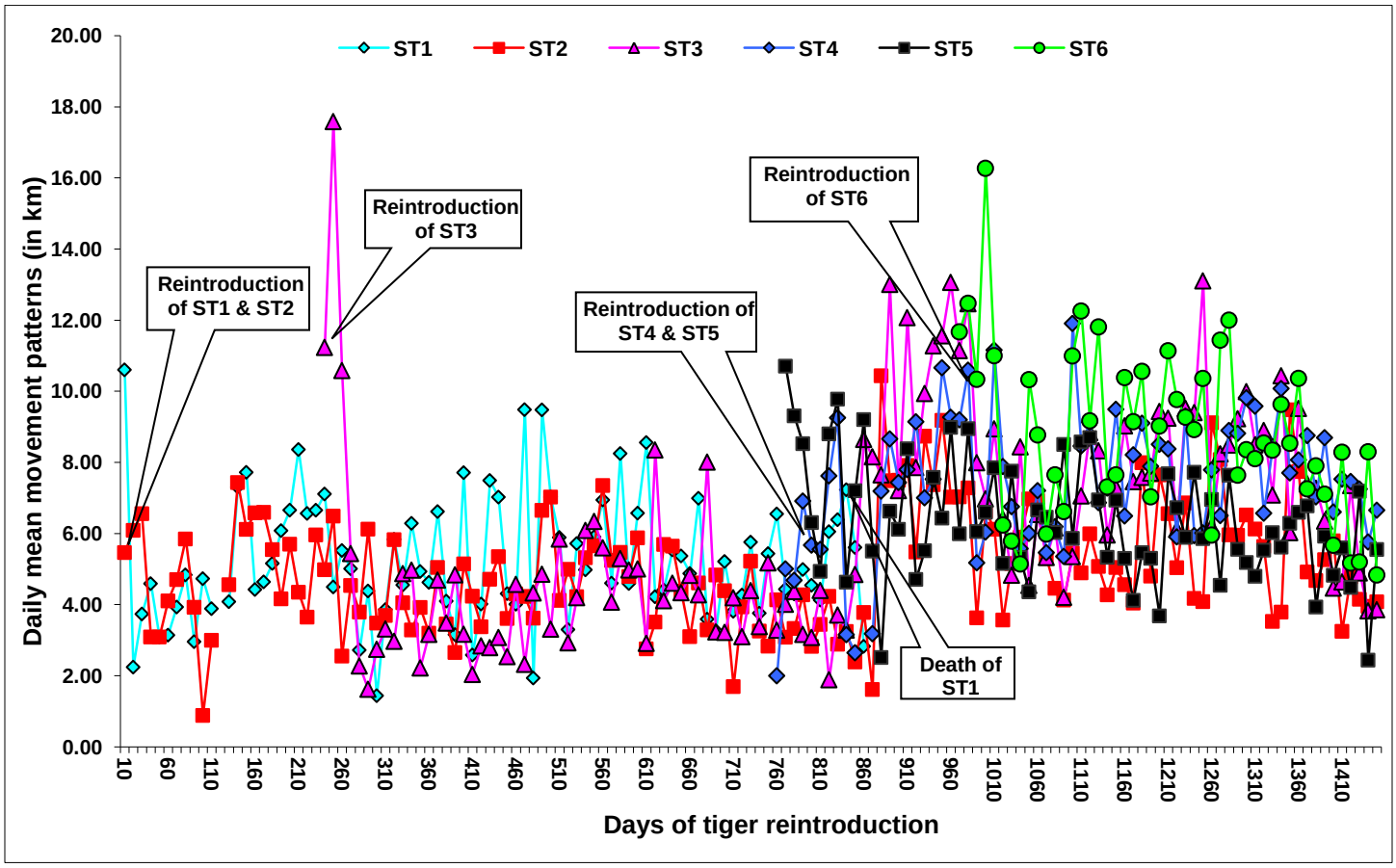
A total of 1218, 2818, 3169, 2181, 2087 and 1889 radio locations were recorded for the first to sixth tigers i.e. ST1 to ST6 respectively during July 2008 to June 2012. In order to study the movement patterns of the reintroduced tigers, a total of 387, 844, 879, 547, 489 and 464 days of monitoring was conducted for ST1 to ST6 respectively. The daily movements of the reintroduced

tigers varied from 0.2 km to 40.81km. The overall mean daily movements were estimated as 5.27±0.16SE km, 5.06±0.11SE km, 6.23±0.15SE km, 7.52±0.18SE km, 6.30±0.14SE km and 8.81±0.23SE km for ST1 to ST6 tigers respectively. Overall mean daily movement of the male tigers (7.06±0.11SE km) was found greater than that of the females (5.78±0.08SE km). In monsoon and winter, the mean daily movements of each tiger were greater than that in the summer (Table 5.1). Mean daily movement of the tiger ST6 was estimated highest (8.81±0.23SE km) among all the tigers across all the seasons and also for the entire study period as well (Table 5.1). The details of the mean daily movements of all the reintroduced tiger within an interval of ten days during the whole study period is given in figure 5.1. The details of seasonal and overall mean daily movement rate of all the tigers are given in table 5.1.

Table 5.1. Details of the movement patterns of reintroduced tigers in Sariska Tiger Reserve during July 2008 – June 2012.

Time / Period	Tiger ID							
	ST1 (km)	**ST2 (km)**	**ST3 (km)**	**ST4 (km)**	**ST5 (km)**	**ST6 (km)**	**Male (km)**	**Female (km)**
Monsoon	5.01 ±0.25SE	5.37 ±0.19 SE	6.12 ±0.20 SE	7.38 ±0.36 SE	6.85 ±0.29 SE	9.48 ±0.39 SE	7.11 ±0.23 SE	5.11 ±0.13 SE
Winter	6.08 ±0.32 SE	5.98 ±0.21 SE	7.84 ±0.28 SE	7.88 ±0.29 SE	6.18 ±0.24 SE	9.01 ±0.46 SE	7.47 ±0.20 SE	6.69 ±0.15 SE
Summer	4.79 ±0.27 SE	4.78 ±0.17 SE	5.98 ±0.24 SE	7.30 ±0.30 SE	5.96 ±0.22 SE	8.39 ±0.33 SE	6.97 ±0.19 SE	5.53 ±0.13 SE
Overall mean movement (July 2008 – June 2012)	5.27 ±0.16 SE	5.06 ±0.11 SE	6.23 ±0.15 SE	7.52 ±0.18 SE	6.30 ±0.14 SE	8.81 ±0.23 SE	7.06 ±0.11 SE	5.78 ±0.08 SE

Figure 5.1. Details of the movement patterns of reintroduced tigers in Sariska Tiger Reserve during July 2008 – June 2012.



5.4.2. RANGING PATTERNS OF REINTRODUCED TIGERS

Ranging pattern of the reintroduced tigers was studied using satellite-GPS and VHF radio-telemetry. A total of 1218, 2818, 3169, 2181, 2087 and 1889 radio locations were recorded for the first to sixth tiger i.e. ST1 to ST6 respectively from July 2008 to June 2012. During ground tracking (VHF radio-telemetry), the radio-locations were recorded using both 'triangulation' and 'homing in' techniques. The details of year wise radio-locations, total number and the type of the location for each tiger from July 2008 to June 2012 are given in Table 5.2.

Table 5.2. Details of radio-locations (number and types) recorded for each reintroduced tigers in Sariska Tiger Reserve during July 2008 to June 2012

Year wise type of radio-locations of each individual tiger		ST1	ST2	ST3	ST4	ST5	ST6
Year 01 (July 2008 - June 2009)	Total Locations	475	507	281	n.a.	n.a.	n.a.
	Triangulated locations	305	371	222	n.a.	n.a.	n.a.
	Homing in locations	170	126	59	n.a.	n.a.	n.a.
Year 02 (July 2009 - June 2010)	Total Locations	547	497	561	n.a.	n.a.	n.a.
	Triangulated locations	354	333	400	n.a.	n.a.	n.a.
	Homing in locations	193	164	161	n.a.	n.a.	n.a.
Year 03 (July 2010 - June 2011)	Total Locations	196	935	967	901	876	526
	Triangulated locations	135	697	824	722	830	438
	Homing in locations	61	238	143	179	46	88
Year 04 (July 2011 - June 2012)	Total Locations	n.a.	879	1360	1280	1211	1363
	Triangulated locations	n.a.	359	1225	1031	1152	1184
	Homing in locations	n.a.	520	135	249	59	179

n.a. - Not applicable

5.4.2.1. MONTH-WISE AREA OCCUPIED BY THE REINTRODUCED TIGERS IN SARISKA TIGER RESERVE FROM JULY 2008 TO JUNE 2012

The ST1 male and ST2 female tigers were reintroduced during the last week of June 2008 and first week of July 2008 respectively. Soon after their reintroduction to Sariska, they explored new areas and moved in opposite directions i.e. ST1 male moved towards the south and ST2 female explored the northern areas of Sariska. Therefore, the occupied areas of these reintroduced tigers for the first two months were found much larger where as at the end of the September 2008 they came in association with each other for the first time and stayed together in a smaller area in Sariska-Kalighati-Pandupole valley.

The ST3 tigress was reintroduced during the last week of February 2009. The ST3 tigress also explored large areas of more than 200 sq. km during its first month after reintroduction (March 2009). During April 2009, ST3 tigress came in contact with the male tiger ST1 and subsequently

settled down in smaller area around the relocated village Bhagani and her home range also got stabilized.

Thereafter, the male tiger ST1 utilized large areas all through the year to cover the home ranges of both the females, ST2 and ST3. The pattern of monthly occupied areas for first three tigers (ST1, ST2 and ST3) during the second year (July 2009 to June 2010) was observed to be similar to that of the first year's last quarter.

During July 2010, two more tigers, a male (ST4) and a female (ST5) were reintroduced in Sariska. The ST4 male and ST5 female also explored large areas soon after their reintroduction. The male tiger ST4 avoided the areas used by ST1 male tiger and occupied areas in South-Western part of the Tiger Reserve without any contact with the tigresses, ST2, ST3 and ST5. Soon after the death of ST1 male tiger (14th November 2010), within 10 days, it was observed that the other male tiger ST4 occupied the entire territory of ST1 and the monthly occupied area by ST4 during December 2011 became much higher. The male tiger ST4 was observed to be associated with all the three female tigers, ST2, ST3 and ST5 during one month period.

During the last week of February 2011, another male tiger ST6 was reintroduced in Sariska. Soon after its reintroduction, the animal explored large areas in South-Western part of the Tiger Reserve following the territory of the female ST3 and avoided confrontation with ST4 male tiger. The monthly occupied area by ST4 male was thus reduced since March 2011 after the reintroduction of ST6 male. The monthly occupied areas by the male tigers were estimated higher than those of the female tigers during the entire study period. During the last week of January 2013, two more tigresses, ST9 and ST10 were reintroduced in Sariska. Till February 2013 they explored new areas, did not meet each other and tried to establish their own home ranges.

It was observed that all the reintroduced tigers initially explored large areas soon after their release into the wild, followed by establishing their own territories in smaller areas after two to three months, thereby settling down in better available habitats with adequate water and cover, more prey abundance and less human disturbance. The male tigers occupied larger areas as compared females (Figure 5.2). The month-wise pattern of occupied areas (in km^2) by the reintroduced tigers for the period 2008-09, 2009-10, 2010-11 and 2011-12 are shown in the figures 5.2, 5.3, 5.4 and 5.5 respectively. The month-wise occupied areas (in km^2) by all reintroduced tigers for the period July 2008 to June 2012 (48 Months) is shown in figure 5.6.

Figure 5.2. Month-wise area occupied by the reintroduced tigers in Sariska Tiger Reserve from July 2008 to June 2009.

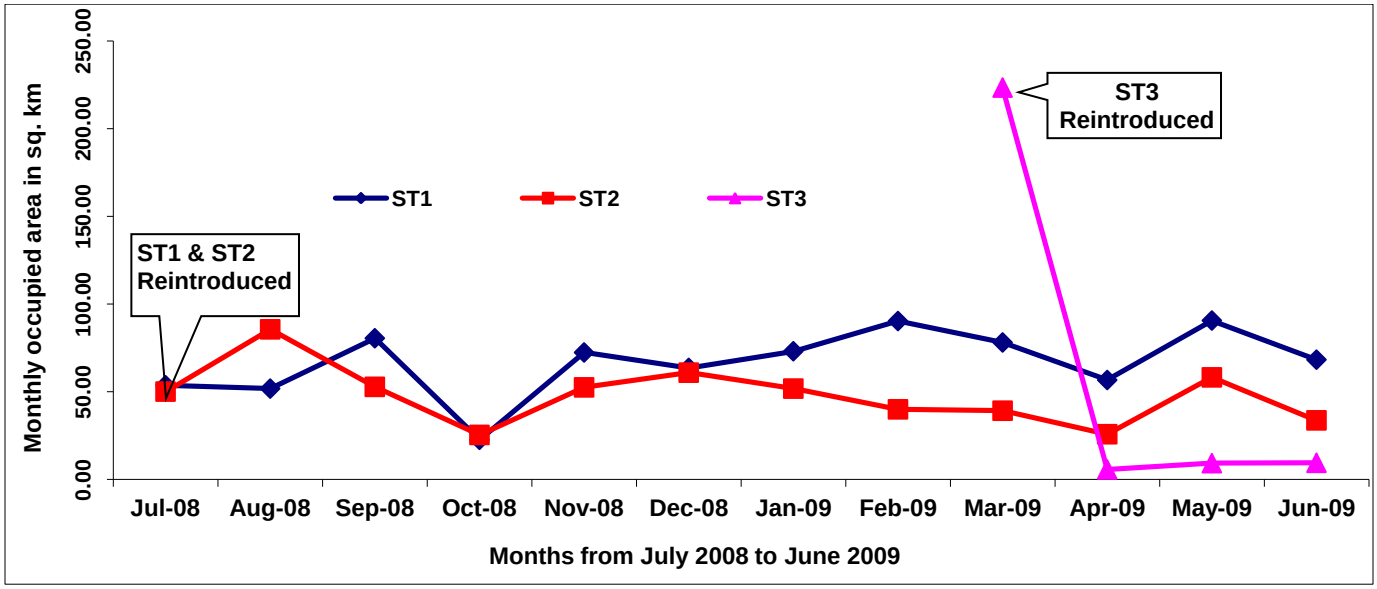


Figure 5.3. Month-wise area occupied by the reintroduced tigers in Sariska Tiger Reserve from July 2009 to June 2010.

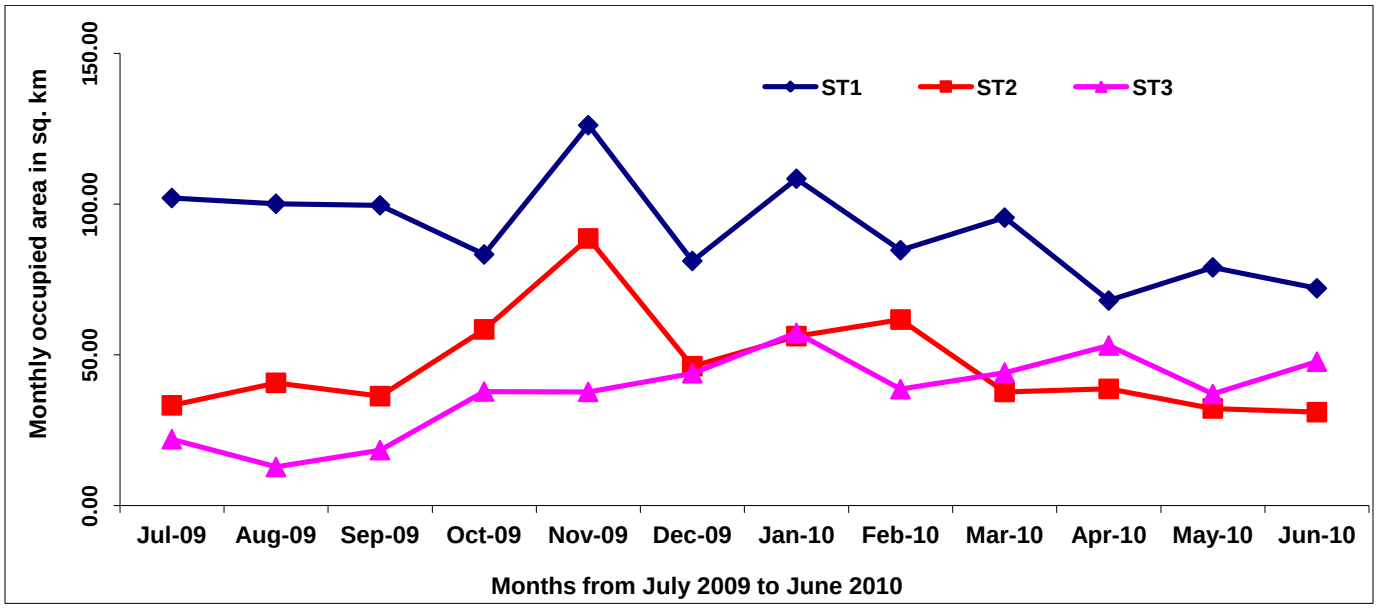


Figure 5.4. Month-wise area occupied by the reintroduced tigers in Sariska Tiger Reserve from July 2010 to June 2011.

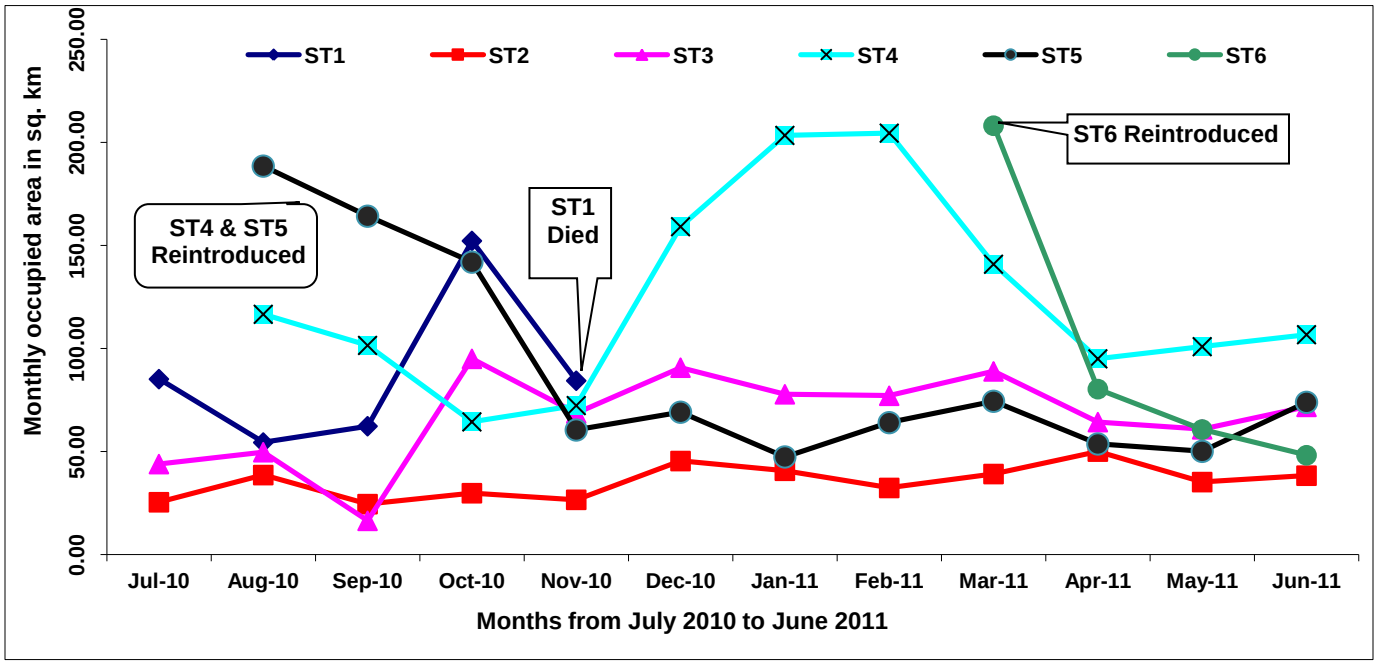


Figure 5.5. Month-wise area occupied by the reintroduced tigers in Sariska Tiger Reserve from July 2011 to June 2012.

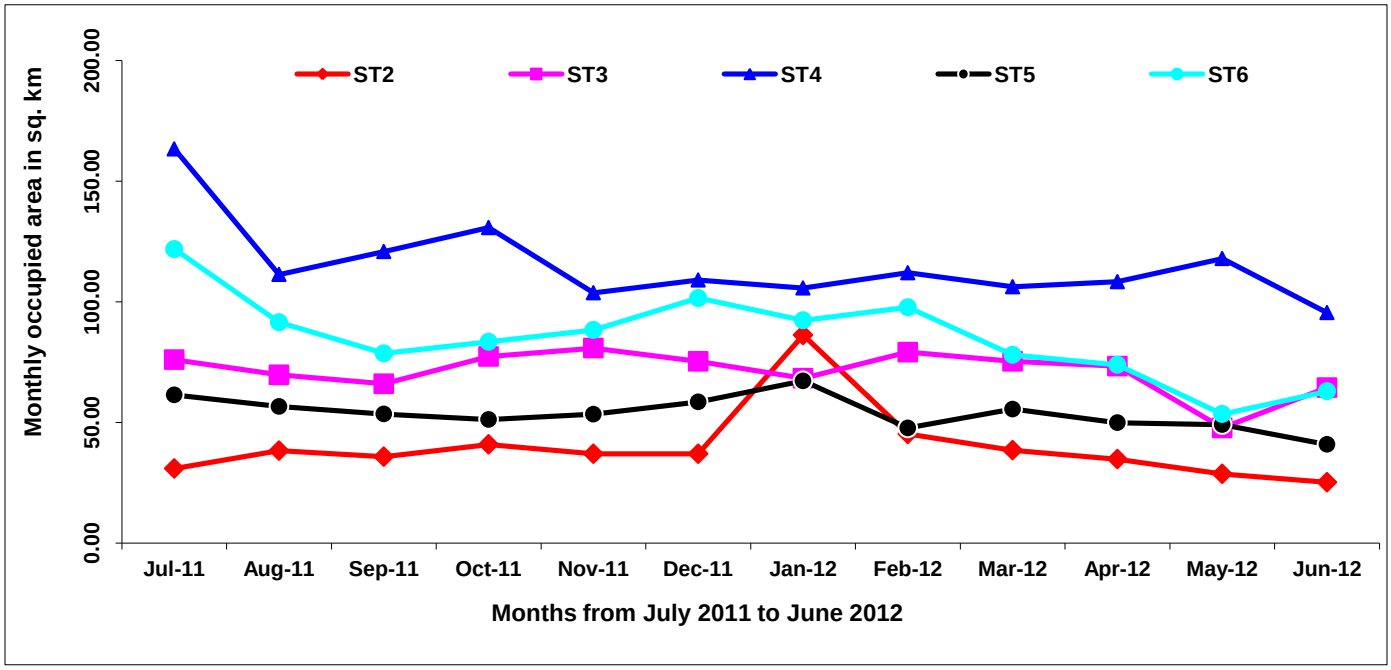
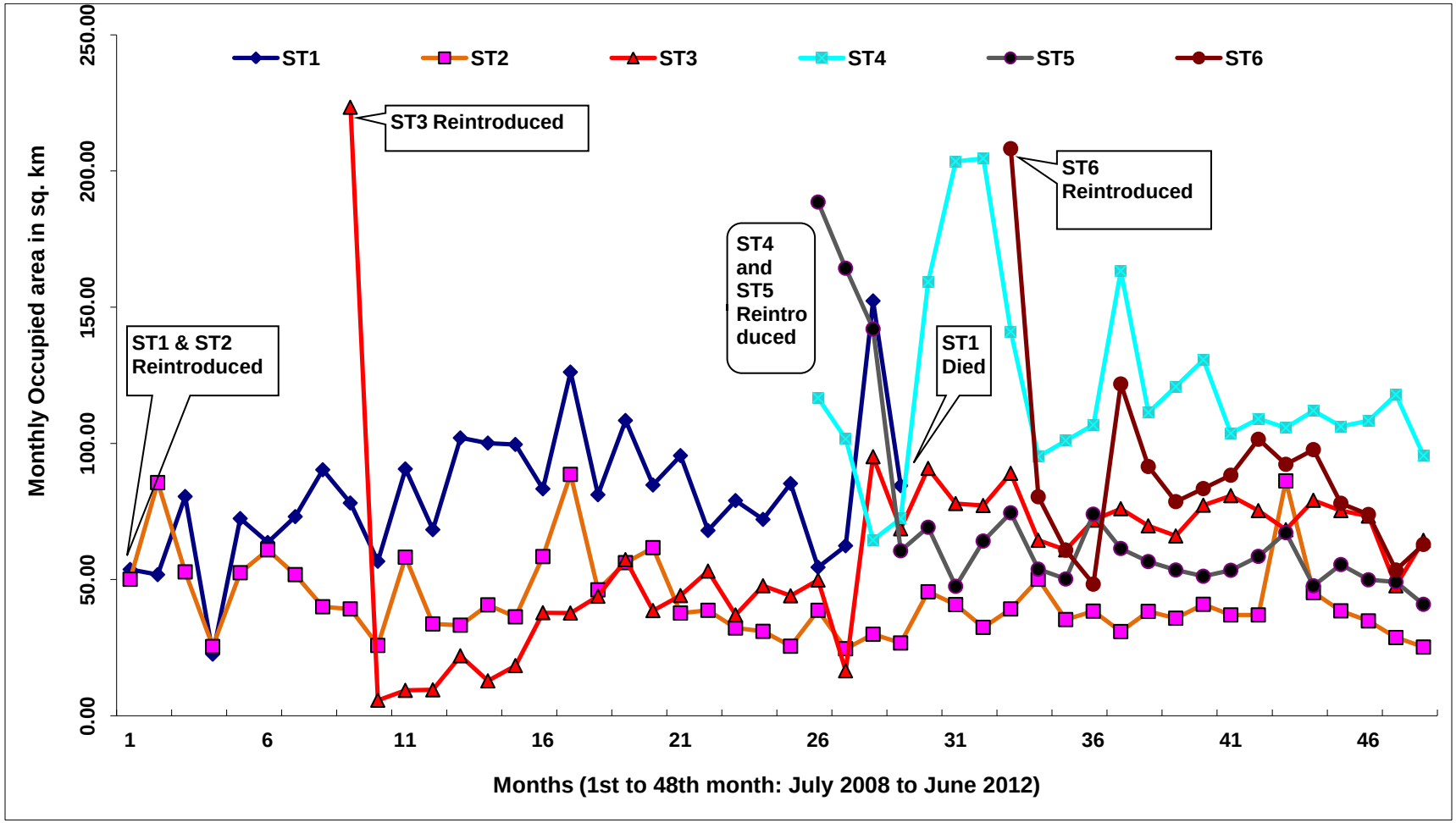


Figure 5.6. Month-wise area occupied by the reintroduced tigers in Sariska Tiger Reserve from July 2008 to June 2012 (48 months).



5.4.2.2. ANNUAL AND SEASONAL HOME RANGES OF TIGERS DURING 2008-09

During 2008 June-July, two tigers (ST1- adult male & ST2- adult female) were reintroduced to Sariska Tiger Reserve from Ranthambhore Tiger Reserve. After they were released into the wild, they started moving in opposite direction. ST1 moved towards the south - southwestern part of the park where as ST2 moved to north - northeastern part of the Tiger Reserve. During the monsoon (July-October 2008) both of them explored large areas of more than 130 sq. km. in Sariska Tiger Reserve.

During 2008, the monsoon home-ranges of ST1 and ST2 were estimated using 100% minimum convex polygon (MCP) as 133.8 km^2 and151.3 km^2 respectively, whereas those estimated by 95% MCP were 75.0 km^2 and 132.1 km^2 respectively for ST1 and ST2 (Figure 5.7). The estimated monsoon home ranges of ST1 and ST2 in 2008 by using 95% fixed kernel were 117.1 km^2 and 117.5 km^2 respectively and the core of the home ranges estimated by 50% fixed kernel were 24.1 and 23.5 km^2 respectively for ST1 and ST2 (Figure 5.8). The results obtained using 95% adaptive kernel estimator for the similar order were 111.2 km^2 and 112.2 km^2 while estimated core home ranges of ST1 and ST2 using 50% adaptive kernel estimator were 14.7 km^2 and 12.4 km^2 respectively (Figure 5.9). Details of the monsoon home ranges and range overlap during 2008 are given in table 5.3.

During the end of September 2008, ST1 and ST2 met each other for the first time since their reintroduction. Therefore, from October 2008 onwards they were observed together and almost up to three months till December, 2008 they utilized smaller area as winter home range.

The winter home ranges of ST1 and ST2 during 2008-09 were estimated using 100% MCP estimator as 107.1 km^2 and 81.4 km^2 respectively. The estimated winter home ranges using 95% MCP estimator were 85.1 km^2 and 77.5 km^2 respectively for ST1 and ST2 (Figure 5.10). Similarly, the winter home ranges of these two individuals were estimated using 95% fixed kernel estimator as 118.3 km^2 and 89.5 km^2 respectively, while core home ranges were estimated using 50% fixed kernel estimators as 29.6 km^2 and 18.8 km^2 respectively for ST1 and ST2 (Figure 5.11). Ninety five percent adaptive kernel estimator estimated winter home ranges of ST1 and ST2 as 109.6 km^2 and 88.2 km^2 respectively, while results obtained using 50% adaptive kernel estimator were 18.5 km^2 and 11.1 km^2 respectively for ST1 and ST2 (Figure 5.12). Details of the winter home ranges and range overlaps during 2008-09 are given in table 5.4.

On 27th February 2009, another adult female ST3 was reintroduced to Sariska from Ranthambhore and she too explored large areas of more than 220 km^2 in the south-southwestern part of Sariska. The male tiger ST1 was observed to get associated with this new female and therefore increased his summer home range. During 2009, the summer home ranges of three reintroduced tigers (ST1, ST2 and ST3) were estimated using 100% MCP estimator as 101.3 km^2, 67.2 km^2 and 223.4 km^2 respectively. The estimated summer home ranges using 95% MCP estimator were 88.5 km^2, 51.9 km^2 and 127.9 km^2 respectively for ST1, ST2 and ST3 (Figure 5.13). The estimated summer home ranges of ST1 to ST3 tigers using 95% fixed kernel estimator were 111.5 km^2, 63.9 km^2 and 124.9 km^2 respectively, while summer core ranges were estimated using 50% fixed kernel estimator as 26.6 km^2, 14.8 km^2 and 15.8 km^2 respectively for ST1 to ST3 (Figure 5.14). The summer home ranges during 2009 of these three tigers ST1, ST2 and ST3 were estimated by the 95% adaptive kernel estimator as 103.6 km^2, 59.3 km^2 and 134.5 km^2 respectively, whereas 50% adaptive kernel estimator measured the core summer ranges as 15.2 km^2, 9.1 km^2 and 9.6 km^2 respectively for ST1 to ST3 (Figure 5.15). Details of the summer home ranges and range overlaps during 2009 are given in table 5.5.

The annual home ranges of first two reintroduced tigers, ST1 and ST2 during 2008-09 were estimated using 100% MCP as 168.6 km^2 and 181.4 km^2 respectively. The estimated summer home ranges using 95% MCP estimator were 112.8 km^2 and 127.8 km^2 respectively for ST1 and ST2 with a range overlap of 57% (100% MCP) and 71% (95% MCP) between them (Figure 5.16). The estimated annual home ranges of ST1 and ST2 during 2008-09 using 95% fixed kernel were 128.0 km^2 and 124.4 km^2 respectively and the core of the home ranges estimated by 50% fixed kernel were 30.4 km^2 and 20.1 km^2 respectively for ST1 and ST2 (Figure 5.17). The estimated annual home ranges of ST1 and ST2 using 95% adaptive kernel estimator were 122.1 km^2 and 122.6 km^2 respectively, whereas the annual core ranges were estimated using 50% adaptive kernel estimator as 19.1 km^2 and 14.0 km^2 respectively for ST1 and ST2 (Figure 5.18). The details of the annual home range estimation and range overlaps of the reintroduced tigers in Sariska Tiger Reserve during 2008-09 are given in Table 5.6.

Figure 5.7. Monsoon home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July – October 2008).

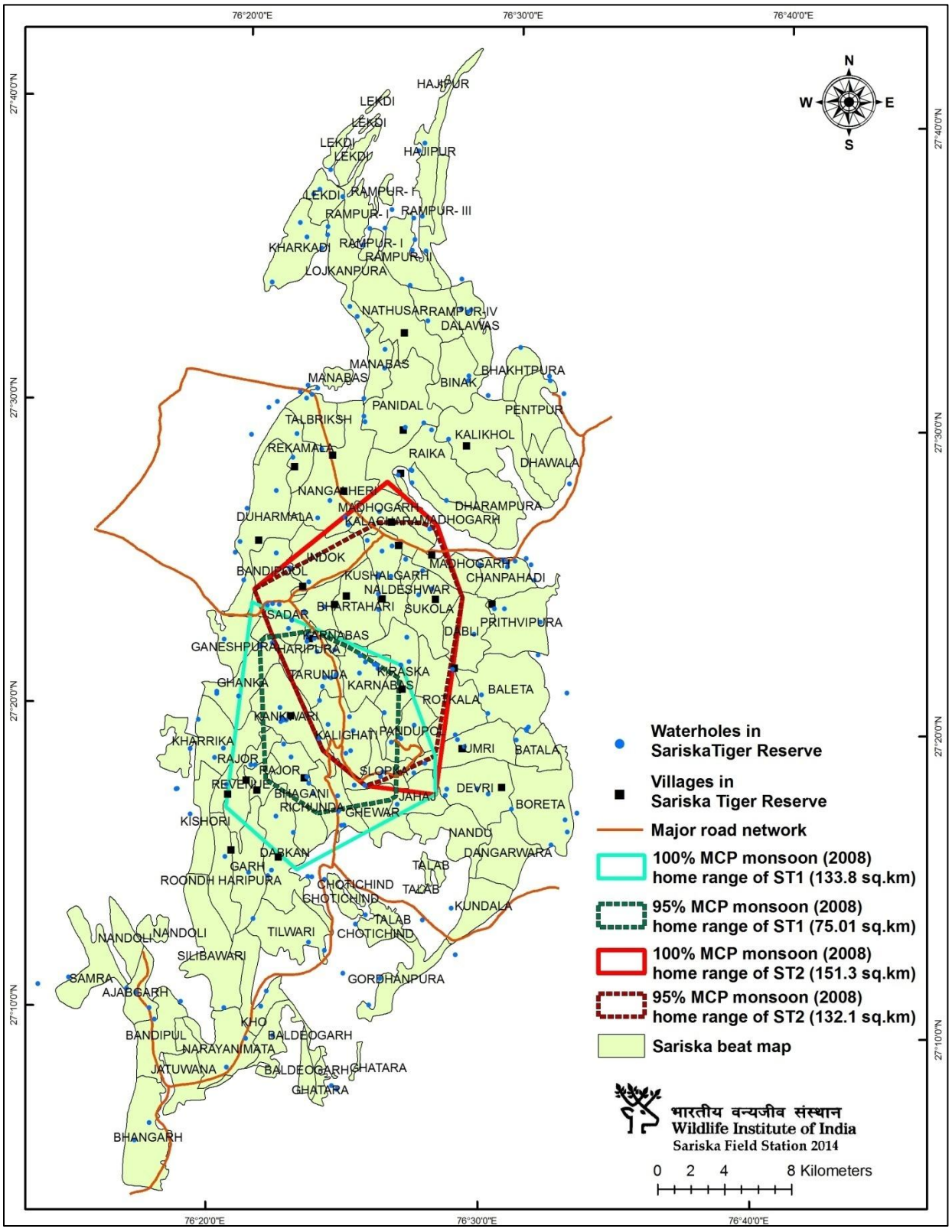


Figure 5.8. Monsoon home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July – October 2008).

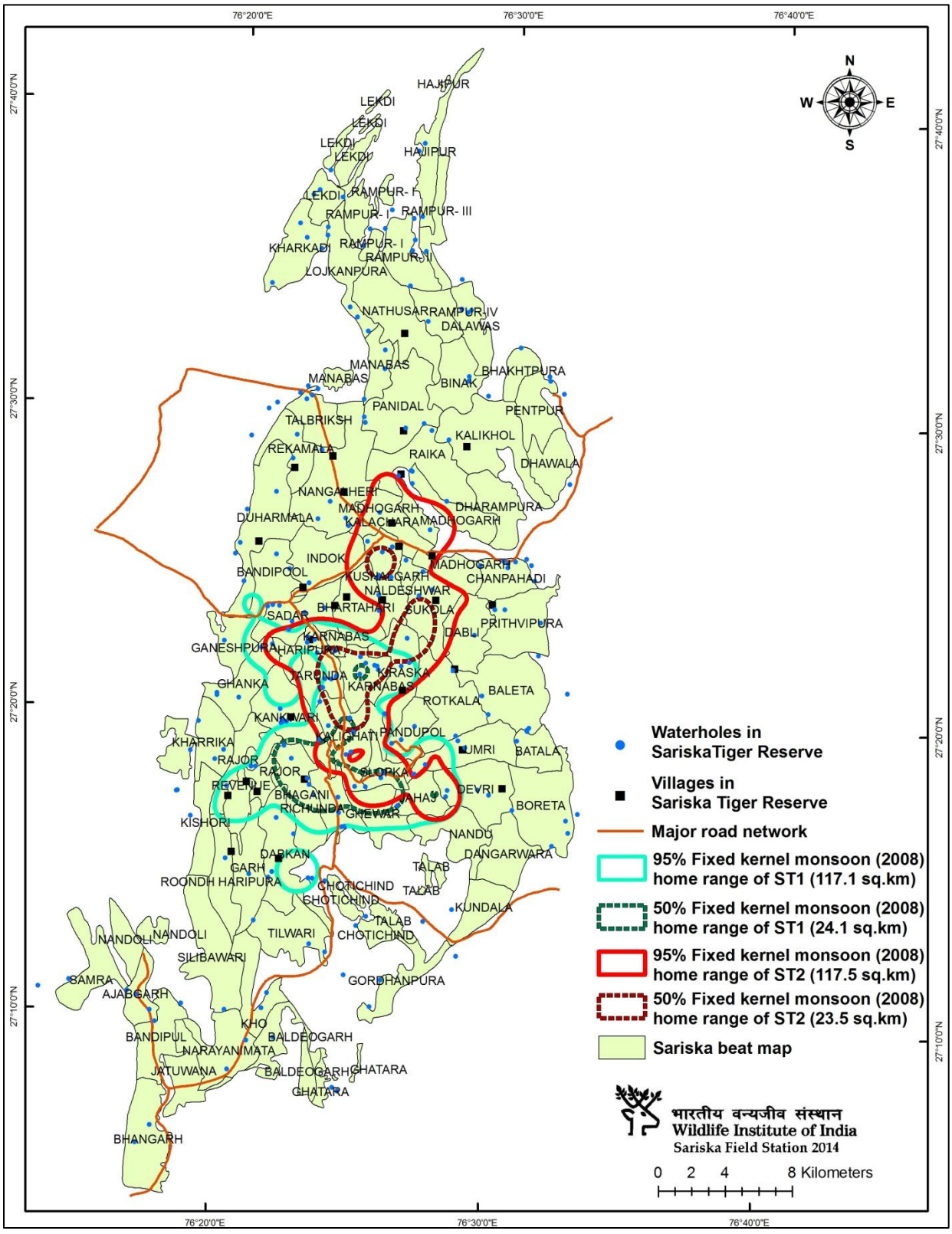


Figure 5.9. Monsoon home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July – October 2008).

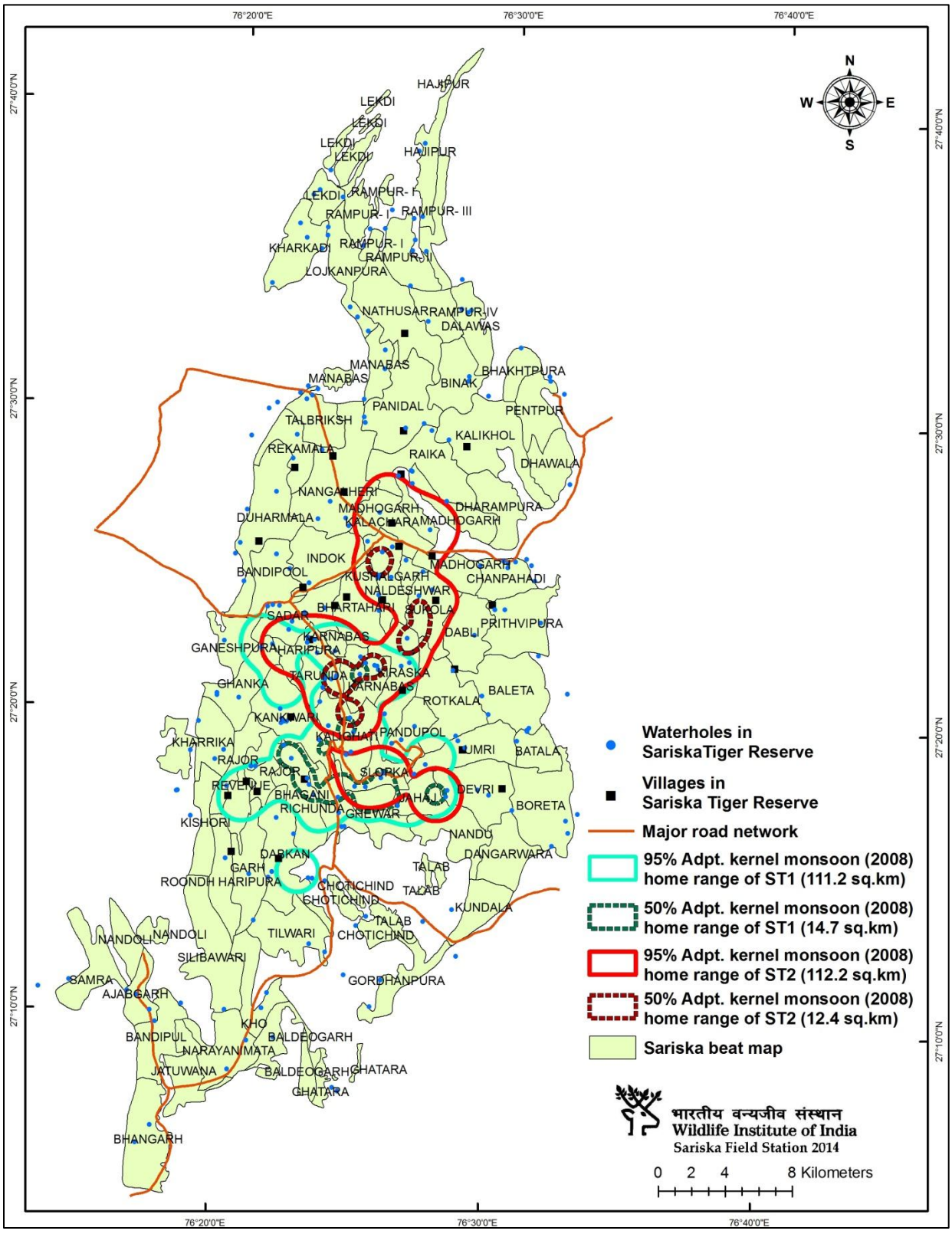


Figure 5.10. Winter home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (November 2008 – February 2009).

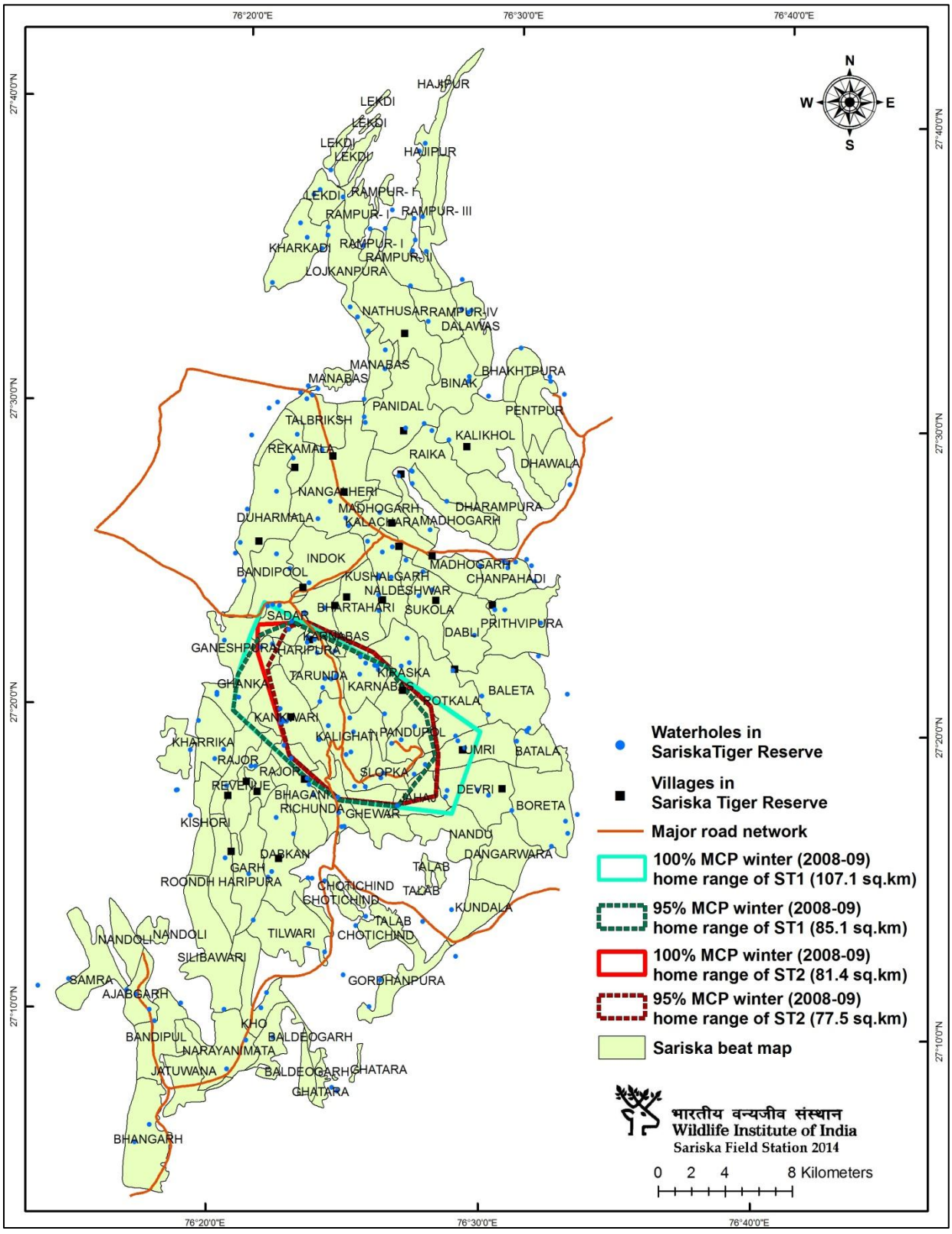


Figure 5.11. Winter home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (November 2008 – February 2009).

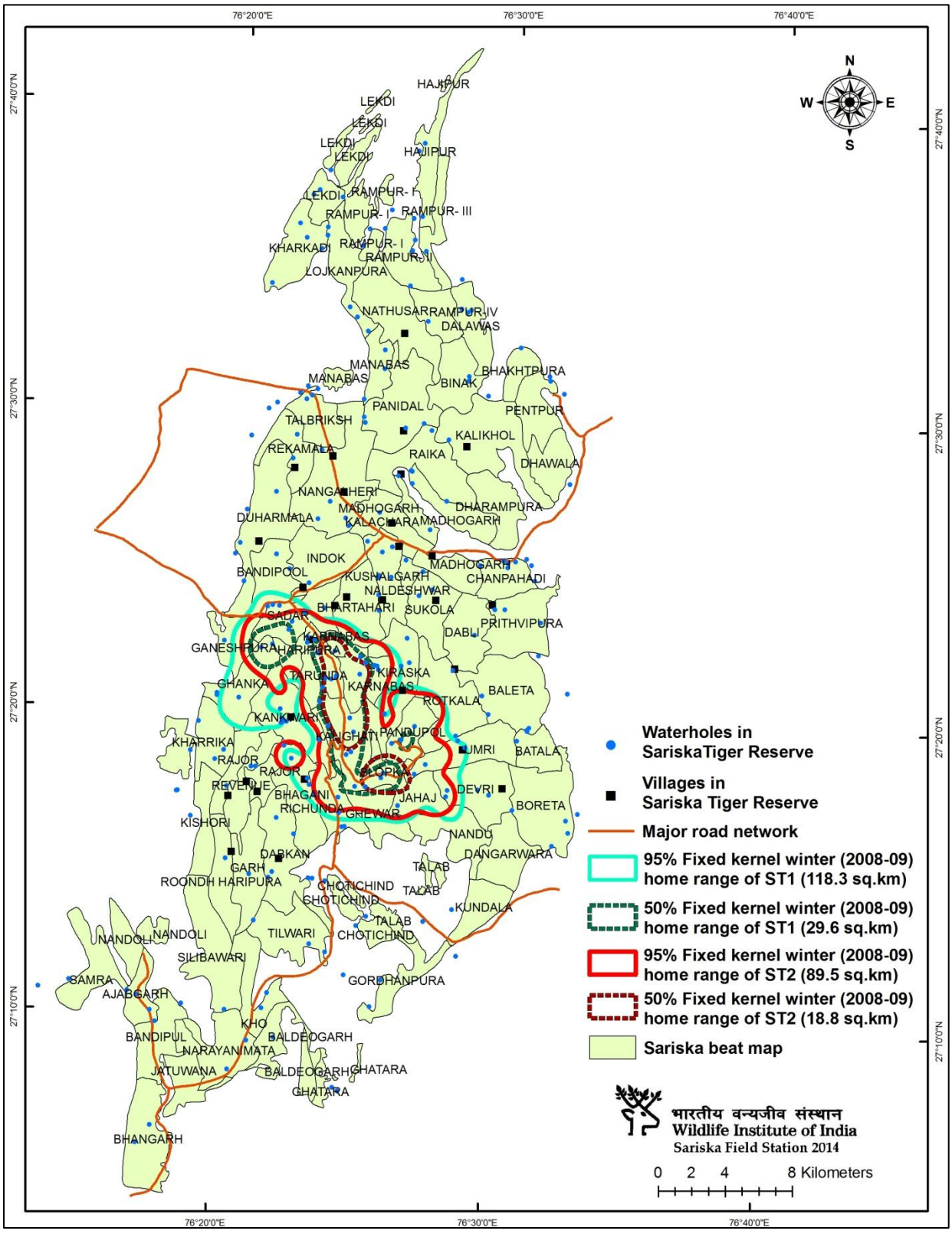


Figure 5.12. Winter home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (November 2008 – February 2009).

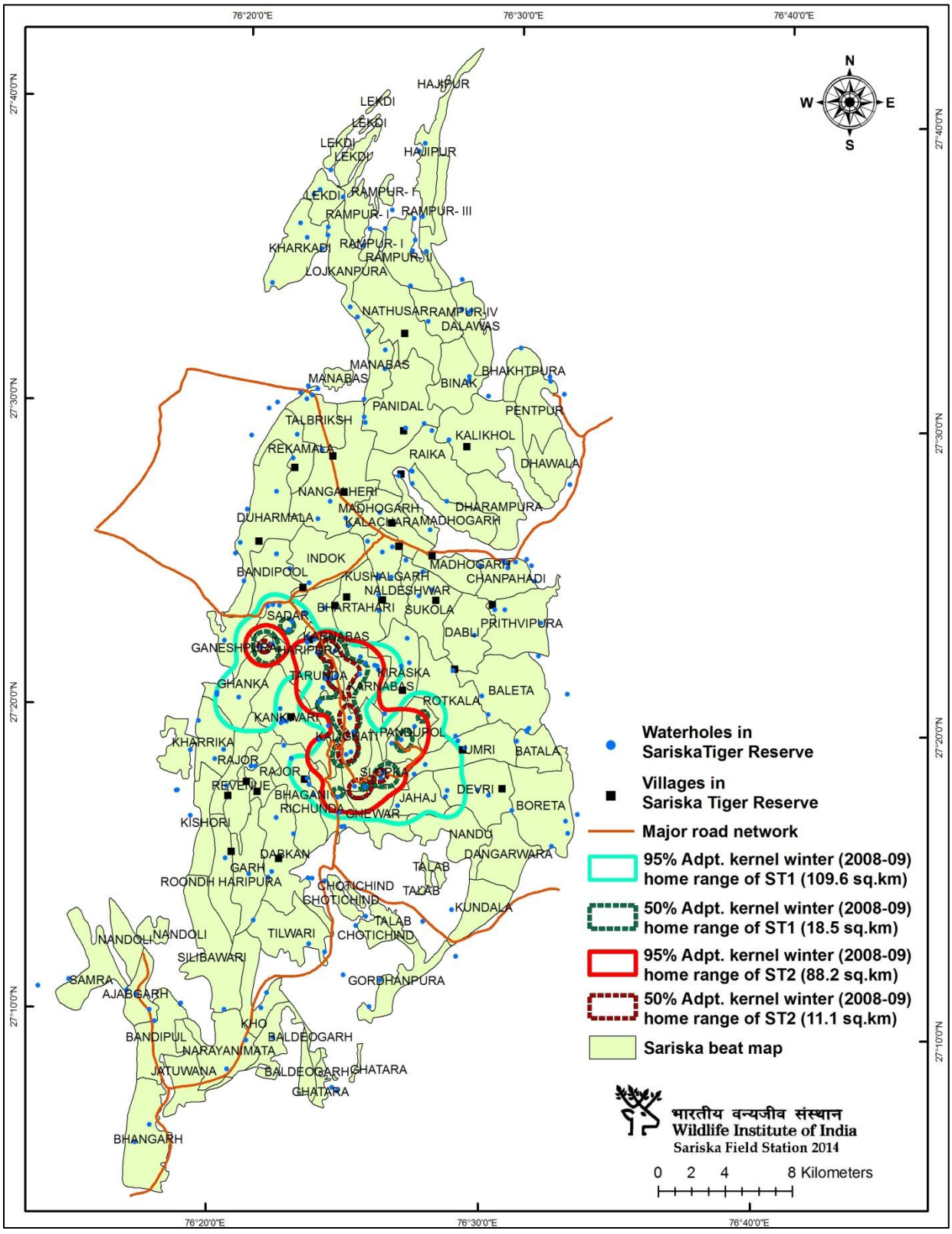


Figure 5.13. Summer home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (March 2009 – June 2009).

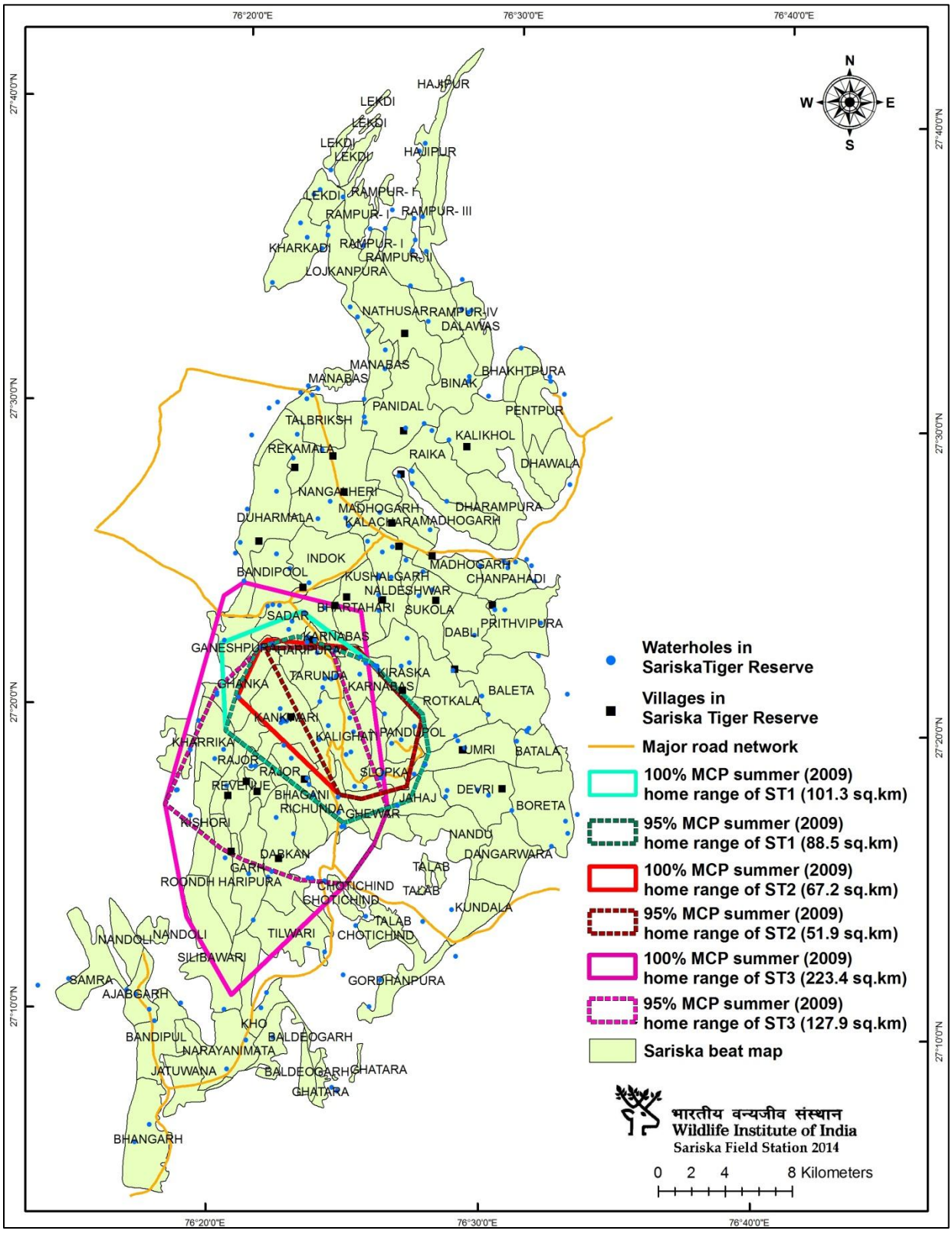


Figure 5.14. Summer home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (March 2009 – June 2009).

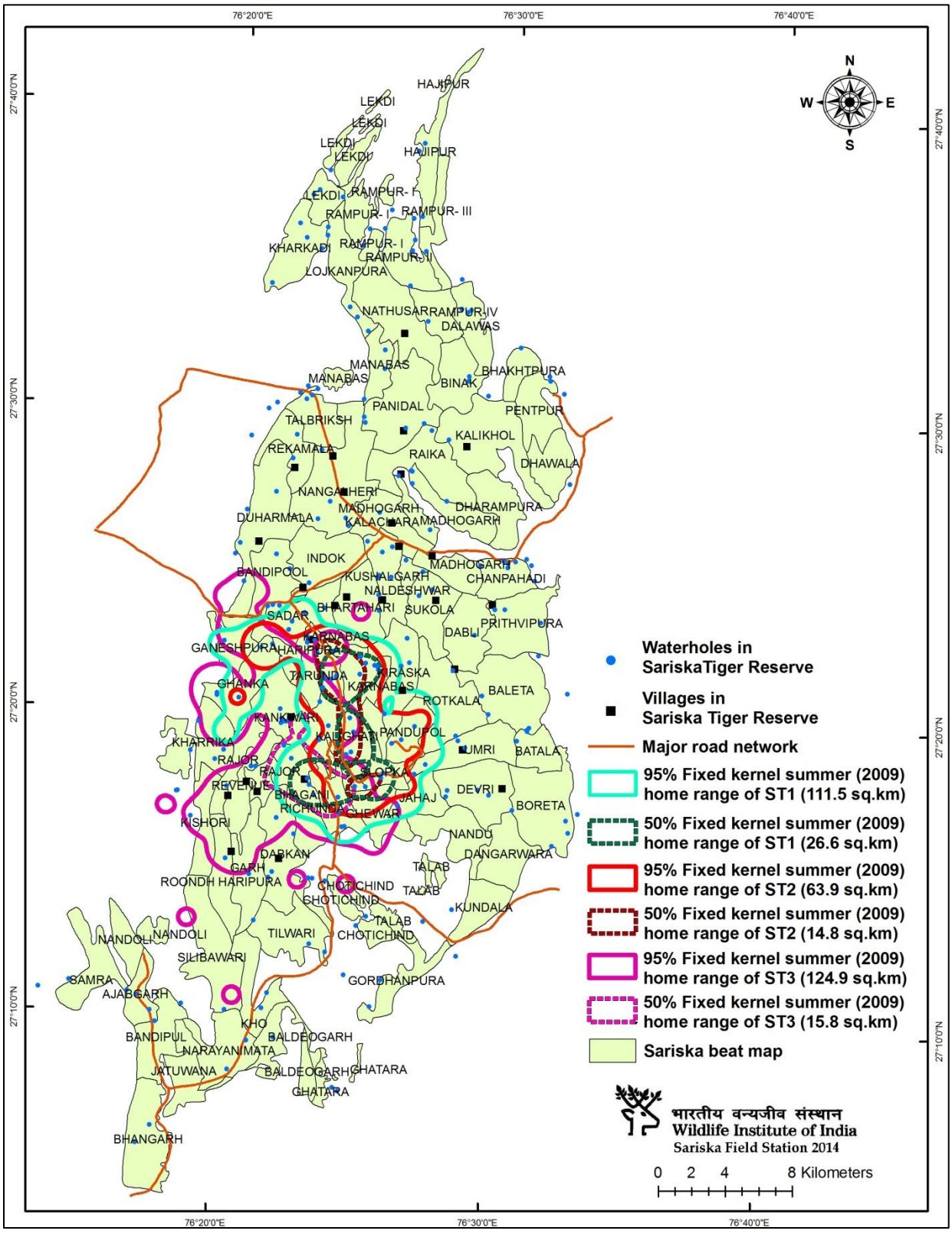


Figure 5.15. Summer home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (March 2009 – June 2009).

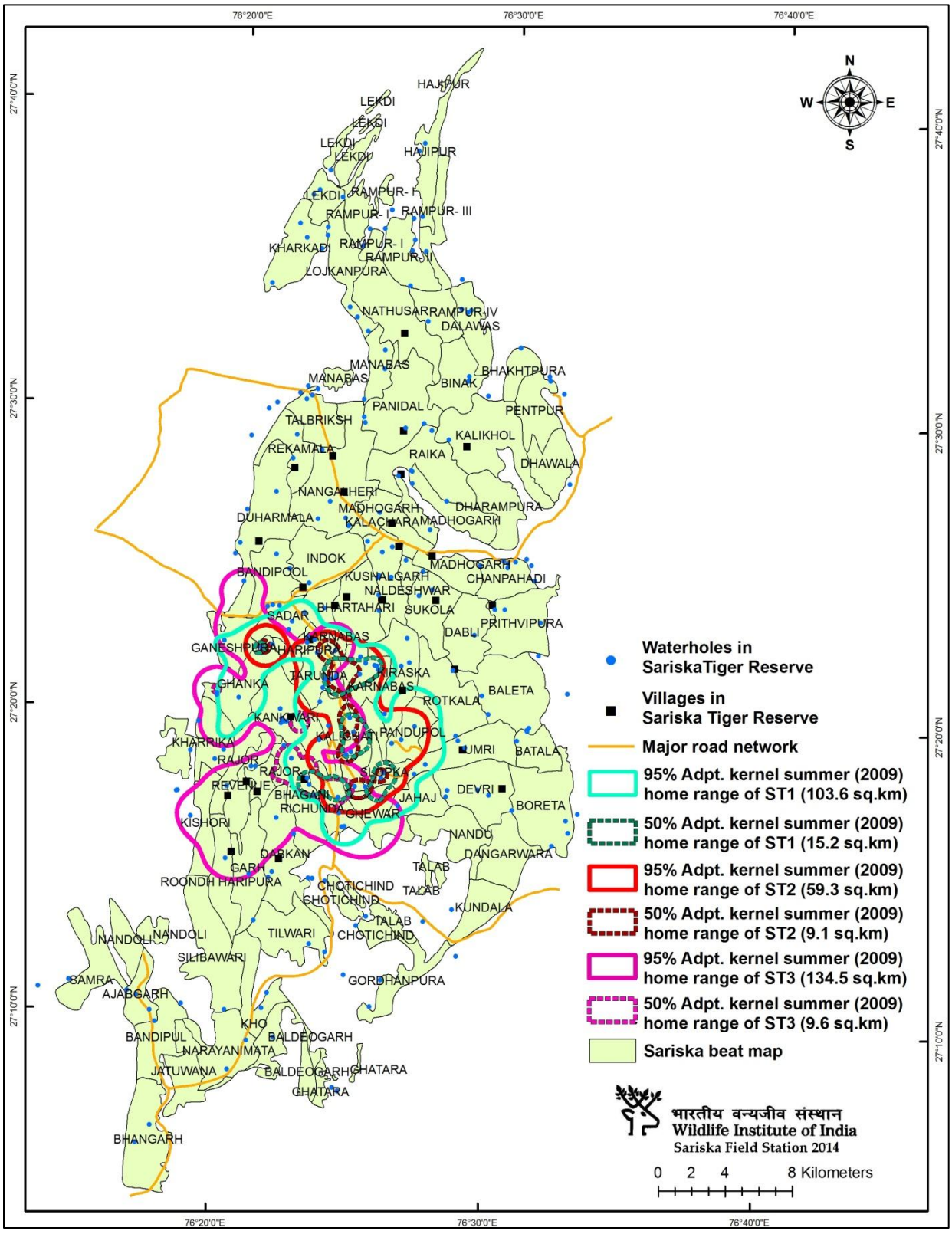


Figure 5.16. Annual home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July 2008 – June 2009).

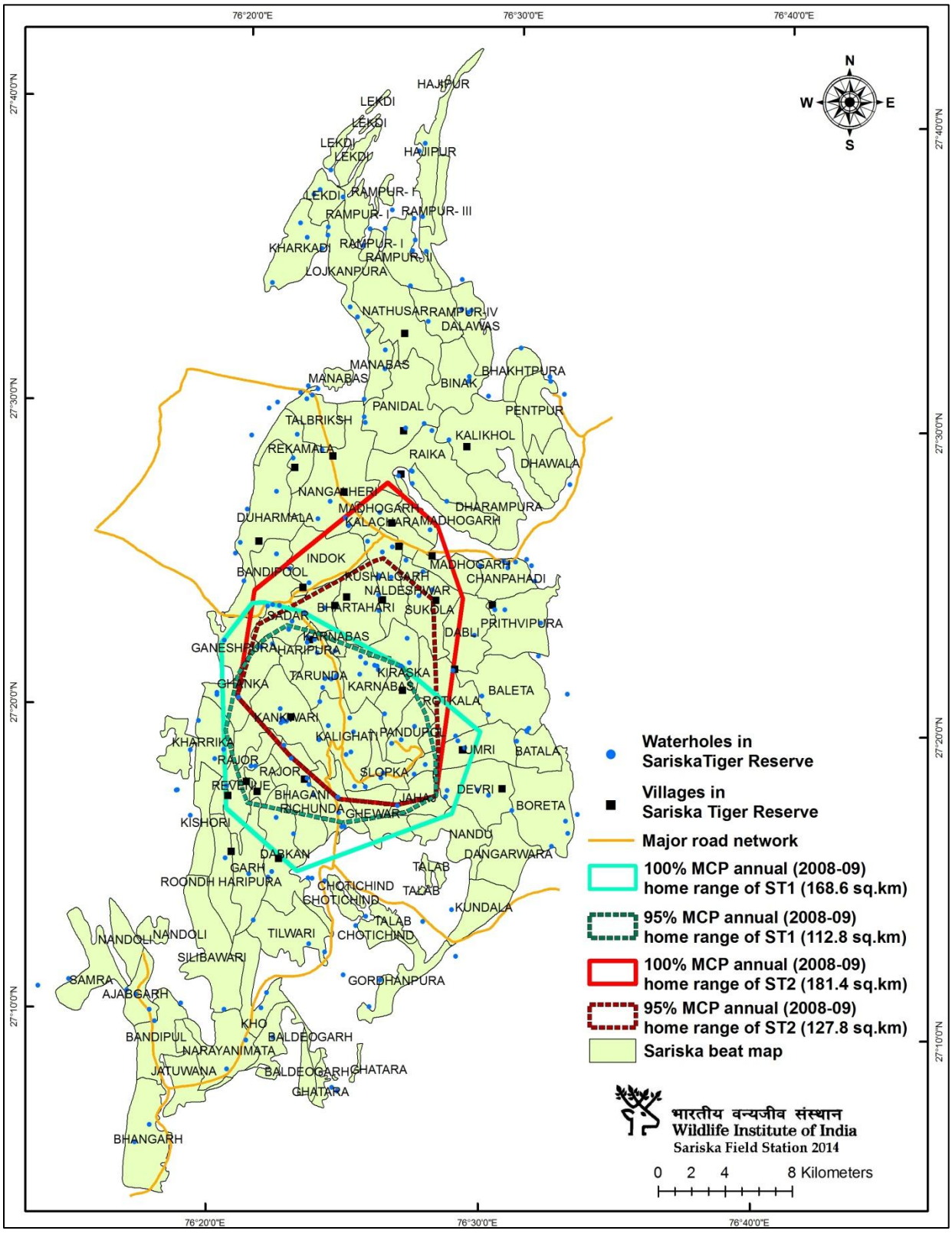


Figure 5.17. Annual home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July 2008 – June 2009).

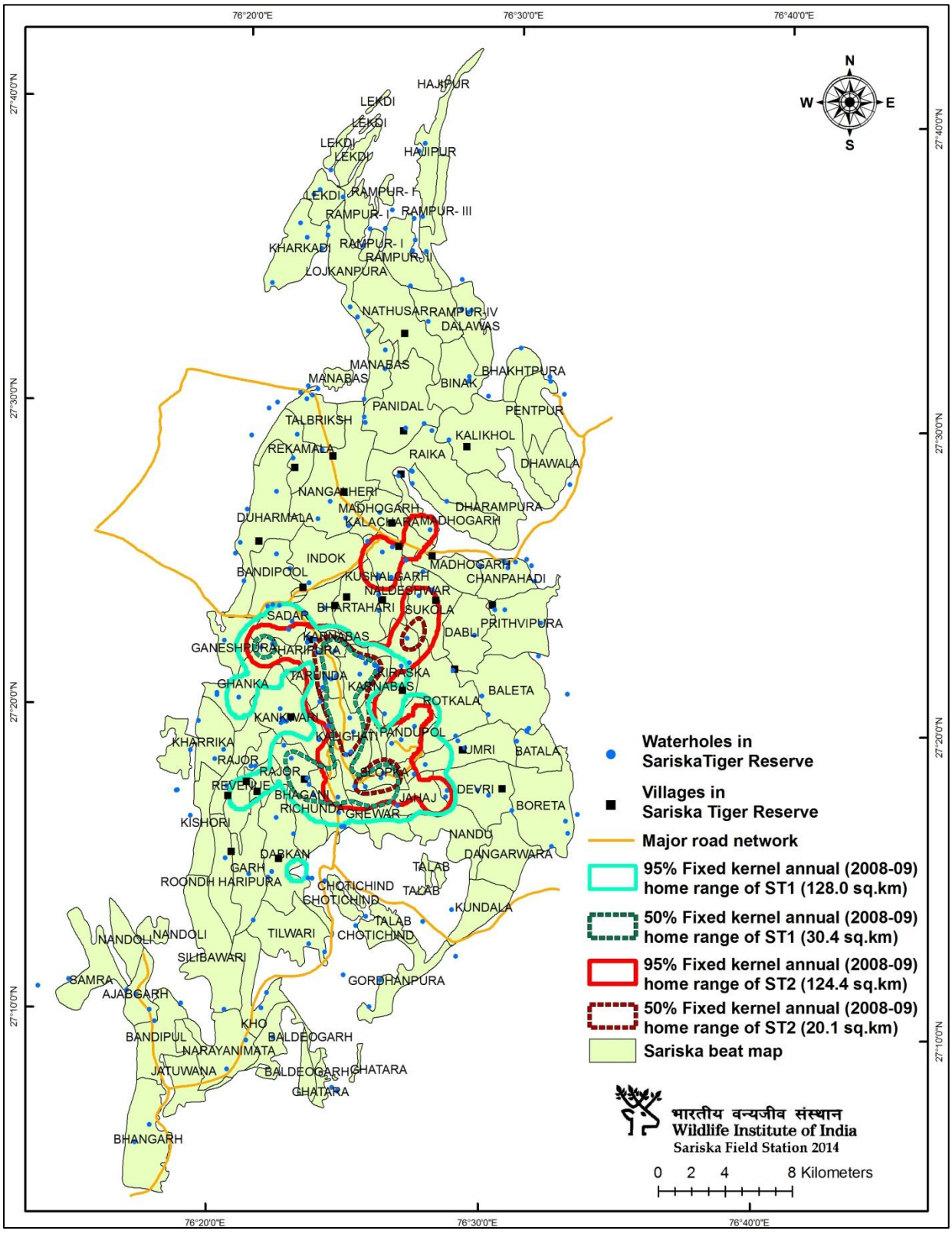


Figure 5.18. Annual home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July 2008 – June 2009).

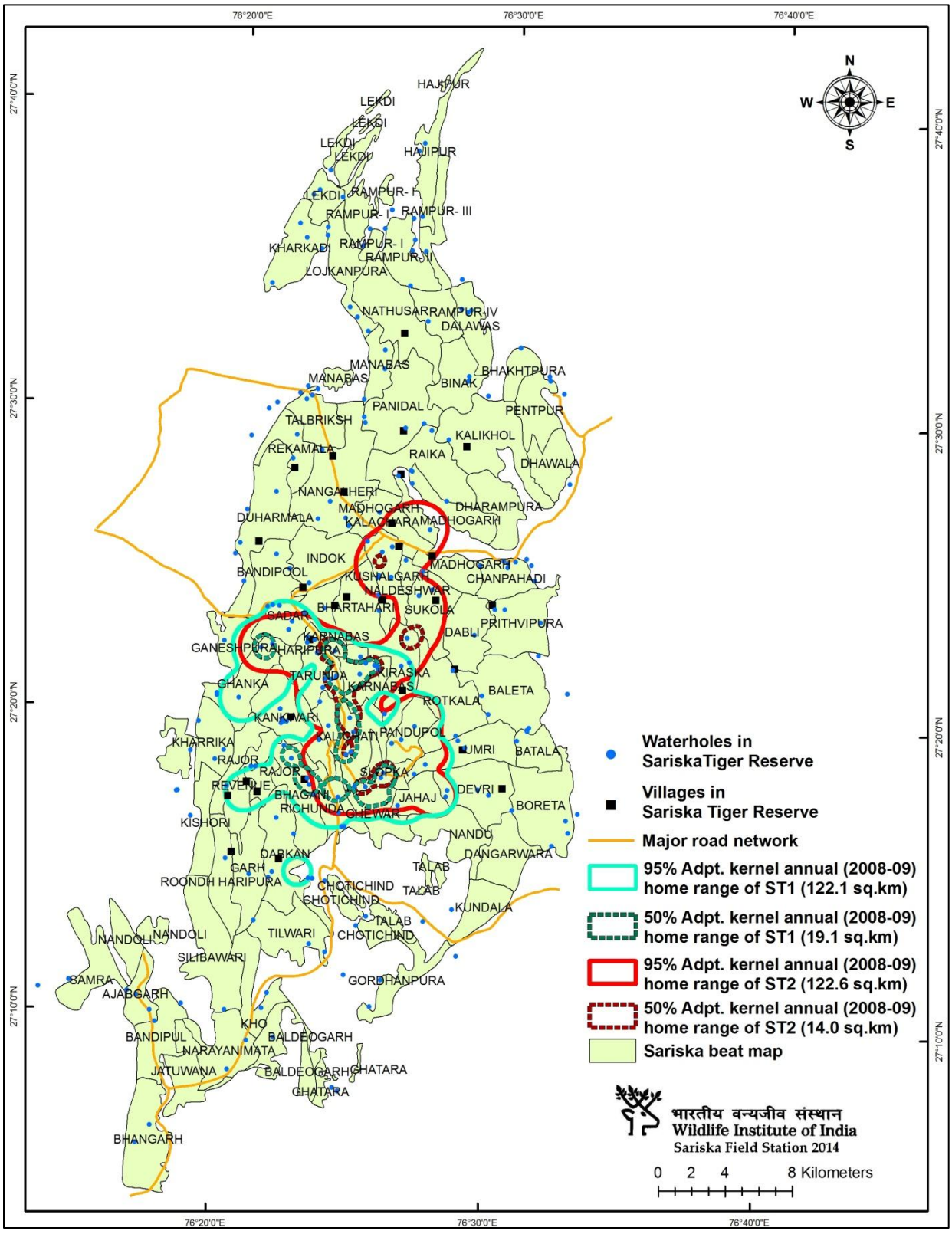


Table 5.3. Details of the monsoon ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July – October 2008.

Year	Season	Tiger ID	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2008	Monsoon	ST1	133.80	n.a.	75.01	n.a.	117.13	n.a.	24.11	n.a.	111.16	n.a.	14.67	n.a.
2008	Monsoon	ST2	151.30	n.a.	132.06	n.a.	117.51	n.a.	23.48	n.a.	112.22	n.a.	12.35	n.a.
2008	Monsoon	ST1-2 overlap	59.40	41.83	42.42	44.34	59.13	50.40	0.96	4.04	55.41	49.61	0.86	6.41

n.a. - Not applicable

Table 5.4. Details of the winter ranging patterns of reintroduced tigers in Sariska Tiger Reserve during November 2008 – February 2009.

Year	Season	Tiger ID	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Area (km^2)	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2008-09	Winter	ST1	107.10	n.a.	85.11	n.a.	118.32	n.a.	29.59	n.a.	109.60	n.a.	18.53	n.a.
2008-09	Winter	ST2	81.40	n.a.	77.46	n.a.	89.50	n.a.	18.82	n.a.	88.15	n.a.	11.09	n.a.
2008-09	Winter	ST1-2 overlap	79.90	86.38	70.71	87.18	87.47	85.83	16.56	71.98	83.48	85.44	9.52	68.61

n.a. - Not applicable

Table 5.5. Details of the summer ranging patterns of reintroduced tigers in Sariska Tiger Reserve during March 2009 – June 2009.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2009	Summer	ST1	101.30	n.a.	88.45	n.a.	111.48	n.a.	26.62	n.a.	103.61	n.a.	15.17	n.a.
2009	Summer	ST2	67.20	n.a.	51.88	n.a.	63.85	n.a.	14.81	n.a.	59.32	n.a.	9.09	n.a.
2009	Summer	ST3	223.40	n.a.	127.86	n.a.	124.91	n.a.	15.76	n.a.	134.46	n.a.	9.61	n.a.
2009	Summer	ST1-2 Overlap	67.10	83.05	51.28	78.41	63.53	78.24	12.08	63.47	57.27	75.91	5.38	47.33
2009	Summer	ST1-3 Overlap	83.60	59.97	60.01	57.39	58.97	50.05	7.75	39.14	60.73	51.89	3.28	27.88
2009	Summer	ST2-3 Overlap	54.00	52.26	28.89	39.14	32.16	38.06	0.25	1.64	33.27	40.42	0.11	1.18

n.a. - Not applicable

Table 5.6. Details of the annual ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2008 – June 2009.

Year	Period	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2008-09	Annual	ST1	168.60	n.a.	112.79	n.a.	127.97	n.a.	30.35	n.a.	122.13	n.a.	19.13	n.a.
2008-09	Annual	ST2	181.40	n.a.	127.75	n.a.	124.41	n.a.	20.08	n.a.	122.57	n.a.	13.96	n.a.
2008-09	Annual	ST1-2 overlap	99.00	56.65	84.98	70.93	87.44	69.31	16.24	67.19	85.40	69.80	9.79	60.65

n.a. - Not applicable

5.4.2.3. ANNUAL AND SEASONAL HOME RANGES OF TIGERS DURING 2009-10

During monsoon 2009, the second reintroduced female ST3 was observed to be associated with the male ST1 and stopped exploring new areas and settled in a smaller area of around 60 km^2. The monsoon home range of the other female ST2 was also similar (50 km^2) and the male tiger ST1 who was associated with both the tigresses had a larger home range of around 150 km^2. During 2009, monsoon home-ranges of ST1, ST2 and ST3 were estimated using 100% MCP as 166.8 km^2, 73.4 km^2 and 68.7 km^2 respectively (Figure 5.19). The estimated monsoon home ranges using 95% MCP were 110.8 km^2, 46.8 km^2 and 38.4 km^2 respectively for ST1 to ST3 (Figure 5.19). The estimated monsoon home ranges of these three tigers (ST1, ST2 and ST3) during 2009 using 95% fixed kernel were 145.8 km^2, 65.3 km^2 and 42.7 km^2 respectively and the monsoon core ranges were estimated using 50% fixed kernel as 34.9 km^2, 15.7 km^2 and 9.0 km^2 respectively for ST1 to ST3 (Figure 5.20). The monsoon home ranges of these three tigers (ST1, ST2 and ST3) were further estimated by 95% adaptive kernel as 139.1 km^2, 62.7 km^2 and 43.2 km^2 respectively, while the estimated core home ranges using 50% adaptive kernel were 24.7 km^2, 10.8 km^2 and 6.2 km^2 respectively for the similar order of individuals (Figure 5.21). Details of the monsoon home ranges and range overlaps during 2009 are given in table 5.7.

During the winter (2009-2010) the ranging pattern was similar to that of the monsoon when the male tiger ST1 was found to associate himself with both ST2 and ST3 tigresses. Thus ST1 had a larger winter home range covering both the female home ranges. The females were settled in their respective smaller home range. The winter home ranges of these three tigers (ST1, ST2 and ST3) during 2009-10 were estimated using 100% MCP as 158.1 km^2, 103.1 km^2 and 63.1 km^2 respectively, whereas 95% MCP estimator estimated the home ranges as 133.1 km^2, 58.5 km^2 and 56.3 km^2 respectively for ST1, ST2 and ST3 tigers respectively (Figure 5.22). Similarly, the winter home ranges of these three individuals were estimated using 95% fixed kernel estimator as 155.2 km^2, 82.7 km^2 and 73.3 km^2 respectively, while 50% fixed kernel estimator estimated the core ranges as 37.7 km^2, 19.2 km^2 and 16.5 km^2 respectively for ST1, ST2 and ST3 (Figure 5.23). Ninety five percent adaptive kernel estimator estimated these winter home ranges following the similar order of the individuals as 143.7 km^2, 80.8 km^2 and 65.1 km^2 respectively, whereas 50% adaptive kernel estimator estimated the core winter home ranges as 24.5 km^2, 13.9 km^2 and 10.2 km^2 respectively for ST1 to ST3 (Figure 5.24). Details of the winter home ranges and range overlaps during 2009-10 are given in table 5.8.

The summer ranging pattern of these three tigers ST1, ST2 and ST3 during 2010 were also similar to those of their previous monsoon and winter home ranges. During 2010, the summer home ranges of three reintroduced tigers ST1, ST2 and ST3 were estimated using 100% MCP estimator as 119.0 km^2, 48.0 km^2 and 79.0 km^2 respectively and estimated summer home ranges using 95% MCP estimator were 85.4 km^2, 35.9 km^2 and 64.5 km^2 for ST1, ST2 and ST3 tigers respectively (Figure 5.25). Correspondingly, these summer home ranges of ST1 to ST3 were measured using 95% fixed kernel as 105.4 km^2, 48.6 km^2 and 72.8 km^2 respectively, while 50% fixed kernel estimator estimated the summer core ranges as 24.0 km^2, 12.7 km^2 and 12.9 km^2 respectively for ST1 to ST3 tigers respectively (Figure 5.26). Further, the summer home ranges during 2010 of these three tigers ST1, ST2 and ST3 were estimated using 95% adaptive kernel estimator as 101.2 km^2, 44.5 km^2 and 68.4 km^2 respectively, whereas the estimated core home ranges using 50% adaptive kernel estimator were 16.0 km^2, 9.1 km^2 and 8.6 km^2 for ST1 to ST3 tigers respectively (Figure 5.27). Details of the summer home ranges and range overlaps during 2010 are given in table 5.9.

The annual home ranges of these three reintroduced tigers ST1, ST2 and ST3, during 2009-10 were estimated using 100% MCP estimator as 185.6 km^2, 123.5 km^2 and 112.2 km^2 respectively, while the estimated annual home ranges of these individuals using 95% MCP were 129.2 km^2, 59.0 km^2 and 91.5 km^2 respectively for ST1, ST2 and ST3 tigers with 79% of range overlap for ST1 and ST2 and 70% range overlap for ST1 and ST3 tigers while range overlap between ST2 and ST3 was 46% (using 100% MCP estimator - figure 5.28 and table 5.10). The estimated annual home ranges of ST1, ST2 and ST3 tigers during 2009-10 using 95% fixed kernel were 133.5 km^2, 66.2 and 73.5 km^2 respectively, whereas the core of the annual home ranges using 50% fixed kernel were estimated as 29.8 km^2, 14.8 km^2 and 12.5 km^2 for ST1 to ST3 respectively (Figure 5.29). Similarly, the annual home ranges of these three individuals ST1, ST2 and ST3 were estimated using 95% adaptive kernel estimator as 130.5 km^2, 66.8 km^2 and 72.7 km^2 respectively and 50% adaptive kernel estimator estimated the core home ranges as 21.7 km^2, 10.6 km^2 and 9.2 km^2 for ST1, ST2 and ST3 respectively (Figure 5.30). The details of the annual home range estimation and range overlaps of the reintroduced tigers in Sariska Tiger Reserve during 2009-10 are given in Table 5.10.

Figure 5.19. Monsoon home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July – October 2009).

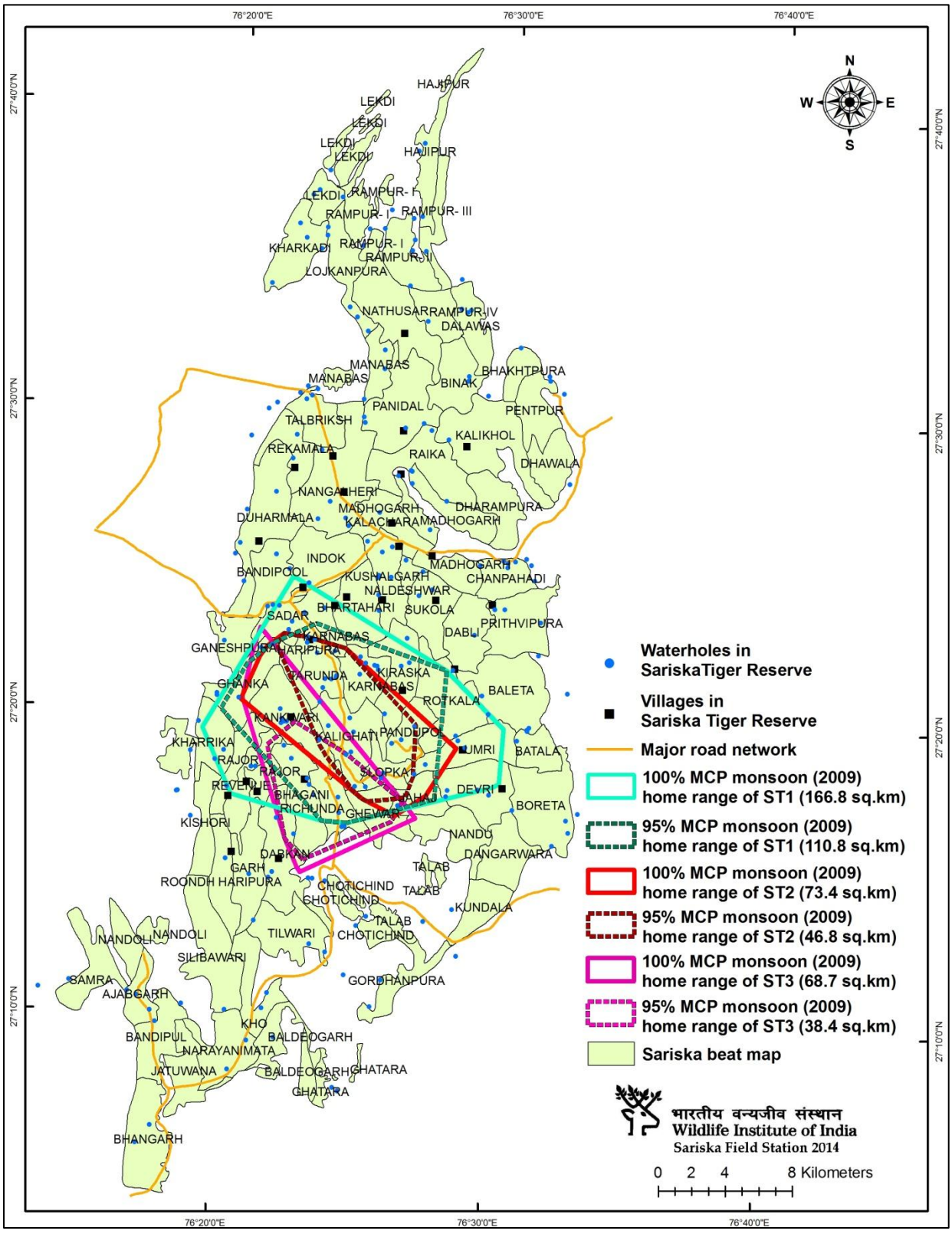


Figure 5.20. Monsoon home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July – October 2009).

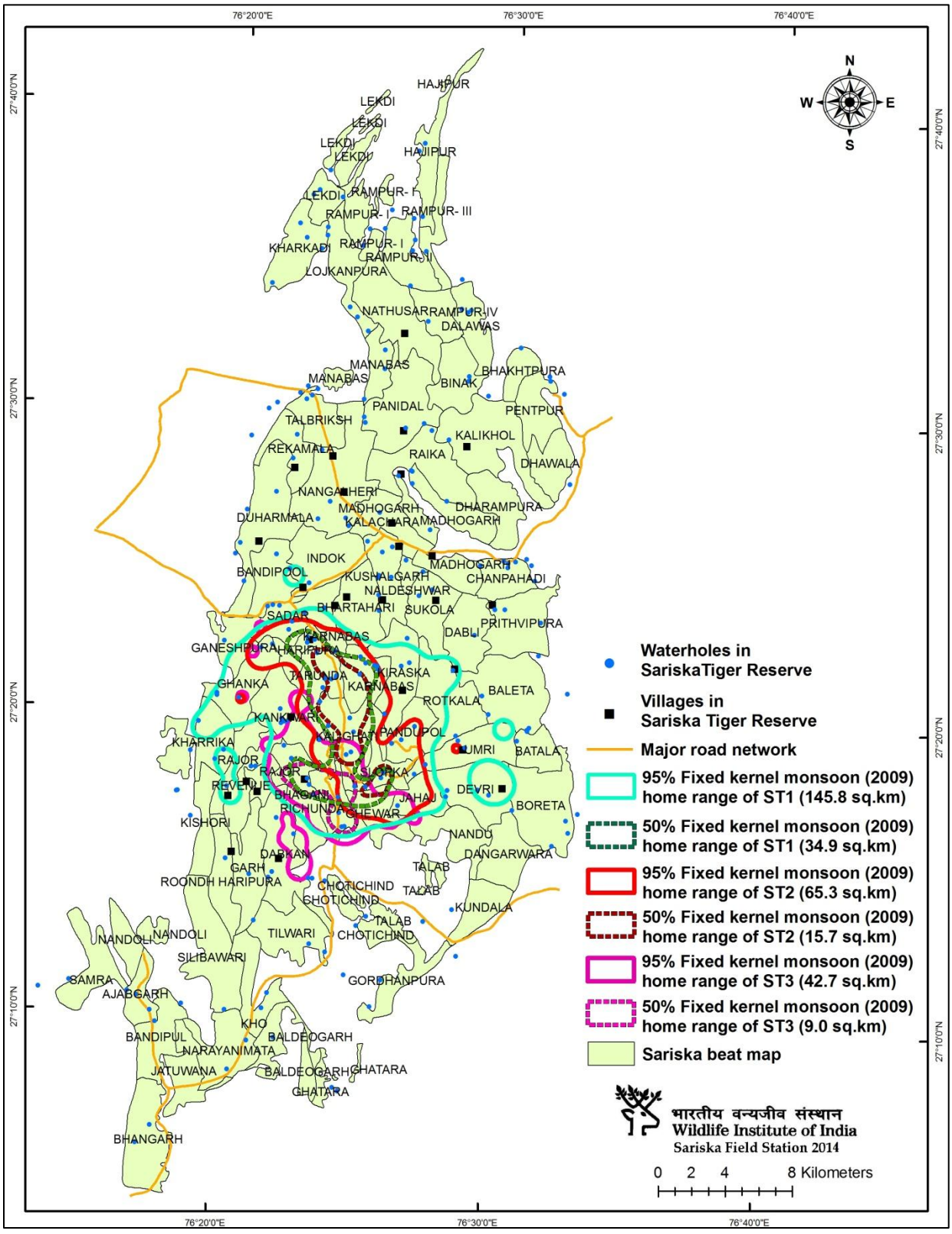


Figure 5.21. Monsoon home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July – October 2009).

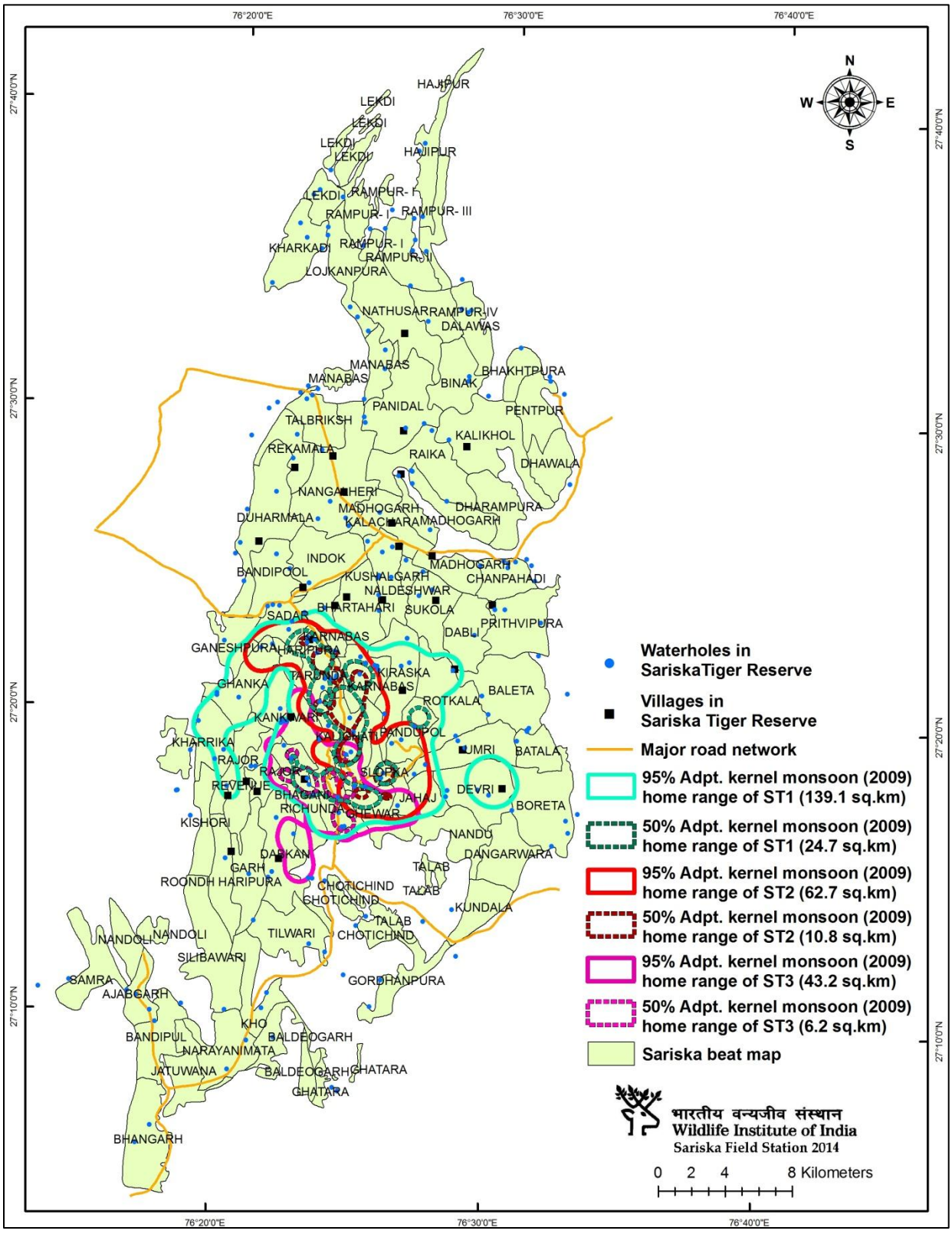


Figure 5.22. Winter home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (November 2009 – February 2010).

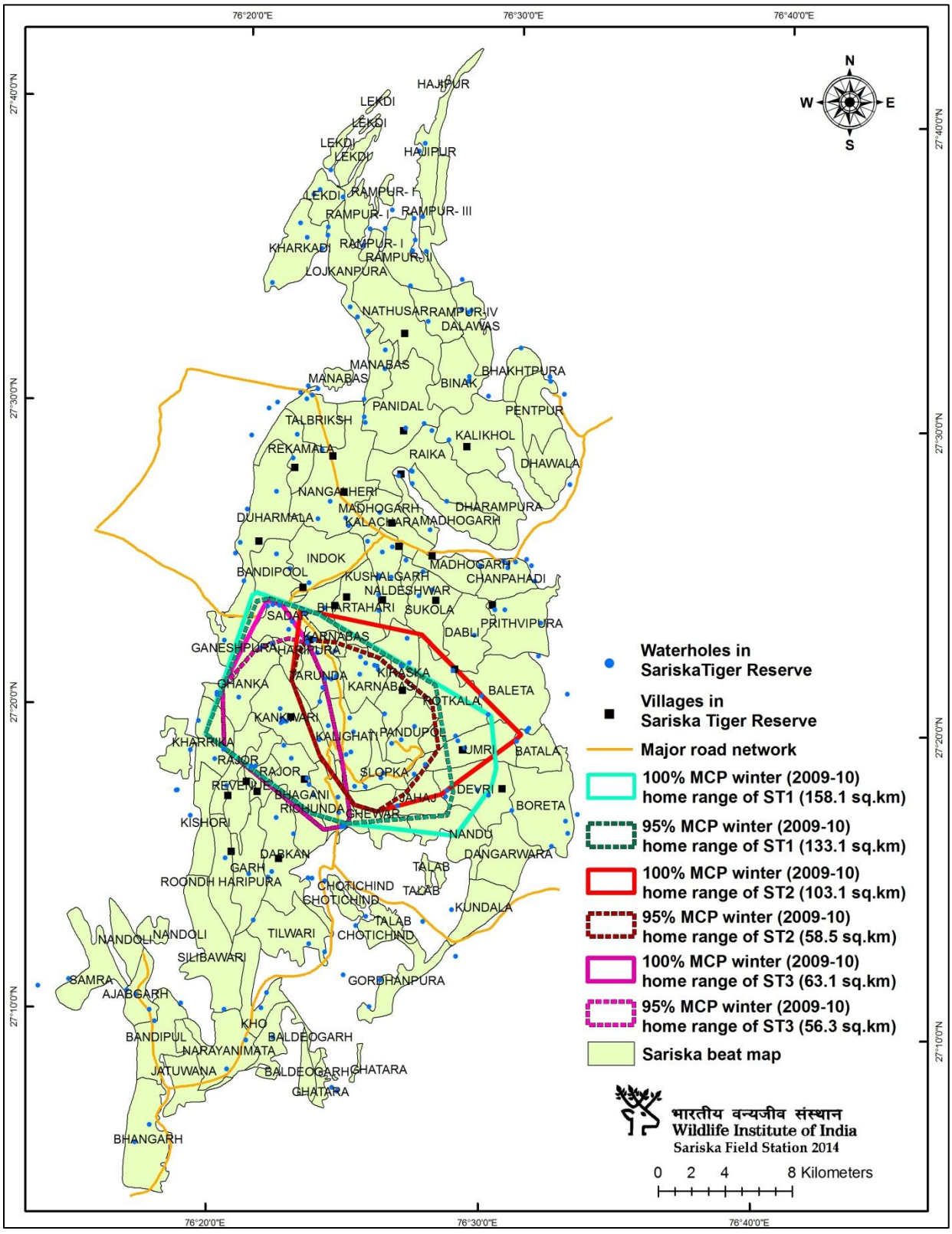


Figure 5.23. Winter home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (November 2009 – February 2010).

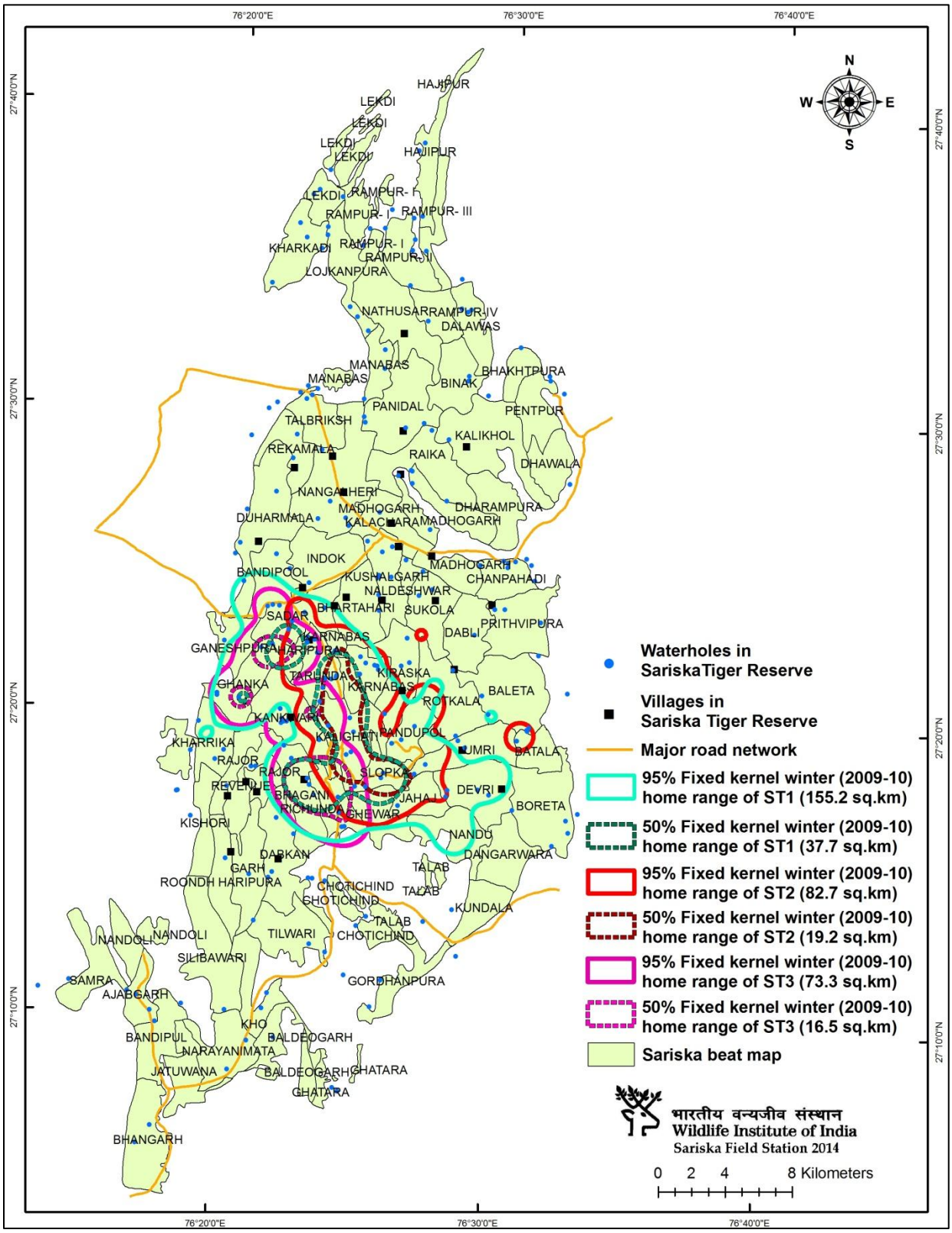


Figure 5.24. Winter home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (November 2009 – February 2010).

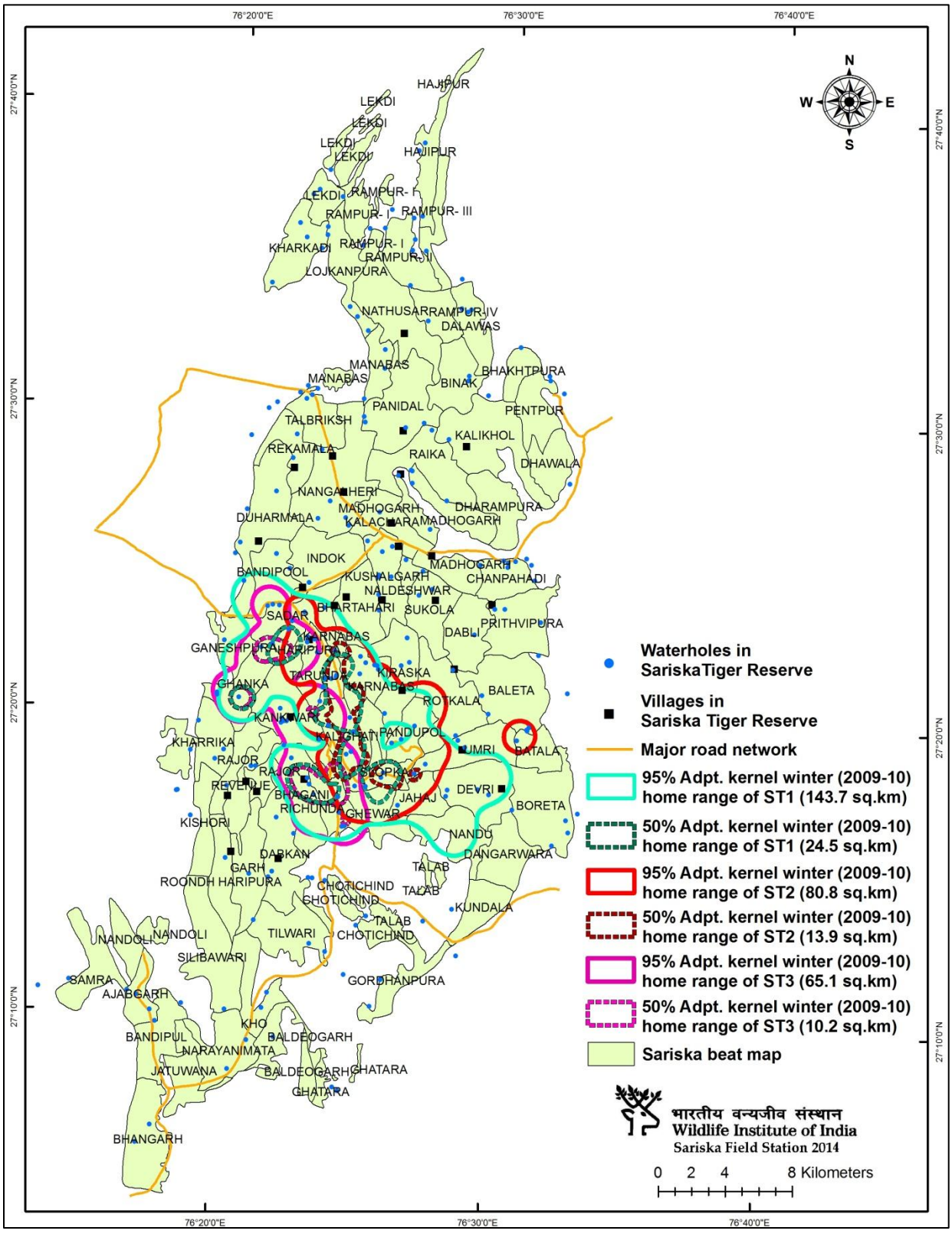


Figure 5.25. Summer home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (March 2010 – June 2010).

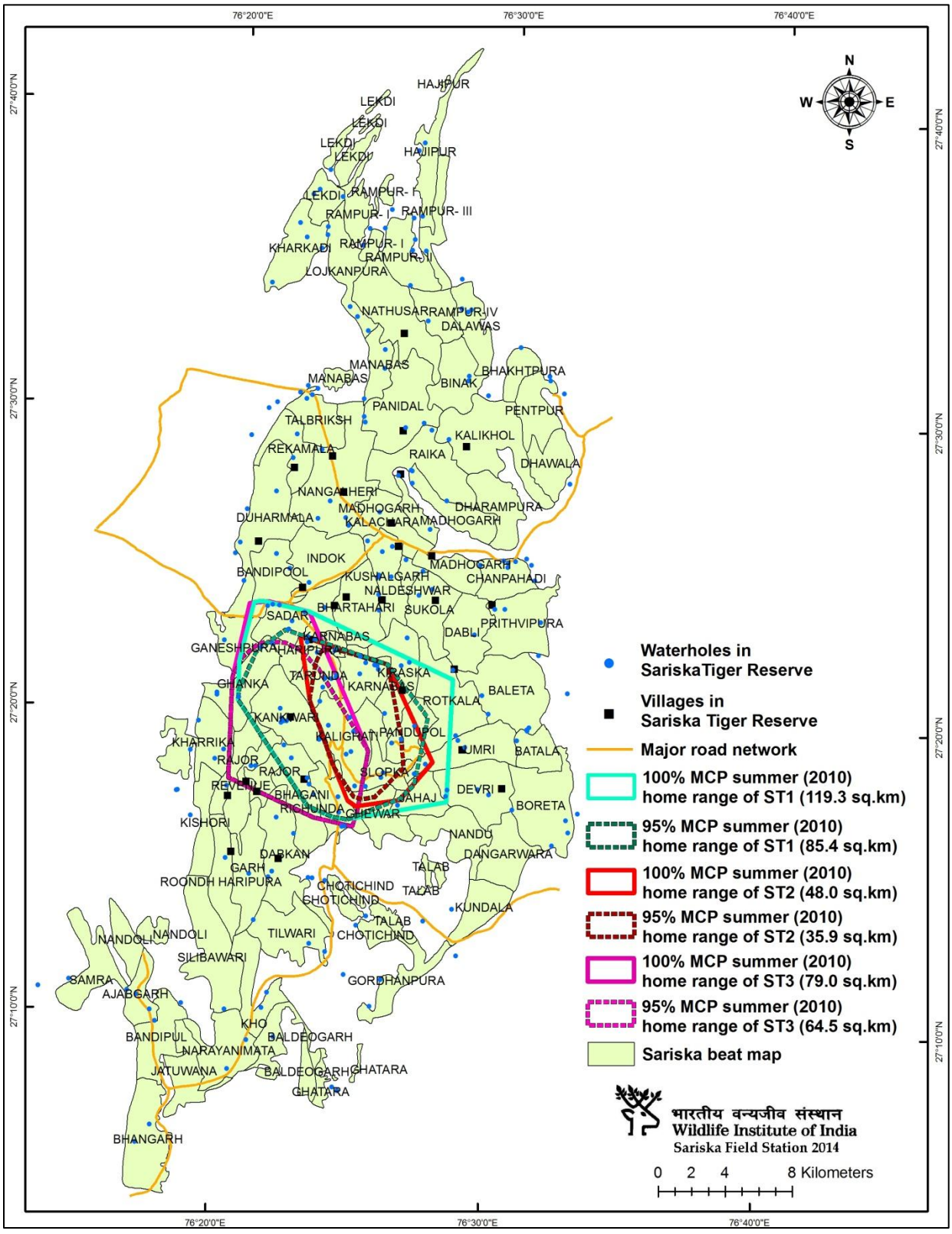


Figure 5.26. Summer home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (March 2010 – June 2010).

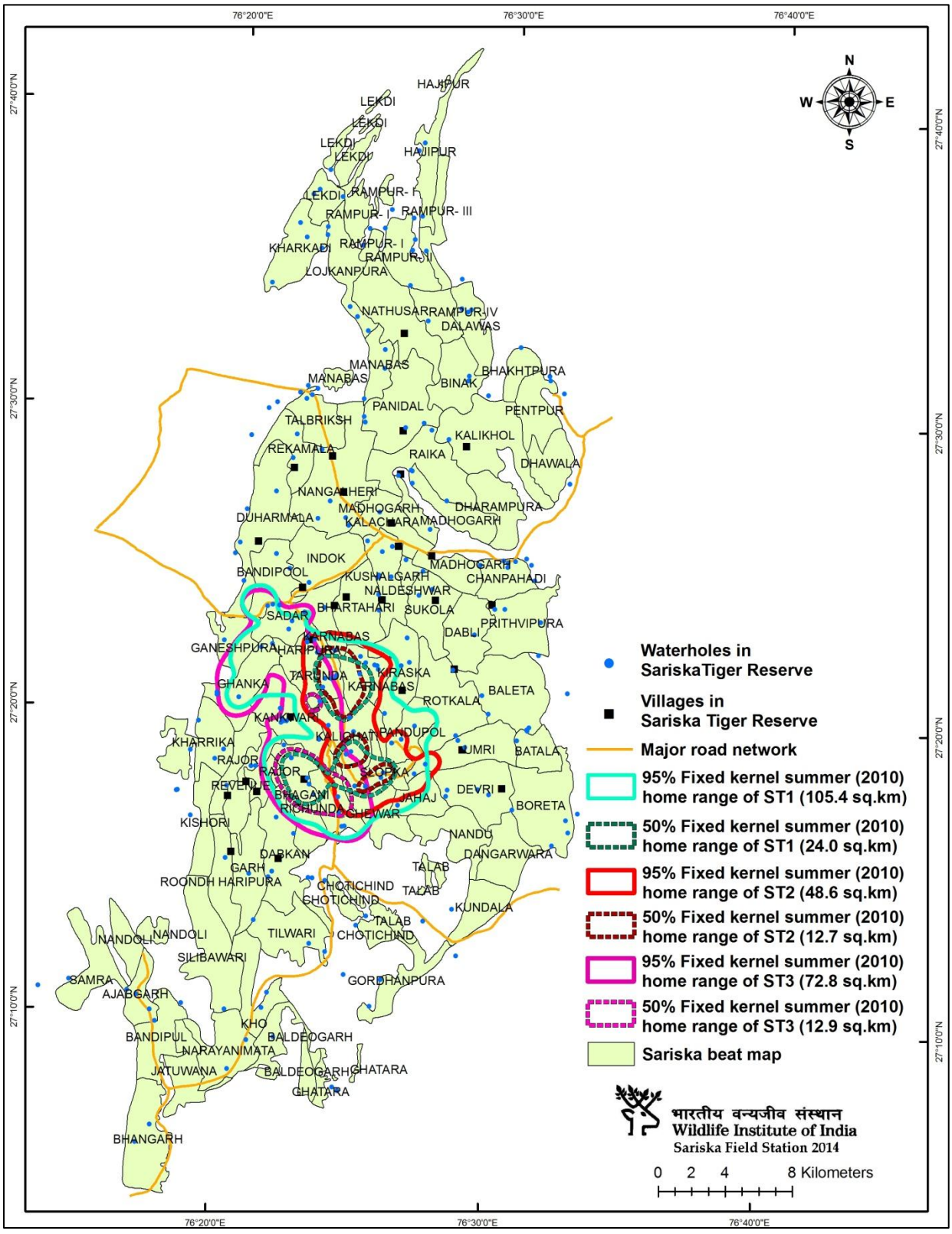


Figure 5.27. Summer home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (March 2010 – June 2010).

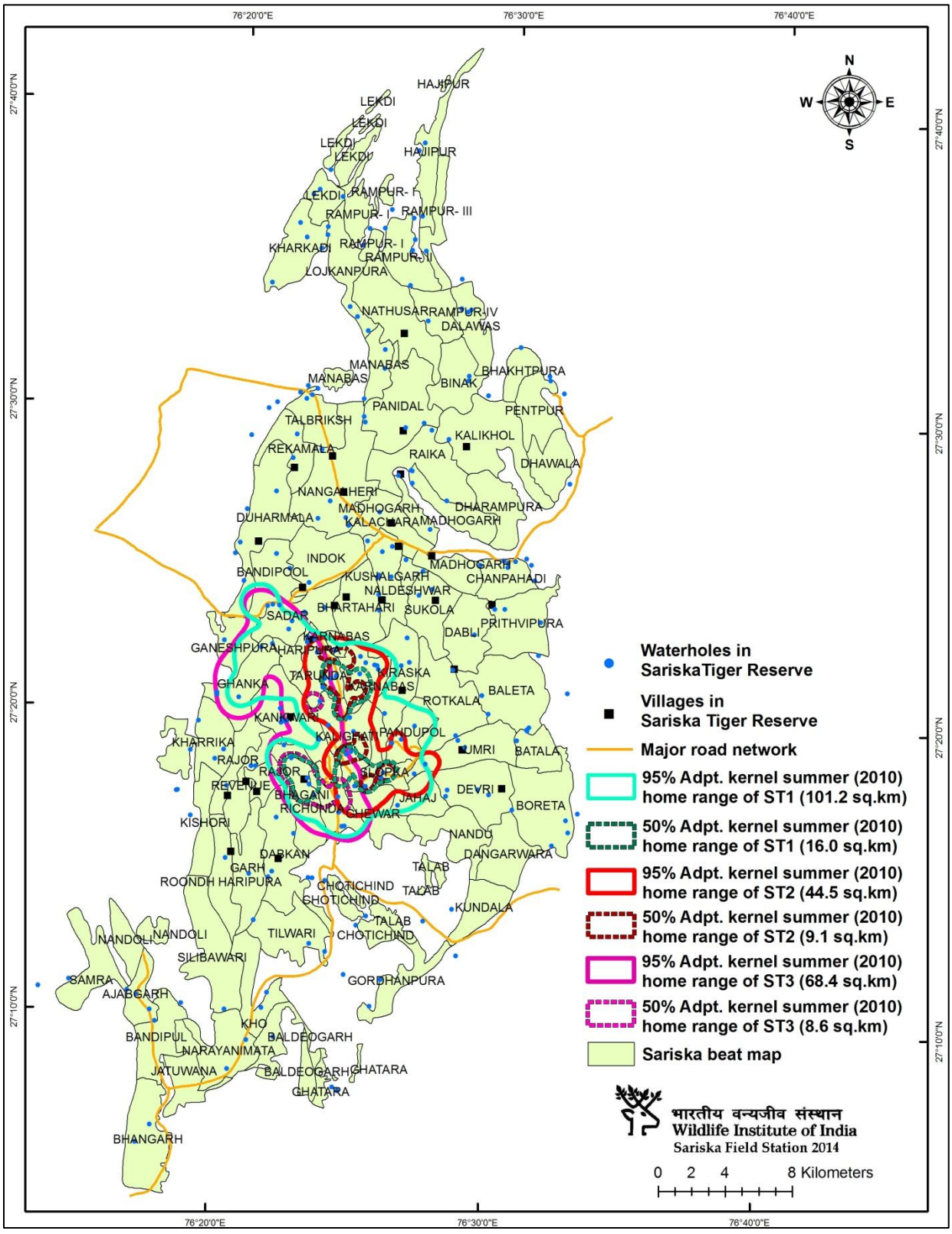


Figure 5.28. Annual home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July 2009 – June 2010).

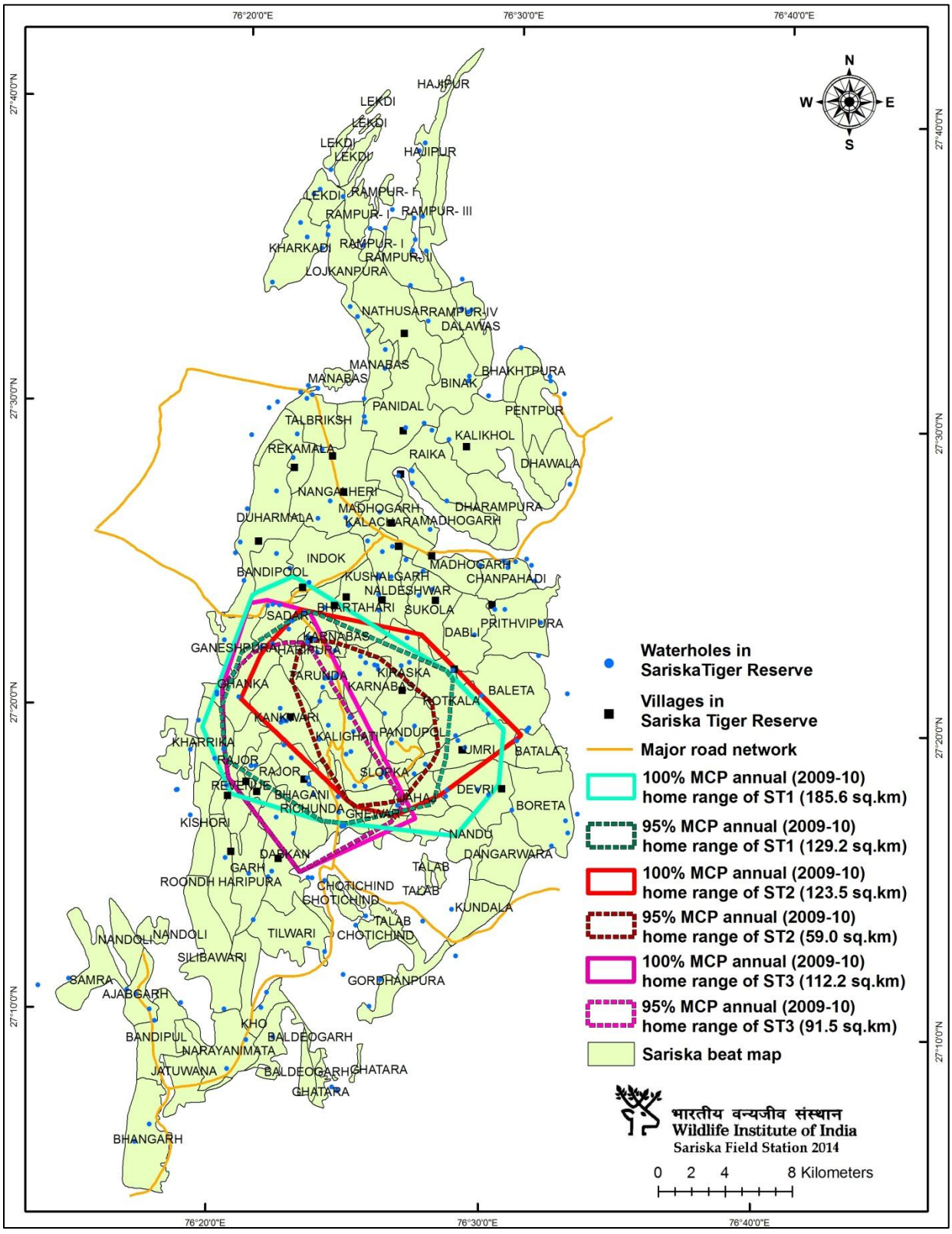


Figure 5.29. Annual home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July 2009 – June 2010).

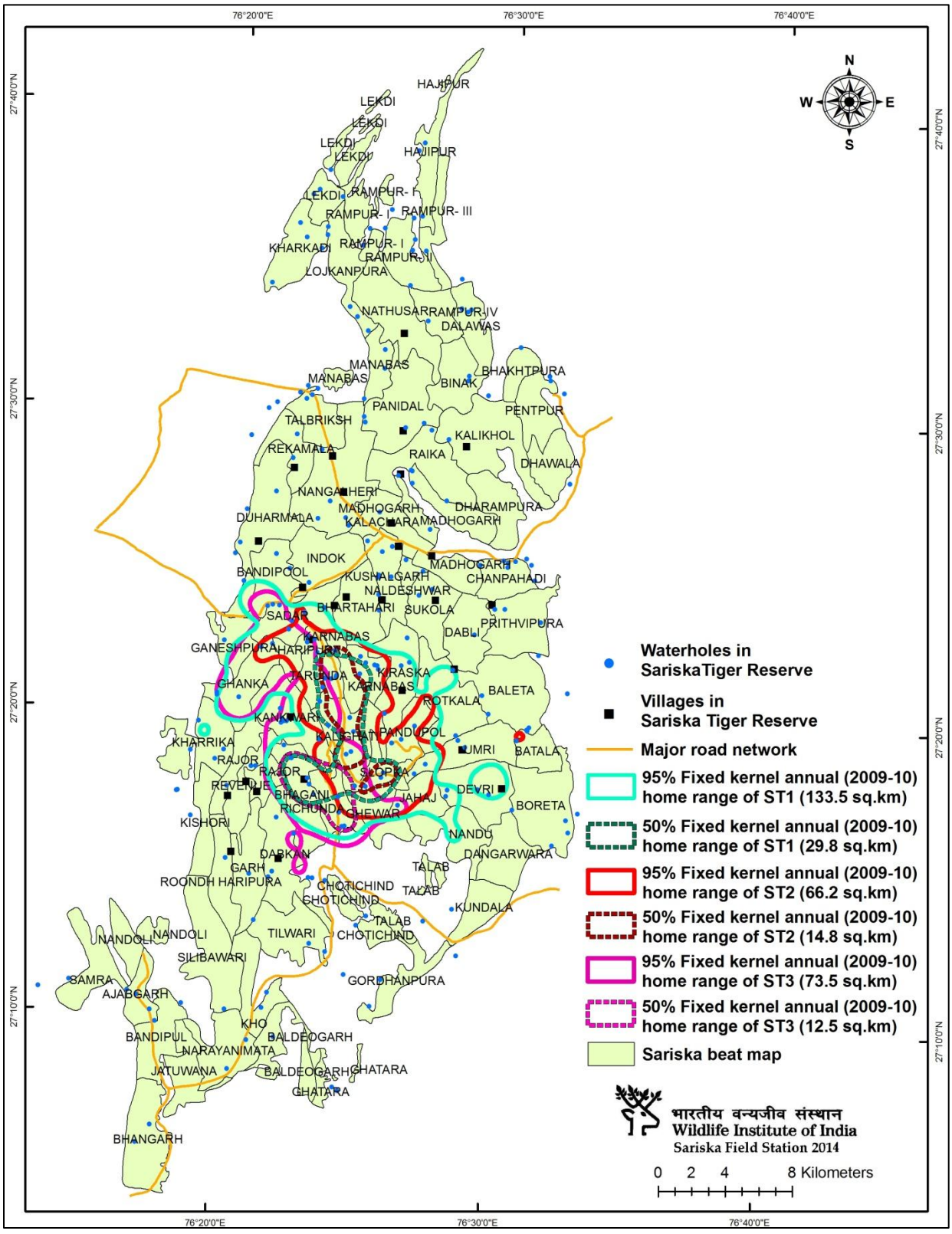


Figure 5.30. Annual home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July 2009 – June 2010).

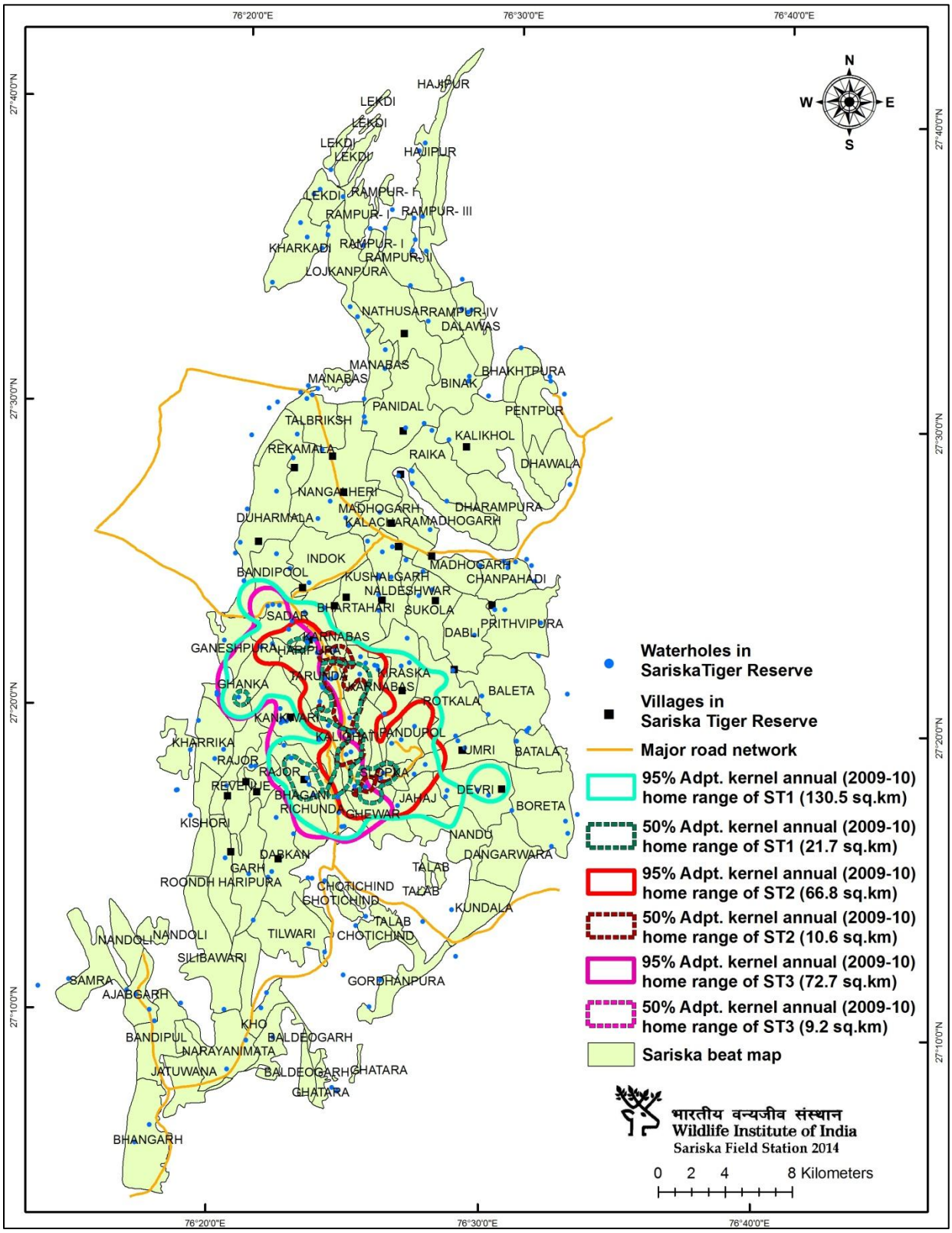


Table 5.7. Details of the monsoon ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2009 – October 2009.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2009	Monsoon	ST1	166.80	n.a.	110.76	n.a.	145.81	n.a.	34.93	n.a.	139.06	n.a.	24.73	n.a.
2009	Monsoon	ST2	73.40	n.a.	46.84	n.a.	65.32	n.a.	15.68	n.a.	62.71	n.a.	10.75	n.a.
2009	Monsoon	ST3	68.70	n.a.	38.37	n.a.	42.67	n.a.	9.00	n.a.	43.16	n.a.	6.21	n.a.
2009	Monsoon	ST1-2 overlap	73.30	71.90	46.74	70.99	65.17	72.23	15.51	71.66	62.70	72.54	9.08	60.60
2009	Monsoon	ST1-3 overlap	54.40	55.90	25.50	44.74	36.47	55.24	6.10	42.62	35.23	53.48	3.68	37.07
2009	Monsoon	ST2-3 verlap	30.60	43.12	5.85	13.87	15.22	29.48	0.00	0.00	13.43	20.39	0.17	2.16

Table 5.8. Details of the winter ranging patterns of reintroduced tigers in Sariska Tiger Reserve during November 2009 – February 2010.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2009-10	Winter	ST1	158.10	n.a.	133.05	n.a.	155.17	n.a.	37.67	n.a.	143.70	n.a.	24.45	n.a.
2009-10	Winter	ST2	103.10	n.a.	58.53	n.a.	82.74	n.a.	19.22	n.a.	80.84	n.a.	13.85	n.a.
2009-10	Winter	ST3	63.10	n.a.	56.33	n.a.	73.34	n.a.	16.53	n.a.	65.10	n.a.	10.20	n.a.
2009-10	Winter	ST1-2 overlap	86.50	69.31	58.53	72.00	77.80	72.08	18.67	73.35	72.76	70.32	10.89	61.58
2009-10	Winter	ST1-3 overlap	61.10	67.74	54.35	68.67	69.30	69.58	11.93	51.92	58.71	65.52	6.69	46.47
2009-10	Winter	ST2-3 overlap	11.90	15.20	11.24	19.58	26.51	34.09	0.77	4.33	21.57	29.91	0.46	3.92

n.a. - Not applicable

Table 5.9. Details of the summer ranging patterns of reintroduced tigers in Sariska Tiger Reserve during March 2010 – June 2010.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2010	Summer	ST1	119.30	n.a.	85.40	n.a.	105.44	n.a.	23.97	n.a.	101.15	n.a.	16.01	n.a.
2010	Summer	ST2	48.00	n.a.	35.86	n.a.	48.63	n.a.	12.69	n.a.	44.45	n.a.	9.08	n.a.
2010	Summer	ST3	79.00	n.a.	64.50	n.a.	72.76	n.a.	12.94	n.a.	68.41	n.a.	8.57	n.a.
2010	Summer	ST1-2 overlap	48.00	70.12	35.86	71.00	47.24	70.97	10.94	65.92	43.05	69.71	6.38	55.06
2010	Summer	ST1-3 overlap	62.80	66.07	47.91	65.19	61.72	71.68	6.87	40.88	56.91	69.73	4.15	37.17
2010	Summer	ST2-3 overlap	17.90	29.97	12.03	26.10	17.40	29.85	0.00	0.00	14.74	27.35	0.00	0.00

Table 5.10. Details of the annual ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2009 – June 2010.

Year	Period	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2009-10	Annual	ST1	185.60	n.a.	129.21	n.a.	133.48	n.a.	29.76	n.a.	130.52	n.a.	21.68	n.a.
2009-10	Annual	ST2	123.50	n.a.	59.00	n.a.	66.23	n.a.	14.82	n.a.	66.81	n.a.	10.59	n.a.
2009-10	Annual	ST3	112.20	n.a.	91.53	n.a.	73.49	n.a.	12.52	n.a.	72.73	n.a.	9.24	n.a.
2009-10	Annual	ST1-2 Overlap	117.00	78.89	59.00	72.83	65.63	74.13	14.25	72.02	66.06	74.85	9.02	63.64
2009-10	Annual	ST1-3 Overlap	97.50	69.72	71.42	66.65	65.93	69.55	7.99	45.33	63.60	68.09	5.00	39.25
2009-10	Annual	ST2-3 Overlap	54.00	45.93	24.70	34.43	26.89	38.60	0.00	0.00	26.14	37.54	0.00	0.00

n.a. - Not applicable

5.4.2.4. ANNUAL AND SEASONAL HOME RANGES OF TIGERS DURING 2010-11

During July 2010, two more tigers, an adult male (ST4) and an adult female (ST5) were reintroduced to Sariska. During the monsoon 2010, both the individuals explored large areas in Sariska of around 150 km^2 and 200 km^2 respectively. While ST4 had moved to the south eastern part of the Tiger Reserve and also moved out of the park boundary quite a few times, ST5 followed the exploring course similar to ST2 and moved to north and north-eastern part of the Tiger Reserve. During 2010 monsoon, home-ranges of already settled three tigers ST1, ST2 and ST3 were similar to that of the previous year (2009).

During 2010 monsoon, the estimated home-ranges of ST1 to ST5 tigers by 100% MCP as 163.7 km^2, 43.1 km^2, 95.1 km^2, 149.1 km^2 and 208.9 km^2 respectively and estimated monsoon home ranges using 95% MCP were 104.7 km^2, 35.7 km^2, 57.2 km^2, 112.0 km^2 and 185.4 km^2 for the tigers ST1, ST2, ST3, ST4 and ST5 respectively (Figure 5.31). The estimated monsoon home ranges of these five tigers (ST1 to ST5) during 2010 using 95% fixed kernel estimator were 118.3 km^2, 49.2 km^2, 98.9 km^2, 130.6 km^2 and 242.7 km^2 respectively, while core of monsoon home ranges were estimated by 50% fixed kernel as 22.8 km^2, 12.6 km^2, 19.9 km^2, 27.2 km^2 and 60.1 km^2 for ST1 to ST5 respectively (Figure 5.32). The estimated monsoon home ranges by 95% adaptive kernel for the similar order of individuals were 118.1 km^2, 46.6 km^2, 83.0 km^2, 134.3 km^2 and 223.7 km^2 respectively, while monsoon core ranges were estimated using 50% adaptive kernel as 17.6 km^2, 9.5 km^2, 13.3 km^2, 21.1 km^2 and 42.7 km^2 for ST1 to ST5 tigers respectively (Figure 5.33). Details of the home ranges and range overlaps during monsoon 2010 are given in table 5.11.

On 14th November 2010, the first reintroduced male ST1 was found dead due to poisoning at "Kalakhet" near Rajore forest naka within the Tiger Reserve boundary. Soon after the death of ST1, the other male ST4 was observed to occupy the entire range of the former and got associated with all the three female tigers (ST2, ST3 and ST5) within a month. Therefore, during winter 2010-11, home range of ST4 became very large (>200 km^2). The estimated home range overlaps among the females were less, whereas the home range of ST4 male almost covered the home ranges of all three females (Figures 5.34, 5.35 and 5.36).

The winter home ranges of these four tigers ST2, ST3, ST4 and ST5 during 2010-11 were estimated using 100% MCP estimator as 52.0 km^2, 109.9 km^2, 234.4 km^2 and 88.5 km^2 respectively, while 95% MCP estimator estimated the winter home ranges as 38.7 km^2, 86.8 km^2, 201.2 km^2 and 74.6 km^2 for ST2 to ST5 tigers respectively (Figure 5.34). Similarly, the winter home ranges of these four

individuals ST2, ST3, ST4 and ST5 were estimated using 95% fixed kernel estimator as 46.8 km^2, 101.5 km^2, 210.3 km^2 and 80.6 km^2 respectively, whereas the estimated winter core ranges using 50% fixed kernel estimator were 12.9 km^2, 31.8 km^2, 50.7 km^2 and 23.0 km^2 for ST2 to ST5 respectively (Figure 5.35). The winter home ranges of ST2 to ST5 tigers were estimated using 95% adaptive kernel estimator as 44.6 km^2, 91.5 km^2, 202.2 km^2 and 73.6 km^2 respectively, while 50% adaptive kernel estimator measured the core home ranges as 8.7 km^2, 21.9 km^2, 36.0 km^2 and 14.8 km^2 respectively for the above-mentioned order of individuals (Figure 5.36). Details of the home ranges and range overlaps during winter 2010-11 are given in table 5.12.

After the death of ST1, during the month of February 2011, a sub-adult male tiger T-07, which had dispersed from Ranthambhore and moved 250 km to Mathura, Uttar Pradesh and further back-tracked to Keoladeo National Park, Bharatpur (Bhattacharjee *et al*., 2012), was translocated to Sariska and renamed as ST6. This male tiger ST6 soon after his reintroduction was observed to associate himself with the tigress ST3 and established his territory in the south-western part of the Tiger Reserve. This male tiger ST6 like other reintroduced tigers, initially explored large areas (>200 km^2) during summer 2011 (Figures 5.37, 5.38 and 5.39).

During 2011 summer, the home ranges of five reintroduced tigers ST2, ST3, ST4, ST5 and ST6 were estimated using 100% MCP estimator as 69.1 km^2, 119.8 km^2, 173.4 km^2, 105.4 km^2 and 210.1 km^2 respectively and the estimated summer home ranges using 95% MCP estimator were 36.0 km^2, 108.8 km^2, 114.6 km^2, 72.0 km^2 and 103.4 km^2 for ST2 to ST6 tigers respectively (Figure 5.37). Similarly, the summer home ranges of ST2 to ST6 tigers were assessed using 95% fixed kernel estimator as 38.6 km^2, 89.9 km^2, 127.4 km^2, 82.4 km^2 and 108.4 km^2 respectively, while the estimated summer core ranges using 50% fixed kernel estimator were 10.7 km^2, 17.7 km^2, 27.8 km^2, 20.8 km^2 and 21.5 km^2 for ST2 to ST6 tigers respectively (Figure 5.38). The summer home ranges during 2011 of these five tigers were estimated by the 95% adaptive kernel estimator as 36.0 km^2, 86.0 km^2, 117.6 km^2, 77.7 km^2 and 105.8 km^2 respectively, whereas 50% adaptive kernel estimated the core home range as 7.5 km^2, 10.4 km^2, 17.7 km^2, 13.3 km^2 and 14.0 km^2 for ST2 to ST6 tigers respectively (Figure 5.39). Details of the home ranges and range overlaps during summer 2011 are given in table 5.13.

During 2010-11, the annual home ranges of ST2, ST3, ST4 and ST5 tigers were estimated using 100% MCP as 76.7 km^2, 144.4 km^2, 405.3 km^2 and 381.6 km^2 respectively and the estimated annual home ranges using 95% MCP were 44.2 km^2, 112.3 km^2, 263.8 km^2 and 235.7 km^2 respectively for ST2 to ST5 tigers (Figure 5.40). The annual home range of two tigers, ST4 male and ST5 female were found

to be much large such as 405 km^2 and 381 km^2, respectively due to their initial exploration of areas. The male-female range overlaps were observed to be much larger as compared to female-female range overlaps, since male tiger ST4 almost covered the territories of all three females, ST2, ST5 and ST3 (Table 5.14). The estimated annual home ranges of the tigers in an order from ST2 to ST5 during 2010-11 by using 95% fixed kernel estimator were 45.6 km^2, 98.8 km^2, 265.8 km^2 and 186.8 km^2 respectively and the core of the home ranges estimated by 50% fixed kernel were 12.1 km^2, 23.4 km^2, 57.0 km^2 and 33.3 km^2 respectively following the similar order (Figure 5.41). The annual home ranges of these four individuals ST2, ST3, ST4 and ST5 were further estimated using 95% adaptive kernel estimator as 42.2 km^2, 93.6 km^2, 265.2 km^2 and 205.5 km^2 respectively, while 50% adaptive kernel estimator estimated the core home ranges as 8.9 km^2, 15.8 km^2, 39.5 km^2 and 23.1 km^2 for ST2 to ST5 respectively (Figure 5.42). The details of the annual home ranges and range overlaps of the reintroduced tigers in Sariska Tiger Reserve during 2010-11 are given in Table 5.14.

Figure 5.31. Monsoon home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July – October 2010).

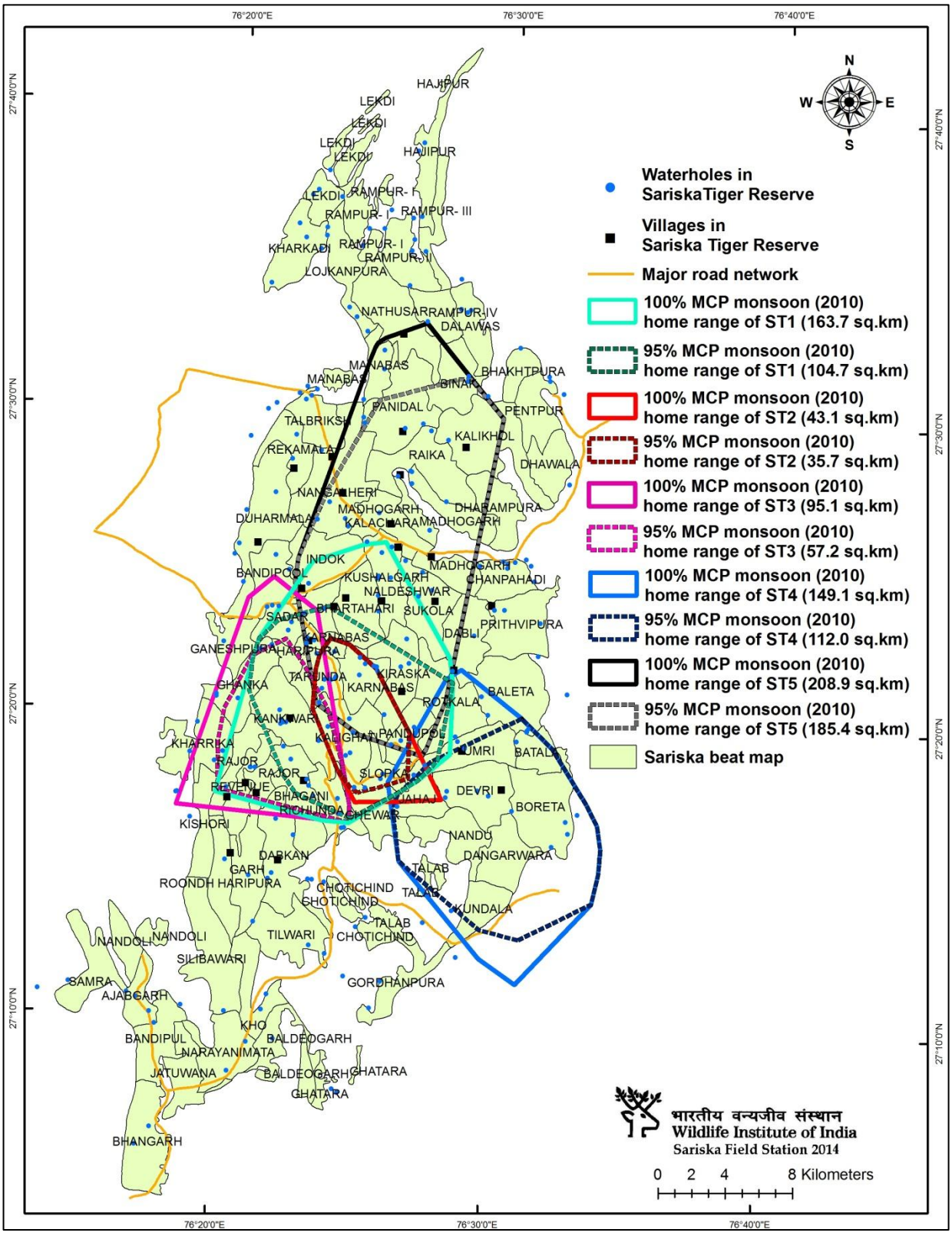


Figure 5.32. Monsoon home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July – October 2010).

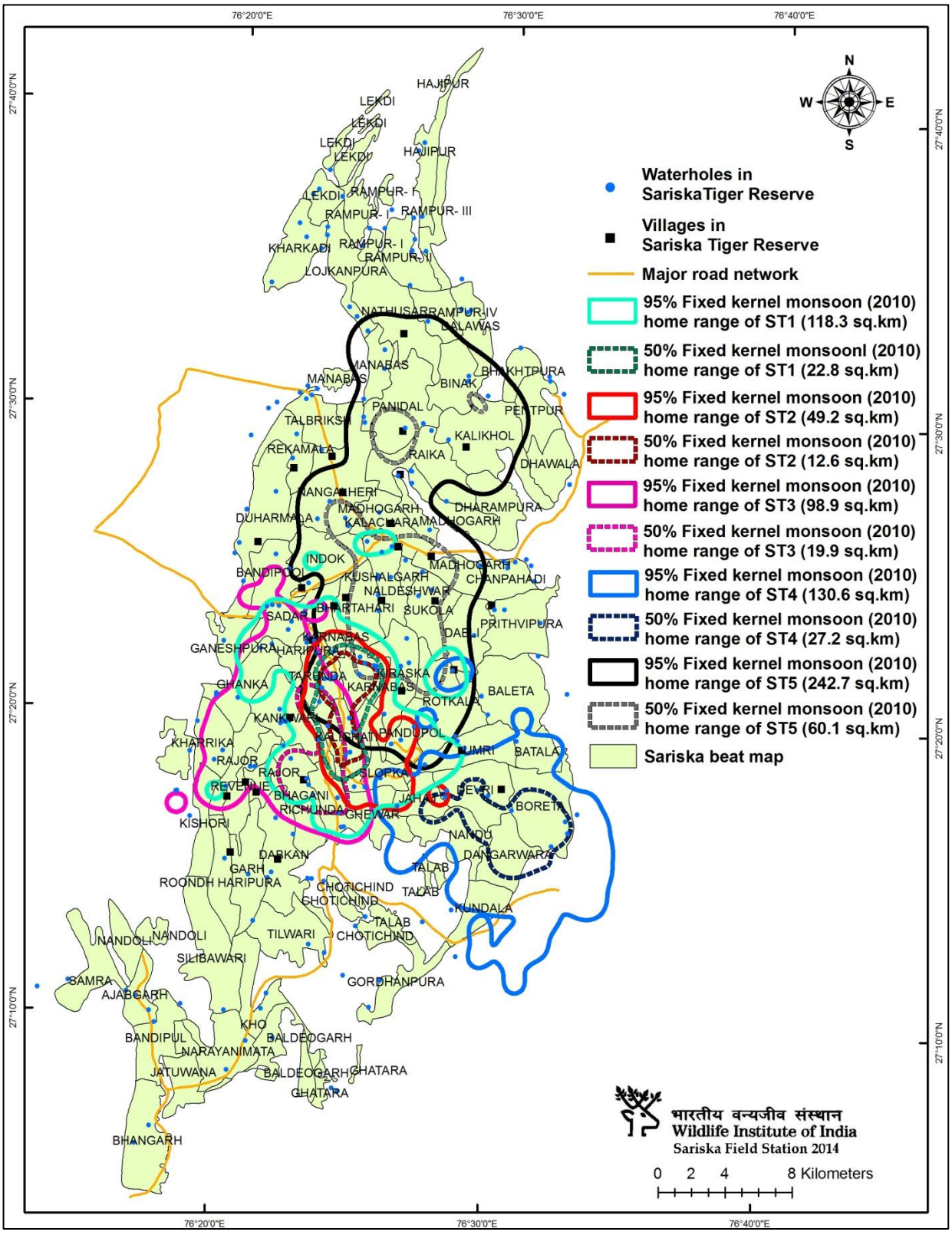


Figure 5.33. Monsoon home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July – October 2010).

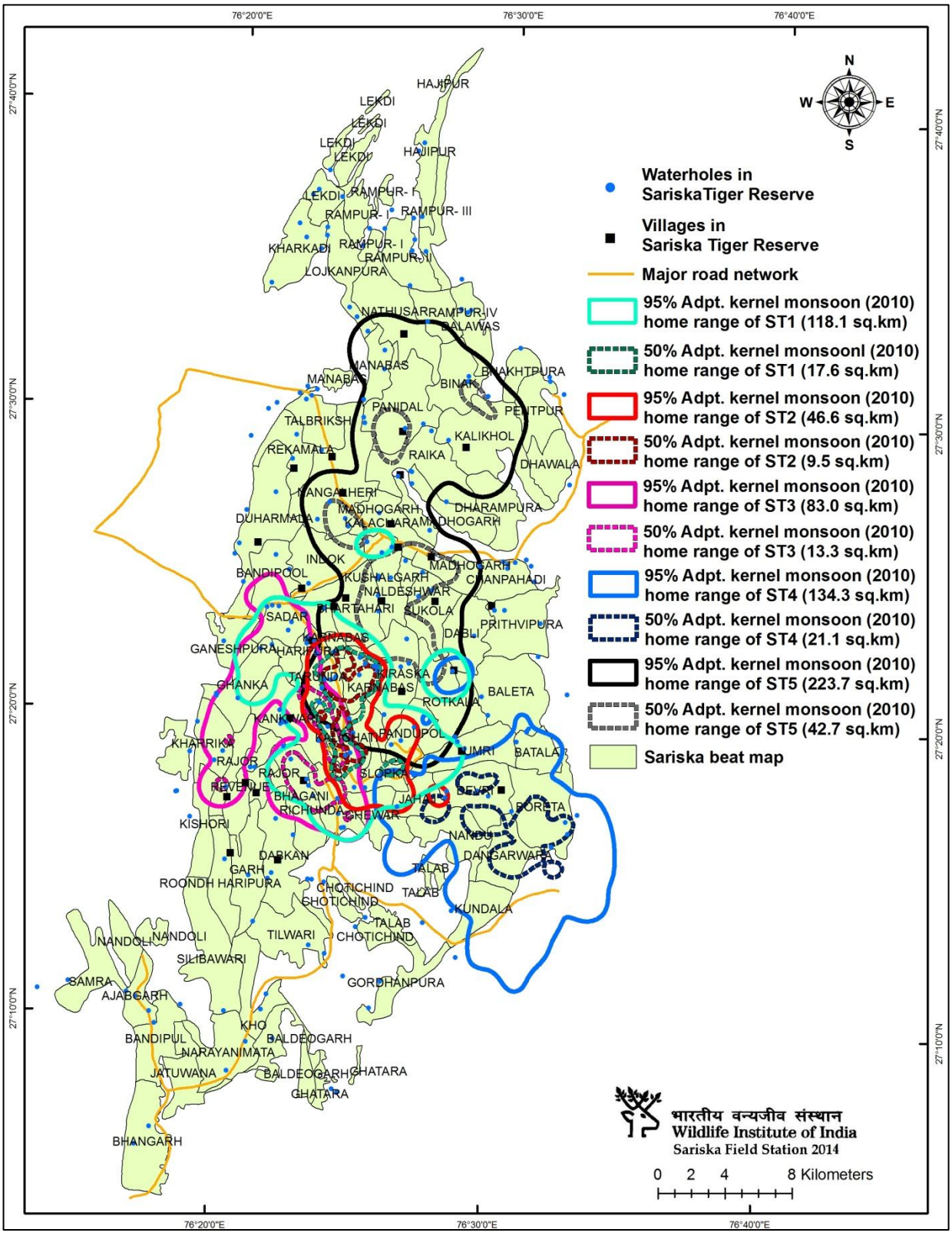


Figure 5.34. Winter home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (November 2010 – February 2011).

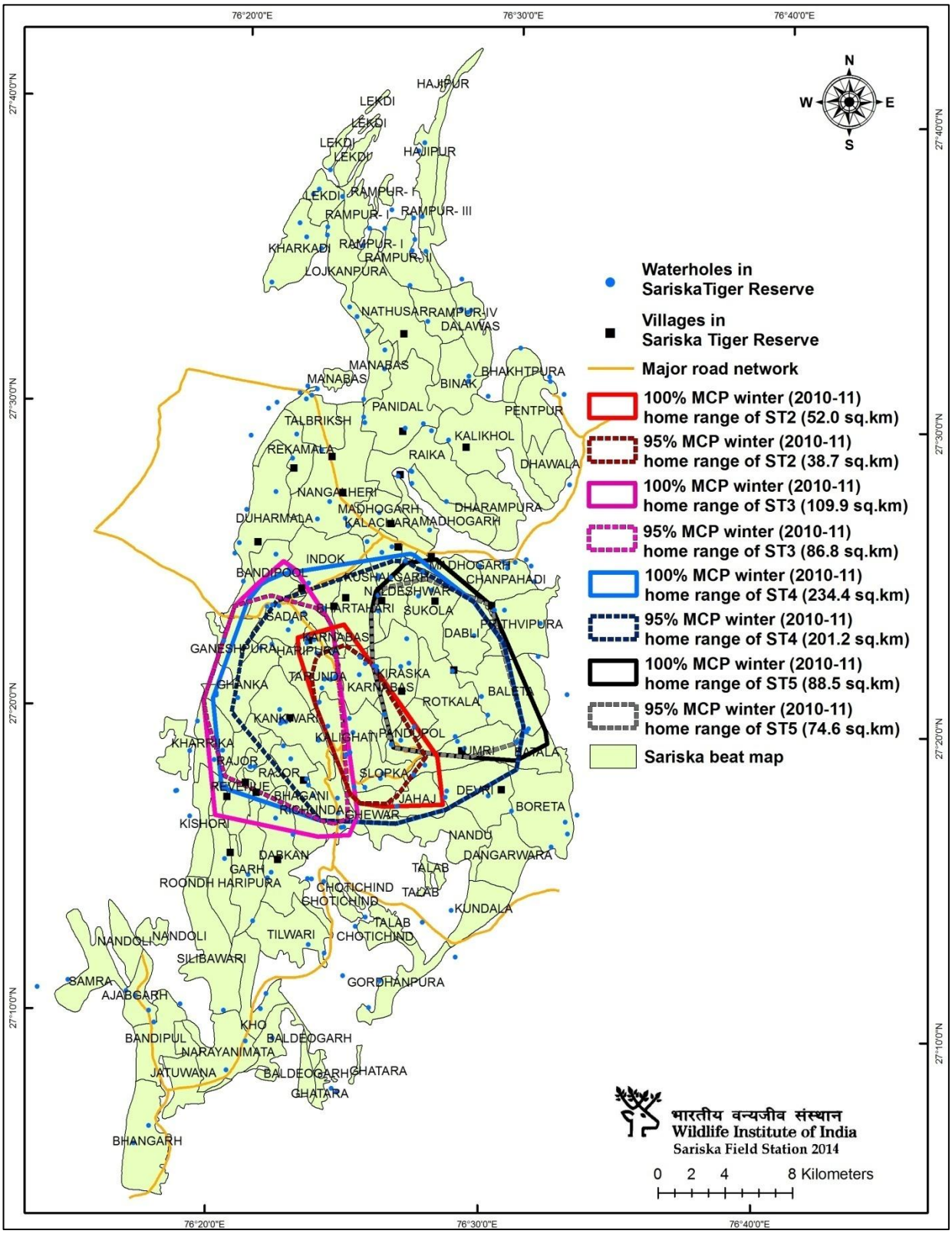


Figure 5.35. Winter home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (November 2010 – February 2011).

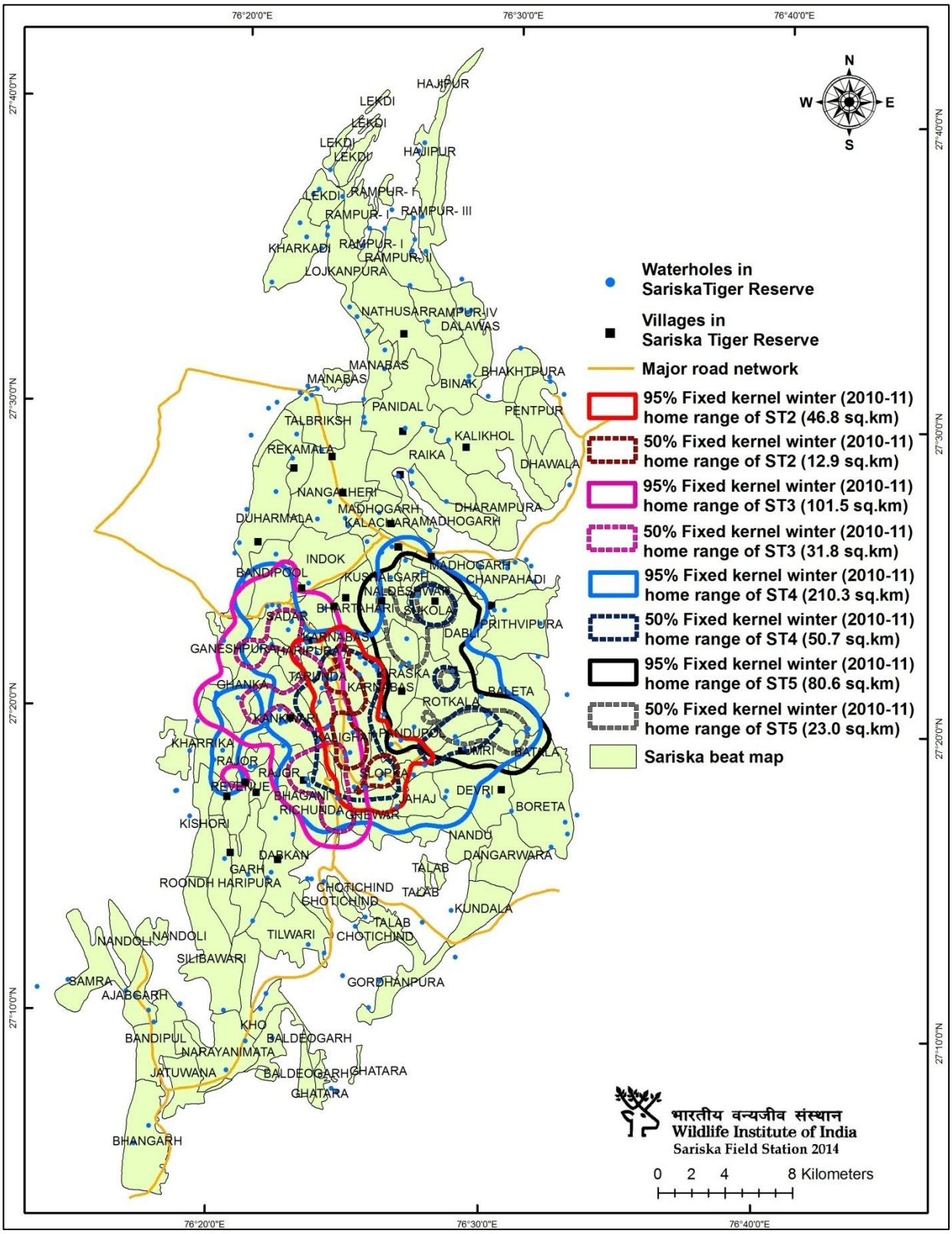


Figure 5.36. Winter home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (November 2010 – February 2011).

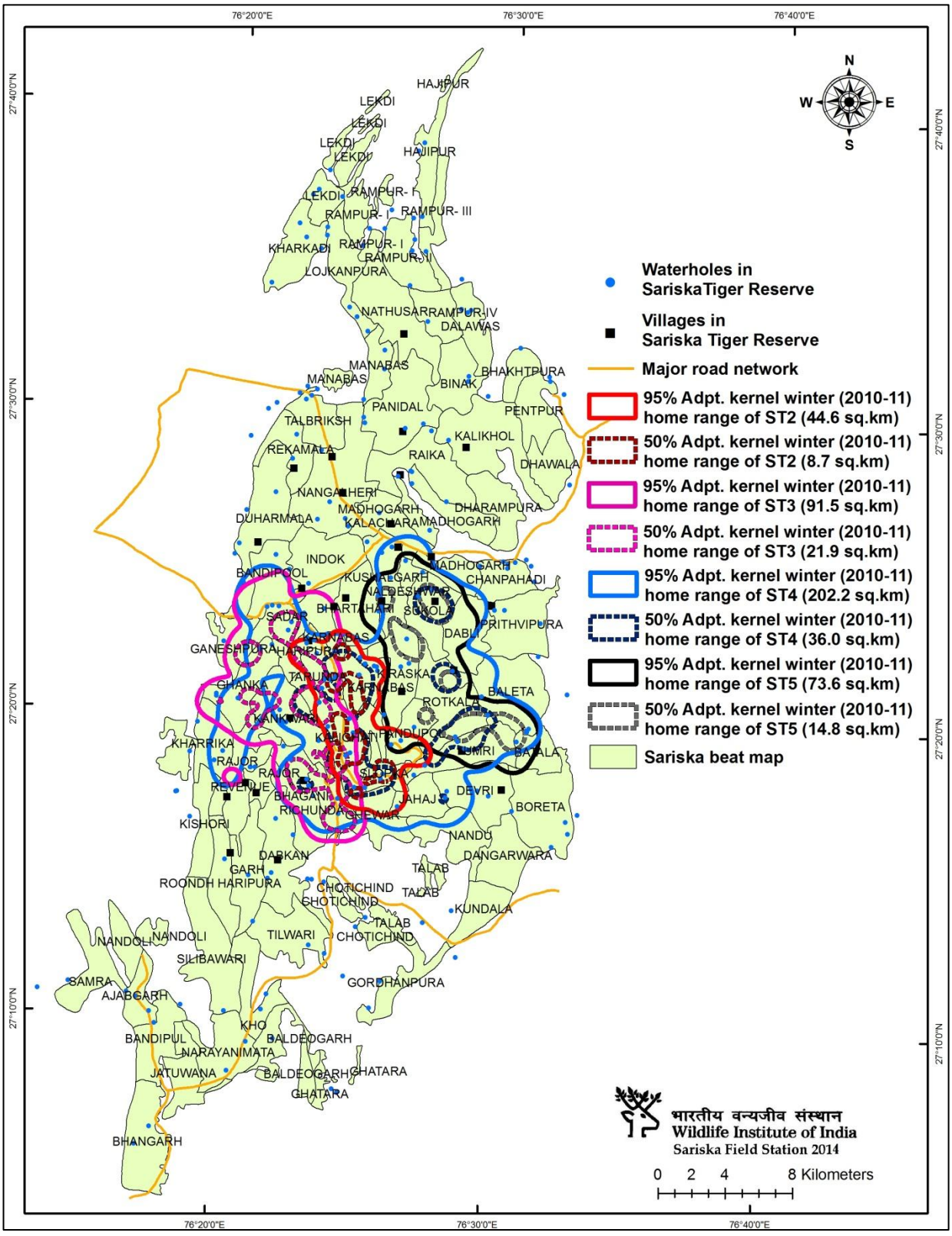


Figure 5.37. Summer home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (March 2011 – June 2011).

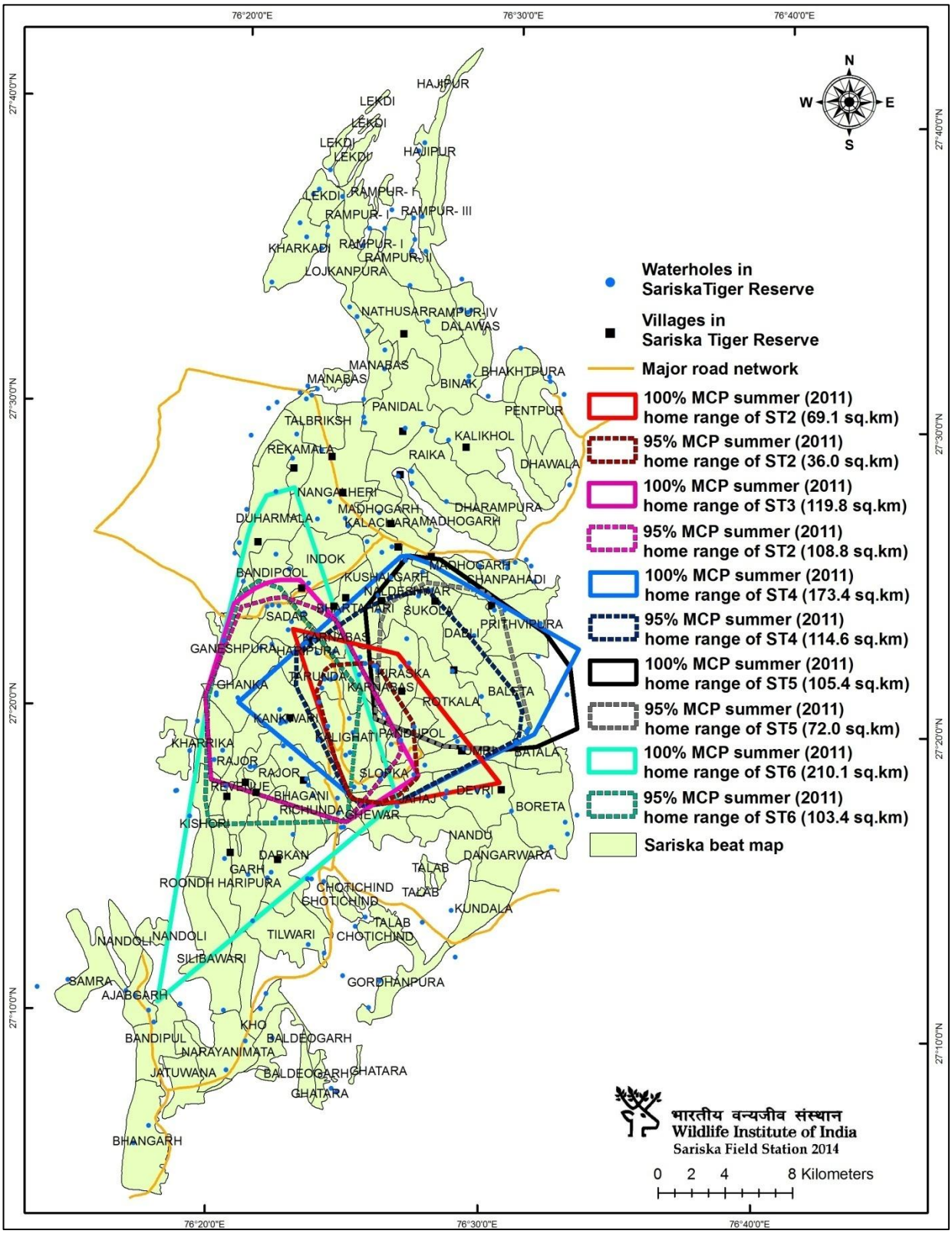


Figure 5.38. Summer home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (March 2011 – June 2011).

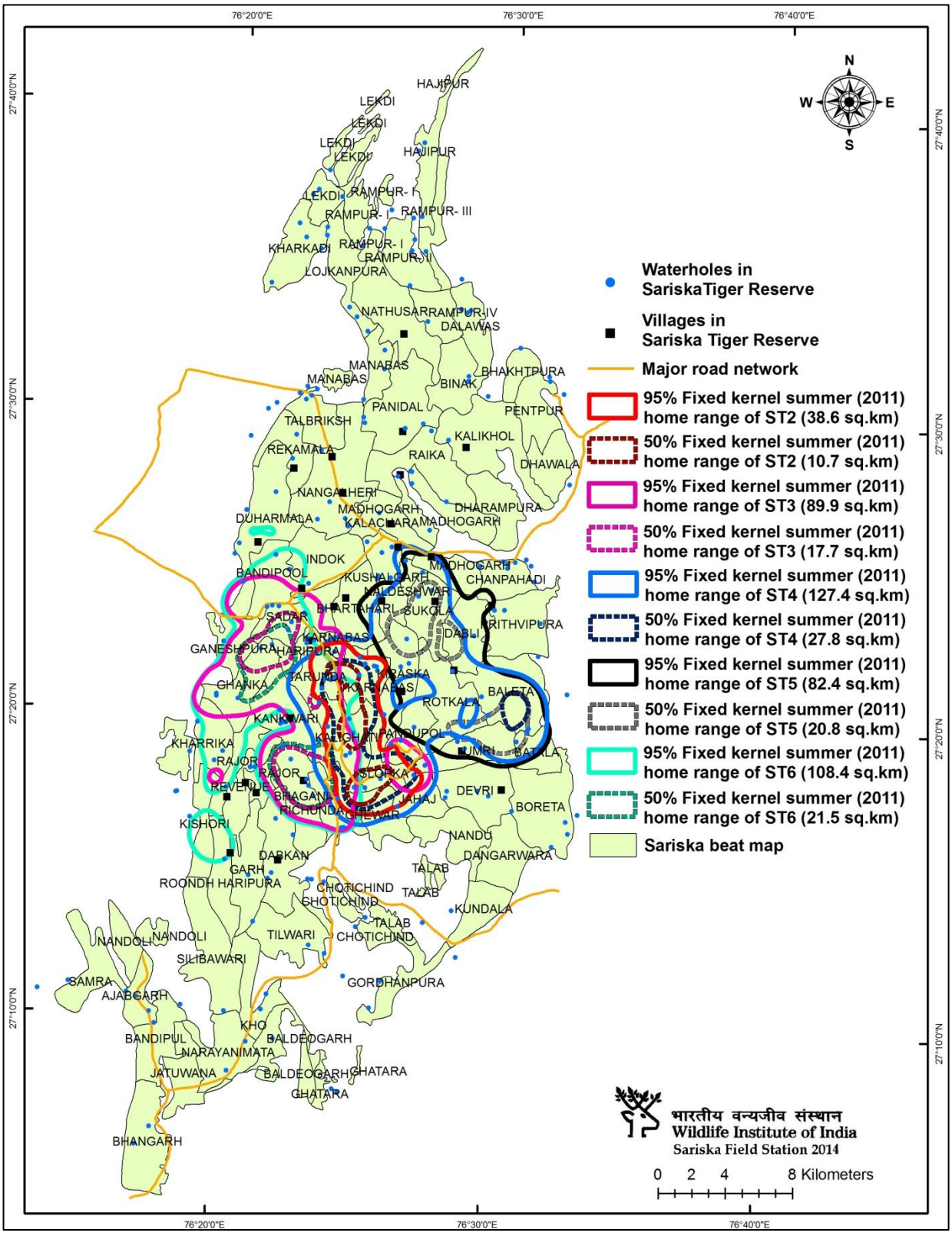


Figure 5.39. Summer home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (March 2011 – June 2011).

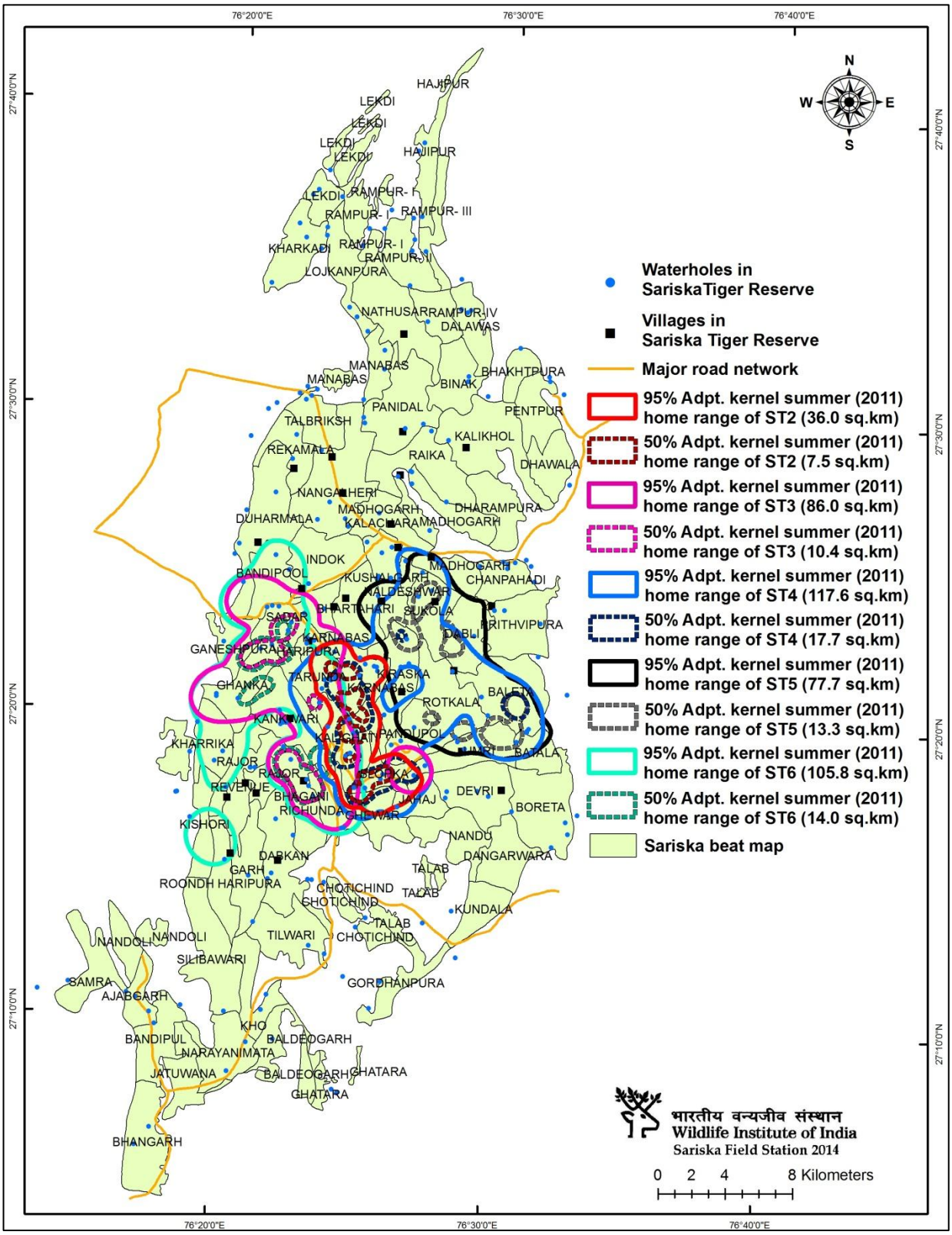


Figure 5.40. Annual home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July 2010 – June 2011).

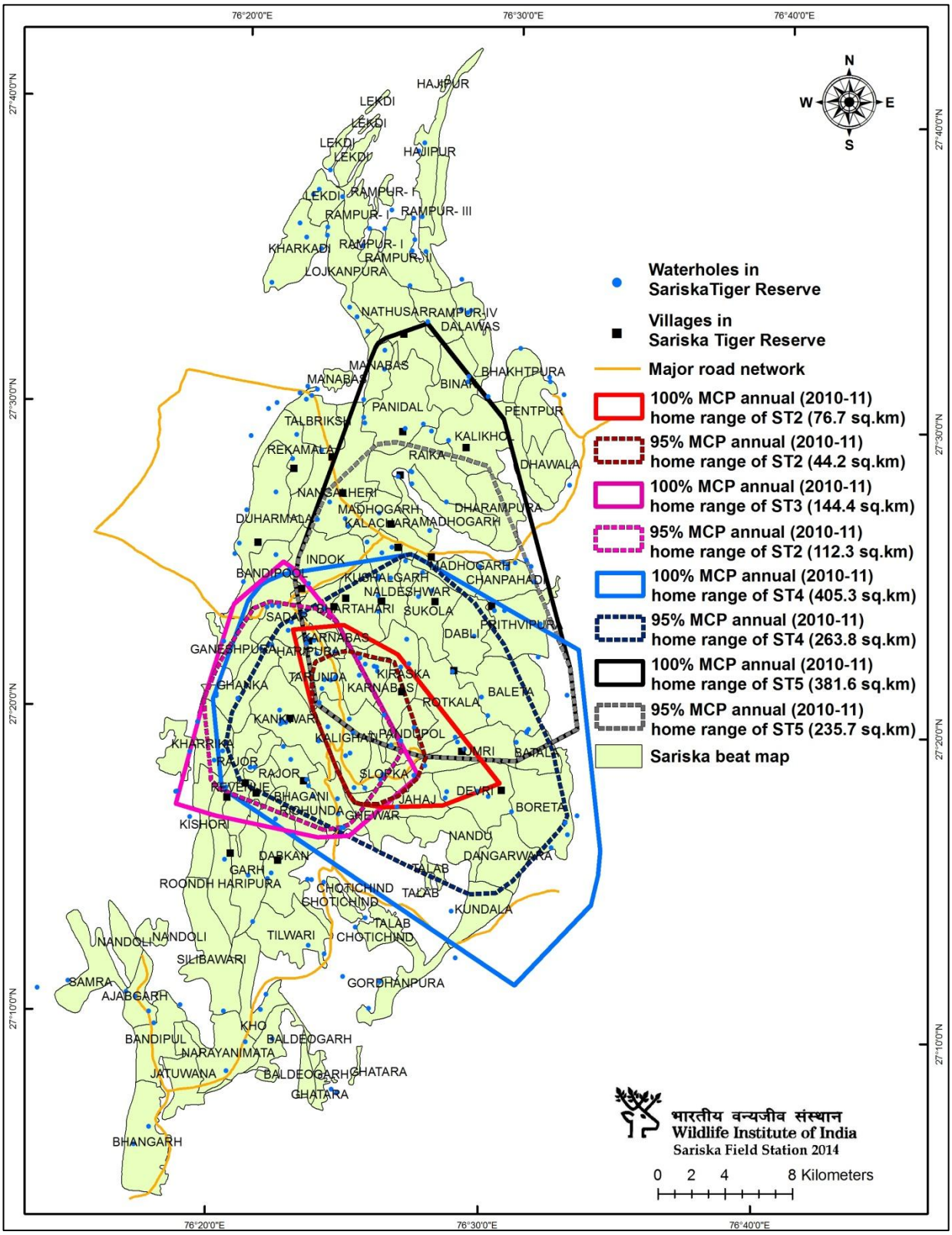


Figure 5.41. Annual home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July 2010 – June 2011).

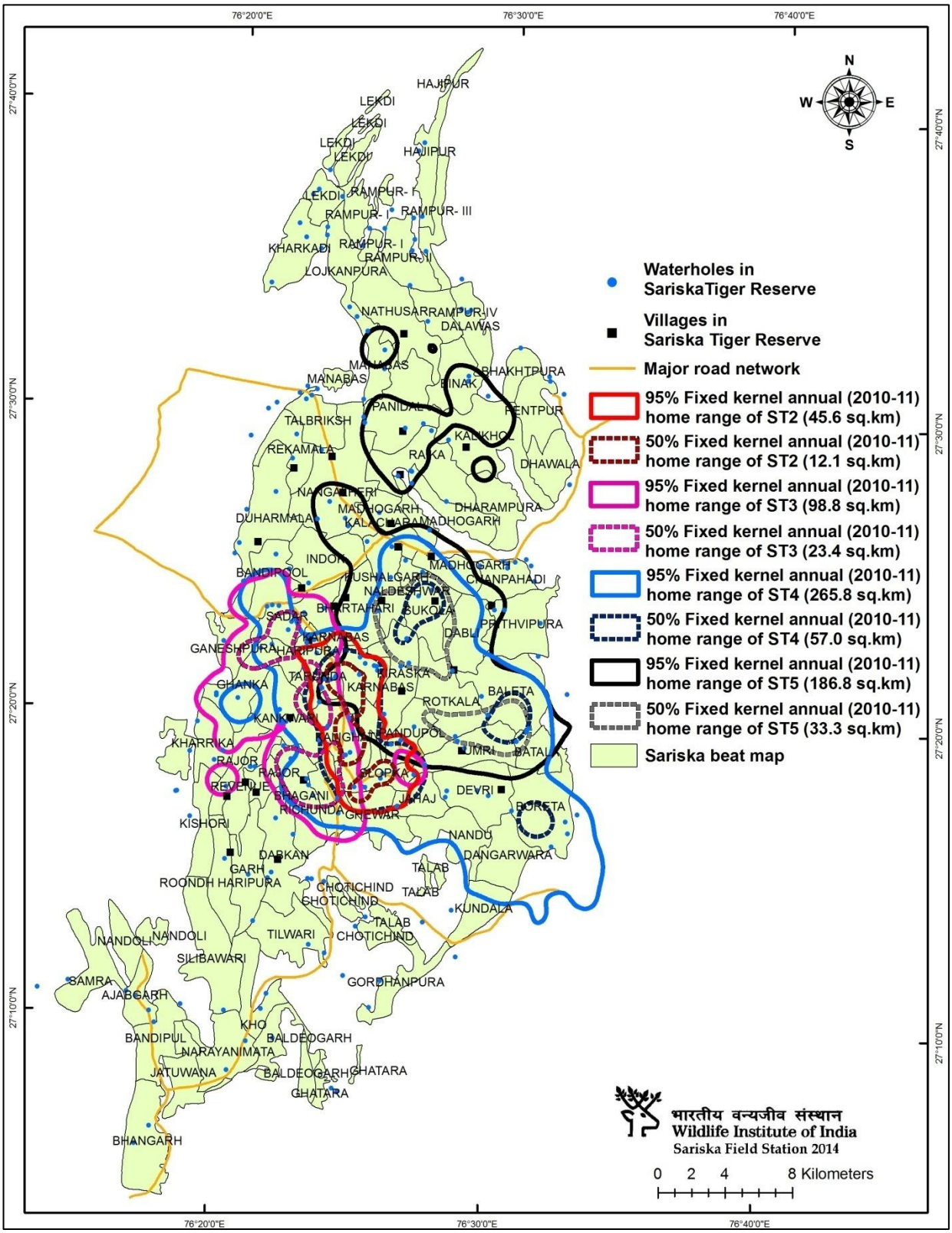


Figure 5.42. Annual home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July 2010 – June 2011).

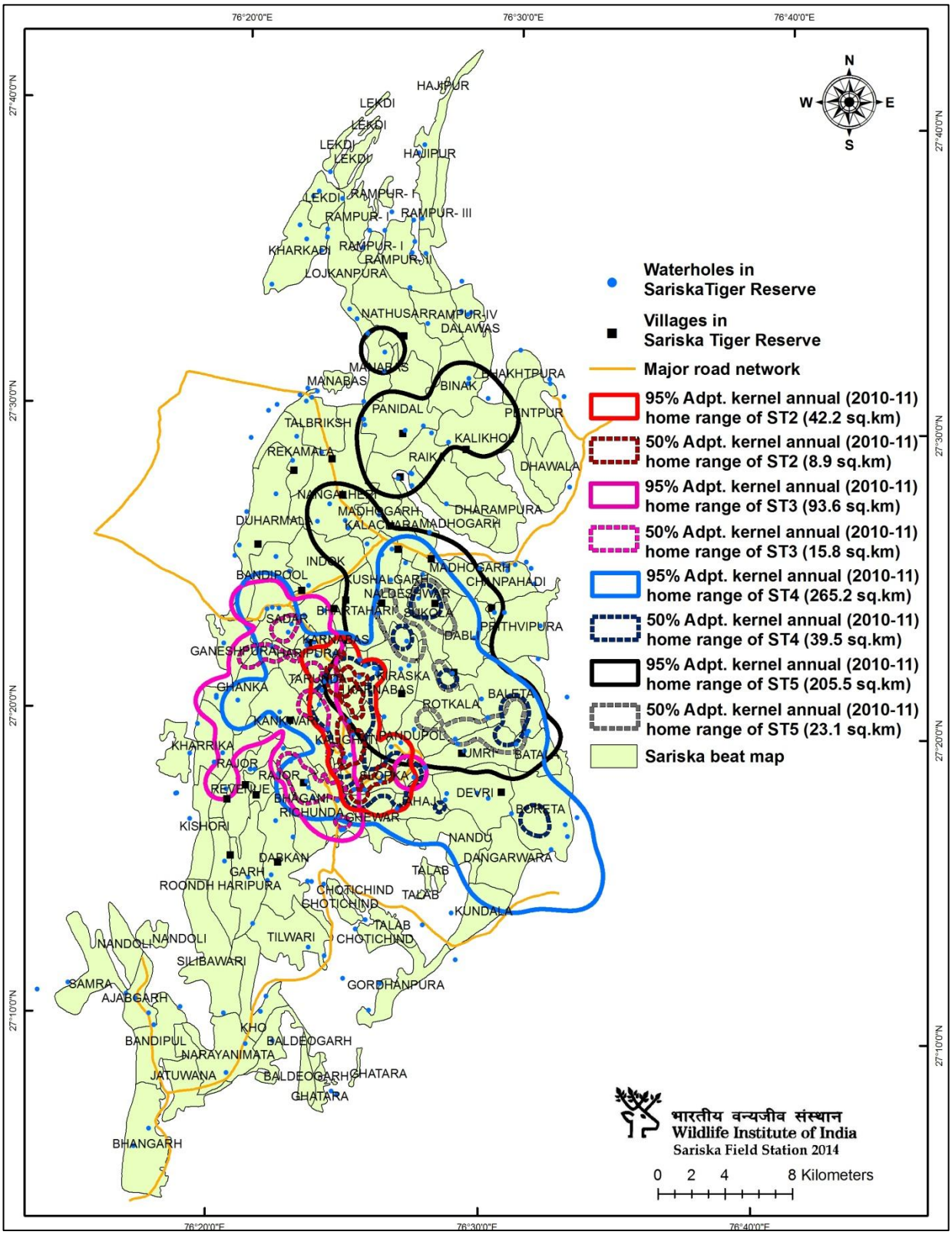


Table 5.11. Details of the monsoon ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2010 – October 2010.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2010	Monsoon	ST1	163.70	n.a.	104.71	n.a.	118.27	n.a.	22.76	n.a.	118.13	n.a.	17.60	n.a.
2010	Monsoon	ST2	43.10	n.a.	35.73	n.a.	49.20	n.a.	12.56	n.a.	46.60	n.a.	9.47	n.a.
2010	Monsoon	ST3	95.10	n.a.	57.18	n.a.	98.94	n.a.	19.92	n.a.	82.96	n.a.	13.30	n.a.
2010	Monsoon	ST4	149.10	n.a.	112.00	n.a.	130.55	n.a.	27.20	n.a.	134.29	n.a.	21.09	n.a.
2010	Monsoon	ST5	208.90	n.a.	185.43	n.a.	242.65	n.a.	60.09	n.a.	223.70	n.a.	42.67	n.a.
2010	Monsoon	ST1-2 overlap	40.30	59.06	35.73	67.06	47.65	68.57	12.56	77.59	45.18	67.60	8.83	71.71
2010	Monsoon	ST1-3 overlap	67.70	56.27	34.75	46.98	59.80	55.50	6.18	29.09	55.48	56.92	2.94	19.41
2010	Monsoon	ST1-4 overlap	11.70	7.50	0.51	0.47	12.00	9.67	0.00	0.00	12.22	9.73	0.00	0.00
2010	Monsoon	ST1-5 overlap	80.80	44.02	46.30	34.59	52.59	33.07	2.27	6.88	49.86	32.25	0.28	1.12
2010	Monsoon	ST2-3 overlap	5.80	9.78	3.12	7.09	20.29	30.87	2.07	13.44	15.52	26.01	0.96	8.68
2010	Monsoon	ST2-4 overlap	6.70	10.02	0.00	0.00	5.84	8.17	0.00	0.00	5.85	8.45	0.00	0.00
2010	Monsoon	ST2-5 overlap	21.70	30.37	21.30	35.55	28.15	34.41	0.92	4.43	26.17	33.93	0.00	0.00
2010	Monsoon	ST 3-4 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	Monsoon	ST 3-5 overlap	6.30	4.82	0.51	0.58	10.05	7.15	0.00	0.00	6.38	5.27	0.00	0.00
2010	Monsoon	ST 4-5 overlap	3.70	2.13	0.00	0.00	5.03	2.96	0.00	0.00	3.95	2.35	0.00	0.00

n.a. - Not applicable

Table 5.12. Details of the winter ranging patterns of reintroduced tigers in Sariska Tiger Reserve during November 2010 – February 2011.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2010-11	Winter	ST2	52.00	n.a.	38.67	n.a.	46.80	n.a.	12.92	n.a.	44.62	n.a.	8.70	n.a.
2010-11	Winter	ST3	109.90	n.a.	86.76	n.a.	101.53	n.a.	31.79	n.a.	91.54	n.a.	21.85	n.a.
2010-11	Winter	ST4	234.40	n.a.	201.15	n.a.	210.30	n.a.	50.73	n.a.	202.17	n.a.	36.04	n.a.
2010-11	Winter	ST5	88.50	n.a.	74.59	n.a.	80.64	n.a.	22.97	n.a.	73.55	n.a.	14.76	n.a.
2010-11	Winter	ST2-3 overlap	13.80	19.55	8.33	15.57	22.07	34.45	0.67	3.65	17.92	29.87	0.86	6.91
2010-11	Winter	ST2-4 overlap	52.00	61.09	38.67	59.61	46.70	61.00	12.52	60.79	44.51	60.88	7.62	54.37
2010-11	Winter	ST2-5 overlap	6.00	9.16	4.18	8.21	1.73	2.92	0.00	0.00	1.89	3.41	0.00	0.00
2010-11	Winter	ST 3-4 overlap	91.80	61.35	60.81	50.16	76.33	55.74	10.35	26.48	69.90	55.47	5.42	19.92
2010-11	Winter	ST 3-5 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010-11	Winter	ST 4-5 overlap	79.30	61.72	73.43	67.47	74.22	63.67	10.60	33.52	68.19	63.22	6.83	32.61

n.a. - Not applicable

Table 5.13. Details of the summer ranging patterns of reintroduced tigers in Sariska Tiger Reserve during March 2011 – June 2011.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2011	Summer	ST2	69.10	n.a.	35.98	n.a.	38.58	n.a.	10.68	n.a.	36.04	n.a.	7.50	n.a.
2011	Summer	ST3	119.80	n.a.	108.77	n.a.	89.91	n.a.	17.74	n.a.	86.02	n.a.	10.37	n.a.
2011	Summer	ST4	173.40	n.a.	114.64	n.a.	127.40	n.a.	27.77	n.a.	117.55	n.a.	17.65	n.a.
2011	Summer	ST5	105.40	n.a.	72.04	n.a.	82.36	n.a.	20.82	n.a.	77.74	n.a.	13.29	n.a.
2011	Summer	ST6	210.10	n.a.	103.36	n.a.	108.42	n.a.	21.45	n.a.	105.79	n.a.	14.00	n.a.
2011	Summer	ST2-3 overlap	36.30	41.42	24.97	46.18	17.22	31.89	0.00	0.00	16.83	33.13	0.00	0.00
2011	Summer	ST2-4 overlap	63.70	64.46	35.97	65.67	38.57	65.12	10.57	68.52	35.93	65.13	6.55	62.22
2011	Summer	ST2-5 overlap	17.10	20.49	4.29	8.94	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00
2011	Summer	ST2-6 overlap	28.50	27.40	11.22	21.02	15.73	27.64	0.00	0.00	14.07	25.51	0.00	0.00
2011	Summer	ST 3-4 overlap	57.40	40.51	35.89	32.15	29.95	28.41	0.00	0.00	27.25	27.43	0.00	0.00
2011	Summer	ST 3-5 overlap	0.90	0.80	0.60	0.69	0.00	0.00	0.00	0.00	0.16	0.20	0.00	0.00
2011	Summer	ST 3-6 overlap	111.20	72.87	88.68	83.66	79.27	80.64	15.41	79.35	75.05	79.10	8.62	72.35
2011	Summer	ST 4-5 overlap	96.80	73.83	56.77	64.16	63.82	63.79	2.54	10.67	60.02	64.15	1.70	11.21
2011	Summer	ST 4-6 overlap	49.80	26.21	19.35	17.80	25.66	21.90	0.02	0.08	22.53	20.23	0.00	0.00
2011	Summer	ST 5-6 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n.a. - Not applicable

Table 5.14. Details of the annual ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2010 – June 2011.

Year	Period	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2010-11	Annual	ST2	76.70	n.a.	44.15	n.a.	45.60	n.a.	12.06	n.a.	42.21	n.a.	8.92	n.a.
2010-11	Annual	ST3	144.40	n.a.	112.26	n.a.	98.80	n.a.	23.44	n.a.	93.58	n.a.	15.77	n.a.
2010-11	Annual	ST4	405.30	n.a.	263.79	n.a.	265.84	n.a.	57.02	n.a.	265.16	n.a.	39.46	n.a.
2010-11	Annual	ST5	381.60	n.a.	235.68	n.a.	186.82	n.a.	33.29	n.a.	205.45	n.a.	23.10	n.a.
2010-11	Annual	ST2-3 overlap	40.40	40.33	29.38	46.36	19.79	31.71	0.09	0.57	17.26	29.67	0.15	1.32
2010-11	Annual	ST2-4 overlap	76.70	59.46	44.15	58.37	43.60	56.01	12.06	60.58	42.21	57.96	8.71	59.86
2010-11	Annual	ST2-5 overlap	43.80	34.29	25.51	34.30	15.34	20.93	0.00	0.00	16.33	23.32	0.00	0.00
2010-11	Annual	ST 3-4 overlap	124.70	58.56	87.57	55.60	64.14	44.52	6.05	18.21	64.17	46.39	2.67	11.85
2010-11	Annual	ST 3-5 overlap	24.50	11.69	22.11	14.54	2.91	2.25	0.00	0.00	2.05	1.60	0.00	0.00
2010-11	Annual	ST 4-5 overlap	151.40	38.52	119.76	48.11	116.39	53.04	10.51	25.00	112.93	48.78	7.93	27.22

n.a. - Not applicable

5.4.2.5. ANNUAL AND SEASONAL HOME RANGES OF TIGERS DURING 2011-12

The monsoon home ranges of the five tigers ST2, ST3, ST4, ST5 and ST6 during 2011 were estimated using 100% MCP as 46.7 km^2, 96.7 km^2, 183.9 km^2, 71.2 km^2 and 134.2 km^2 respectively and the estimated monsoon home range using 95% MCP were 38.9 km^2, 71.3 km^2, 125.0 km^2, 63.1 km^2 and 92.0 km^2 for ST2 to ST6 tigers respectively (Figure 5.43). The estimated monsoon home ranges of these five tigers ST2 to ST6 during 2011 by using 95% fixed kernel estimator were 45.1 km^2, 81.5 km^2, 142.4 km^2, 74.1 km^2 and 104.4 km^2 respectively, while the core home ranges were estimated using 50% fixed kernel estimator as 11.4 km^2, 21.0 km^2, 35.3 km^2, 20.9 km^2 and 29.5 km^2 for ST2 to ST6 respectively (Figure 5.44). These home ranges were further estimated by 95% adaptive kernel following the above mentioned order of the individual tigers ST2, ST3, ST4, ST5 and ST6 as 41.9 km^2, 75.5 km^2, 130.7 km^2, 67.4 km^2 and 91.9 km^2 respectively, whereas the estimated core home ranges during monsoon 2011 using 50% adaptive kernel were 8.2 km^2, 12.7 km^2, 24.9 km^2, 14.2 km^2 and 20.4 km^2 for ST2 to ST6 tigers respectively (Figure 5.45). Details of the home ranges and home range overlaps during monsoon 2011 are given in table 5.15.

The area explored by the female tigers ST2 and ST3 during winter 2011-12 was observed much larger (>100 and >90 km^2 respectively). During the previous year (2010-11), tigresses ST2 and ST5 were observed to share a territory with the male tiger ST4, whereas the tigress ST3 was found to share her territory with the male tiger ST6. But due to new associations among ST3-ST4 and ST2-ST6 tigers during winter 2011-12, the winter home ranges of the female tigers ST2 and ST3 were observed to enlarge with subsequent large home range overlap between them (Figures 5.46, 5.47 and 5.48).

The winter home ranges of these five tigers ST2 to ST6 during 2011-12 were estimated using 100% MCP as 102.0 km^2, 95.2 km^2, 136.2 km^2, 83.6 km^2 and 123.2 km^2 respectively, whereas the estimated winter home ranges using 95% MCP estimator were 46.7 km^2, 86.0 km^2, 115.3 km^2, 61.5 km^2 and 99.6 km^2 for ST2 to ST6 tigers respectively (Figure 5.46). Similarly, the winter (2011-12) home ranges of these five individuals ST2 to ST6 were estimated using 95% fixed kernel estimator as 57.0 km^2, 90.6 km^2, 125.9 km^2, 68.2 km^2 and 102.8 km^2 respectively, while the estimated winter core home ranges using 50% fixed kernel estimator were 12.0 km^2, 24.0 km^2, 34.6 km^2, 19.5 km^2 and 25.8 km^2 for ST2 to ST6 respectively (Figure 5.47). These winter home ranges of ST2 to ST6 tigers during 2011-12 were further estimated using 95% adaptive kernel estimator as 57.9 km^2, 83.7 km^2, 116.6 km^2, 63.5 km^2 and 93.4 km^2 respectively, whereas 50% adaptive kernel estimator estimated the core ranges as 7.9 km^2, 15.5 km^2, 22.5 km^2, 13.4 km^2 and 17.0 km^2 for ST2 to ST6 tigers respectively

(Figure 5.48). Details of the home ranges and home range overlaps during winter 2011-12 are given in table 5.16.

During summer 2012, the home range areas were found much reduced than previous monsoon and winter seasons for ST2 to ST6 tigers (Figures 5.49, 5.50 and 5.51). During 2012 summer, the home ranges of five reintroduced tigers ST2, ST3, ST4, ST5 and ST6 were estimated using 100% MCP estimator as 40.5 km^2, 89.8 km^2, 127.4 km^2, 62.5 km^2 and 97.1 km^2 respectively and the estimated summer home range using 95% MCP estimator were 36.5 km^2, 75.4 km^2, 106.1 km^2, 57.2 km^2 and 80.9 km^2 for ST2 to ST6 tigers respectively (Figure 5.49). The summer home ranges of ST2 to ST6 tigers were measured using 95% fixed kernel estimator as 47.8 km^2, 75.5 km^2, 124.3 km^2, 58.8 km^2 and 83.7 km^2 respectively, while the estimated summer core ranges using 50% fixed kernel estimator were 12.5 km^2, 12.0 km^2, 39.8 km^2, 16.8 km^2 and 18.8 km^2 for ST2 to ST6 tigers respectively (Figure 5.50). The summer home ranges during 2012 of these five tigers ST2 to ST6 were further estimated by the 95% adaptive kernel estimator as 42.8 km^2, 77.7 km^2, 107.9 km^2, 51.7 km^2 and 81.1 km^2 respectively, while 50% adaptive kernel estimator estimated the summer core ranges as 8.1 km^2, 6.5 km^2, 26.3 km^2, 10.6 km^2 and 10.9 km^2 for ST2 to ST6 tigers respectively (Figure 5.51). Details of the home ranges and home range overlaps during summer 2012 are given in table 5.17.

The annual home ranges of three tigers ST3, ST4 and ST5 during 2011-12 were observed to be much smaller in comparison to the previous years. The home range overlap between the tigresses ST2 and ST3 was observed much larger (70% using 100% MCP and 43% using 95% fixed kernel estimator) during 2011-12 due to their new associations with male tiger ST6 and ST4. In contrast, there was no range overlap between the females ST3 and ST5 as well as between male ST6 and female ST5 observed during 2011-12.

The annual home ranges of ST2, ST3, ST4, ST5 and ST6 tigers were estimated using 100% MCP during 2011-12 as 134.4 km^2, 112.7 km^2, 194.1 km^2, 100.2 km^2 and 149.2 km^2 respectively and the estimated annual home ranges using 95% MCP were 79.1 km^2, 88.0 km^2, 121.6 km^2, 67.0 km^2 and 101.2 km^2 for ST2 to ST6 tigers respectively (Figure 5.52). The estimated annual home ranges of the tigers in an order from ST2 to ST6 during 2011-12 using 95% fixed kernel estimator were 78.3 km^2, 81.7 km^2, 127.1 km^2, 65.6 km^2 and 92.5 km^2 respectively and the core of the home ranges estimated by 50% fixed kernel were 14.5 km^2, 19.3 km^2, 37.2 km^2, 19.0 km^2 and 23.6 km^2 for ST2 to ST6 respectively (Figure 5.53).The annual home ranges of these five individuals ST2, ST3, ST4, ST5 and ST6 were further estimated using 95% adaptive kernel estimator as 81.2 km^2, 78.0 km^2, 117.1 km^2,

61.3 km^2 and 84.9 km^2 respectively and the estimated annual core home ranges using 50% adaptive kernel estimator were 10.3 km^2, 12.1 km^2, 26.3 km^2, 13.3 km^2 and 15.3 km^2 for ST2 to ST6 tigers respectively (Figure 5.54). The details of the annual home ranges and home range overlaps of the reintroduced tigers in Sariska during 2011-12 are given in Table 5.18.

Figure 5.43. Monsoon home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July 2011 – October 2011).

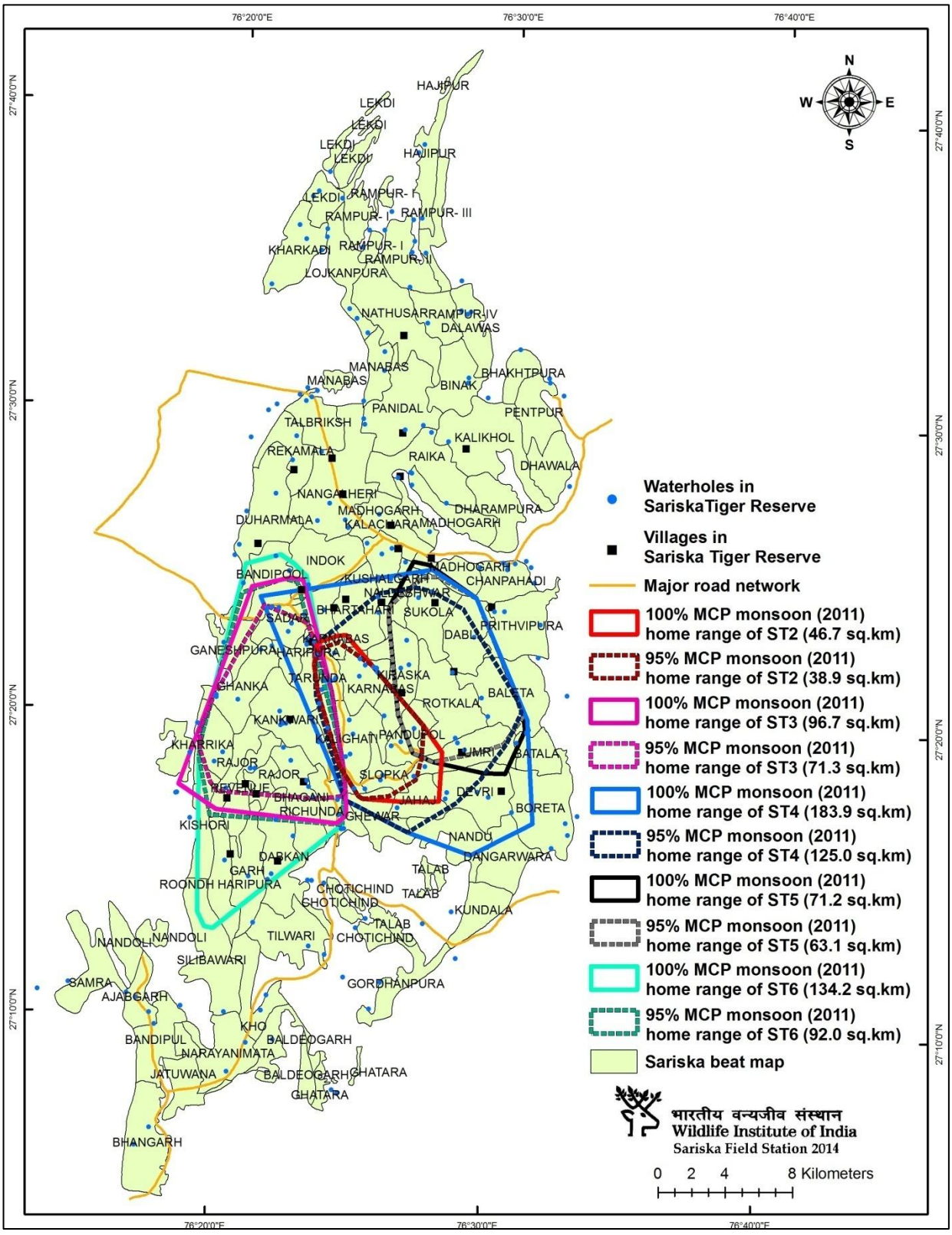


Figure 5.44. Monsoon home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July 2011 – October 2011).

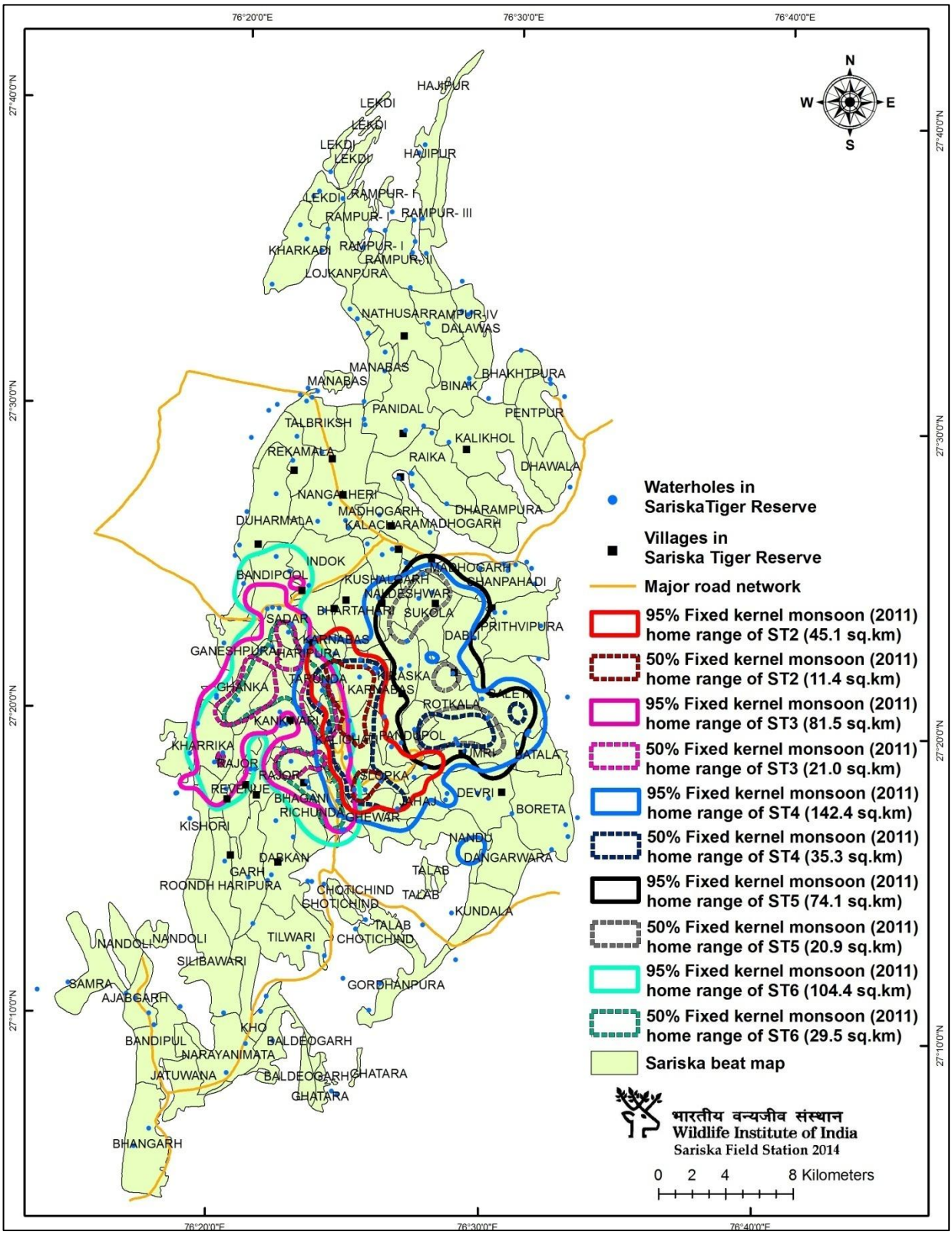


Figure 5.45. Monsoon home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July 2011 – October 2011).

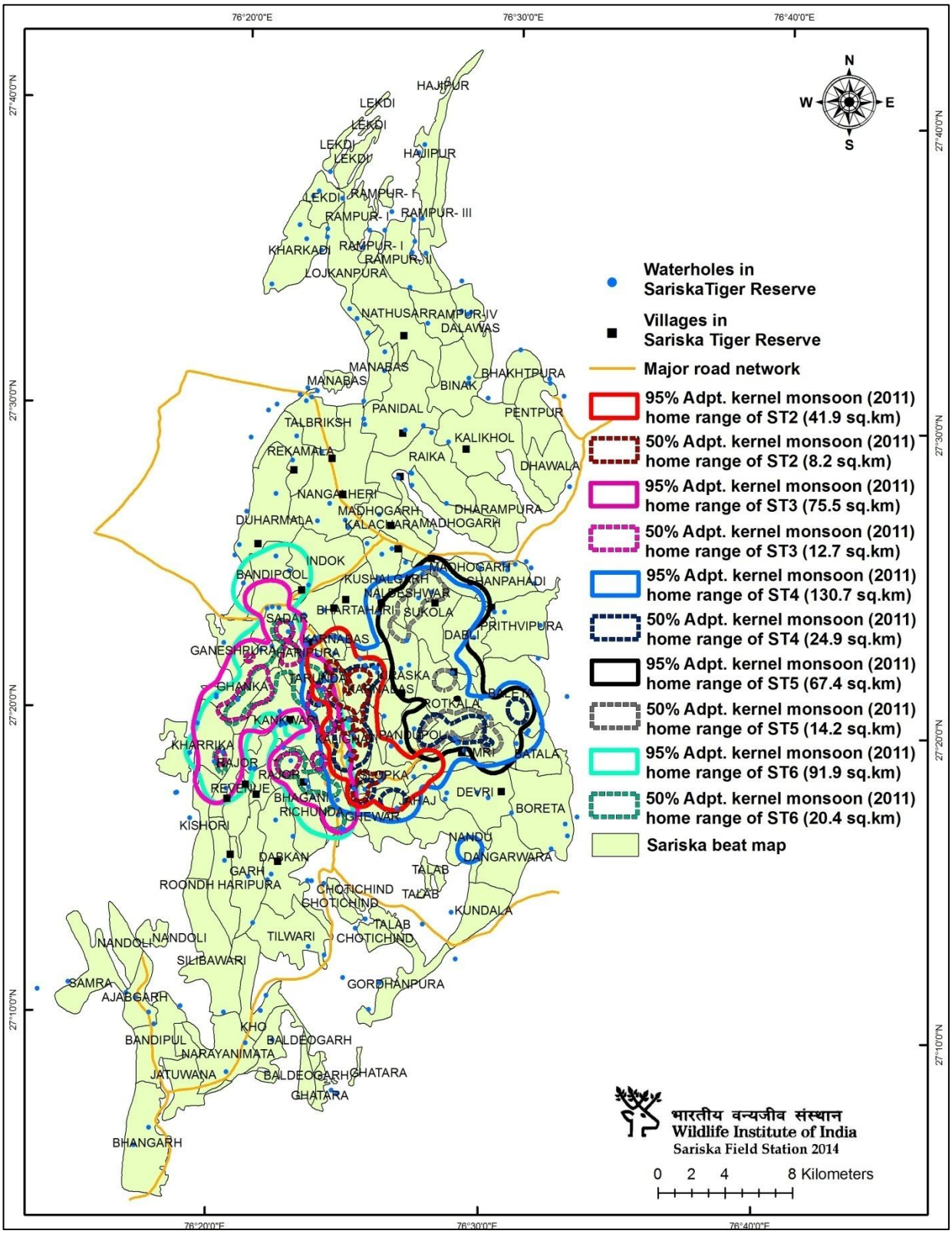


Figure 5.46. Winter home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (November 2011 – February 2012).

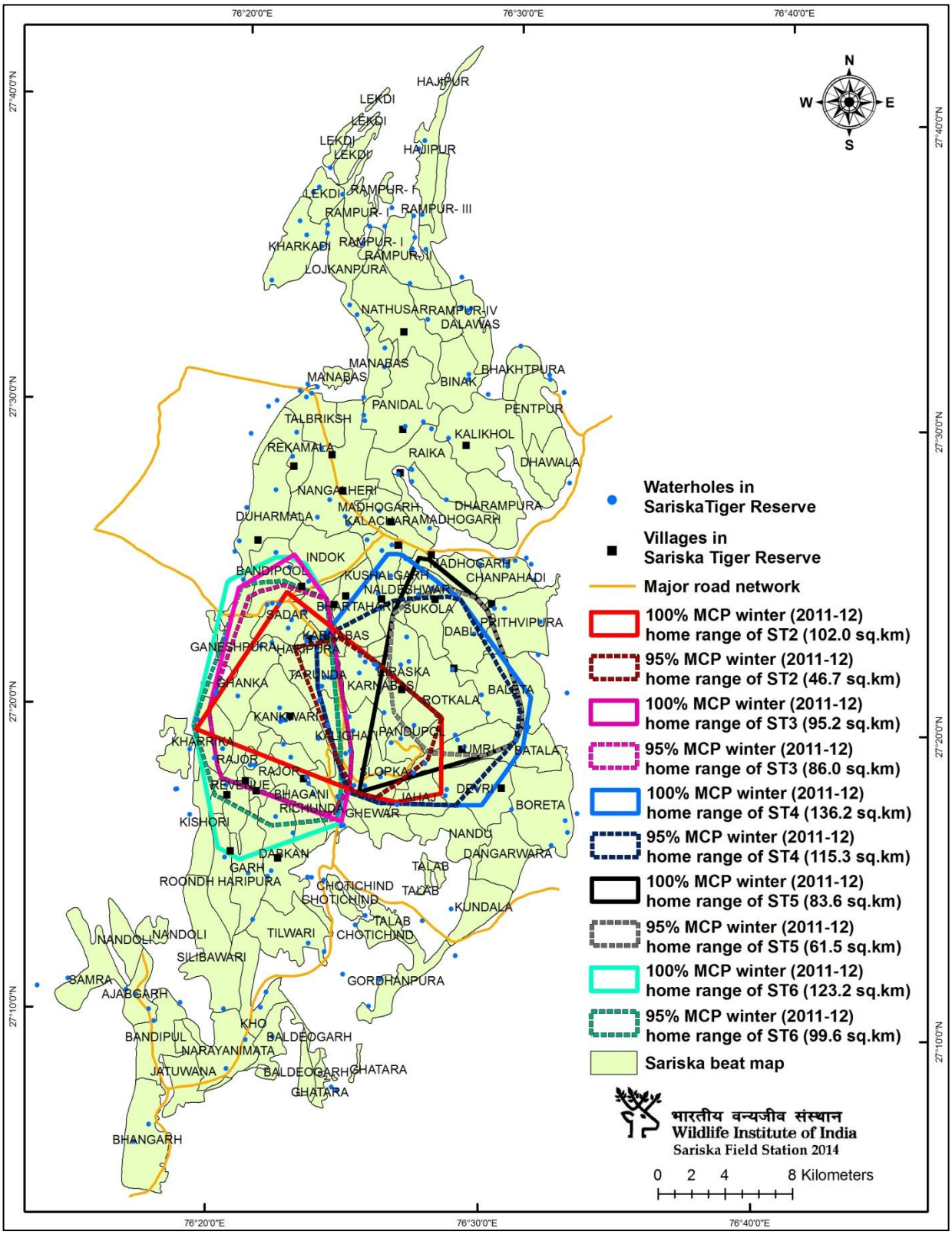


Figure 5.47. Winter home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (November 2011 – February 2012).

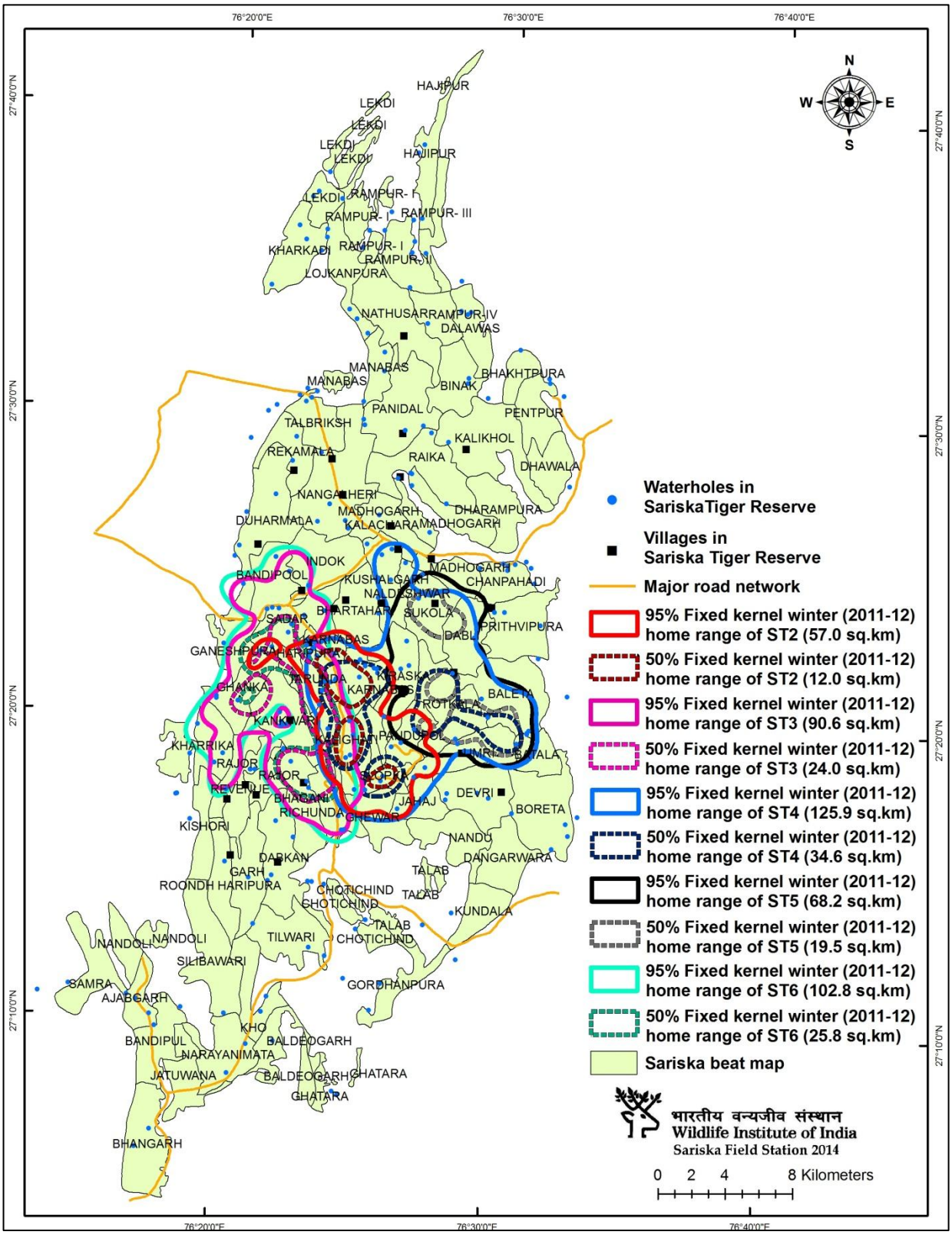


Figure 5.48. Winter home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (November 2011 – February 2012).

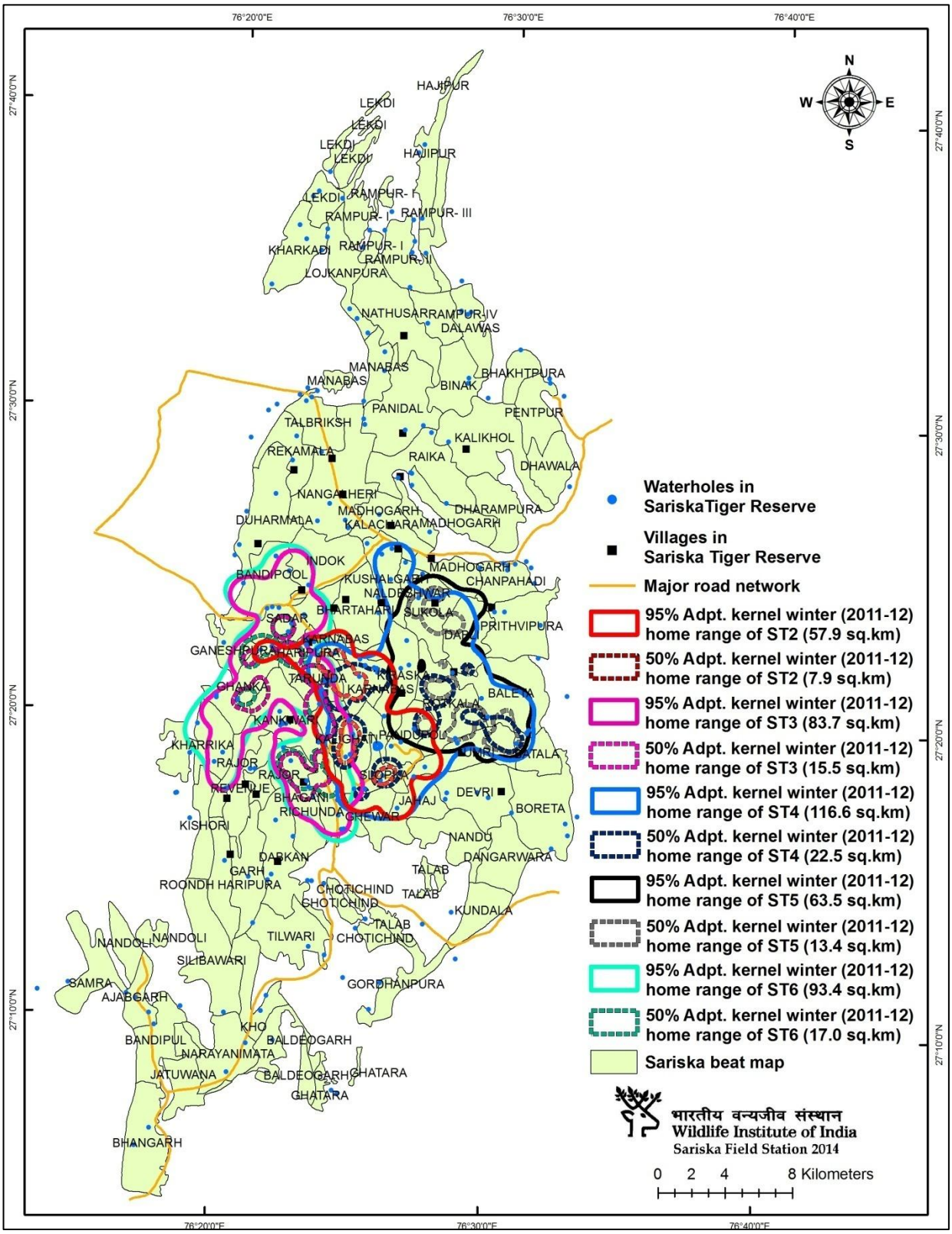


Figure 5.49. Summer home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (March 2012 – June 2012).

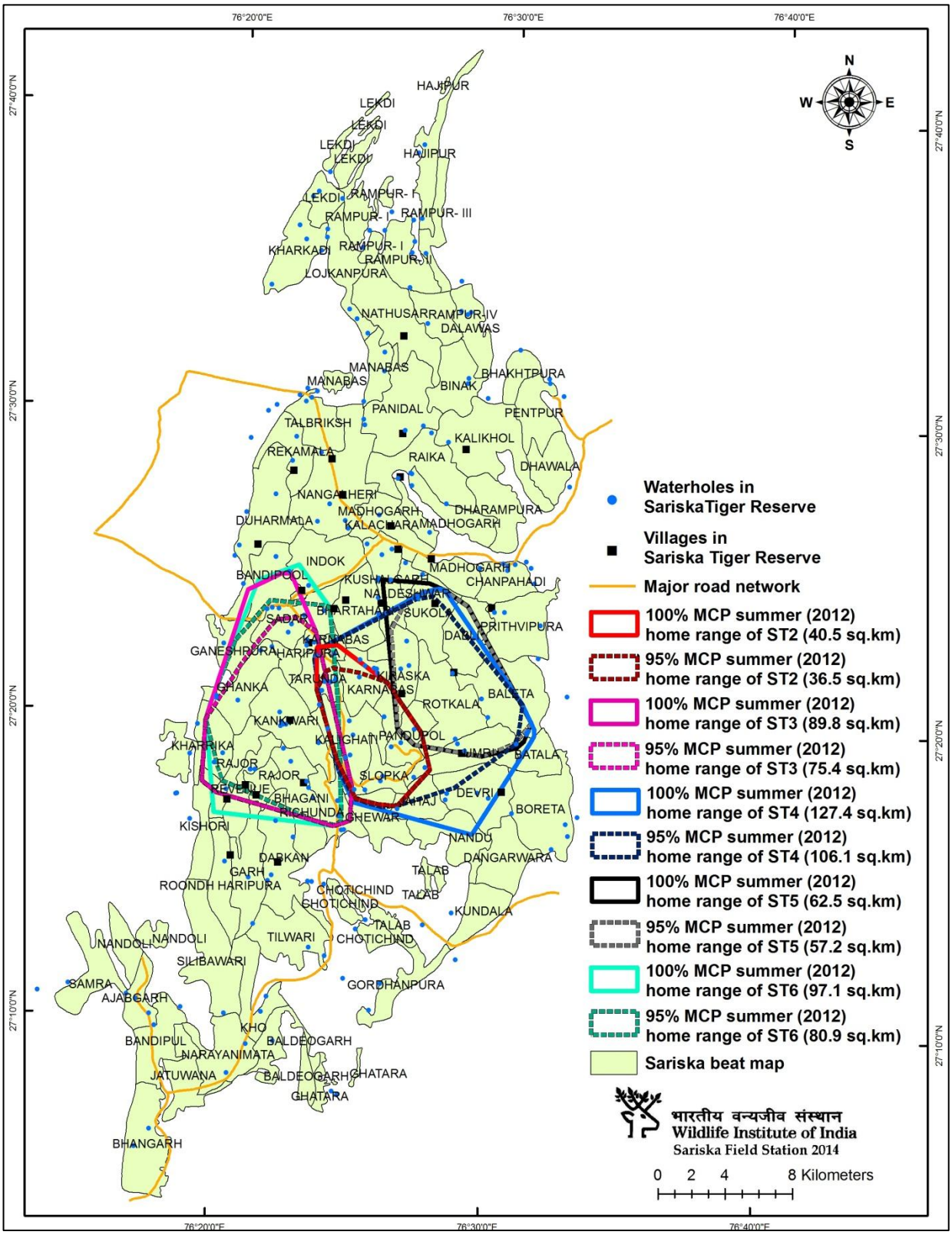


Figure 5.50. Summer home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (March 2012 – June 2012).

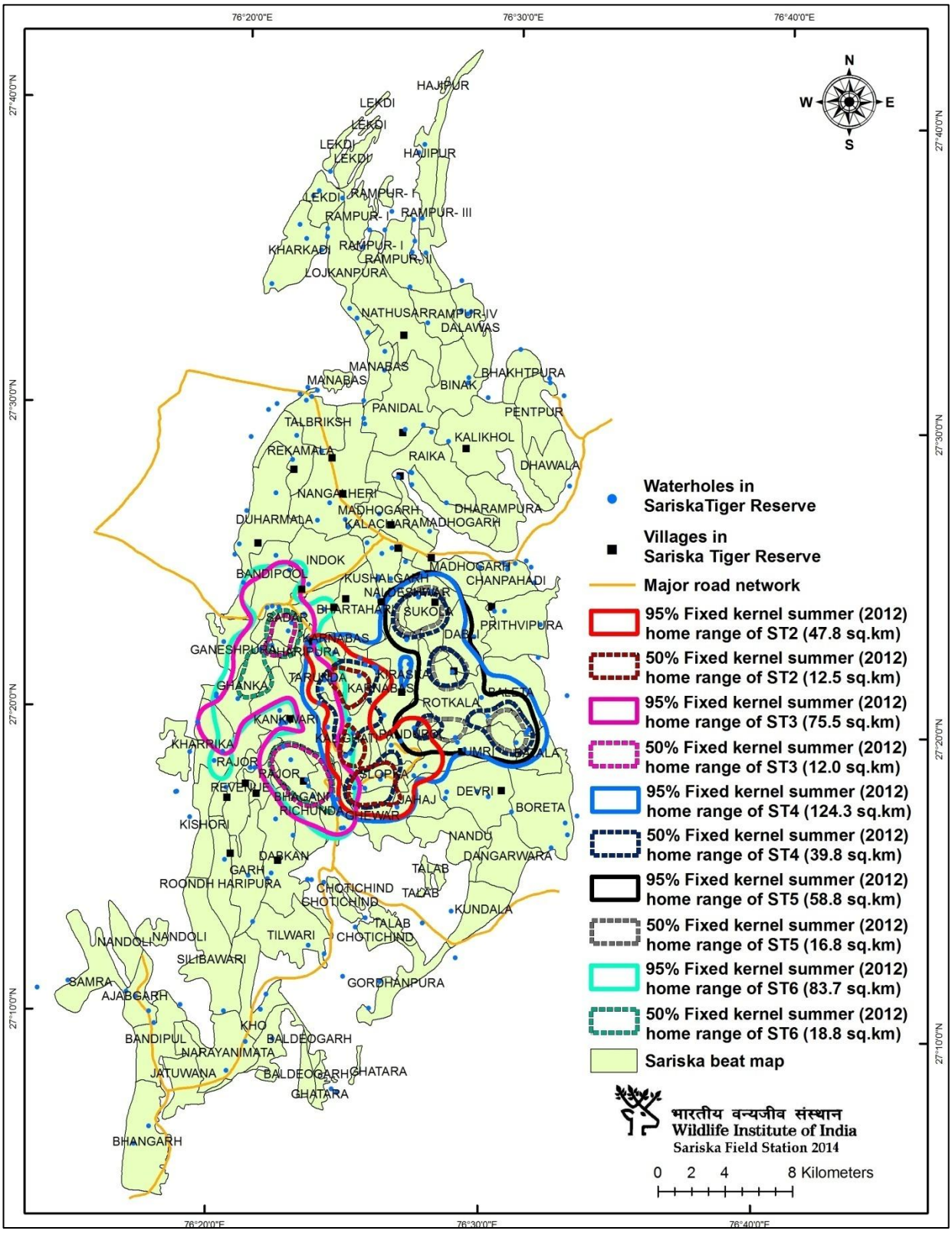


Figure 5.51. Summer home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (March 2012 – June 2012).

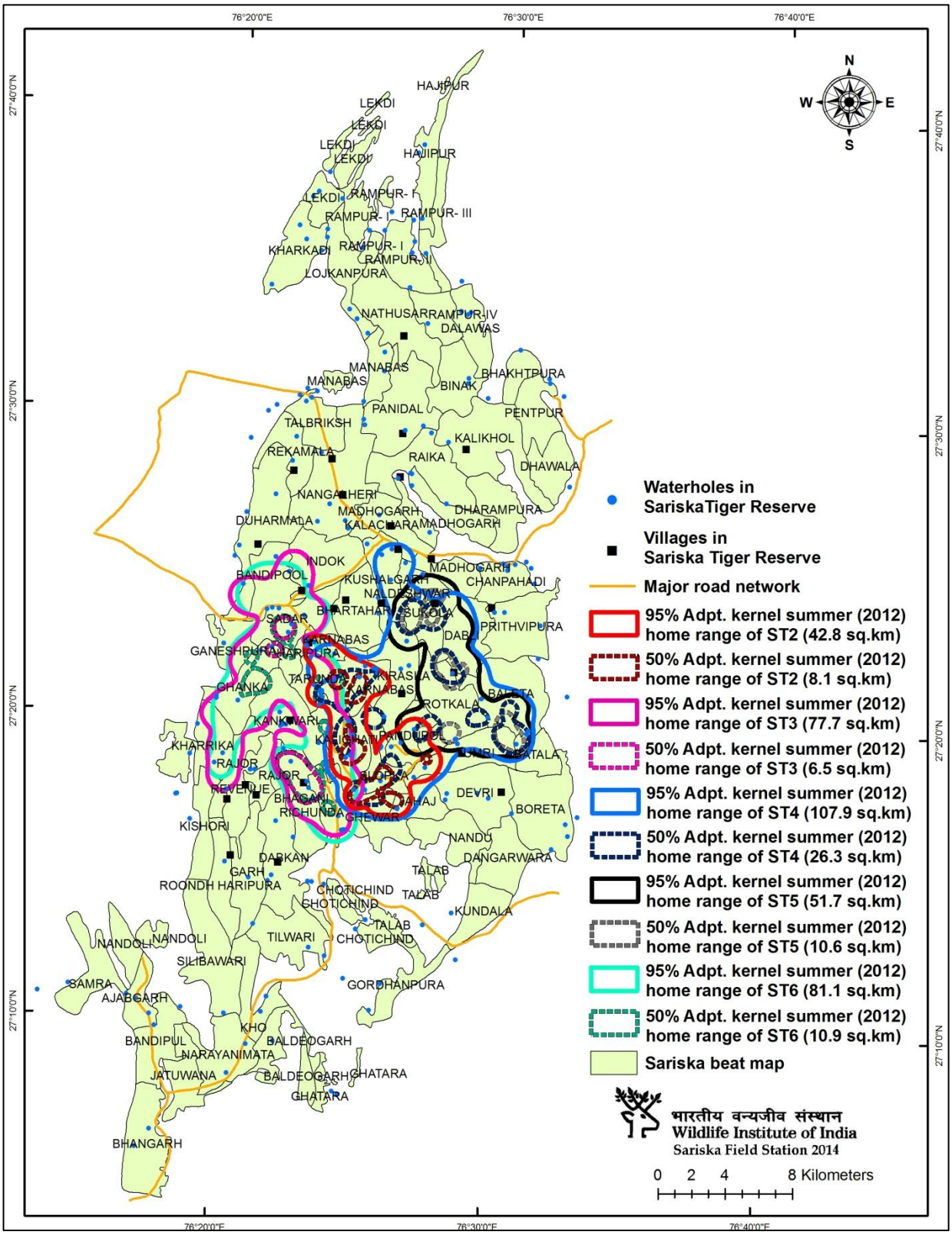


Figure 5.52. Annual home range of the reintroduced tigers using 100% and 95% MCP estimators in Sariska Tiger Reserve (July 2011 – June 2012).

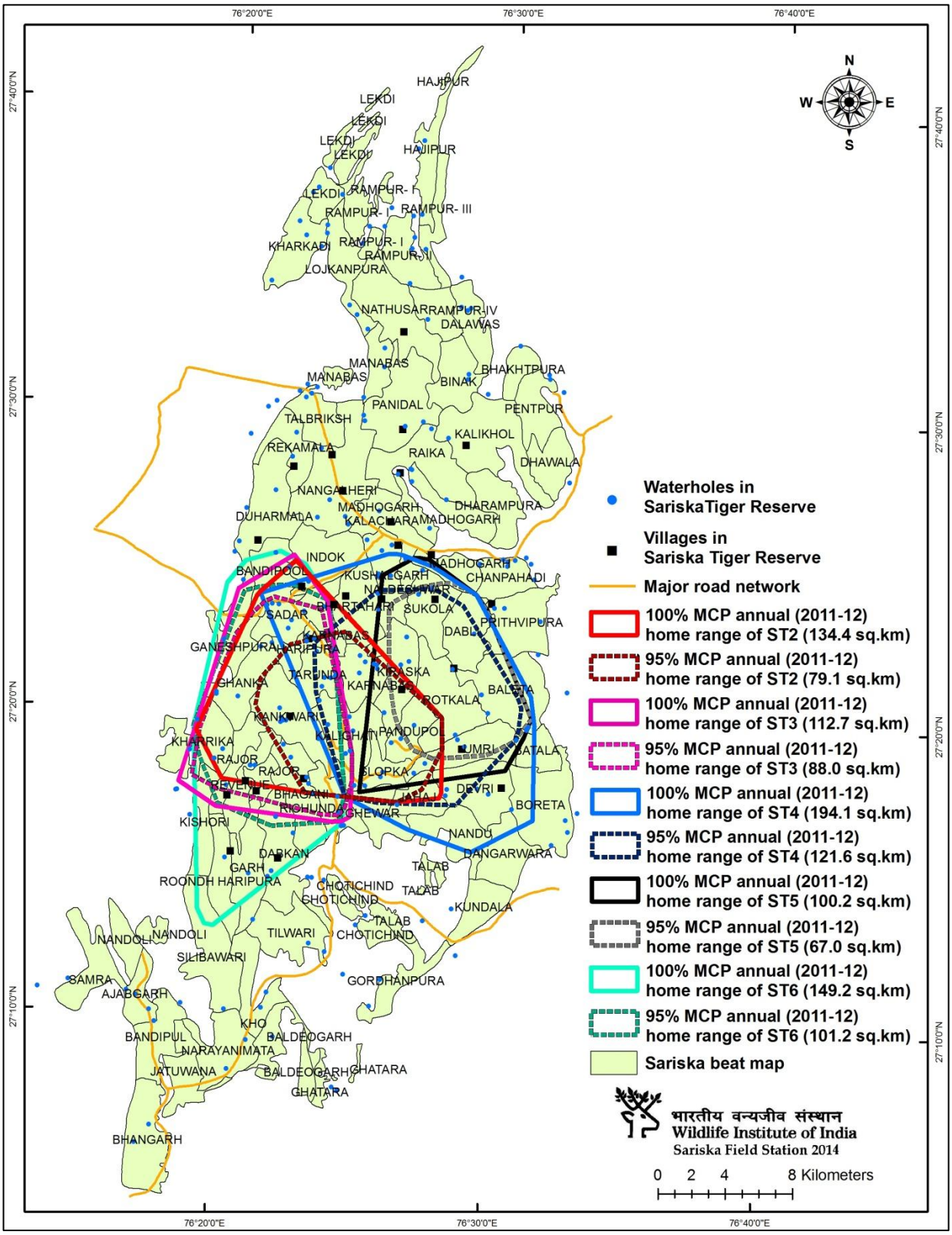


Figure 5.53. Annual home range of the reintroduced tigers using 95% and 50% fixed kernel estimators in Sariska Tiger Reserve (July 2011 – June 2012).

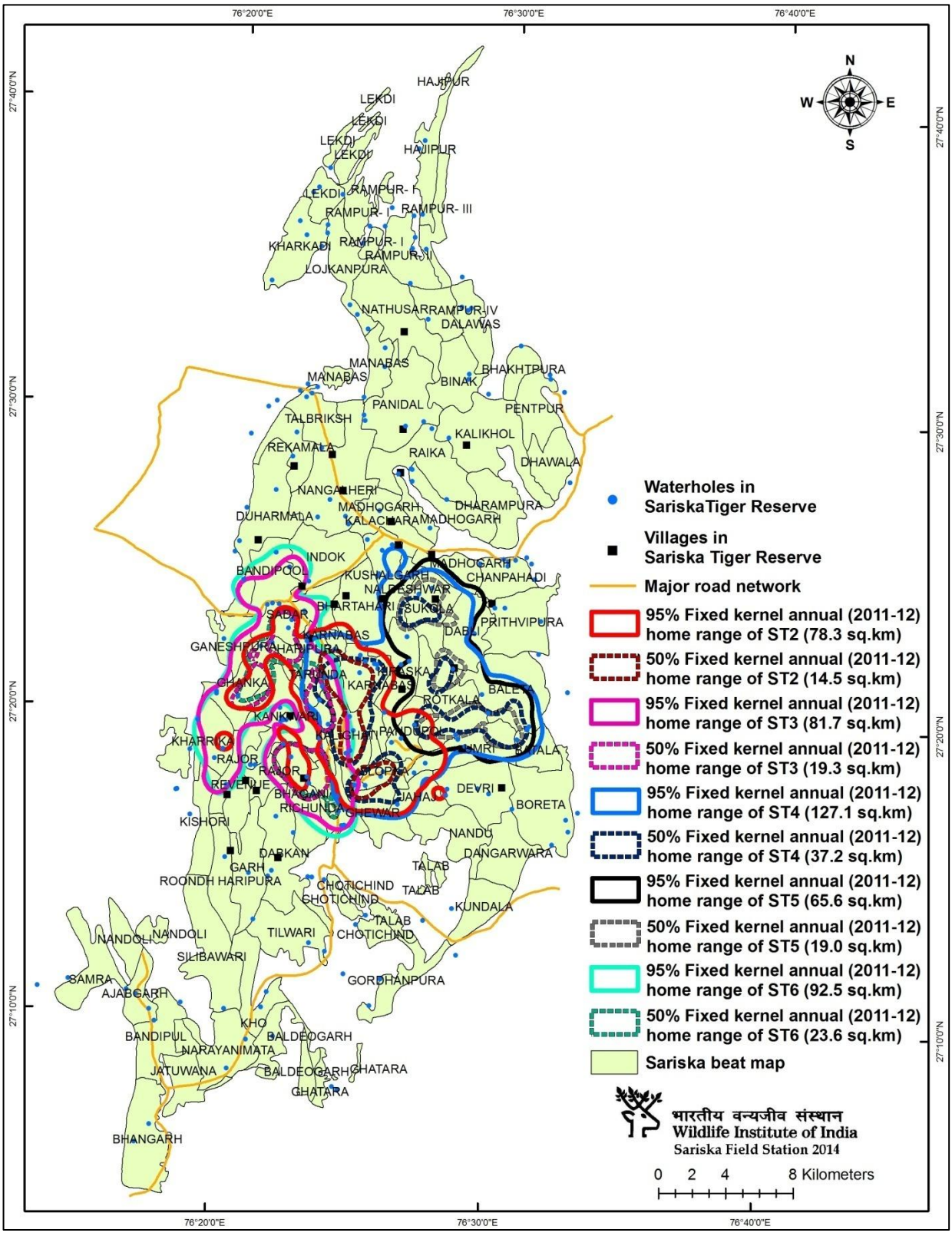


Figure 5.54. Annual home range of the reintroduced tigers using 95% and 50% adaptive kernel estimators in Sariska Tiger Reserve (July 2011 – June 2012).

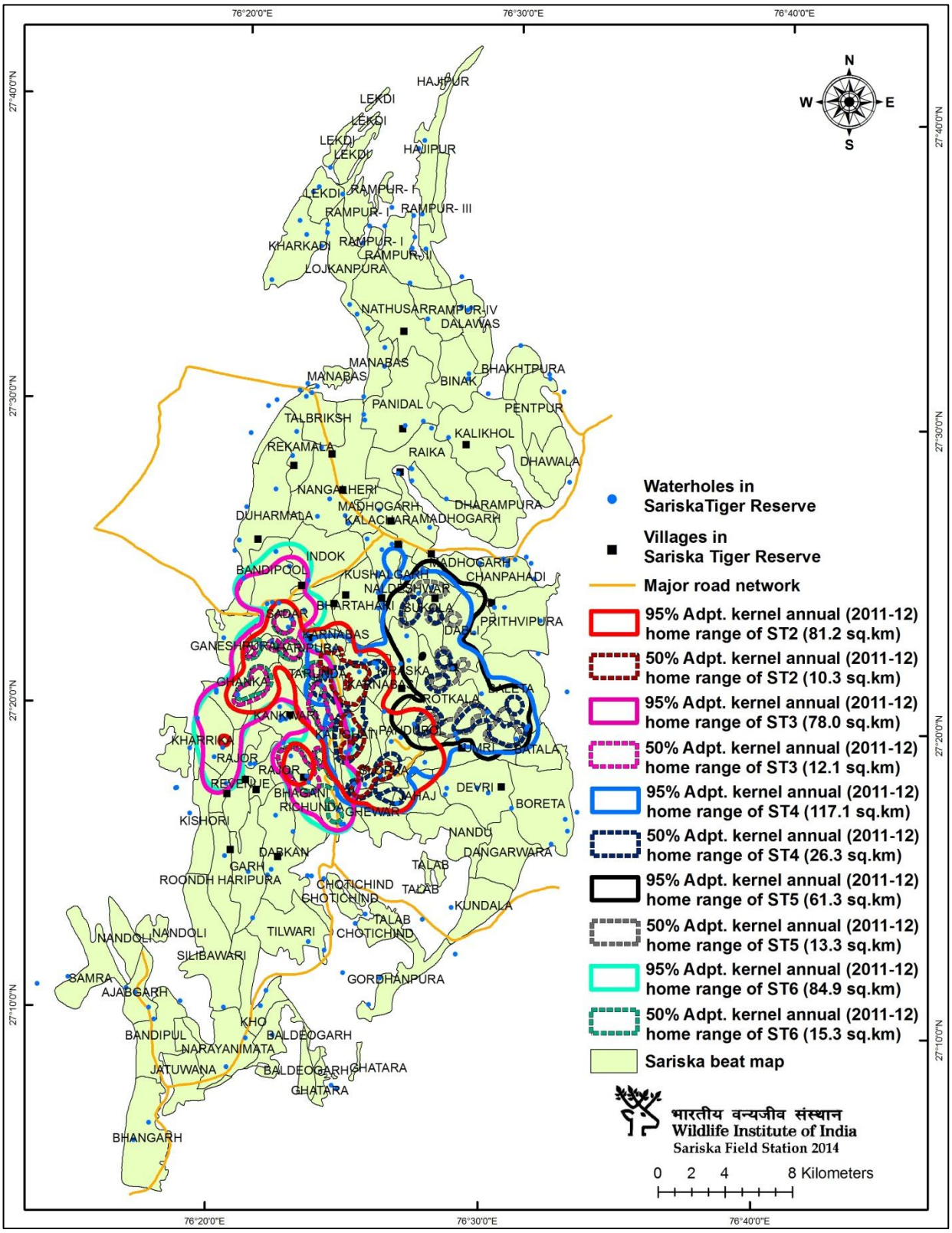


Table 5.15. Details of the monsoon ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2011 – October 2011.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2011	Monsoon	ST2	46.70	n.a.	38.86	n.a.	45.12	n.a.	11.40	n.a.	41.87	n.a.	8.18	n.a.
2011	Monsoon	ST3	96.70	n.a.	71.30	n.a.	81.53	n.a.	21.00	n.a.	75.45	n.a.	12.67	n.a.
2011	Monsoon	ST4	183.90	n.a.	124.96	n.a.	142.38	n.a.	35.27	n.a.	130.73	n.a.	24.89	n.a.
2011	Monsoon	ST5	71.20	n.a.	63.05	n.a.	74.05	n.a.	20.91	n.a.	67.41	n.a.	14.18	n.a.
2011	Monsoon	ST6	134.20	n.a.	91.99	n.a.	104.44	n.a.	29.46	n.a.	91.91	n.a.	20.40	n.a.
2011	Monsoon	ST2-3 overlap	4.10	6.51	3.62	7.20	11.44	19.69	0.06	0.41	8.80	16.34	0.00	0.00
2011	Monsoon	ST2-4 overlap	46.70	62.70	38.86	65.55	44.34	64.71	11.36	65.93	41.13	64.85	7.00	56.85
2011	Monsoon	ST2-5 overlap	4.50	7.98	2.90	6.03	1.29	2.30	0.00	0.00	0.58	1.13	0.00	0.00
2011	Monsoon	ST2-6 overlap	3.30	4.76	2.23	4.08	13.69	21.72	0.00	0.00	9.70	16.86	0.00	0.00
2011	Monsoon	ST 3-4 overlap	20.60	16.25	5.21	5.74	20.02	19.31	2.94	11.17	15.12	15.80	1.00	5.95
2011	Monsoon	ST 3-5 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	Monsoon	ST 3-6 overlap	92.60	82.38	69.40	86.39	78.63	85.87	17.00	69.33	70.13	84.63	10.07	64.42
2011	Monsoon	ST 4-5 overlap	70.40	68.58	56.52	67.44	67.34	69.12	7.27	27.69	61.32	68.94	4.40	24.36
2011	Monsoon	ST 4-6 overlap	19.90	12.82	3.62	3.42	22.46	18.64	2.35	7.32	15.92	14.75	0.77	3.43
2011	Monsoon	ST 5-6 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n.a. - Not applicable

Table 5.16. Details of the winter ranging patterns of reintroduced tigers in Sariska Tiger Reserve during November 2011 – February 2012.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2011-12	Winter	ST2	102.00	n.a.	46.66	n.a.	57.00	n.a.	11.98	n.a.	57.86	n.a.	7.86	n.a.
2011-12	Winter	ST3	95.20	n.a.	85.97	n.a.	90.62	n.a.	23.97	n.a.	83.74	n.a.	15.48	n.a.
2011-12	Winter	ST4	136.20	n.a.	115.27	n.a.	125.88	n.a.	34.56	n.a.	116.63	n.a.	22.49	n.a.
2011-12	Winter	ST5	83.60	n.a.	61.52	n.a.	68.22	n.a.	19.54	n.a.	63.46	n.a.	13.40	n.a.
2011-12	Winter	ST6	123.20	n.a.	99.64	n.a.	102.83	n.a.	25.78	n.a.	93.43	n.a.	16.97	n.a.
2011-12	Winter	ST2-3 overlap	59.80	60.72	12.10	20.00	20.19	28.85	0.18	1.13	10.96	16.01	0.07	0.67
2011-12	Winter	ST2-4 overlap	51.10	43.81	43.43	65.38	51.90	66.14	10.47	58.85	50.38	65.13	6.21	53.31
2011-12	Winter	ST2-5 overlap	22.40	24.38	6.59	12.42	4.33	6.97	0.00	0.00	5.16	8.53	0.00	0.00
2011-12	Winter	ST2-6 overlap	56.40	50.54	8.53	13.42	21.05	28.70	0.03	0.18	16.72	23.40	0.03	0.28
2011-12	Winter	ST 3-4 overlap	9.60	8.57	9.35	9.49	17.90	16.99	1.52	5.37	11.76	12.06	0.00	0.00
2011-12	Winter	ST 3-5 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011-12	Winter	ST 3-6 overlap	90.50	84.26	81.58	88.38	87.74	91.07	19.41	78.13	80.26	90.87	12.01	74.18
2011-12	Winter	ST 4-5 overlap	78.40	75.67	55.46	69.13	62.69	70.85	8.68	34.77	58.37	71.02	5.75	34.24
2011-12	Winter	ST 4-6 overlap	5.60	4.33	5.48	5.13	18.54	16.38	1.65	5.59	11.26	10.86	0.01	0.06
2011-12	Winter	ST 5-6 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n.a. - Not applicable

Table 5.17. Details of the summer ranging patterns of reintroduced tigers in Sariska Tiger Reserve during March 2012 – June 2012.

Year	Season	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2012	Summer	ST2	40.50	n.a.	36.45	n.a.	47.76	n.a.	12.51	n.a.	42.76	n.a.	8.08	n.a.
2012	Summer	ST3	89.80	n.a.	75.40	n.a.	75.54	n.a.	11.97	n.a.	77.73	n.a.	6.53	n.a.
2012	Summer	ST4	127.40	n.a.	106.12	n.a.	124.26	n.a.	39.76	n.a.	107.92	n.a.	26.31	n.a.
2012	Summer	ST5	62.50	n.a.	57.15	n.a.	58.84	n.a.	16.78	n.a.	51.66	n.a.	10.58	n.a.
2012	Summer	ST6	97.10	n.a.	80.89	n.a.	83.74	n.a.	18.79	n.a.	81.14	n.a.	10.89	n.a.
2012	Summer	ST2-3 overlap	3.40	6.09	3.60	7.33	9.98	17.05	0.00	0.00	9.40	17.04	0.00	0.00
2012	Summer	ST2-4 overlap	40.30	65.57	36.35	66.99	47.16	68.35	10.45	54.91	41.25	67.34	5.18	41.90
2012	Summer	ST2-5 overlap	2.30	4.68	2.26	5.08	3.84	7.28	0.00	0.00	3.25	6.95	0.00	0.00
2012	Summer	ST2-6 overlap	5.90	10.32	4.05	8.06	13.97	22.97	0.00	0.00	11.93	21.30	0.00	0.00
2012	Summer	ST 3-4 overlap	4.70	4.46	4.64	5.26	14.05	14.95	0.00	0.00	11.89	13.16	0.00	0.00
2012	Summer	ST 3-5 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	Summer	ST 3-6 overlap	84.80	90.88	68.01	87.14	71.24	89.69	11.42	78.09	72.12	90.83	5.69	69.70
2012	Summer	ST 4-5 overlap	56.80	67.73	50.62	68.14	57.21	71.64	14.12	59.83	48.49	69.40	7.77	51.49
2012	Summer	ST 4-6 overlap	6.00	5.44	5.96	6.49	17.91	17.90	0.00	0.00	14.14	15.26	0.22	1.43
2012	Summer	ST 5-6 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n.a. - Not applicable

Table 5.18. Details of the annual ranging patterns of reintroduced tigers in Sariska Tiger Reserve during July 2011 – June 2012.

Year	Period	Tiger Id	Different types of home range estimators											
			100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
			Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
2011-12	Annual	ST2	134.40	n.a.	79.09	n.a.	78.26	n.a.	14.48	n.a.	81.19	n.a.	10.27	n.a.
2011-12	Annual	ST3	112.70	n.a.	87.99	n.a.	81.74	n.a.	19.27	n.a.	78.01	n.a.	12.10	n.a.
2011-12	Annual	ST4	194.10	n.a.	121.59	n.a.	127.08	n.a.	37.15	n.a.	117.12	n.a.	26.33	n.a.
2011-12	Annual	ST5	100.20	n.a.	66.95	n.a.	65.55	n.a.	19.00	n.a.	61.33	n.a.	13.33	n.a.
2011-12	Annual	ST6	149.20	n.a.	101.16	n.a.	92.47	n.a.	23.58	n.a.	84.91	n.a.	15.25	n.a.
2011-12	Annual	ST2-3 overlap	86.30	70.39	36.98	44.39	34.63	43.31	0.00	0.00	38.78	48.74	0.00	0.00
2011-12	Annual	ST2-4 overlap	77.80	48.98	52.09	54.35	56.78	58.62	13.48	64.69	51.98	54.20	7.99	54.08
2011-12	Annual	ST2-5 overlap	28.50	24.82	8.93	12.31	4.60	6.45	0.00	0.00	4.40	6.30	0.00	0.00
2011-12	Annual	ST2-6 overlap	83.20	58.83	34.91	39.32	36.24	42.75	0.00	0.00	37.41	45.07	0.02	0.17
2011-12	Annual	ST 3-4 overlap	29.80	20.90	10.01	9.80	15.48	15.56	0.87	3.43	11.33	12.10	0.41	2.48
2011-12	Annual	ST 3-5 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011-12	Annual	ST 3-6 overlap	107.00	83.33	84.29	89.56	80.06	92.26	17.51	82.56	75.47	92.81	10.68	79.15
2011-12	Annual	ST 4-5 overlap	99.50	75.28	59.36	68.74	62.10	71.80	11.90	47.33	57.52	71.45	7.24	40.91
2011-12	Annual	ST 4-6 overlap	26.60	15.77	8.03	7.27	16.98	15.86	0.87	3.02	11.61	11.79	0.36	1.87
2011-12	Annual	ST 5-6 overlap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n.a. - Not applicable

5.5. DISCUSSION

Tigers are endangered in South East Asia and yet little is known about their resource needs which are to be secured for long term conservation. The present study used radio telemetry to investigate movement and ranging patterns of reintroduced tigers in Sariska Tiger Reserve. Considering the tiger's elusive and cryptic nature, radio telemetry is probably the best available means to investigate home range size and behavioral observation in a systematic manner (Chundawat and Malik, 2010). This technique has been used extensively in the tiger's geographical range from Indian subcontinent to south east Asia up to Russian far east (Seidensticker, 1976; Sunquist, 1981; Smith *et al*., 1987a; Karanth and Sunquist, 2000; Chundawat, 2001; O'Brien *et al*., 2003; Chakravarthy, 2009; Goodrich *et al*., 2010; Sharma *et al*., 2010; Sunquist, 2010; Burlow *et al*., 2011; Sharma *et al*., 2011; Priatna *et al*., 2012 and Majumder *et al*., 2012).

In the present study, three adult male and three adult female radio-collared tigers were monitored in Sariska Tiger Reserve to study their movements and ranging patterns, prey selection and habitat utilization patterns. Since all the tigers were brought from outside Sariska Tiger Reserve (Ranthambhore TR) and released inside Sariska, initially they explored larger areas and subsequently established their new home ranges in much smaller areas within two to three months.

Each of the reintroduced tigers was observed to move at an average rate of 10-20 km per day till 40-50 days of their reintroduction during the initial exploration period (Figure 5.1). Thereafter, these rates were subsequently reduced as they started settling down in smaller areas. During courtship and successful predation events, movements of the tigers were reduced to 0.2 to 0.3 km per day, while the maximum movement by an individual recorded in a day was 40.81 km. The mean daily movement of the male tigers (7.06±0.11SE km) was found greater than that of the females (5.78±0.08SE km). During monsoon and winter, the mean daily movements of each tiger were estimated greater than summer (Table 5.1). This may be due to the severe heat condition and scarcity of water in Sariska during summer when tigers largely rested near the available waterholes during the day hours. Barlow *et al*., (2011) communicated maximum distance moved by a tigress in a day as 11.3 km with the mean daily movement rate of two radio-collared tigresses as 3.6 km in Bangladesh Sunderban. The study by Priatna *et al*., (2012) showed that the maximum distance moved by four rescued and subsequently translocated radio-collared Sumatran tigers ranged from 8.5 km to 18.9 km per day. Thus the movement patterns of the reintroduced tigers in the present study therefore can be compared with the

above-mentioned observations for future translocation plan of any conflict tiger or tiger reintroduction events.

In the present study, the home ranges of the reintroduced tigers were estimated using 100% and 95% minimum convex polygon (MCP) estimators along with fixed kernel estimators (95% and 50%) and adaptive kernel estimators (95% and 50%) as these techniques were universally accepted for comparing with other available studies on tiger home ranges. The estimated mean monsoon and winter home ranges of the male tigers using 100% MCP method were 155.25±8.1SE km^2 and 151.80±22.27SE km^2 respectively which are much larger than the estimated mean summer range i.e. 138.10±18.20SE km^2 (Table 5.19). This may be attributed to the widespread distribution of water and prey species during monsoon and winter in the entire study area in contrast to the sparse availability of water and patchy ungulate distribution during summer. The analysis with 95% fixed kernel estimators revealed similar findings regarding female ranging pattern where the estimated mean monsoon (90.78±20.75SE km^2) and winter (76.71±5.76SE km^2) home ranges of the tigresses were found larger than the estimated mean summer (70.31±7.96SE km^2) home range (Table 5.19). In contrary, the estimated mean summer home range of the tigresses using 100% MCP was 90.47±16.66SE km^2 which was slightly larger than the estimated mean winter range i.e. 86.53±6.36SE km^2 (Table 5.19). This may be due to their occasional visits to new areas during courtship association with different male tigers in summer.

The range overlap between the male and female tigers ranged from 41% to 56% in each season and annually whereas female-female and male-male range overlap varied from 10% to 30% and 10% to 18% respectively season wise and annually. No range overlap between the tigers ST5 (female) and ST6 (male) was observed during the study period. The overlaps between the core areas of activity among the female tigers were observed much less (zero to two percent season wise and annually), whereas the male-female mean overlap of the core areas was found much larger (10% to 55%) in each season as well as annually. On an average, zero to three percent of overlap between the core areas of activity of the male tigers was estimated season wise and annually during the study period. The mean seasonal and annual home ranges of male and female tigers during 2008-12 and range overlap among male-male, male-female and female-female tigers are given in Table 5.19.

The mean home range estimates (100% MCP and 95% fixed kernel) of male and female reintroduced tigers from the present study were compared with other available studies in Indian subcontinent, Russian Far East and South-east Asia (Table 5.20). It was found that both the male and female home

ranges estimated in Sariska Tiger Reserve were much larger as compared to other areas of Indian subcontinent except in the forests of Sumatra and Russian Far East (Table 5.20). Estimates from various regions were made using a variety of techniques, which probably accounts for a large degree of variation, but even when analyses were restricted to those made using the 100% MCP and 95% fixed kernel estimators, estimates of tiger home range size varied from 9.3 km^2 to 1385 km^2. Though worldwide studies were conducted in a variety of habitats, with large variation in prey abundance, different rainfall regime with coexistence or absence of other larger sympatric carnivores as well as disparities in other factors such as study being conducted inside protected area or outside protected areas, yet it may be suggested that the home ranges of tiger in tropical deciduous forest are much smaller than that in the temperate forest or tropical rain forest (Chundawat, 2001; Goodrich *et al*., 2010; Priatna *et al*., 2012). The home range size of tiger has direct influence on the effective population size and density of tiger in all the aforesaid habitat types (larger the home range of tiger in any habitat, lesser will be the ecological density and vice versa) which should be considered to design the site-specific management strategies and policy planning for effective conservation of the species.

Table 5.19. Details of the seasonal and annual home range and home range overlap of reintroduced tigers in STR during 2008 to 2012.

Year	Detail of the home range and range overlaps	Different types of home range estimators											
		100% MCP		95% MCP		95% Fixed Kernel		50% Fixed Kernel		95% Adaptive Kernel		50% Adaptive Kernel	
		Area (km^2)	% value	Area (km^2)	% value	Area (km^2)	% value	Area (km^2)	% value	Area (km^2)	% value	Area (km^2)	% value
2008-12	Mean monsoon home range of male (n=06)	155.25 ±8.1SE	n.a.	103.24 ±7.14SE	n.a.	126.43 ±6.54SE	n.a.	28.96 ±2.17SE	n.a.	120.88 ±7.19SE	n.a.	20.56 ±1.63SE	n.a.
2008-12	Mean monsoon home range of female (n=09)	95.01 ±17.83SE	n.a.	74.31 ±17.04SE	n.a.	90.78 ±20.75SE	n.a.	21.56 ±5.09SE	n.a.	84.01 ±18.99SE	n.a.	14.42 ±3.63SE	n.a.
2008-12	Mean monsoon Male - Male home range overlap (n=02)	15.80 ±4.10SE	10.16 ±2.66SE	2.07 ±1.56SE	1.94 ±1.47SE	17.23 ±5.23SE	14.16 ±4.49SE	1.18 ±1.18SE	3.66 ±3.66SE	14.07 ±1.85SE	12.24 ±2.51SE	0.39 ±0.39SE	1.72 ±1.72SE
2008-12	Mean monsoon Male - Female home range overlap (n=15)	41.33 ±8.50SE	38.39 ±7.67SE	26.91 ±6.15SE	35.86 ±8.16SE	37.05 ±7.05SE	40.46 ±7.68SE	5.48 ±1.56SE	27.07 ±7.85SE	34.07 ±6.61SE	39.62 ±7.75SE	3.21 ±0.98SE	23.19 ±7.09SE
2008-12	Mean monsoon Female - Female home range overlap (n=07)	10.43 ±4.24SE	14.65 ±5.98SE	5.33 ±2.76SE	10.05 ±4.60SE	12.35 ±3.79SE	17.70 ±5.47SE	0.44 ±0.30SE	2.61 ±1.91SE	10.13 ±3.47SE	14.72 ±4.93SE	0.16 ±0.14SE	1.55 ±1.23SE
2008-12	Mean winter home range of male (n=05)	151.80 ±22.27SE	n.a.	126.84 ±20.22SE	n.a.	142.50 ±18.96SE	n.a.	35.67 ±4.28SE	n.a.	133.11 ±19.08SE	n.a.	23.70 ±3.36SE	n.a.
2008-12	Mean winter home range of female (n=09)	86.53 ±6.36SE	n.a.	65.17 ±5.68SE	n.a.	76.71 ±5.76SE	n.a.	19.75 ±2.01SE	n.a.	72.10 ±5.18SE	n.a.	13.02 ±1.42SE	n.a.
2008-12	Mean winter Male - Male home range overlap (n=01)	5.60	4.33	5.48	5.13	18.54	16.38	1.65	5.59	11.26	10.86	0.01	0.06
2008-12	Mean winter Male - Female home range overlap (n=12)	61.38 ±8.72SE	55.87 ±7.82SE	46.24 ±7.83SE	54.24 ±8.68SE	56.09 ±8.42SE	56.80 ±7.96SE	10.06 ±1.93SE	41.28 ±8.32SE	51.25 ±8.03SE	55.28 ±8.21SE	5.91 ±1.18SE	37.13 ±7.81SE
2008-12	Mean winter Female - Female home range overlap (n=07)	16.27 ±7.86SE	18.43 ±7.87SE	6.06 ±1.86SE	10.83 ±3.19SE	10.69 ±4.42SE	15.33 ±6.16SE	0.23 ±0.13SE	1.30 ±0.72SE	8.21 ±3.33SE	12.53 ±4.95SE	0.20 ±0.13SE	1.64 ±1.03SE
2008-12	Mean summer home range of male (n=06)	138.10 ±18.20SE	n.a.	96.48 ±5.48SE	n.a.	110.12 ±6.38SE	n.a.	26.39 ±2.99SE	n.a.	102.86 ±4.92SE	n.a.	16.67 ±2.14SE	n.a.
2008-12	Mean summer home range of female (n=10)	90.47 ±16.66SE	n.a.	66.59 ±9.86SE	n.a.	70.31 ±7.96SE	n.a.	14.67 ±0.99SE	n.a.	67.86 ±9.12SE	n.a.	9.27 ±0.59SE	n.a.
2008-12	Mean summer Male - Male home range overlap (n=02)	27.90 ±21.9SE	15.83 ±10.38SE	12.66 ±6.70SE	12.15 ±5.65SE	21.79 ±3.88SE	19.90 ±2.00SE	0.01 ±0.01SE	0.04 ±0.04SE	18.34 ±4.20SE	17.75 ±2.49SE	0.11 ±0.11SE	0.72 ±0.72SE
2008-12	Mean summer Male - Female home range overlap (n=16)	50.73 ±8.80SE	49.83 ±7.81SE	36.70 ±6.65SE	48.39 ±7.90SE	41.40 ±6.48SE	50.26 ±7.46SE	6.38 ±1.47SE	35.05 ±8.09SE	38.50 ±6.24SE	49.41 ±7.46SE	3.42 ±0.79SE	29.77 ±7.00SE
2008-12	Mean summer Female - Female home range overlap (n=08)	16.49 ±6.93SE	19.46 ±7.06SE	9.58 ±4.02SE	16.68 ±6.38SE	10.08 ±4.09SE	15.52 ±5.63SE	0.03 ±0.03SE	0.20 ±0.20SE	9.71 ±4.12SE	15.64 ±5.77SE	0.01 ±0.01SE	0.15 ±0.15SE
2008-12	Mean annual home range of male (n =05)	220 ±46.82SE	n.a.	145.71 ±29.89SE	n.a.	149.37 ±30.01SE	n.a.	35.57 ±5.78SE	n.a.	143.97 ±31.27SE	n.a.	24.37 ±4.18SE	n.a.
2008-12	Mean annual home range of female (n=09)	151.9 ±30.33SE	n.a.	100.49 ±18.96SE	n.a.	91.21 ±14.06SE	n.a.	18.77 ±2.21SE	n.a.	91.54 ±16.05SE	n.a.	13.03 ±1.47SE	n.a.
2008-12	Mean annual Male - Male home range overlap (n=01)	26.60SE	15.77	8.03	7.27	16.98	15.86	0.87	3.02	11.61	11.79	0.36	1.87
2008-12	Mean annual Male - Female home range overlap (n=12)	88.63 ±11.77SE	54.09 ±7.04SE	58.96 ±9.81SE	52.86 ±7.49SE	57.82 ±9.04SE	53.96 ±7.44SE	9.24 ±1.80SE	40.53 ±8.67SE	55.67 ±8.87SE	53.46 ±7.56SE	5.79 ±1.16SE	36.61 ±8.04SE
2008-12	Mean annual Female - Female home range overlap (n=07)	39.64 ±10.15SE	32.49 ±8.77SE	21.09 ±4.75SE	26.62 ±6.70SE	14.88 ±4.95SE	20.46 ±6.77SE	0.01 ±0.01SE	0.08 ±0.08SE	14.99 ±5.35SE	21.02 ±7.17SE	0.02 ±0.02SE	0.19 ±0.19SE

n.a. – not applicable; % value – Percentage value; SE – Standard error; MCP – Minimum convex polygon

Table 5.20. Estimated home range of tiger across different study sites.

Study area – Country	MCP Home Range of tiger sq. km				Reference
	Adult Male		Adult Female		
	ID	Area (km^2)	ID	Area (km^2)	
Sariska Tiger Reserve, Rajasthan, India	ST1 (mean)	177.1(100% MCP)	ST2 (mean)	129.0(100% MCP)	Present study (2008-2012)
	ST4 (mean)	299.7(100% MCP)	ST3 (mean)	123.1(100% MCP)	
	ST6 (mean)	149.2(100% MCP)	ST5 (mean)	240.1(100% MCP)	
	Male annual (mean; n= 05)	220±46.82SE (100% MCP) 149.37±30.0SE (95% Fixed Kernel)	Female annual (mean; n=09)	151.9±30.33SE (100% MCP) 91.21±14.06SE (95% Fixed Kernel)	
Royal Chitwan National Park, Nepal	---	---	Female (mean; n= 05)	9.3	Seidensticker, 1976
Royal Chitwan National Park, Nepal	Male (mean; n= 02)	54.1	Female (mean; n= 03)	16	Sunquist, 1981; Sunquist, 2010
Royal Chitwan National Park, Nepal	---	---	Female (mean; n= 07)	20.7	Smith *et al.*,1987
Nagarhole National Park, Karnataka, India	Male (mean; n= 01)	25.7	Female (mean; n= 01)	16.5	Karanth and Sunquist, 2000
Panna Tiger Reserve, Madhya Pradesh, Central India	M-91	167.2	F-111	50.9	Chundawat, 2001
	M -125	210.0	F-113	67.5	
	---	---	F-118	31.3	
	---	---	F-120	35.7	
	Male (mean; n= 02)	188.6	Female (mean; n= 04)	42.7	
Tropical Forest, Indonesia	Male (mean; n= 01)	16.0	---	---	O'Brien *et al.*, 2003 (Sumatran Tiger)
Ranthambhore Tiger Reserve, India	Male (mean; n= 04)	46.1	Female (mean; n= 02)	20.1	Chakravarthy, 2009
Sikhote-Alin, Russia	Male (mean; n= 06)	1385.0	Female (mean; n= 14)	390.0	Goodrich *et al.*, 2010 (Amur Tiger)
Kanha Tiger Reserve, Madhya Pradesh, India	Male (mean; n= 02)	102.0	Female (mean; n= 04)	10.5	Sharma *et al.*, 2010
Sunderban, Bangladesh	---	---	Female (mean; n= 02)	12.3	Burlow *et al.*, 2011
Sunderban Tiger Reserve, India	---	---	Female (mean; n= 01)	44	Sharma *et al.*, 2011
Indonesia	Male (mean; n= 04)	236.0	---	---	Priatna *et al.*, 2012 (Sumatran Tiger)
Pench Tiger Reserve, Madhya Pradesh, India	Male (mean; n= 01)	55.0	Female (mean; n= 01)	44.0	Majumder *et al.*, 2012

--- Data not available.

CHAPTER SIX

6. HABITAT UTILIZATION AND RESOURCE SELECTION BY THE REINTRODUCED TIGERS

6.1. INTRODUCTION

The extirpation of large vertebrates from the tropical forests of south and south east Asia may be the next biological affront of the global extinction history. Large mammalian predators and their prey are at particular risk in these forests, where they are threatened by poaching and incessant habitat degradation and fragmentation with constantly losing crucial connectivities within the landscapes (Wikramanayake *et al*., 1998; Peyton, 1999; Tirira *et al*., 2001). Habitat fragmentation has less influences on generalized species (Virgo´s, 2002; Virgo´s and Garcia, 2002), whereas specialists are affected significantly by that and thus they have further difficulty in maintaining minimum viable populations (Beier, 1993; Maehr and Cox, 1995; Lidicker and Koenig, 1996). Animals generally prefer habitats that satisfy their demands for food, water, and resting sites to optimize survival and reproduction (Boyce and McDonald, 1999; Chamberlain *et al*., 2002). Several hypotheses have been proposed to explain the coexistence patterns of sympatric carnivores such as tiger, leopard and dhole in forested habitat (Seidensticker, 1976; Karanth and Sunquist, 1995) where a comparison of habitat use by sympatric species allows an assessment of their interactions.

In India, tiger (*Panthera tigris tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) were found to utilize a wide range of habitats (Johnsingh, 1983; Karanth and Sunquist, 1995; Edgaonkar, 2008; Jhala *et al*., 2008, 2010; Ramesh, 2010) within a landscape. In tropical Asia, tigers inhabit forests of deciduous, evergreen, riverine, swamp and mangrove showing incredible tolerance to variation in altitude, temperature and rainfall regimes. Conservation of habitat of these sympatric carnivores in the human dominated landscape of India has always been a challenging task for wildlife managers (Wikramanayake *et al*., 1998) as their habitats have been fragmented because of anthropogenic pressure (Qureshi *et al*., 2006; Jhala *et al*., 2008). With the decline of most of the large carnivore populations (Nowel and Jackson, 1996), there was an urgent need for adopting the effective practical methods to understand the utilization patterns of different habitat resources by tiger, leopard and other sympatric carnivores.

In Indian subcontinent, tiger is a wide-ranging large carnivore that is much susceptible to disturbance, is a generalist with respect to habitat and prey species requirements, and can

survive on a wide range of prey species (Karanth and Sunquist, 1995). Though tigers are considered habitat generalists, they are so much vulnerable to habitat loss and fragmentation. But very little information is available on the resource selection of tiger populations in Indian sub-continent (Chundawat, 2001).

Resource selection by animals is a hierarchical process of behavioral responses to particular environmental characteristics (Manly *et al*., 2002; Horne *et al*., 2008). Establishment of a home range within a landscape and the movement of individuals within a home range may be influenced by different environmental factors and scales, and therefore animal- landscape relationships should be evaluated across a range of scales (Johnson, 1980; Anderson and Martinez-Meyer, 2004; Anderson *et al*., 2005; Boyce, 2006). This is particularly significant when assessing the resource selection dynamics of species inhabiting fragmented or human-dominated landscapes (Anderson *et al*., 2005). Therefore, resource selection by animals may be referred to as scale-dependent hierarchical process of behavioral responses to environmental factors. Lack of information on habitat selection dynamics can affect the conservation management actions of such species and habitats. For example, little is known about the space-use patterns of tiger in the semi-arid landscape of Western India.

In many of the research and management areas of conservation biology, population viability analysis, reserve management design and landscape level occupancy by the carnivore are the matter of concern, which is directly related with the trophic status of the species. It is commonly assumed that a conservation plan focused on large carnivores will protect most other species down in the trophic level as well. Evidently, tigers as the top carnivores act as the "umbrella species" and provide a "coattail effect" (Soule, 1985) for all the species associated in the eco-system. Hence it is always necessary to understand the habitat requirements and the pattern of habitat use by the carnivore for conservation of a landscape. In the present study, habitat utilization and resource selection patterns of reintroduced tiger were examined comparing different vegetation types, elevation, prey species and livestock encounter rate with presence of water, major roads, villages and other human disturbances such as wood cutting, lopping etc. in Sariska Tiger Reserve, Western India. A combination of first order and second order resource selection patterns were evaluated to understand the habitat selection of the reintroduced tigers in the study area. The first order of selection is the selection of entire range utilized by the population in the available landscape for them where as second order of selection is the selection of individual home-ranges within the entire home range area occupied by the population (Johnson, 1980). Generalized Linear Model was followed to understand the resource selection of the reintroduced tigers in the study area, but

with a modification that assigns values based on the Utilization Distribution (UD) of each animal in the study area (Millspaugh *et al*., 2006).

6.2. LITERATURE REVIEW

Habitats can be defined as regions in environmental space (Aarts *et al*., 2008; Hirzel and Lay 2008) that are composed of multiple dimensions, each representing a biotic or abiotic environmental variable. Therefore, any component or characteristic of the environment is either related directly (e.g. forage biomass and quality) or indirectly (e.g. elevation) to the use of a location by the animal. Environmental variables can be dynamic or static and may be positively or negatively associated with consumption. The distribution of habitats in geographical space can be simple or complex varying from regions of landscape level spaces to a patchy distribution within a landscape (Hirzel and Lay 2008).

Neu *et al*., (1974) described a statistical technique for analyzing utilization- availability data. The technique was useful in determining preference of a dietary component in relation to its availability. Krausman (1978) used that technique to assess forage preferences of deer in relation to availability. Nelson (1979) further adopted the similar framework to evaluate the hypothesis that deer used available habitat types in proportion to their occurrence. Thereafter, models of habitat utilization and preference are widely used to quantify animal–habitat interactions and also to describe and predict differential space use by animals so that the important habitat to an animal within a landscape or even a significant smaller patch within a small area can be identified. Quantifying habitat selection or preference involves the statistical comparison of samples of habitat utilization and availability. The degree of preference is therefore dependent upon both of these samples. The inferences that can be drawn from use against availability designs are influenced by subjectivity in defining what is available to the animal. Here accessibility is one of the major problems in quantifying the available resources to design the framework in which preference parameters would be modeled.

Resource selection function (RSF) is a statistical function defined to be proportional to the probability of an available resource unit being utilized. Differential resource selection is one of the principal relationships which permit species to coexist (Rosenzweig, 1981). It is often assumed that a species would select resources that are best to satisfy its life requirements. Therefore, high quality resources would be selected more than low quality ones. The availability of various resources is not generally uniform in nature, and use may change as availability changes. Therefore, used resources should be compared to available (or unused)

resources in order to reach valid conclusions concerning resource selection. When resources are used disproportionately to their availability, use is said to be selective.

The usage of a resource is defined as that quantity of the resource that is utilized by an animal (or population of animals) in a fixed period of time. The availability of a resource is the quantity accessible to the animal (or population of animals) during the same period of time. It is possible to distinguish between availability and abundance by defining the latter as the quantity of the resource in the environment. Although selection and preference are often used as synonyms in the literature, here they are defined differently: selection is the process in which an animal chooses a resource, and preference is the likelihood that a resource will be selected if offered on an equal basis with others (Johnson, 1980).

Most commonly, selection studies deal with food or habitat selection. Food selection may be among various prey species or among sizes, colors, shapes, components, etc. of the same species. Habitat selection may be among various discrete habitat categories or among a continuous array of habitat attributes such as shrub density, percentage cover, distance to water, canopy height, etc. Thus, the variables observed in a selection study may be discrete, or continuous or some combination of the two. There is sometimes a need to provide quantitative information that is indicative of the long-term resource requirements of a population. However, it should be noted that a resource item may be highly favored but if it is difficult to find then it cannot be utilized much. Conversely, if any resources which are less favored are the only available ones then they may form a large proportion of those being utilized because of sheer compulsion or stern necessity. Another use of resource selection studies is projecting the impact of habitat change. Under certain assumptions the ratio of animal densities equals the ratio of resource availabilities for any two habitats at equilibrium (Fagen, 1988). These relationships are used to calculate relative habitat values from habitat selection studies and to define hypothetical carrying capacity curves based on habitat values under various natural conditions as well as effects of human disturbance. In such studies undisturbed sites often serve to provide baseline information which helps managers to evaluate the impact of man on animals and further on entire ecosystem. A recent use of resource selection study was in the estimation of population size using resource selection functions (Boyce and McDonald, 1999).

Habitat selection has been studied in the field by measuring the amount of time spent by individuals in each of the available habitats (Spitz and Janeau, 1995; Durbin, 1998) or through a count of the number of seasons a plot is used. Studies may involve classifying resource units into categories, or measures of specific variables characteristic of those units

may be obtained. For example, Murphy *et al*., (1985) collected habitat use data for white-tailed deer (*Odoncoileus virginianus*) by classifying radio locations into one of six habitat types. The proportion of radio locations in each habitat type was then compared to the relative availability of the respective habitat type in the study area. Alternatively, Dunn and Braun (1986) examined the selection of habitat by juvenile sage grouse (*Centocerus urophasianus*) by comparing habitat attribute data such as the shrub density and the distance to another cover type for radio locations and random sites.

A wide variety of methods can be adopted to collect habitat data. For example, resource availability may be evaluated from a map (Neu *et al*., 1974), digitally assessed using a geographic information system (McLean *et al*., 1998; Mladenoff *et al*., 1999) or sampled by randomly selecting sites (Marcum and Loftsgaarden, 1980). Briefly, it can be referred that the data used to evaluate resource selection may be collected through a census or by sampling with one or more procedures, may be categorical or continuous, and are generally multivariate. There may be three probable options for habitat data collection where

i. Available units are either randomly sampled or surveyed and used resource units are randomly sampled or
ii. Available resource units are either randomly sampled or surveyed and a random sample of unused resource units is taken or
iii. Unused resource units and used resource units are independently sampled.

Further there are three distinct sampling designs of habitat or resource selection studies according to Johnson, 1980 and Manly *et al*., (2002) as follows:

a) Habitat / resource selection sampling design type I: Proportion of habitat utilized by the population to the habitat available in landscape scale (Individuals not identified),
b) Habitat / resource selection sampling design type II: Proportion of habitat utilized by the individuals to the habitat available in population scale (Individuals identified) and
c) Habitat / resource selection sampling design type III: Proportion of habitat utilized by the individuals to the habitat available in individual scale. (Individuals identified).

In Indian sub-continent not much information is available regarding habitat utilization and resource selection by tigers. The study by Chundawat, 2001 in Panna Tiger Reserve, Madhya Pradesh, central India showed that tigers largely used forested areas as compared to other habitats. Within the forested habitats, dense mixed forest along the base of the slope was used

most (>40%) where dense ground cover, presence of water and caves as shelter favored the tigers. The study also revealed that tiger distribution in Panna was positively correlated to distribution of the major prey species such as chital and sambar and negatively correlated to anthropogenic disturbance.

No such study on tiger in the western Indian habitats has so far been carried out. But a similar study of resource selection by two problem or conflict leopards released in Sariska Tiger Reserve assessed that these trans-located leopards mostly preferred areas with *Zizyphus* mixed forest and *Acacia* mixed forest while avoided areas with *Anogeissus*-dominated forest. Further, they selected habitats with higher encounter rate of wild pig and nilgai and avoided the habitats with high encounter rate of chital and common langur. Finally, it was observed that the 'problem' leopards in this study showed significant positive selectivity to the available natural vegetation types and wild-prey abundance as compared to degraded habitats and domestic prey species. This kind of resource selection study for tigers and other large carnivores in different landscape is very crucial to design effective management policies for the species and ecosystem conservation.

6.3. METHODOLOGY

6.3.1. HABITAT USE BY THE REINTRODUCED TIGERS

Habitat utilization patterns of six reintroduced tigers ST1, ST4 and ST6-male; ST2, ST3 and ST5-female were studied in Sariska Tiger Reserve from July 2008 to June 2012. The radio-collared tigers were monitored periodically through satellite-GPS and VHF telemetry (ground tracking) using 'triangulation' and 'homing in' techniques. A total of 1218, 2818, 3169, 2181, 2087 and 1889 radio locations were recorded for the ST1 to ST6 tigers respectively during the period of July 2008 to June 2012. On each radio location of tigers, the GPS location, habitat type used as well as microhabitat and terrain types were recorded. The vegetation type for each tiger location was extracted from a multispectral (Landsat 7 ETM+) high resolution (28.5m) classified satellite imagery (1:50,000) from the Global Land Cover Facility, NASA for better representation. The information on proportion of different categories of habitat availability was also extracted from the same classified satellite imagery incorporating the entire area of Sariska Tiger Reserve. Habitat preference by the tigers was assessed using Bonferroni confidence interval method and Ivlev's index (Ivelev 1961; Neu *et al*., 1974). Similarly, on each radio location of tigers, the topography related parameters such as altitude, aspect, ruggedness and slope were analyzed from a high resolution (10m) Digital

Elevation Map (DEM) prepared from the contour map. Density of human disturbance (lopping and wood cutting) were estimated from 15 m radius circular plots on every 200 m distance of 52 line transect (n = 520), 112 radial line transect of length 2 km each around each of 28 villages (n = 1148) and also from kill, scat and homing in locations of tiger (n = 1470). The following parameters were recorded from these above-mentioned 3138 habitat sampling plots:

1. Major vegetation type
2. Major terrain type.
3. Wood cutting and lopping density (15 m radius) (total no. of tree cut down and branch lopped per ha)
4. Distance to the nearest
    - Waterhole
    - Road
    - Temple
    - Village

6.3.2. RESOURCE SELECTION BY THE REINTRODUCED TIGERS

The resource selection patterns of reintroduced tigers in Sariska Tiger Reserve were evaluated using Generalized Linear Model (GLM) at their population level (1st order resource selection) as well as gender based selection of resources at the similar geographic level (2nd order resource selection) (Johnson, 1980). The third order resource selection (resource selection of individual tiger within its home range) was not considered (Johnson, 1980) in the present study since I wanted to evaluate the resource selection by the population of reintroduced tigers and further by gender based groups (upto male and female tigers). The GLMM, which is an extension of Generalized linear model (GLM) synthesizes likelihood-based approach to regression analysis for a variety of outcome measures (Breslow and Clayton, 1993) and it is useful for accommodating the over-dispersion often observed among outcomes that often have binomial (Williams, 1982) or Poisson (Breslow and Clayton, 1993) distributions. In the present study, boundary map of Sariska Tiger Reserve was divided into four square km (2km x 2km) grids. Subsequently, The values of kernel utilization distribution (UD – the probability of utilization of any area) of the reintroduced tigers and other habitat parameters such as the percentage area of different vegetation types and mean

and variance of elevation were extracted in each grid (2 km X 2 km) from land use/ land cover and SRTM maps of Sariska Tiger Reserve.

Utilization – Distribution (UD) of the tigers were estimated in each grid by fixed kernel estimator method. Encounter rate of prey species in the study area was estimated by line transect method under distance sampling technique and then extracted from each grid of four km^2 (2 km x 2 km). Hence, information on vegetation types, elevation, encounter rate of prey species and presence of village, waterhole, major roads and human disturbances such as wood cutting and lopping were collected and recorded for each grid. Based on these information, 1^{st} and 2^{nd} orders of resource selection patterns (Johnson, 1980) of reintroduced tigers were studied in the present study.

All the resource / habitat parameters were chosen as fixed effects (independent variables) and utilization distributions in each grid were chosen as the variable effect (dependent variable) for GLMM models. Poisson distribution and log link function were selected based on the utilization distribution of male, female and all the reintroduced tigers in each grid for the analysis.

A total of 30 habitat variables such as slope, aspect (eight types – north, north-east, east, south-east, south, south-west, west and north-west), ruggedness, landuse - landcover types (nine categories - *Anogeissus* forest, *Zizyphus* forest, *Boswellia* forest, *Acacia* forest, *Butea* forest, scrubland, riverine forest, barren land and agricultural field), mean elevation, encounter rates of the prey species (such as sambar, chital, nilgai, wild pig and domestic livestock), Euclidean distances to nearest village, water hole and major road and also the encounter rates of the disturbance activities such as wood cutting and lopping were estimated in each grid of the Sariska Tiger Reserve. Collinearity and correlation test was carried out in between these 30 variables to select the non-collinear variables.

Encounter rates of prey species such as sambar, chital, nilgai, wild pig and livestock were estimated from each line transect out of total 52 line transects walked during 2008 to 2012. Density of human disturbance (lopping and wood cutting activities per ha) were estimated from 15 m radius circular plots on every 200m distance of 52 line transect (n = 520), 112 radial line transect of length 2 km each around each of 28 villages (n = 1148) and also from kill, scat and homing in locations of tiger (n = 1470).

Three types of resource selection models such as resource models (with landuse-landcover, vegetation and prey and water), disturbance models (with barren land, agriculture, village and anthropogenic disturbance parameters) and mixed models of the former two models were tested and the model with the lowest AIC value with the variables having model significance

was selected as the best-fit model to understand the resource-selection pattern of the reintroduced tigers in Sariska Tiger Reserve (Table 6.1, 6.2, 6.3 and 6.4).

6.4. RESULTS

6.4.1. HABITAT USE BY THE REINTRODUCED TIGERS

The tigers largely used *Anogeissus* forests (47.4%) followed by *Zizyphus* (15.7%), *Boswellia* (12.1%), *Butea* (10.6%), scrubland (8.6%), *Acacia* (4.5%) and Riverine forests (1.0%). The overall habitat preference of tigers was in the following order: Riverine >Zizyphus >Butea >Anogeissus >Boswellia >Acacia >scrubland. In monsoon similar habitat preference was observed where as in summer and winter tigers preferred *Zizyphus* forest over Riverine forest.

Tigers largely utilized gentle slope of 400 m to 550 m elevation (52.5%) as compared to areas with steep slope of more than 550 m altitude (30.3%) and flat terrain of less than 400 m MSL (17.2%). The mean elevation utilized was 441.4±6.8SE m. Except the scrubland, the reintroduced tigers utilized all other vegetation types such as *Anogeissus* forest, *Zizyphus* forest, *Boswellia* forest, *Acacia* forest, *Butea* forest and riverine forest more than their availability (Figure 6.1).

In Sariska, riverine habitat is found only 0.03% of the total available vegetation types where as the riverine habitat utilization by the tigers was estimated as 1%. This difference between utilization and availability made riverine forest as most preferred habitat type by the tigers. Among all three terrain types, only medium elevation range of 400 m to 550 m was utilized more than their availability by the tigers where as the steep terrain of more than 550 m elevation and gentle flat terrain of less than 400m height was utilized less than their availability (Figure 6.1).

The mean Euclidean distance of all the tiger locations (during 2008-2012) from the nearest waterhole was estimated as 684.1±3.8SE m which was found less as compared to their mean Euclidean distances from roads 2000.1±15.8SE m and the nearest village 2309.3±10.1SE m. In summer the mean distance to nearest waterhole was estimated as 646±5.5SE m which was found less than that in winter (673±6.1SE m) and monsoon (722±7.9SE m). This signified that water is a limiting factor for the habitat utilization pattern of the re-introduced tigers in Sariska.

The mean density of the human disturbance activities were estimated as 4.63 ± 0.19SE tree cut ha^{-1} and 132.61 ± 21.33SE tree lopped ha. The five worst affected tree species by human

disturbances were recorded as *Anogeissus pendula*, *Acacia catechu*, *Acacia lucophloea*, *Butea monosperma* and *Zizyphus mauritiana*. A comparative account of disturbance density recorded at different locations of village radial transect (from 0 m or village centre to 2000 m at four directions at an interval of 200 m) and homing in locations of tiger are shown in figure 6.2. At each of the village centre or the 0 m locations, almost no evidence of human disturbance could be recorded as the areas were completely denuded and devoid of even any remnants of tree species. Evidences of wood cutting and lopping were observed much within the distance of 1000 m to 1400 m from each village center and both of these activities were recorded till 2000 m distance from each village (Figure 6.2).

Figure 6.1. Percentage Frequency of the available and utilized vegetation and terrain types by the reintroduced tigers in Sariska Tiger Reserve during July 2008 to June 2012.

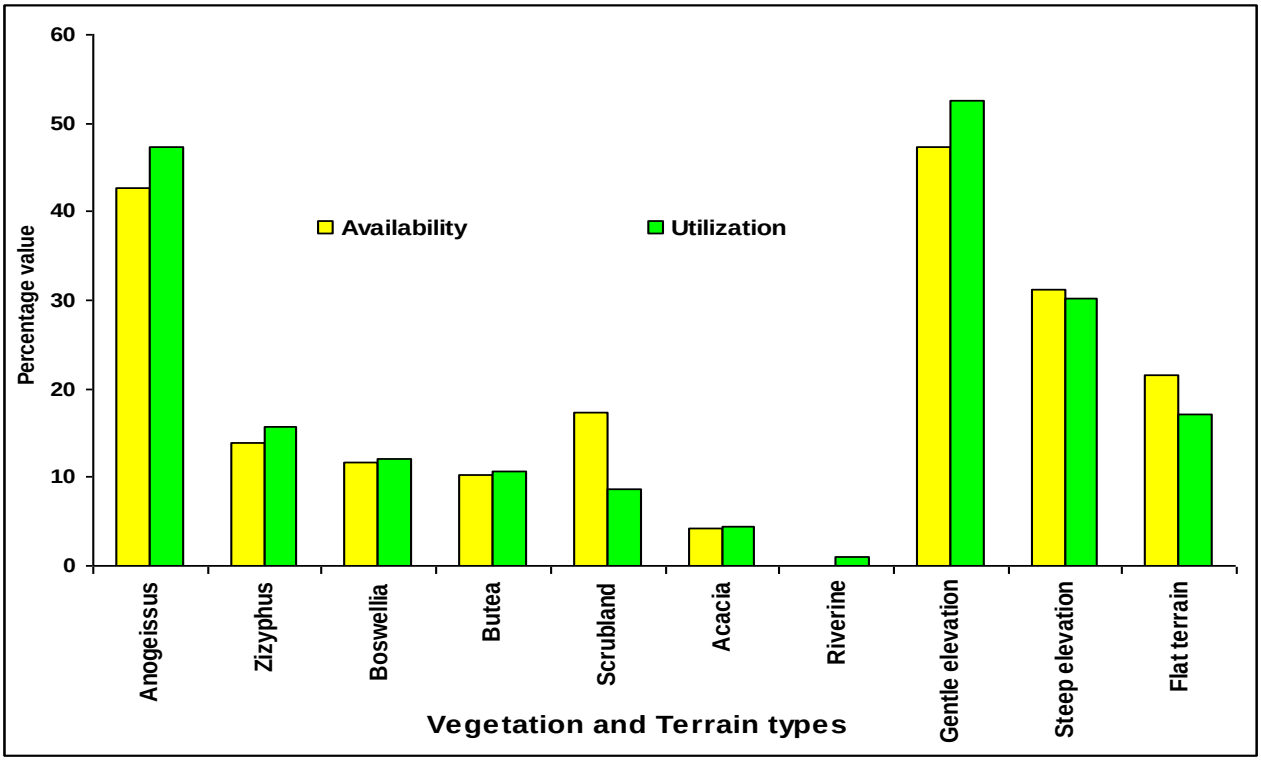
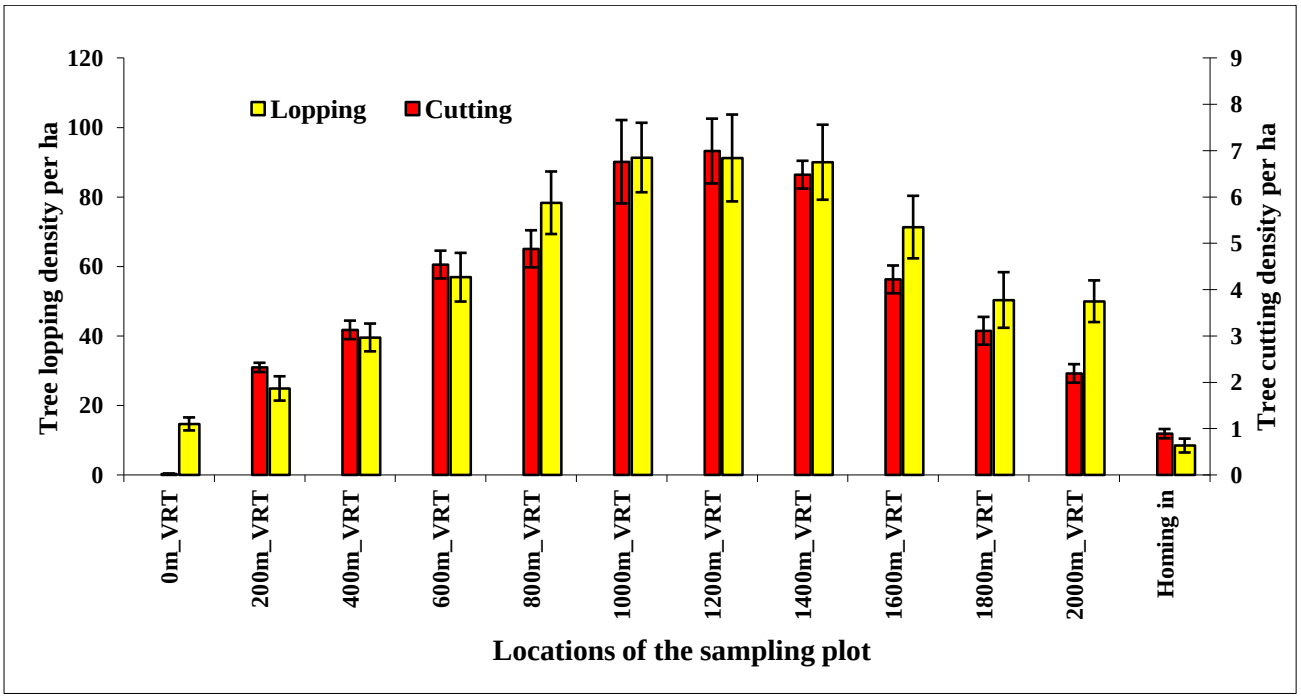


Figure 6.2. Human disturbance (tree cutting and lopping) density patterns in Sariska Tiger Reserve



(VRT – Village Radial Transect; Homing in – Sampling plot at the homing in locations of tiger)

6.4.2. RESOURCE SELECTION BY THE REINTRODUCED TIGERS

A total of ten resource selection models were tested for the model significance and finally a mixed model with ten habitat variables such as north east aspect, percentage availability of *Anogeissus* and *Zizyphus* forests, encounter rates of sambar, chital and livestock, Euclidean distance to nearest waterhole and village and encounter rates of anthropogenic disturbances such as wood cutting and lopping were found to have the lowest AIC and ΔAIC value along with model significance to the resource selection patterns of the tigers (Table 6.1). Results of Generalized linear model (GLM) showed that north east aspect, *Anogeissus* and *Zizyphus* forests, encounter rates of sambar, chital and livestock and distance to village had positive ß value w.r.t. tigers' utilization distribution pattern where as distance to nearest waterhole and encounter rates of the anthropogenic disturbances such as wood cutting and lopping had negative ß value (Table 6.1, 6.2, 6.3 and 6.4 and Figure 6.3, 6.4 and 6.5). A similar trend was found in male and female tigers' resource selection as well as in the seasonal variation of the resource selection by them (Table 6.3 and 6.4).

Table 6.1. Model selection statistics of Generalized Linear Model (GLM) analysis for resource selection of reintroduced tigers in Sariska Tiger Reserve (2008-2012).

Model Name in GLM analysis	AIC value	AICC	∆_AICC	∆_AIC
NE, Barr, Agri, Scrub, Rugg, D_VILL, D_ROAD, Ls_ER, Lop_ER, Wc_ER	2261.412	2264.399	49.015	49.015
NE, Ziz, Riv, But, Aca, Anog, Bos, Elev_mean, Slope_mean, D_WH, S_ER, Chi_ER, Nil_ER, Wpig_ER	2235.356	2239.854	22.959	24.470
NE, Barr, Ziz, Agri, Scrub, Aca, Anog, Elev_mean, Rugg, D_WH, D_VILL, S_ER, Chi_ER, Ls_ER, Lop_ER, Wc_ER	2222.968	2228.350	10.571	12.966
NE, Ziz, Anog, D_WH, D_VILL, S_ER, Ls_ER, Lop_ER, Wc_ER	2221.226	2223.887	8.829	8.503
NE, Ziz, Scrub, Anog, D_WH, D_VILL, D_ROAD, S_ER, Ls_ER, Lop_ER, Wc_ER	2221.005	2224.338	8.608	8.954
NE, Ziz, Anog, D_WH, D_VILL, D_ROAD, S_ER, Ls_ER, Lop_ER, Wc_ER	2219.735	2222.721	7.338	7.337
NE, Barr, Ziz, Agri, Anog, Rugg, D_WH, D_VILL, D_ROAD, S_ER, Chi_ER, Nil_ER, Wpig_ER, Ls_ER, Lop_ER, Wc_ER	2218.212	2223.593	5.815	8.209
NE, Ziz, Anog, D_WH, D_VILL, S_ER, Chi_ER, Ls_ER, Lop_ER, Wc_ER, Elev_mean, Slope_mean	2216.379	2220.079	3.982	4.695
NE, Ziz, Anog, Rugg, D_WH, D_VILL, S_ER, Chi_ER, Ls_ER, Lop_ER, Wc_ER	2214.220	2217.553	1.823	2.169
NE, Ziz, Anog, D_WH, D_VILL, S_ER, Chi_ER, Ls_ER, Lop_ER, Wc_ER	**2212.397**	**2215.384**	**0.000**	**0.000**

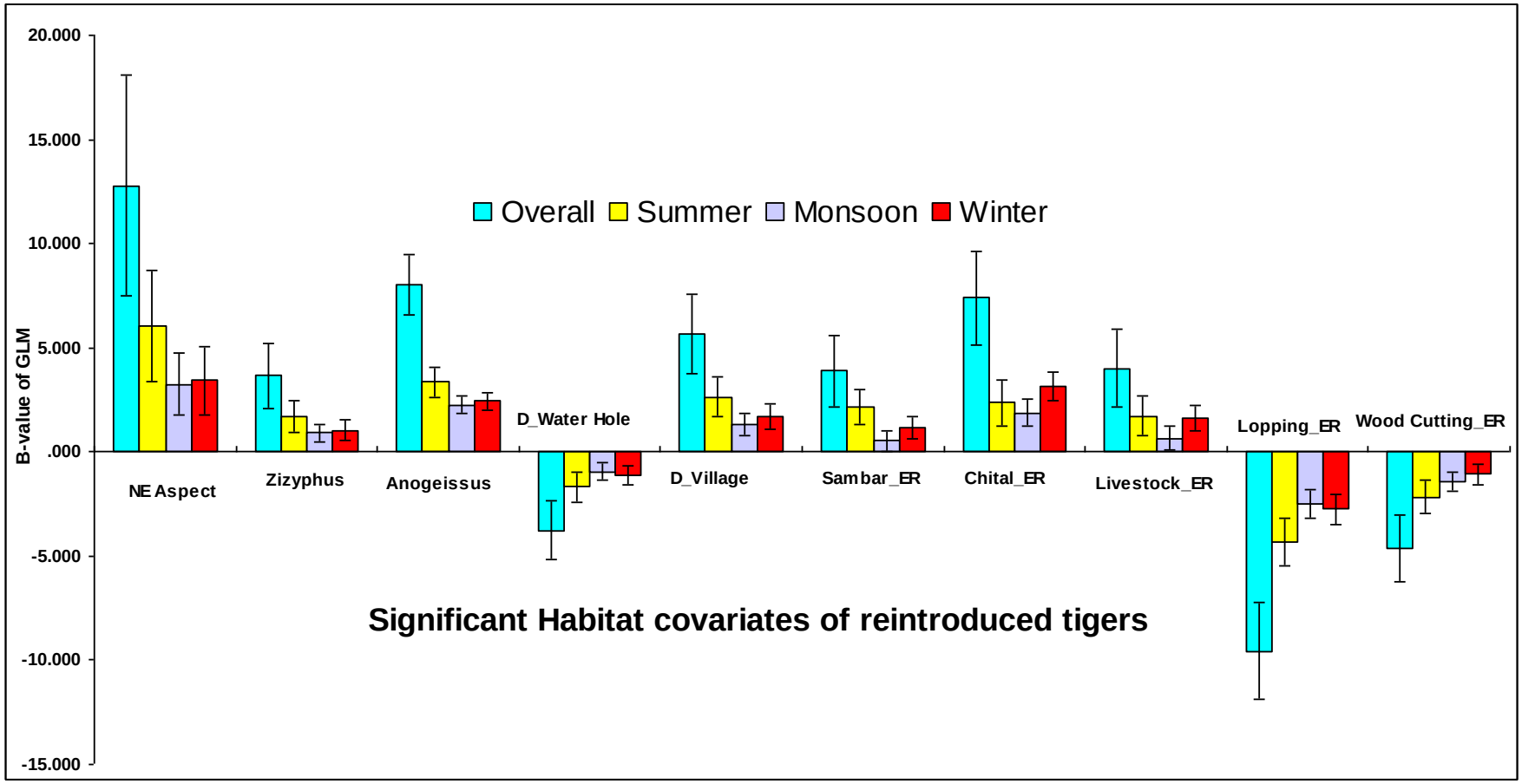
(NE – North East Aspect; Barr – Barren land; Agri – Agricultural land; Scrub – Scrubland; Rugg – Ruggedness; D_VILL – Distance to nearest village; D_ROAD – Distance to nearest major road; Ls_ER – Encounter rate of Livestock; Lop_ER - Encounter rate of Lopping; Wc_ER - Encounter rate of Wood cutting; Ziz – *Zizyphu*s forest; Riv – Riverine forest; But – *Butea* forest; Aca – *Acacia* forest; Anog – *Anogeissu*s forest; Bos – *Boswellia* forest; Elev_mean – Mean Elevation; Slope_mean – Mean of Slope; D_WH – Distance to nearest Waterhole; S_ER - Encounter rate of Sambar; Chi_ER - Encounter rate of Chital; Nil_ER - Encounter rate of Nilgai; Wpig_ER - Encounter rate of Wild pig).

Table 6.2. Model significance statistics of Generalized Linear Model (GLM) analysis for resource selection of reintroduced tigers (population level) in Sariska Tiger Reserve (2008-2012).

Resource Selection Parameters	All Seasons From 2008-2012				Summer (2008-2012)				Monsoon (2008-2012)				Winter (2008-2012)			
	ß	Std. Error	Hypothesis Test		ß	Std. Error	Hypothesis Test		ß	Std. Error	Hypothesis Test		ß	Std. Error	Hypothesis Test	
			Wald Chi-Square	Sig.			Wald Chi-Square	Sig.			Wald Chi-Square	Sig.			Wald Chi-Square	Sig.
(Intercept)	7.067	4.5944	2.366	.124	2.989	2.2766	1.724	.189	1.616	1.2953	1.557	.212	2.461	1.4441	2.903	.088
North East Aspect (NE)	15.113	5.3499	7.980	.005	6.900	2.6509	6.775	.009	3.836	1.5083	6.469	.011	4.376	1.6816	6.773	.009
***Zizyphus* (Ziz)**	5.251	1.5493	11.489	.001	2.273	.7677	8.768	.003	1.308	.4368	8.971	.003	1.670	.4870	11.758	.001
***Anogeissus* (Anog)**	7.310	1.6627	19.326	.000	2.928	.8239	12.630	.000	2.048	.4688	19.090	.000	2.333	.5226	19.932	.000
Chi_ER	3.698	1.8624	3.942	.047	3.244	1.1452	8.025	.005	2.062	.6516	10.014	.002	2.628	.7264	13.086	.000
Sambar_ER	5.735	1.6085	12.712	.000	-1.310	.9229	2.015	.156	-1.188	.5251	5.122	.024	-1.199	.5854	4.197	.040
Livestock_ER	4.787	2.0010	5.723	.017	-2.519	.7885	10.208	.001	-1.620	.4486	13.044	.000	-1.698	.5002	11.529	.001
Lopping_ER	-15.057	2.7582	29.801	.000	2.737	.7970	11.789	.001	.978	.4535	4.651	.031	2.020	.5056	15.965	.000
Wood cutting_ER	-5.838	1.5912	13.459	.000	2.030	.9915	4.192	.041	.940	.5642	2.777	.096	1.817	.6290	8.345	.004
D_WH	-3.809	1.4658	6.751	.009	-1.673	.7263	5.304	.021	-.901	.4133	4.753	.029	-1.235	.4608	7.184	.007
D_VILL	7.934	2.3111	11.785	.001	-6.170	1.3667	20.382	.000	-4.097	.7776	27.764	.000	-4.789	.8670	30.516	.000
(Scale)	389.382b	34.9676			95.606b	8.5857			30.951b	2.7795			38.471b	3.4548		

(NE – North East Aspect; *Zizyphus* – *Zizyphus* forest; *Anogeissus* – *Anogeissus* forest; Chi_ER - Encounter rate of Chital; Sambar_ER - Encounter rate of Sambar; Livestock_ER – Encounter rate of Livestock; Lopping_ER - Encounter rate of Lopping; Wood cutting_ER - Encounter rate of Wood cutting; D_WH – Distance to nearest Waterhole; D_VILL – Distance to nearest village)

Figure 6.3. Model significance statistics of Generalized Linear Model (GLM) analysis for resource selection of reintroduced tigers (population level – Level 1) in Sariska Tiger Reserve (2008-2012).



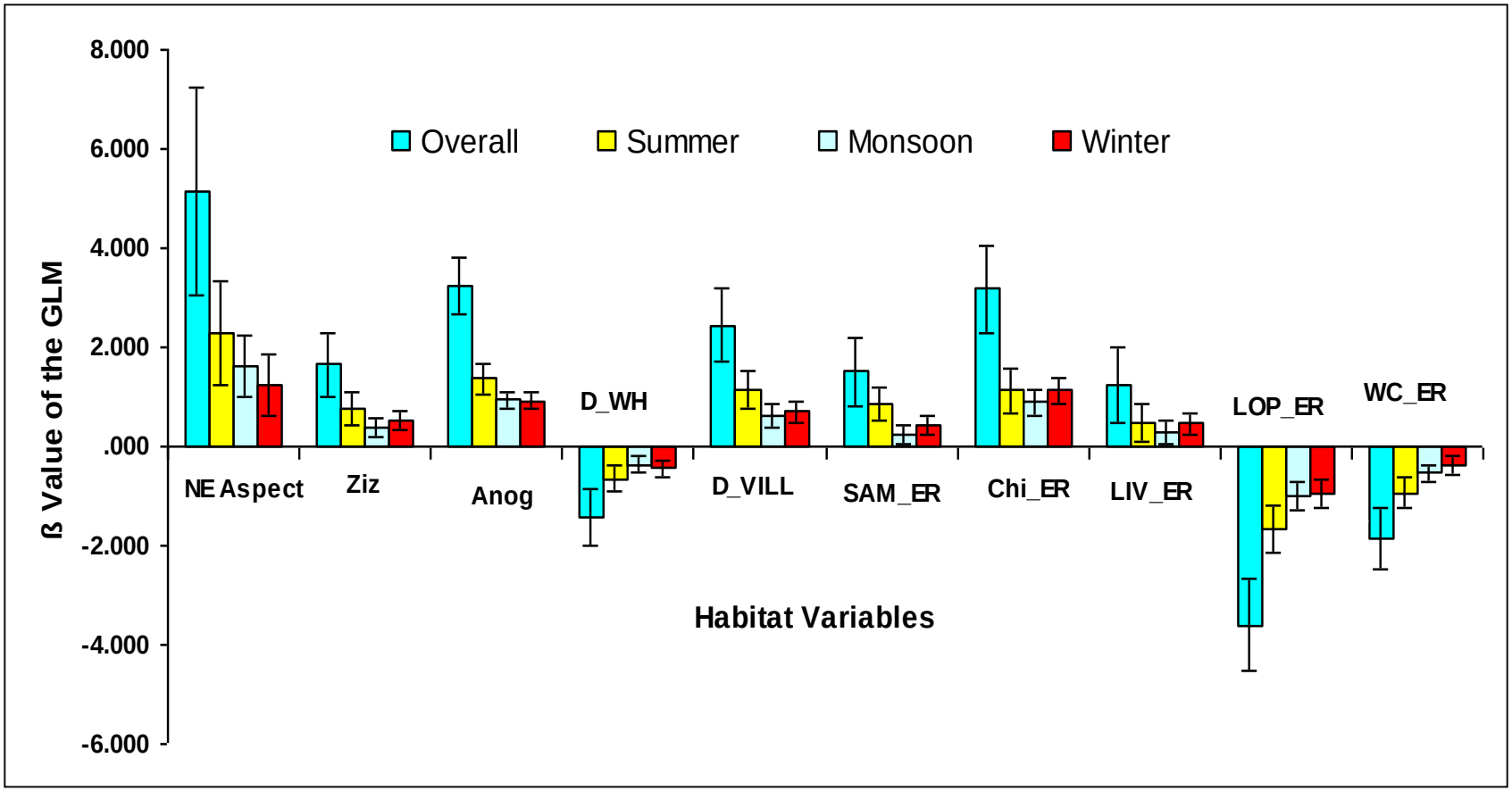
(NE – North East Aspect; Zizyphus – *Zizyphus* forest; Anogeissus – *Anogeissus* forest; D_WH – Distance to nearest Waterhole; D_VILL – Distance to nearest village; Sambar_ER - Encounter rate of Sambar; Chi_ER - Encounter rate of Chital; Livestock_ER – Encounter rate of Livestock; Lopping_ER - Encounter rate of Lopping; Wood cutting_ER - Encounter rate of Wood cutting).

Table 6.3. Model significance statistics of Generalized Linear Model (GLM) analysis for resource selection of the male reintroduced tigers (sex based level – Level 2) in Sariska Tiger Reserve (2008-2012).

Resource Selection Parameters	All Seasons From 2008-2012				Summer (2008-2012)				Monsoon (2008-2012)				Winter (2008-2012)			
			Hypothesis Test				Hypothesis Test				Hypothesis Test				Hypothesis Test	
	ß	Std. Error	Wald Chi-Square	Sig.	ß	Std. Error	Wald Chi-Square	Sig.	ß	Std. Error	Wald Chi-Square	Sig.	ß	Std. Error	Wald Chi-Square	Sig.
(Intercept)	3.241	1.8028	3.232	0.072	1.585	0.9047	3.069	0.08	0.505	0.5265	0.919	0.338	1.151	0.5311	4.7	0.03
(NE)	5.139	2.1134	5.912	0.015	2.278	1.0606	4.612	0.032	1.613	0.6172	6.827	0.009	1.248	0.6226	4.018	0.045
(Ziz)	1.647	0.6277	6.888	0.009	0.757	0.315	5.78	0.016	0.38	0.1833	4.293	0.038	0.51	0.1849	7.611	0.006
(Anog)	3.229	0.5754	31.495	0	1.359	0.2888	22.153	0	0.948	0.1681	31.789	0	0.923	0.1695	29.619	0
D_WH	-1.44	0.5628	6.545	0.011	-0.645	0.2824	5.219	0.022	-0.363	0.1644	4.887	0.027	-0.431	0.1658	6.763	0.009
D_VILL	2.447	0.7561	10.472	0.001	1.126	0.3795	8.809	0.003	0.624	0.2208	7.986	0.005	0.697	0.2228	9.777	0.002
S_ER	1.518	0.6849	4.909	0.027	0.848	0.3437	6.084	0.014	0.249	0.2	1.547	0.214	0.421	0.2018	4.351	0.037
Chi_ER	3.167	0.8831	12.86	0	1.127	0.4432	6.472	0.011	0.898	0.2579	12.125	0	1.141	0.2602	19.247	0
Liv_ER	1.241	0.7541	2.709	0.1	0.495	0.3784	1.708	0.191	0.29	0.2202	1.733	0.188	0.457	0.2222	4.226	0.04
Lop_ER	-3.598	0.9273	15.05	0	-1.663	0.4654	12.772	0	-0.993	0.2708	13.433	0	-0.942	0.2732	11.882	0.001
WC_ER	-1.86	0.6385	8.482	0.004	-0.937	0.3204	8.543	0.003	-0.545	0.1865	8.533	0.003	-0.378	0.1881	4.044	0.044
(Scale)	60.013b	5.3893			15.114b	1.3573			5.119b	0.4597			5.209b	0.4678		

(NE – North East Aspect; Ziz – *Zizyphu*s forest; Anog – *Anogeissus* forest; D_WH – Distance to nearest Waterhole; D_VILL – Distance to nearest village; S_ER - Encounter rate of Sambar; Chi_ER - Encounter rate of Chital; Liv_ER – Encounter rate of Livestock; Lop_ER - Encounter rate of Lopping; WC_ER - Encounter rate of Wood cutting)

Figure 6.4. Model significance statistics of Generalized Linear Model (GLM) analysis for resource selection of the male reintroduced tigers (sex based level – Level 2) in Sariska Tiger Reserve (2008-2012).



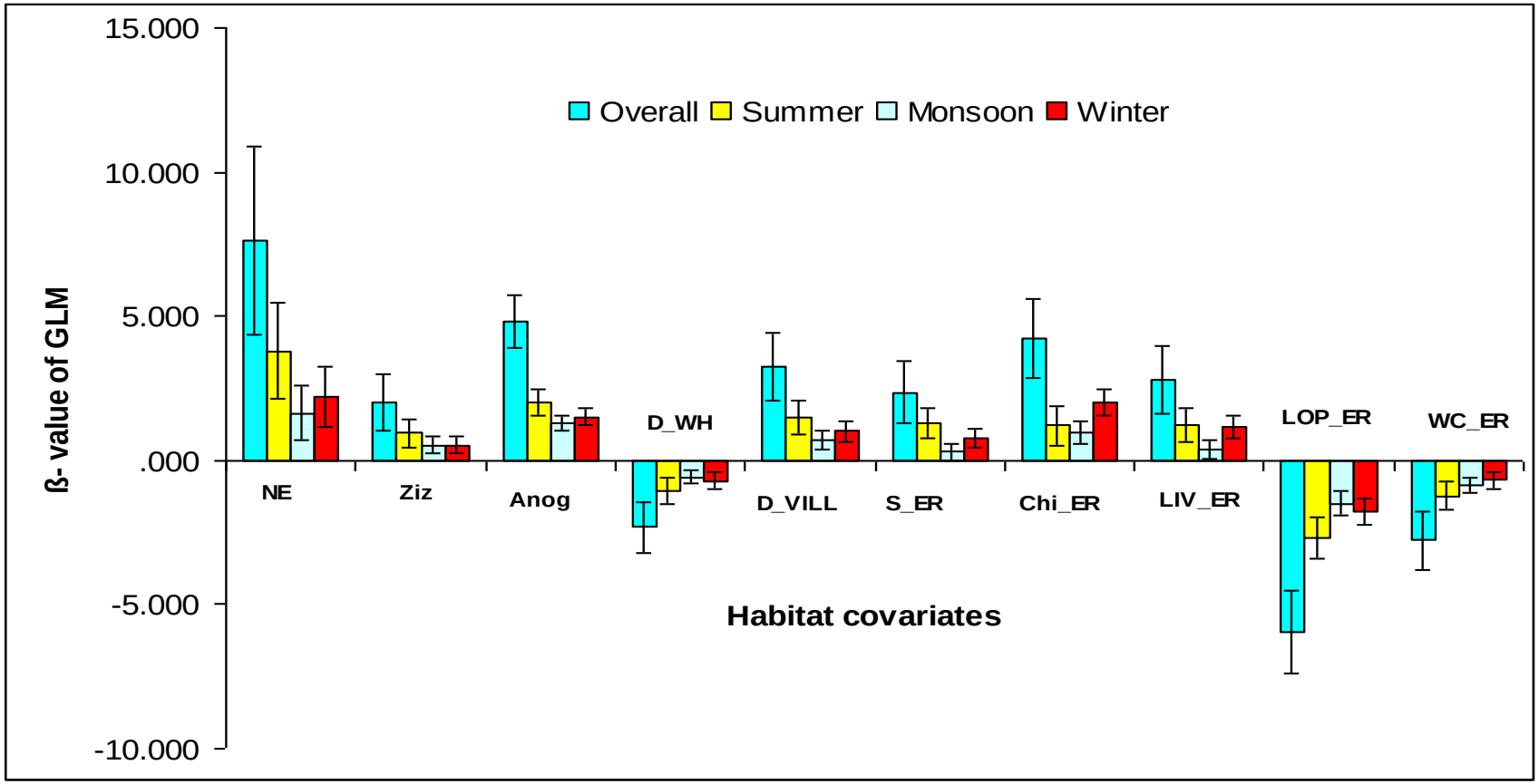
(NE – North East Aspect; Ziz – *Zizyphus* forest; Anog – *Anogeissus* forest; D_WH – Distance to nearest Waterhole; D_VILL – Distance to nearest village; S_ER - Encounter rate of Sambar; Chi_ER - Encounter rate of Chital; Liv_ER – Encounter rate of Livestock; Lop_ER - Encounter rate of Lopping; WC_ER - Encounter rate of Wood cutting).

Table 6.4. Model significance statistics of Generalized Linear Model (GLM) analysis for resource selection of the female reintroduced tigers (sex based level – Level 2) in Sariska Tiger Reserve (2008-2012).

Resource Selection Parameters	All Seasons From 2008-2012				Summer (2008-2012)				Monsoon (2008-2012)				Winter (2008-2012)			
			Hypothesis Test								Hypothesis Test				Hypothesis Test	
	ß	Std. Error	Wald Chi-Square	Sig.	ß	Std. Error	Wald Chi-Square	Sig.	ß	Std. Error	Wald Chi-Square	Sig.	ß	Std. Error	Wald Chi-Square	Sig.
(Intercept)	4.442	2.8342	2.456	.117	1.660	1.4090	1.389	.239	1.918	.9345	2.558	.110	1.498	.9233	2.632	.105
NE	7.631	3.2848	7.217	.007	4.183	1.6406	6.500	.011	.719	.2706	4.215	.040	2.764	1.0751	6.611	.010
Ziz	2.001	.9756	8.860	.003	1.214	.4751	6.529	.011	-.127	.2729	7.064	.008	.911	.3113	8.571	.003
Anog	4.821	.8944	19.986	.000	1.841	.5099	13.032	.000	1.233	.2904	18.035	.000	1.511	.3341	20.457	.000
D_WH	-2.322	.8747	6.579	.010	-1.010	.4495	5.053	.025	-.534	.2560	4.348	.037	-.775	.2946	6.922	.009
D_VILL	3.246	1.1752	11.289	.001	1.955	.7088	7.612	.006	1.200	.4037	8.837	.003	1.635	.4644	12.389	.000
S_ER	2.359	1.0645	3.870	.049	-.800	.5711	1.964	.161	-.732	.3253	5.058	.025	-.728	.3743	3.782	.052
Chi_ER	4.218	1.3725	11.630	.001	1.586	.4933	10.338	.001	.502	.2810	3.190	.074	1.296	.3232	16.076	.000
LIV_ER	2.774	1.1721	6.918	.009	1.423	.6137	5.380	.020	.551	.3495	2.487	.115	1.272	.4021	10.008	.002
LOP_ER	-5.958	1.4413	29.535	.000	-3.731	.8458	19.453	.000	-2.434	.4818	25.525	.000	-3.082	.5543	30.921	.000
WC_ER	-2.786	.9924	11.955	.001	-1.365	.4880	7.820	.005	-.929	.2780	11.168	.001	-1.100	.3198	11.843	.001
(Scale)	148.175b	13.3065			36.620b	3.2886			11.881b	1.0669			15.724b	1.4121		

(NE – North East Aspect; Ziz – *Zizyphus* forest; Anog – *Anogeissus* forest; D_WH – Distance to nearest Waterhole; D_VILL – Distance to nearest village; S_ER - Encounter rate of Sambar; Chi_ER - Encounter rate of Chital; Liv_ER – Encounter rate of Livestock; Lop_ER - Encounter rate of Lopping; WC_ER - Encounter rate of Wood cutting).

Figure 6.5. Model significance statistics of Generalized Linear Model (GLM) analysis for resource selection of the female reintroduced tigers (sex based level – Level 2) in Sariska Tiger Reserve (2008-2012).



(NE – North East Aspect; Ziz – *Zizyphus* forest; Anog – *Anogeissus* forest; D_WH – Distance to nearest Waterhole; D_VILL – Distance to nearest village; S_ER - Encounter rate of Sambar; Chi_ER - Encounter rate of Chital; Liv_ER – Encounter rate of Livestock; Lop_ER - Encounter rate of Lopping; WC_ER - Encounter rate of Wood cutting).

6.5. DISCUSSION

The analysis of habitat utilization and resource selection patterns is not straightforward, owing to the problem of sampling level, unit-sum constraint, differential use and definition of availability (Aebischer *et al*., 1993; Larson *et al*., 2004). In the present study, habitat use and resource selection of reintroduced tigers were estimated by its trajectory, sub-sampled by radio locations. Although the number of locations per animal determines the accuracy with which its habitat use was estimated, it was the number of animal monitored that determined the sample size upon which to base and test hypotheses concerning habitat use by population. Since the present study is based on a species recovery plan and scientific protocol of reintroduction and the subsequent monitoring, it was not in my jurisdiction to estimate the required sample size. Though in many areas, tigers were radio-collared and studied in forested areas, not much literature is available on detailed habitat utilization and resource selection patterns of those radio-collared tigers. Hence, the present study documented for the first time detailed habitat utilization and resource selection patterns of reintroduced tigers, which successfully established their home ranges in forested areas.

Though the home ranges of all reintroduced tigers were inside Sariska Tiger Reserve boundary, but sometimes tigers were found to traverse even outside Sariska Tiger Reserve. During the study period, in all seasons (monsoon, winter and summer) tigers (both males and females) significantly ($P<0.001$) selected the north-east aspect. In the semi-arid regions, the eastern and western slopes get equal sunlight but the afternoon sun in the western side makes it much warmer than the eastern one. Similarly during the summer in India, sun's movement towards west from east happens through southern region making the northern aspect much cooler. Therefore, north-east aspect being one of the cooler aspects (Yadav and Gupta, 2006) positively favored the utilization distribution (UD) of the reintroduced tigers as tigers being an obligate carnivore favors cooler areas than warmer ones.

Similarly during the study period across all the seasons, *Zizyphus* and *Anogeissus* forests positively correlated with the utilization distribution (UD) of the reintroduced tigers in Sariska Tiger Reserve. In Sariska, distribution of *Zizyphus* and *Anogeissus* forests are found all along the valley areas and terrain with gentle to steep slopes. The areas of *Zizyphus* forest and *Anogeissus* forests are found 13.8% and 42.7% respectively in the total available habitat within the home ranges of all the tigers, but both the forest types were used more than their availabilities, thereby

influenced most in the resource selection of reintroduced tigers in the study area. Ecologically, the *Zizyphus* forest always plays a key role in the ecosystem of a tropical dry deciduous forest. The *Zizyphus* patches allow a number of palatable grasses to grow under it, such as *Chloris dolichostachya, Heteropogon contortus* and *Cynodon dactylon*. These grass species along with fallen *Zizyphus mauritiana* leaves and fruits which contain high protein (Sankar, 1994), influenced assemblage of a number of prey species of tiger (ungulates and primates) in the study area. Similarly *Anogeissus pendula* forest along with palatable shrub species such as *Grewia flavescence* and *Capparis sepiaria* provided suitable habitat for sambar. Hence, tigers utilized this forest type significantly and this forest type positively influenced the utilization distribution (UD) of the reintroduced tigers.

The Euclidean distance of the tigers to the nearest waterhole negatively affected the tigers' UD which meant that more was the distance from any waterhole less was the UD by the tigers. Therefore, it can be concluded that tigers preferred to stay near waterholes. It was found that 32 prominent waterholes are located adjacent to the State High-way in prime habitat of notified National Park area of Sariska. Since, the tigers had preference close to water locations, the vehicular traffic (>20 vehicles/ hour – Forest Department data) in the State Highway needs to be regulated to avoid any further conflict issue with the tigers as well as other wild prey species.

The Euclidean distance of the tigers to the nearest village showed positive control on the UD of the tigers. This signified that tigers avoided the village and human-habitation areas and kept an average distance of more than two kilometer during the study period. No incidence of tiger venturing into the villages and attacking livestock or human was reported during the study period.

Amongst the prey species of tiger, abundance (encounter rates) of sambar, chital and domestic livestock positively influenced the resource selection of all the tigers including male and female individuals. Sambar and chital both being the preferred prey species of tigers found in high abundance in *Zizyphus* and *Anogeissus* forests in the prime habitats of Sariska Tiger Reserve. Therefore, both of them positively affected the UD of the tigers in Sariska. Since there are 29 villages present in the Tiger Reserve and eight in the notified National Park area, huge populations of domestic livestock exist in there and their density was estimated as 30 – 70 individuals/km^2 during 2008 to 2012. The predation of domestic livestock by tigers was also high (>20%). The livestock used to graze freely in the forested habitat without any guidance

from their owners and go back to the village by themselves. But in the forest, they seemed to be another prey species for tigers like wild ungulates. In retaliation to such predation, the first reintroduced male tiger (ST1) was found dead during November 2010 due to poisoning on a buffalo carcass inside the Tiger Reserve area. Therefore, relocation process of the existing villages and the restricted and supervised grazing practice along with proper timely compensation schemes were highly recommended to reduce further such retaliatory conflict issues.

Anthropogenic disturbance activities such as lopping and wood cutting showed a significant negative relation with the UD of the reintroduced tigers. There are eight villages yet to be relocated from the prime habitat of the notified National Park area of Sariska. Till these villages are relocated, the anthropogenic activities such as wood cutting, lopping and grazing should be restricted for future survival of tigers in Sariska. Once these villages are relocated, an inviolate area of around 300 km^2 will be available for the wild prey species and tigers. According to Sankar *et al*., (2005) this inviolate area along with the high wild prey base of Sariska can therefore support a population of 15-20 adult tigers which can further play the role as a sink population to supplement tiger reintroduction programme in other parts of the state and country.

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Research Article

Monitoring of reintroduced tigers in Sariska Tiger Reserve, Western India: preliminary findings on home range, prey selection and food habits

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Abstract

Home range and food habits of tigers (*Panthera tigris tigris*) were studied in Sariska Tiger Reserve from July 2008 to June 2009. Three tigers (one male and two females) were radio-collared and reintroduced in Sariska Tiger Reserve from Ranthambhore Tiger Reserve, Western India during 2008-2009. The reintroduced tigers were monitored periodically through ground tracking using "triangulation and homing in techniques." The estimated annual home ranges were 168.6 km^2 and 181.4 km^2 for tiger and tigress-1 respectively. The estimated summer home range of tigress-2 was 223.4 km^2. In total, 115 kills and 103 scats of tigers were collected to study the food habits. The line transect method was used to estimate the prey availability. The density of peafowl (*Pavo cristatus*) was found to be highest (125.2 ± 15.3/ km^2) in Sariska followed by livestock (*Bubalis bubalis* and *Bos indicus*) (59.9 ± 22.3/ km^2), chital (*Axis axis*) (46.7 ± 9.5/ km^2), sambar (*Rusa unicolor*) (26.2 ± 4.9/ km^2), common langur (*Semnopithecus entellus*) (22.8 ± 6.5/ km^2), nilgai (*Boselaphus tragocamelus*) (19.5 ± 3.3/ km^2) and wild pig (*Sus scrofa*) (15.4 ± 4.4/ km^2). Tigers fed on seven prey species as shown by kill data. Tigers' scat analysis revealed the presence of five prey species. Prey selection by tigers based on scat analysis was in the following order: sambar> chital> nilgai> livestock> common langur. It is proposed to restock the tiger population initially with five tigers in Sariska and subsequent supplementation of two tigers every three years for a period of six years, which will allow the population to achieve demographic viability. Removal of anthropogenic pressure from the national park will be crucial for the long term survival of tigers in Sariska.

Keywords Food habits, home range, reintroduction, Sariska, tiger.

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Introduction

Reintroductions have proved to be a valuable tool for the recovery of species that have become either globally or locally extinct in the wild [1]. Reintroducing species to parts of their former range where they have become locally exterminated is one of the last measures that can be employed to conserve the threatened species in the concerned habitat. Reintroductions can also give us an insight into the reasons for disappearance of a species from the areas where they formerly occurred. Therefore, it is required to be genuinely experimental and properly monitored [2]. Reintroduction of large predators had a poor success rate in the past [3-5] and the overall conservation benefits in the long term are questionable [6-7]. Since the reintroduction programs are expensive and time-consuming, and corresponding success rates are low, it is difficult to justify spending precious conservation money in these activities as against other *in situ* conservation measures [8]. Therefore it becomes highly imperative that reintroductions should be based on sound scientific principles and methodology so that the success rates will be high and the efforts fruitful enough. The reintroduction and recovery of the Florida Panther (*Puma concolor coryi*) in Florida, USA, during 1981 and reintroduction of the African wild dog (*Lycaon pictus*) in Africa in the 1990s are two such instances, among others, that have enriched our knowledge about the science and management of carnivore reintroductions. It was reported [5] that there is a dearth of published studies documenting the reintroduction of large predators in Africa. In a series of 30 events of large carnivore reintroduction reported from Africa, the final outcome was known only from nine which were considered successful [7]. However, translocation events of large carnivores are a common practice in Africa [9-11] although seldom published in literature. In most of the projects, post-release monitoring rarely occurred and the results of the rest did not suggest a high success rate, with the causes of failures poorly analyzed [12].

A few incidents of translocation of wild tigers have been reported from the Indian subcontinent and the Russian Far East [13-15]. In such events the conflict tigers were captured and released in the wild and the post-release monitoring or rather fate of the translocated animals was reported only in two cases [14-15]. After the extermination of tigers (*Panthera tigris tigris*) in Sariska Tiger Reserve (Sariska), western India in 2004 due to poaching, reintroduction of tigers from Ranthambhore Tiger Reserve (Ranthambhore) was envisaged by translocating an initial population of five tigers (two males and three females), with a supplementation of two tigers (male and female) in every three years for a period of six years [16]. The simulations showed the probability of tiger survival as 0.9620 (0.0086 SE). The disappearance of tigers in Sariska during 2004 illustrates the threat that exists to isolated tiger populations in many parts of the country. Based on the past trends and experiences, it is presumed that such losses and local extinctions in future will be more frequent and there is a need to undertake immediate reintroduction and species recovery programs to save the large cat in the wild. It is perhaps not an isolated situation, and the recent national scale assessment reported that tigers had gone locally extinct from 97 districts in India in the last 150 years [17]. Thus a study was envisaged to reintroduce tigers in Sariska in a phased manner, and home range, prey selection, and food habits of the reintroduced tigers were studied from July 2008 to June 2009.

Methods

Study Area

The Sariska Tiger Reserve (76°17' E to 76°34'E and 27°5 to 27° 33 N) is situated in the Aravalli Hill Range and lies in the semi-arid part of Rajasthan [3]. The total area of the Tiger Reserve is 881 km^2, with 274 km^2 as notified national park. The terrain is undulating to hilly in nature and has numerous narrow valleys, two large plateaus (Kiraska and Kankwari), and two large lakes (Mansarovar and Somasagar). The altitude of Sariska ranges from 540 to 777 m. There are two state highways: the

Alwar-Thanagazhi-Jaipur and the Sariska-Kalighati-Tehla, which are over 44 km in length and traverse the heart of the notified national park. The vegetation of Sariska corresponds to northern tropical dry deciduous forests and northern tropical thorn forest [18]. Apart from reintroduced tigers, other carnivores present are leopard *(Panthera pardus),* striped hyena *(Hyaena hyaena)*, jackal *(Canis aureus)*, jungle cat (*Felis chaus*), common mongoose *(Herpestes edwardsi*), small Indian mongoose (*H. auropunctatus*), ruddy mongoose (*H. smithi*) palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), and ratel (*Mellivora camensis*). Chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), and wild pig (*Sus scrofa*) are the wild ungulates found in Sariska. Other wild prey species found are common langur (*Semnopithecus entellus*), rhesus macaque (*Macaca mulatta*), porcupine (*Hystrix indica*), rufous tailed hare (*Lepus nigricollis ruficaudatus*), and Indian peafowl (*Pavo cristatus*) [19].

Thirty-two villages are located inside the Tiger Reserve, of which 10 are in the notified national park and have been due for relocation since 1984. One village, Bhagani, was relocated during November 2007 from the notified National Park. The majority of the population (87%) inhabiting the villages in Sariska belongs to the *Gujjar* community who are traditionally pastoralists and practice animal husbandry. The estimated livestock population for the entire tiger reserve was 19,132 individuals with 12,098 goats, 5,079 buffaloes, 1,528 cattle and 1,528 sheep [16].

The capture and translocation of tigers

Five adult tigers (3 females and 2 males) were chemically immobilized and radio-collared (VHF-Argos-Satellite) in Ranthambhore from June 23 to July 4, 2008. A mixture of Xylazine and Ketamine (500 mg + 400 mg, HBM) was used as 2.5 ml for females and 3.2-3.5 ml for males. A 250 kg container (length 5' 11", breadth 3' 6.5" and height 3' 10") was fabricated with non-slip wooden planks on the bottom and angle iron frames on sides and top for the transport of the animals. Two small windows were kept on the top of the container and also on two sides of the container for monitoring the animal during transportation and injection of medicaments if needed. Ventilation holes of 25 mm were created at regular intervals all over the container for proper ventilation. Care was taken to keep the container dark from inside so that the animal would remain calm during the transport. A small truck was used to transport the tiger in its container from the site of immobilization to the helipad inside Ranthambhore. An Indian Air Force helicopter (MI-17) was used to transport the tiger from Ranthambhore to Sariska (see photos in section on Implications for conservation).

Among the five tigers immobilized and radio-collared, one adult male and one adult female were selected to be shifted to Sariska. The selected candidates were chemically immobilized in Ranthambhore on June 28 and July 4, 2008, respectively. The captured tigers were kept under sedated condition in a container, and transported to Sariska by helicopter. The air journey from Ranthambhore to Sariska took 45 minutes for both the animals. In Sariska the tiger and tigress were released into a 1 ha enclosure on June 28 and July 4, 2008 respectively. A visual barrier of 2.5 m height was fixed along the enclosure to minimize any stress to the tigers due to movement of people around the enclosure. The tiger was released into the wild after eight days of observation, on July 6, 2008, and the tigress was released into the wild on July 8, 2008, after three days of observation. Thereafter on Feb. 25, 2009, another tigress was chemically immobilized and fitted with VHF radio-collar in Ranthambhore. She was then airlifted and brought to Sariska by Indian Air force MI-17 helicopter following the precautionary protocols as taken for the first two individuals. After arriving at Sariska she was kept inside the 1 ha enclosure for two days. On Feb. 27, this tigress was released into the wild.

Home range of the re-introduced tigers

The radio-collared tigers were monitored periodically through ground tracking using "homing in" and "triangulation" techniques [20-22]. The satellite data up-linking in both the radio-collars stopped functioning by mid-September, 2008. Thereafter the tigers were tracked only by VHF signals (ground tracking). The Minimum Convex Polygon (MCP) technique was used for home-range calculation [23-25]. The interpretation and comparison of home-range size was also measured by 100% MCP. The use of MCPs was justified because of the sample size in the one-year study period and the temporally clustered nature of fixes that resulted in autocorrelation of results [26]. Accurate analyses using Kernel methods would not be suitable within this data set because it generally requires larger samples with a more even distribution of the locations to maintain accuracy [27]. At the same time the MCP technique is one of the oldest techniques for home-range estimation, comparable between species globally, and its inclusion as one or more methods of range calculation is therefore valuable.

Estimation of prey abundance

Prey species abundance in the study area was estimated by the line transect method under the distance sampling technique [28]. This method has been widely applied to estimate densities of prey species in different forests of the Indian subcontinent [29-34]. In total, 32 line transects varying in length from 1.6 km to 2 km were laid covering 160 km^2 area in tiger- occupied landscapes. The total transects length of 60.4 km were walked three times in early morning resulting in a total effort of 181.2 km. On each sighting of potential prey species on line transects, the total number of individuals, animal bearing, and angular sighting distance were recorded. Program DISTANCE 5 [35] was used to estimate the density of prey species. Prey biomass availability was estimated by multiplying densities of each prey species with their respective body weights [31-33].

Food habits

Diet and food preferences of tigers can be estimated from scat analysis as well as from kills [36-37, 32-34]. Tiger scats were collected whenever encountered during the study period. All the scats were washed, oven-dried and subsequently preserved for future analysis. Micro-histological structures of hairs were used to identify the prey species [32-34, 37, 38-41]. Tiger kills were recorded whenever encountered. The biomass and number of individuals of the prey consumed by tigers was estimated using Ackerman's equation [42] to get a more accurate estimate of prey consumption [31-34]. The assumption for extrapolating of the above equation was that the tigers and cougars (*Felis concolor concolor*) had similar utilization and digestibility [31]. It was also presumed that the scats containing various prey items had similar decay rates and that their detection was equally probable and subject to the same formula as mentioned above [42] to estimate the prey consumption by tigers. Prey selectivity by tigers was estimated for each prey species by comparing their availability and utilization data. The expected proportion of scats in the environment (i.e. availability) was calculated using the following equation [30]: $fi = [(di /dt) * \lambda i]/ \Sigma [(di/dt) * \lambda i]$, where fi= expected scat proportion in the environment, di= density of i^{th} species, dt = sum of density of all species, $\lambda i = X/Y$ = the average number of collectible scats produced by leopards from an individual of i^{th} prey species, X = average body weight of the species, and $Y = 1.980 + 0.035 X$ [42]. Percentage biomass consumption and percentage individual consumption were also estimated using the parameters of percentage occurrence of the prey species in the scats, Ackerman's correction factor, and average body weight of the prey species. The prey selection was also determined by using Ivelev's index [43], $E = (u – a) / (u + a)$, where, 'u' was observed relative frequency occurrence of prey items in predator scats and 'a' was expected scat proportion in the environment.

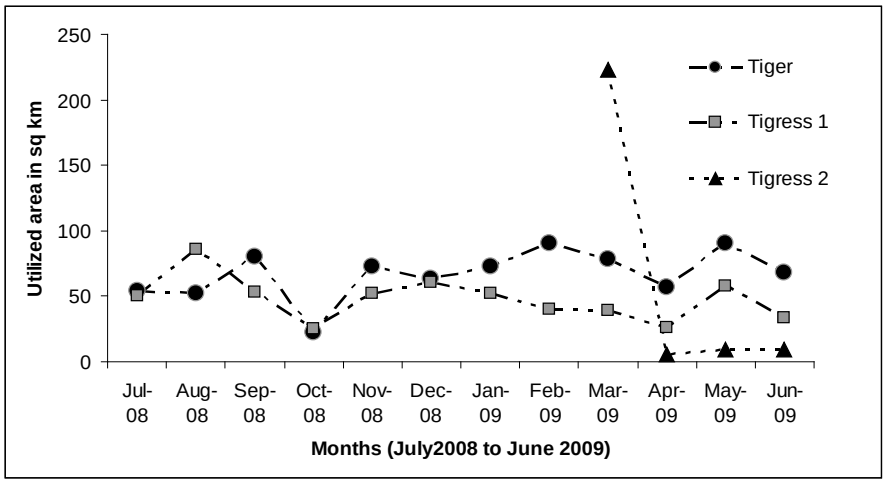

Fig. 1. Month-wise area of utilization of reintroduced tigers in Sariska Tiger Reserve (July 2008 to June 2009). Tigress-2 was reintroduced in March 2009. The tiger utilized a larger area all through the year. Tigress-1 and Tigress-2 utilized large areas soon after reintroduction, but subsequently their home ranges stabilized.

Results

Home range of tigers

It was observed that the tiger and tigress moved in two different directions (tiger toward the south and the tigress toward the north) soon after release into wild. They occupied different areas and did not meet each other till September 2008. In total, 437 locations for tiger, 463 locations for tigress-1, and 229 locations for tigress-2 were obtained using a hand-held Global Positioning System (GPS) (July 2008 to June 2009). These positions were later transferred into the Sariska beat map required for home-range estimation. The utilized areas (in km^2) by the reintroduced tigers month-wise is given in Fig. 1. It was found that all three individuals initially explored large areas soon after their release into the wild, followed by settling down in smaller areas after 2 to 3 months. The monsoon (July 2008 to October 2008) home ranges of the tiger and the tigress-1 were 133.8 km^2 and 151.3 km^2, respectively, and the home-range overlap was 59.4 km^2 (Fig. 2). In winter (November 2008 to February 2009), the home ranges of the tiger and tigress-1 were estimated to be 107.1 km^2 and 81.4 km^2, respectively, with an overlapped home range of 79.9 km^2 (Fig. 3). After having surveyed the new areas in monsoon, the tiger and tigress were settled in the best available habitats in winter with adequate prey base, water availability, and less anthropogenic pressure. The high home-range overlap (79.9 km^2) in winter between the tiger and tigress-1 may be attributed to their pairing and courtship observed periodically. The estimated home ranges in summer (March 2009 to June 2009) of the three tigers were 101.3 km^2 (tiger), 67.2 km^2 (tigress-1), and 223.4 km^2 (tigress-2) (Fig. 4). The largest home range of tigress-2 (223.4 km^2) was attributed to exploration of areas soon after her release into the wild. The home-range overlap between the tiger and tigress-1 in summer was estimated as 67.1 km^2, whereas the overlap between the tiger and tigress-2 was 83.6 km^2. Similarly, the estimated overlapped area between tigress-1 and tigress-2 was 54 km^2. During the first week of April 2009 the tiger located tigress-2 for the first time since its reintroduction and mated with her. The estimated annual home ranges (from July 2008 to June 2009) were 168.6 km^2 and 181.4 km^2 for tiger and tigress-1, respectively, with an overlapped area of 99.04 km^2 (Fig. 5).

Fig. 2

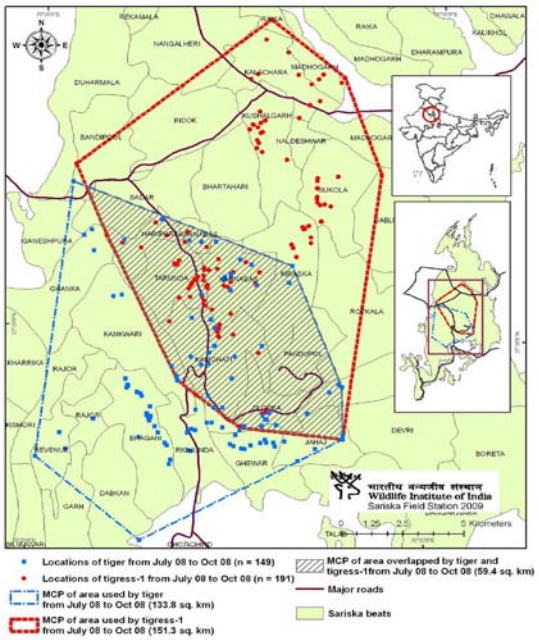

Fig. 3

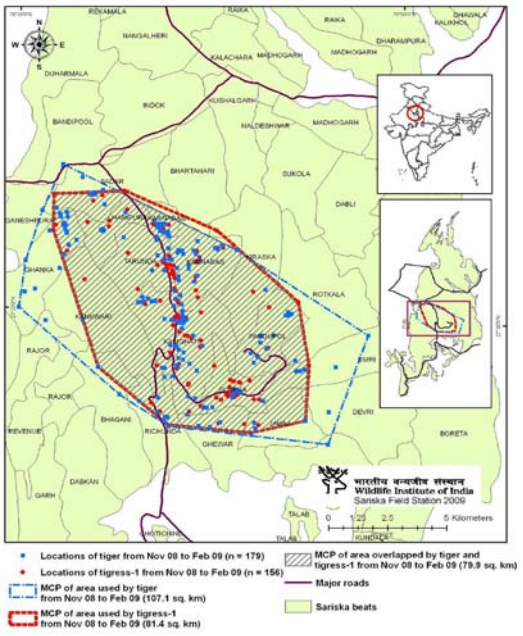

Fig. 4

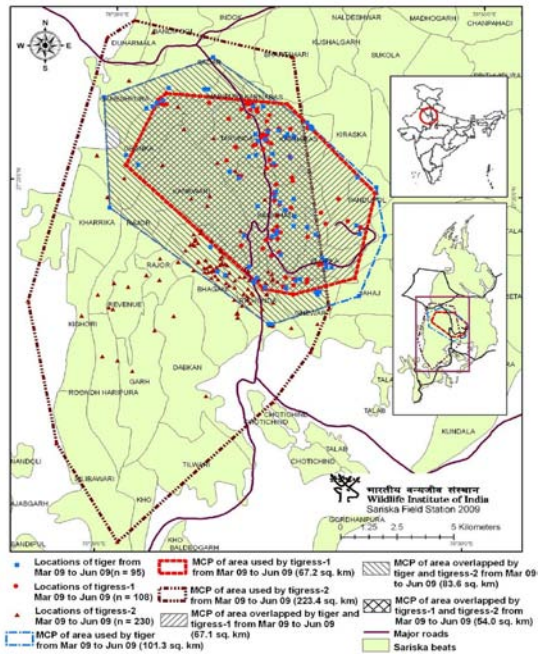

Fig. 5

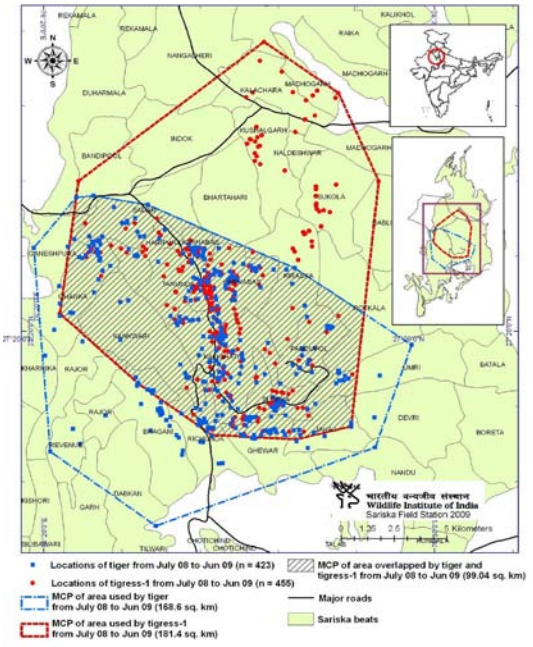

Fig. 2. Monsoon (July 2008 to October 2008) home range of reintroduced tigers in Sariska Tiger Reserve with shaded part showing the overlapped area between the tiger and tigress-1. New habitats were explored by them during monsoon. Fig. 3. Winter (November 2008 to February 2009) home range of reintroduced tigers in Sariska Tiger Reserve. The complete overlap of tigress-1 home range by the tiger was due to pairing and courtship during winter. Fig. 4. Summer (March 2009 to June 2009) home range of reintroduced tigers in Sariska Tiger Reserve. Tigress-2 explored new areas during this period and hence had a larger home range as compared to the other tigers. Fig. 5. Annual home range of reintroduced tigers in Sariska Tiger Reserve (July 2008 to June 2009) with shaded part showing the overlapped area between the tiger and tigress-1.

Prey abundance

The individual prey densities and mean group size were estimated for all prey species (Appendix 1). The half-normal key function with cosine adjustment was the best-fitted model for density estimation of all prey species. This was selected on the basis of the lowest Akaike Information Criteria (AIC) [28, 45]. The study area was found to harbor a high ungulate density of 107.8 animals/ km^2. The total prey density excluding peafowl was estimated to be 190.5 animals/ km^2. The density of peafowl was found to be the highest among all the prey species (125.2 ± 15.3/ km^2) followed by livestock (buffalo and brahminy cattle) (59.9 ± 22.3/ km^2), chital (46.7 ± 9.5/ km^2), sambar (26.2 ± 4.9/ km^2), common langur (22.8 ± 6.5/ km^2), nilgai (19.5 ± 3.3/ km^2), and wild pig (15.4 ± 4.4/ km^2) (Appendix 1). The total ungulate biomass was estimated to be 10072.8 kg/ km^2. The estimated total biomass of all the potential prey species, including livestock and peafowl was 21618.1 kg/ km^2 (Appendix 1).

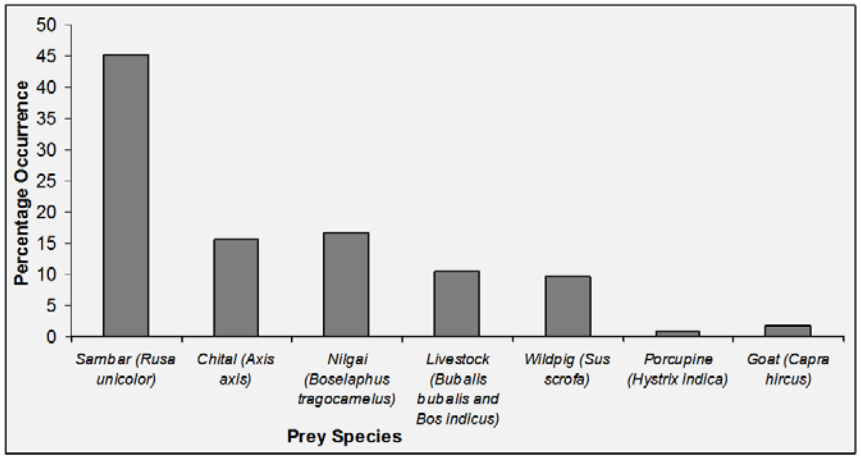

Fig. 6. Percentage occurrence of prey species in tiger diet based on kill data in Sariska Tiger Reserve (n=115)

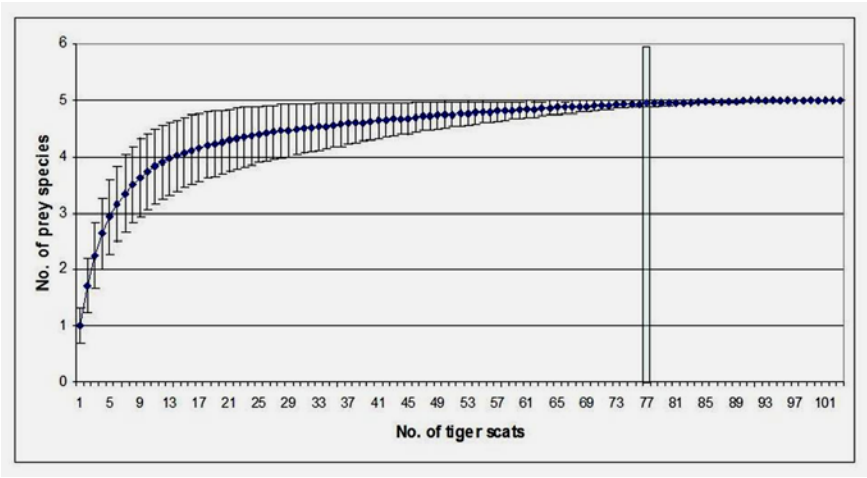

Fig. 7. Scat sample stabilization curve for the reintroduced tigers in Sariska Tiger Reserve.

Food Habits

In total, 115 kills of tigers were recorded. Sambar was found to be the most consumed prey species (45.2%) followed by nilgai (16.5%), chital (15.7%), livestock (buffalo and cattle) (10.4%), wild pig (9.6%), goat (1.7%), and porcupine (0.9%) (Fig. 6). A total of 103 scats of tigers were collected and analyzed during the study period. Presence of five prey species was revealed through the scat analysis. Analysis of 75 to 80 tiger scats was found adequate to stabilize the dietary spectrum of the reintroduced tigers

in Sariska [EstimateS, 46] (Fig. 7). Scat analysis also revealed that sambar (41.7%) remained as the major prey species for tigers followed by chital (26.3%), livestock (buffalo and cattle) (19.4%), nilgai (10.7%), and common langur (1.9%) (Appendix 2). Although wild pig, porcupine and goat kills by tigers were recorded in the study area, no remains of these species were found in tiger scats. The peafowl density was found to be the highest among the potential prey species in the study area, but their remains were not found in tiger scats. Sambar and chital were the major prey species of the tigers in Sariska before the local extermination of tigers [33, 47]. A similar finding of the dietary pattern of tigers was reported from Kanha [38], Bandipur [40], Rajaji National Park [48], and Ranthambhore [34]. Based on availability of prey species obtained from distance sampling and utilization based on scat analysis, it was found that sambar and chital were preferred prey species by tigers (Appendix 2). The order of prey selection by tiger at the individual species level was in the following order: sambar> chital> nilgai> livestock> common langur. In terms of percentage biomass consumption of prey species by tigers, a similar trend was observed, i.e., sambar was consumed the most followed by livestock, chital, nilgai, and common langur (Appendix 3).

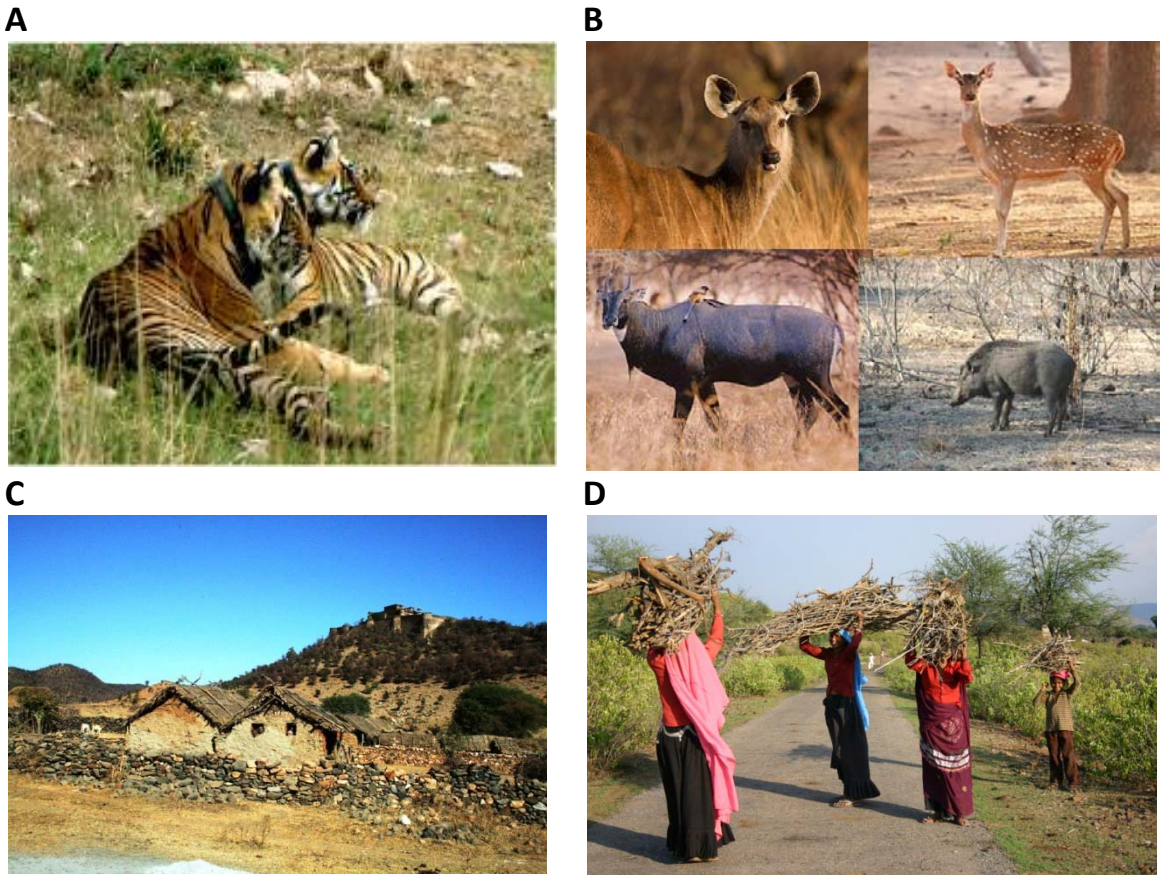

Fig.8. The free ranging tigers (A), wild ungulates (B), Kankwari, one of the villages to be relocated (C) and fuel wood collection by villagers in Sariska Tiger Reserve.

Discussion

It was observed that all three tigers utilized larger areas, up to 220 km^2 initially soon after the reintroduction (Fig. 8). The reported high annual home range of tigers in Sariska as compared to other studies in the Indian sub-continent [13, 38, 44] (Appendix 4) may be attributed to their initial habitat exploration after reintroduction.

It was [49] reported that the non-sustainable extraction of fuel wood and fodder in Sariska may lead to forest degradation (Fig. 8). Rapid population growth and resultant human activities increase pressures and competition on the limited resources, thus exacerbating conflicts between local communities and the government [50-52], and the resulting conflicts are the biggest hindrances to conservation efforts [53]. A questionnaire survey conducted in all villages in Sariska during 2006-2007 [54] after the tiger extermination revealed that the proposal to reintroduce tigers into the area was found well supported by a majority of respondents from the national park (98%) and the sanctuary (81%). Fifty-eight percent of the national park inhabitants were found readily willing to relocate anytime from the area, contrary to the remaining 42% who were ready to do so only if assured by attractive packages of land, money, and accessibility to basic amenities. Nearly the entire community believed that the tigers play a significant role in the grazing economy through their livestock depredations as they tend to kill the weaker individuals from the stock, thus preventing the spread of diseases among the entire population. Though the present study revealed that domestic livestock (buffalo and cattle) formed a substantial portion (<20%) in the tigers' diet, tigers were not observed killing livestock close to village premises. Only unguarded livestock were killed by tigers in Sariska.

It seems that carnivores are closely tied with prey size, prey biomass, and disturbance factors [55-57]. Prey density is critical for the maintenance of large carnivore populations. Looking at the current socio-political scenario, it is important to maintain core-breeding areas for tigers at landscape level. In any given national park, it is important to maintain mini-cores as a source area for tigers and their prey. In Sariska Tiger Reserve, the Sariska-Pandupole valley and adjoining hills (ca. 100 km^2) is the only area that can be considered as mini-core. The Sariska notified national park (274 km^2) could possibly support 15 tigers (95% confidence interval: 10 to 21) based on the tiger-prey equation [16, 55]. The present wild prey density (Fig. 8) and biomass in Sariska was high and comparable with other tiger reserves such as Ranthambhore, Pench, Nagarhole, Bandipur, and Mudumalai [32, 34, 40-41]. The 10 villages from the notified national park, once relocated, may make a 274 km^2 area available free from biotic interference which can support at least 15 adult tigers [16]. The estimated mean livestock grazing distance from different villages of the national park and the sanctuary was 3.3 km and 3.1 km, respectively, thus leaving only 15% of the area in the whole tiger reserve as undisturbed wildlife habitat [54]. The future of Sariska lies in successful relocation of the remaining 10 villages from the national park (Fig. 8). The successful relocation of *Bhagani* village can set as an example to expedite the entire relocation process. In contrast, the relocation of national park villages, though not easy and even if accomplished in a given time span, does not provide Sariska with a safe and undisturbed wildlife habitat all alone, since the sanctuary villages are much more populated than those of the national park and will continue to exploit the forest resources. To achieve success in making people less dependent on forest resources, implementation of eco-development programs in and around the tiger reserve with the involvement of Non-Governmental Organizations (NGOs) is recommended.

A

B

C

D

Fig. 9. Tiger darted at Ranthambhore Tiger Reserve (A), radio-collaring operation at Ranthambhore Tiger Reserve (B), translocation of tiger by helicopter (C) and the tiger released in an enclosure at Sariska Tiger Reserve.

Implications for conservation

As per the proposed plan, two more tigers (male and female) were reintroduced in Sariska during July 2010 for establishing the initial population of five tigers (Fig. 9). The proposed supplementation of three tigers (one male and two females) in every two years for a period of six years and removal of anthropogenic pressure from the national park will be crucial for the long-term survival of tigers in Sariska.

Since the tiger population in the wild is dwindling drastically in its entire distribution range, and since Sariska, which had the western-most distribution of tigers, has seen their complete extinction once, it has grown even more necessary to monitor and study the relevant ecological aspects such as ranging pattern with regard to anthropogenic pressure, food habits, and prey selection of the reintroduced

tigers. Therefore the outcome of long-term monitoring studies on tigers will be helpful for the park administration to manage this top-most predator and it habitats, and as a whole the complete ecosystem, more effectively.

Acknowledgments

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Appendix 1. Encounter rate, density, and group size of prey species estimated by line transect sampling in Sariska Tiger Reserve.

Species	Number of animals encountered	Encounter rate/ km	SE	Density/ km^2	SE	Mean group size	SE
Chital (*Axis axis*)	414	0.37	0.06	46.7	9.5	6.02	0.7
Sambar (*Rusa unicolor*)	217	0.44	0.07	26.2	4.9	2.8	0.2
Nilgai (*Boselaphus tragocamelus*)	191	0.41	0.05	19.5	3.3	2.4	0.2
Common langur (*Semnopithecus entellus*)	183	0.11	0.02	22.8	6.5	10.3	1.3
Livestock (*Bubalis bubalis* and *Bos indicus*)	613	0.23	0.06	59.9	22.3	13.5	3.0
Wild pig (*Sus scrofa*)	140	0.14	0.03	15.4	4.4	5.4	1.0
Peafowl (*Pavo cristatus*)	1137	1.23	0.10	125.2	15.3	5.3	0.4

Appendix 2. Prey selectivity of the reintroduced tigers in Sariska Tiger Reserve, Rajasthan

Species	Observed frequency of occurrence in scats	Density in the wild/ km^2	Ackerman's correction factor	Expected frequency	Ivlev's index (u-a/u+a)
Chital (*Axis axis*)	26.3	46.7 ± 9.5	3.555	15.52	0.26
Sambar (*Rusa unicolor*)	41.7	26.2 ± 4.9	6.355	15.91	0.44
Nilgai (*Boselaphus tragocamelus*)	10.7	19.5 ± 3.3	8.42	15.69	- 0.19
Common langur (***Semnopithecus entellus***)	1.9	22.8 ± 6.5	2.47	5.38	- 0.49
Livestock (*Bubalis bubalis* and *Bos indicus*)	19.4	59.9 ± 22.3	8.28	47.39	- 0.42

Appendix 3. Biomass and individual prey consumption of the reintroduced tigers in Sariska Tiger Reserve, Rajasthan.

Species	Observed frequency of occurrence in scats	Average body weight (kg)	Percentage biomass consumption	Percentage individual consumption
Chital (*Axis axis*)	26.3	45	15.18	35.03
Sambar (*Rusa unicolor*)	41.7	125	43.19	35.88
Nilgai (*Boselaphus tragocamelus*)	10.7	180	14.68	8.28
Common langur (*Semnopithecus entellus*)	1.9	8	0.76	5.67
Livestock (*Bubalis bubalis* and *Bos indicus*)	19.4	180	26.18	15.10

Appendix 4. Home ranges of tigers estimated in different protected areas of Indian subcontinent.

Study area	Home Range of tiger				Reference
	Male		Female		
	ID	Area (km^2)	ID	Area (km^2)	
Sariska Tiger Reserve, Rajasthan, Western India	Tiger	168.6	Tigress-1	181.4	Present study (2008-09)
			Tigress-2	223.4	
Kanha National Park, Madhya Pradesh, Central India	-	-	-	65	Schaller (1967)
Royal Chitwan National Park, Nepal	-	-	-	9.3	Seidensticker (1976)
Panna Tiger Reserve, Madhya Pradesh, Central India	M-91	98.25	F-111	50.9	Chundawat (2001)
			F-113	67.5	
			F-118	31.3	
			F-120	35.7	
Pench Tiger Reserve, Madhya Pradesh, Central India	-	-	F1	17	Sankar pers.comm. (2008-2009) (ongoing study)
			F2	27	

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Full Length Research Paper

Response of leopards to re-introduced tigers in Sariska Tiger Reserve, Western India

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Tigers got exterminated from Sariska Tiger Reserve before 2005. After that, five tigers were re-introduced to Sariska during 2008 to 2010. The present study compared the abundance, site occupancy and temporal activity pattern of leopard before and after tiger re-introduction. The population of leopard was estimated by mark-recapture technique using camera traps during 2008 to 2010 in an effective trapping area of 223.3 km^2. Before tiger re-introduction (2008), the leopard density was estimated to be 7.6±0.6 (SE) /100 km^2 and after tiger reintroduction it was 6.2±0.8 /100 km^2 (2009) and 3.1±0.4 /100 km^2 (2010). It was observed that the density of leopard declined significantly (Two sample T-Test; P = 0.0002) from 2008 to 2010. Rate of site occupancy was calculated through site-wise capture history of leopard obtained from camera traps. Before tiger re-introduction the probability of site utilization of leopard was 0.75, while after tiger re-introduction probabilities of site utilization of leopard and tiger were estimated at 0.54 and 0.52 respectively and the co-occurrence of both the species was 0.51. Temporal activity patterns of tiger and leopard were investigated from photo captures. Prior to the release of tigers, mean activity time of leopard was 20: 57 h (95% CI 20: 19 to 22: 53) but shifted to 22: 35 h (21: 02 to 01: 25 h) after tiger release (Watson's U^2 test: p<0.005). The present study showed that there was a decline in the leopard population after tiger re-introduction and considerable segregation between the two carnivores along the spatial and temporal axes.

Key words: Competition, density, leopard, population, reintroduction, spatial distribution, temporal activity, tiger.

INTRODUCTION

Competition in carnivores may result in reduced fecundity, growth or energy stores of individuals and reduced density and/or an altered age structure at a population level (MacNally, 1983; Petren and Case, 1998). Substantial data shows that large carnivores can limit the density of smaller carnivores by stealing food (Gorman et al., 1998), monopolizing areas of high prey density (Johnson and Franklin, 1994), competing for food (Hayward and Kerley, 2008), or by direct aggression and predation (Palomares and Caro, 1999). For example, studies showed that lions (*Panthera leo*) and/or hyenas (*Crocuta crocuta*) affect wild dogs (*Lycaon pictus*) through partial exclusion from preferred habitat (Creel et al., 2001) and direct killing (Ginsberg et al., 1995). Consequently, wild dog densities are low where the densities of lions or hyenas are high (Creel and Creel, 1996) and local extinctions are more likely to occur where competition is intense (Vucetich and Creel, 1999). Brown and Maurer (1986) suggested that the ecological advantages of large body size, such as greater energy efficiency, greater mobility and more efficient homeo-static mechanisms, enable large bodied species to use a greater range of habitats. Also, large species can dominate resource use within habitats (Jones and Barmuta, 1998).

Tigers (*Panthera tigris*) and leopards (*Panthera pardus*) are sympatric in several parts of Asia. Karanth and Sunquist (1995, 2000) studied prey selection and

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interactions between these large cats in Nagarahole, India, where the densities of both species were reported high (Karanth, 1993, 1995), and their prey base is rich and diverse in terms of species and sizes (Karanth and Sunquist, 1992). The authors observed similar patterns between the species in space use and activity patterns (Karanth and Sunquist, 2000), but differences in prey selection with respect to prey size (Karanth and Sunquist, 1995). Similar differences are found in the preferred weight range throughout the entire distributions of tigers and leopards (Hayward et al., 2006, 2012).

A small population of tigers (10 to 12 individuals) got exterminated from Sariska Tiger Reserve (Sariska) due to poaching in 2004 (Sankar et al., 2009). Subsequently, leopard took over the entire tiger habitat, which was the best habitat available in Sariska and became the top predator (Sankar et al., 2009). The re-introduction of tigers from Ranathambore Tiger Reserve (RTR) to Sariska TR was envisaged by translocating initial population of five tigers (two males and three females) during 2008 to 2010 (Sankar et al., 2010). Accordingly, two tigers (male and female) in 2008, a tigress in 2009 and two tigers (male and female) in 2010 were re-introduced in Sariska. It was imperative to study the responses of resident leopards to re-introduced tigers in the study area. In Sariska, studies on prey selection of leopard and re-introduced tigers showed that both the carnivores preferred wild prey species such as sambar (*Rusa unicolor*) and chital (*Axis axis*) in similar manner (Mondal et al., 2011; Sankar et al., 2010) and size and sex classes of prey species consumed by leopard and tiger were not investigated. Based on photo-capture rate through camera traps and pugmark evidences of leopard before and after tiger re-introduction, it was assumed that there might be some change in site utilization and activity pattern of leopard, which are accounted for in the present study.

Theory and empirical data suggested that behavioral factors may play a role in tiger–leopard co-existence in certain circumstances. Seidensticker (1976) and McDougal (1988) observed indications of avoidance of tiger by leopard Chitwan National Park, Nepal. Furthermore, theoretically the size difference between tigers and leopards, their similar feeding habits, and their close taxonomic relatedness are strong indicators of a high risk of intra-guild predation (Donadio and Buskirk, 2006; Palomares and Caro, 1999; Polis et al., 1989). Empirical studies have demonstrated that an inferior competitor may avoid interference competition by inhabiting ‘‘competition refuges’’, areas where encounters with the superior opponent are less frequent (Durant, 1998; Odden et al., 2010; Saleni et al., 2007; Woodroffe and Ginsberg, 2005). Other competitors avoid interference competition by partitioning their activity times (Hayward and Slotow, 2009). Two main types of refuges are reported in the literature; some species avoid conflicts by inhabiting the margins of their competitors' home ranges, whereas others seek out areas within the ranges of their opponents that are low in resource density, thereby, reducing the probability of inter-specific encounters (Odden et al., 2010; Woodroffe and Ginsberg, 2005). According to Creel et al. (2001), a sound approach of detecting avoidance due to interference competition among carnivores requires objective methods of mapping habitat quality for the competitors and of recording their spatial distributions. In the present study, the non-invasive method of camera trapping technique under a mark-recapture framework was used for: (a) estimation of population of leopard before and after tiger re-introduction, (b) site utilization of leopard and tiger in the study area and (c) temporal activity pattern of leopard and tiger.

MATERIALS AND METHODS

Study area

The study area is the Sariska Tiger Reserve (Sariska), Western India. The park lies between Longitude: N27°05' to N27°45' and Latitude: E76°15' to E76°35' and is situated in the Aravalli hill range in the semi-arid part of Rajasthan (Rodgers and Panwar, 1988). It became a Wildlife Sanctuary in 1955 and Tiger Reserve in 1982. The total area of the Tiger Reserve is 881 km^2 (Figure 1), of which 273.8 km^2 is a notified National Park. The altitude of Sariska varies from 540 to 777 m. Sariska terrain is undulating to hilly in nature and has numerous narrow valleys.

The climate of this tract is subtropical, characterized by a distinct summer, monsoon, post monsoon and winter. The vegetation of Sariska falls under Northern tropical dry deciduous forests and Northern tropical thorn forest (Champion and Seth, 1968). Apart from leopard and tiger, other carnivores present are striped hyena *(Hyaena hyaena)*, jackal *(Canis aureus)*, jungle cat (*Felis chaus*), common mongoose *(Herpestes edwardsi*), small Indian mongoose (*Herpestes auropunctatus*), ruddy mongoose (*Herpestes smithi*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*) and honey badger (*Mellivora capensis*). In 2009, desert cat (*Felis silvestris*) was reported from Sariska (Gupta et al., 2009). Prey species of leopards and tigers in the area include chital (*A. axis*), sambar (*R. unicolor*), nilgai (*Boselaphus tragocamelus*), common langur (*Seminopithecus entellus*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*), porcupine (*Hystrix indica*), rufous tailed hare (*Lepus nigricollis ruficaudatus*) and Indian peafowl (*Pavo cristatus).* The predominant domestic livestock found inside the reserve are buffaloes (*Bubalis bubalis*), brahminy cattle (*Bos indicus*) and goats (*Capra hircus*). There are 10 villages located inside the National Park area which are still due for relocation since 1984. The human population is over 1700 in the villages of National Park along with a population 10,000 livestock including buffalo, cow, goat and sheep (Sankar et al., 2009). There are 21 villages located outside the National Park but within the Tiger Reserve. The human population in these villages is around 6000 and the livestock population is more than 20,000 (Sankar et al., 2009).

Estimation of population of leopard before and after tiger re-introduction

To estimate the population of leopard, camera trapping was used under a mark-recapture framework (Karanth, 1995). A

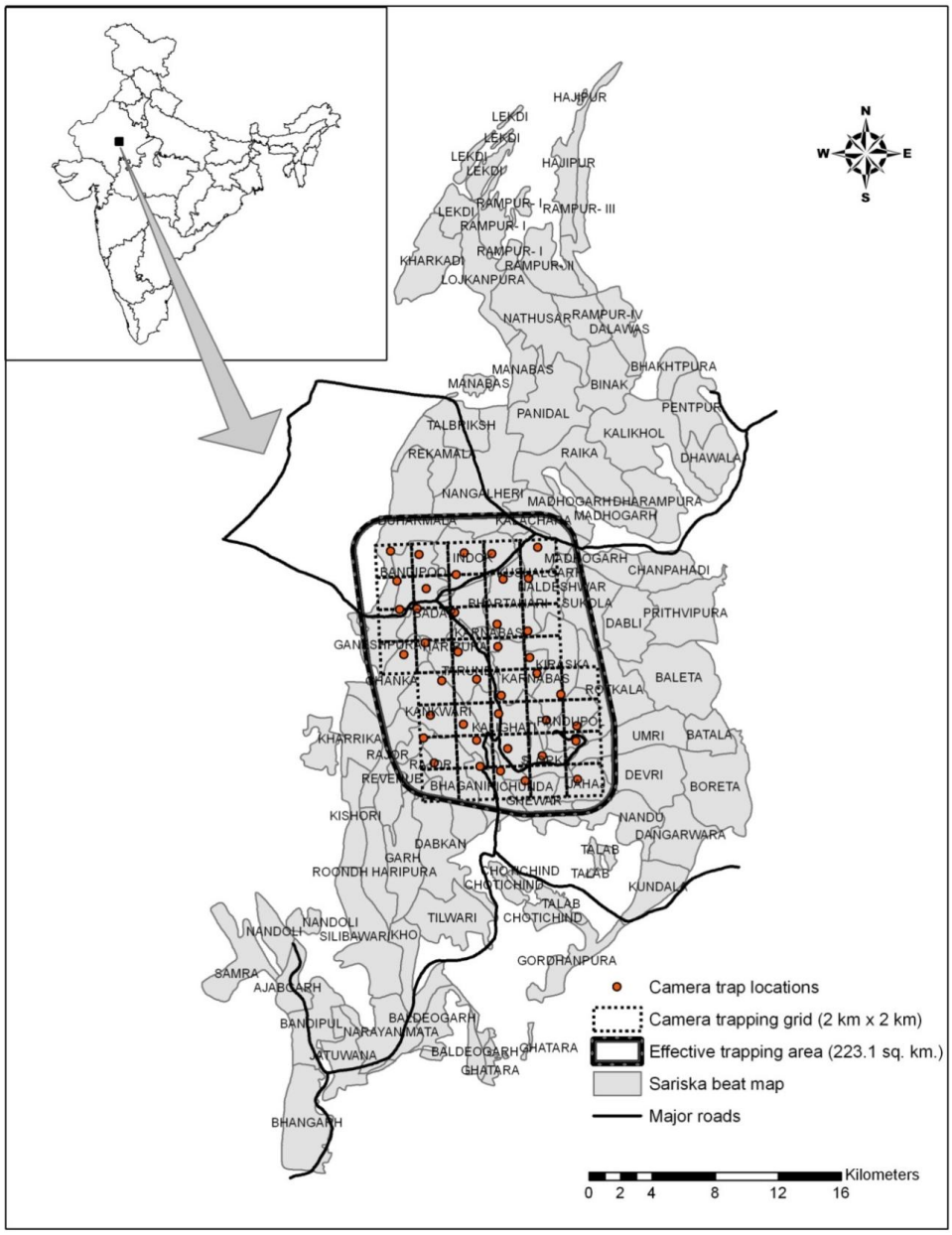

Figure 1. Geographic location of Sariska Tiger Reserve and location of camera traps in the intensive study area.

comprehensive overview of camera trapping tigers and leopards for the purpose of estimating abundance is given by Karanth (1995) and Karanth and Nichols (1998). Camera trapping was done in the study area from December, 2007 to June, 2008, from January to June, 2009 and from January to May, 2010. A preliminary survey was carried out during November to December 2007 in the intensive study area of 160 km^2 in the National Park by surveying available trails. Indirect signs such as spoor and scats of leopard were identified and marked using a handheld Global Positioning System. The entire study area was divided into two 80 km^2 blocks and each block was subdivided into 20 grids of 2 × 2 km^2. A pair of cameras was placed in each 2 × 2 km^2 grid (Figure 1). Camera traps were placed on the basis of leopard evidence (spoor, scats) on the trails. Forty units of analog and digital cameras were used which worked on passive infrared motion/ heat sensors. The camera traps were equipped with 35 mm lens and date and time of each photograph were recorded. The camera delay was kept at minimum (15 s) and sensor sensitivity was set high. A total of 40 locations were selected for the placement of camera traps in the study area. Camera traps were operated for 117 consecutive nights in 2008, 130 in 2009 and 85 in 2010. The main concern was to cover the area fairly completely, in the sense that it would be difficult for a tiger or leopard in the sampled area to travel about and not encounter at least one camera trap (Karanth and Nichols, 2002). Every two nights were considered as a single occasion, resulting in 59 occasions and effort of 4680 trap nights in 2008, 65 occasions and effort of 5200 trap nights in 2009 and 43 occasions and 3400 trap nights in 2010. Individual leopard obtained from

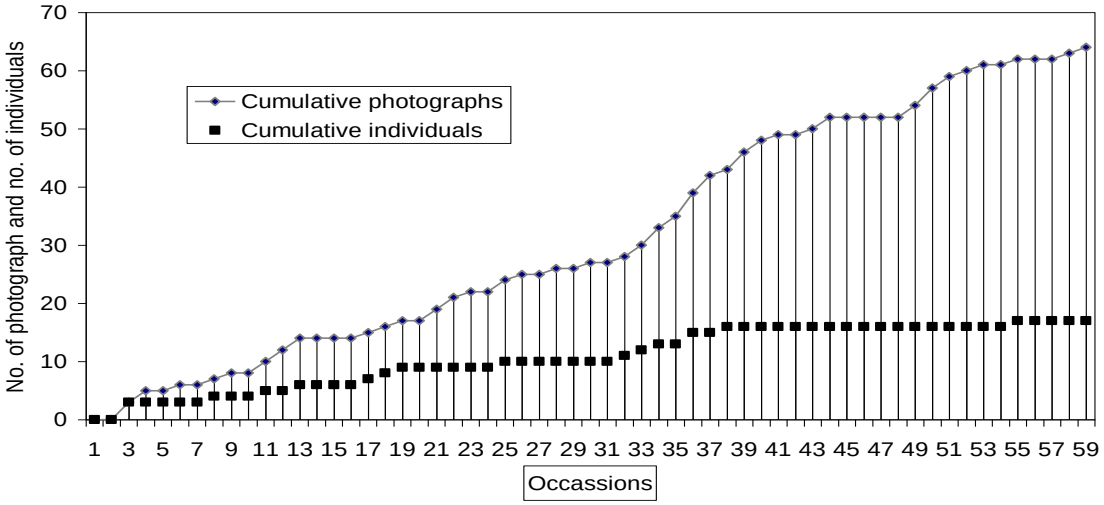

Figure 2. Number of individual leopard photographed and number of leopard photographs with increasing number of sampling occasions in Sariska Tiger Reserve to evaluate sampling adequacy in 2008.

camera trap photographs were identified by a combination of distinguishing characters, such as position and shape of rosettes on flanks, limbs and forequarters (Schaller, 1967; Karanth, 1995). Any photograph with a distorted perspective or which lacked clarity, were discarded (n = 3). Every leopard captured was given a unique identification code like L1, L2, and L3 etc.

Occasion wise capture history of each individual was generated in an X matrix format (Otis et al., 1978) for the analysis of population estimation. Population closure test was performed using software CAPTURE (Otis et al., 1978; Rexstad and Burnham, 1991). The density of leopard was calculated by four different methods such as full MMDM, half MMDM, spatially explicit Inverse Prediction density (IP dens) and spatial maximum likelihood density (ML dens) using program DENSITY 4.1 (Efford et al., 2004) and SPACECAP (Singh et al., 2010).

Spatial distribution of leopard and tiger

Spatial distribution of leopard and tiger were studied through photographic evidences obtained from camera trapping study and later used in a Geographical Information System (GIS) domain to understand site-utilization of both the species. The number of photographs per 100 trap nights was calculated in each camera trapping grid (2 × 2 km^2) for both species. This data was then projected in GIS along with the Sariska map to get a visual interpretation of site utilization of leopard and tiger in the study area. One binary matrix of camera trap locations against photo-captures was prepared for tiger and leopard (before and after tiger release) from camera trap data. This matrix was then analyzed for presence/absence site utilization in program PRESENCE 4.0 (Hines, 2006) following single session two species model. The detection probabilities of leopard and tiger in the study area in the presence or absence of either species were analyzed using the program PRESENCE 4.0 (Hines, 2006).

Temporal activity pattern of leopard and tiger

Temporal activity pattern of leopard and tiger was studied thorough the photographic time evidence obtained from camera traps. In total the camera traps yielded 81 and 64 leopard photographs before and after tiger release respectively along with 27 tiger photographs. These photographs were further pooled (Hayward and Hayward, 2007) into following categories for leopard and tiger: 9:01-12:00 hrs, 12:01 to 15:00 h, 15:01 to 18:00 h, 18:01 to 21:00 h, 21:01 to 0:00 h, 0:01 to 3:00 h, 3:01 to 6:00 h and 6:01 to 9:00 h. Peak activity period (95% CI) and peak activity time were analyzed in program ORIANA (Andersen et al., 2000).

RESULTS

Estimation of population of leopard before and after tiger re-introduction

The camera trapping study resulted in a total of 81 photographs of 17 individual leopards in 2008, 64 photographs of 14 individual leopards in 2009 and 31 photographs of 8 individual leopards in 2010, based on the number of individuals identified from the rosette pattern. Effective trapping area (ETA) and density (D) was calculated by different methods using program DENSITY 4.1 (Efford et al., 2004). The 40 trapping locations covered a minimum convex polygon area of 118 km^2 and an effective trapping area (ETA) of 223.8, 223.1 and 250.3 km^2 with a buffer of half mean maximum distance moved model (1/2 MMDM) in 2008, 2009 and 2010 respectively.

The number of individual leopard was found to stabilize after the 37^{th} occasion (74 days) of camera trapping in 2008, hence, it was inferred that a minimum of 80 days camera trapping is necessary to capture the entire leopard population in the study area (Figure 2). As population estimation was done separately between years, it was found to be geographically and demographically closed for the sample period in 2008 (P = 0.06), 2009 (P = 0.07) and 2010 (P = 0.08). The overall model selection test based on discriminant functions using the model selection algorithm of program

Table 1. Population and density estimation of leopard before and after tiger release in Sariska Tiger Reserve between 2008 and 2010.

Estimates	Pre-release of tigers	Post-release of tigers (2009)	
	2008	2009	2010
Population (Mh Jackknife)	17.9 (3.0)	16.3 (3.3)	9.0 (1.5)
Population (Mh Chao)	18.6 (2.2)	18.2 (4.9)	8.0 (0.7)
Population (Mo Null)	17.0 (0.6)	14.0 (0.6)	8.0 (0.3)
Density (MMDM/2)	7.6 (0.6)	6.2 (0.8)	3.1 (0.4)
Density (Max likelihood)	8.0 (2.0)	5.7 (1.5)	3.3 (1.2)
Density (Bayesian)	7.4 (1.3)	5.2 (0.8)	2.3 (0.5)

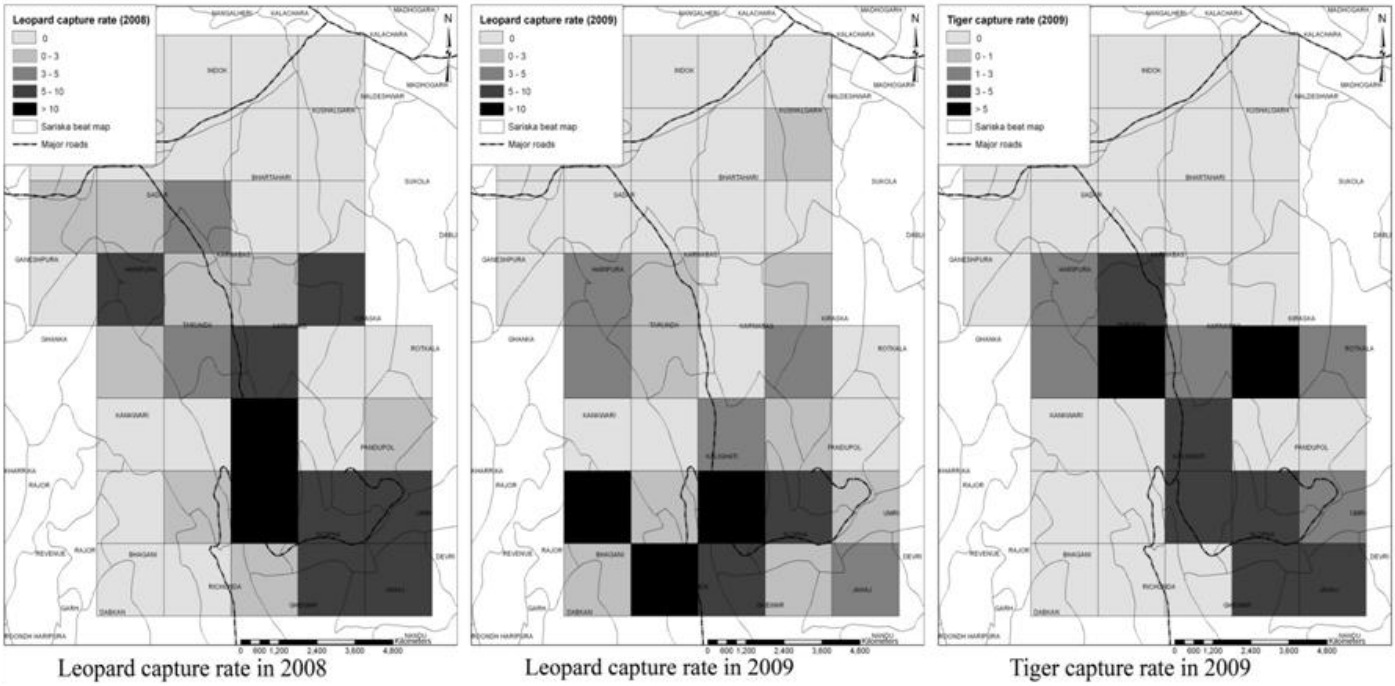

Figure 3. Spatial distribution of tiger and leopard based on camera trap photo-captures in the study area of Sariska Tiger Reserve.

CAPTURE identified Mh (heterogeneity model) as the most appropriate model in our study. With Mh (jackknife) estimator, the leopard population (N) was estimated at 17.9 ± SE 3.0 in 2008 (before tiger release), 16.3 ± SE 3.3 in 2009 and 9.0 ± SE 1.5 in 2010 (after tiger release) (Table 1). The estimated population of leopard with other models such as Mh (Chao) and Mo are given in Table 1. For estimation of density of leopard in the study area, half normal detection function fitted the best for both maximum likelihood approach and Bayesian approach. The density of leopard estimated using maximum likelihood approach was 8.0 individual/ 100 km^2 (SE 2.0) in 2008 (before tiger release), 5.7 individual/ 100 km^2 (SE 1.5) in 2009 and 3.3 individual/ 100 km^2 (SE 1.2) in 2010 (after tiger release). The estimated density of leopard following Bayesian approach was 7.4 individual/ 100 km^2 (SE 1.3) in 2008 (before tiger release), 5.2 individual/ 100 km^2 (SE 0.8) in 2009 and 2.3 individual/ 100 km^2 (SE 0.5) in 2010 (after tiger release). Density of leopard calculated with half MMDM model is given in Table 1. It was observed that the density of leopard (using Bayesian approach) declined significantly (Two samples T-Test; P = 0.0002) from 2008 to 2010.

Spatial distribution of leopard and tiger in the study area

The capture rate of leopard and tiger per 100 trap nights in each grid was calculated and projected on Sariska grid map through color gradient (Figure 3). It was found that the grids with maximum tiger photo-captures were largely

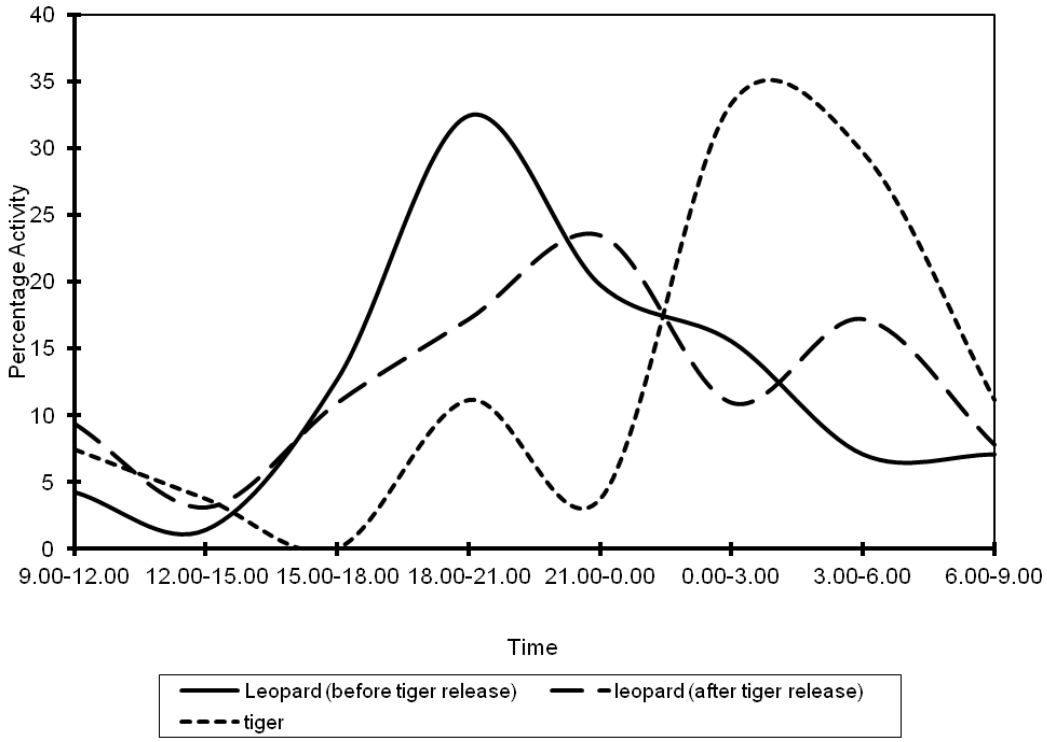

Figure 4. Temporal activity of leopard and tiger in Sariska Tiger Reserve between 2008 and 2010.

Table 2. Activity period of tiger and leopard (before and after tiger release) in Sariska Tiger Reserve between 2008 and 2010.

Variable	Leopard before tiger release	Leopard after tiger release	Tiger
Mean peak activity	20:57 h	22:35 h	03:02 h
Peak activity period	20:19 – 22:53 h	21:02 – 01:25 h	01:15 – 04:37 h
U^2 value	0.869 (P<0.005)	0.342 (P<0.005)	0.520 (P<0.005)

avoided by leopard that selected areas where tiger occurrence is less. Site utilization of both the species was estimated with site-wise capture records. Before release of the tiger in 2008, the probability of site utilization of leopard was 0.75 in the study area. But after tiger release the site utilization of leopard and tiger were 0.55 and 0.53 respectively in the absence of either species, while that of both leopard and tiger together was 0.51. The detection probability of leopard was estimated to be 0.36 in the absence of tiger and it was 0.07 when tiger is present. Detection probability of leopard and tiger together was only 0.008 when both the species were utilizing the same area.

Temporal activity pattern of leopard and tiger

Leopard was found to be most active in the evening between 18:00 to 21:00 h before tiger release and it was shifted to late evening that is, 21:00 to 0:00 h after tiger release (Figure 4). Tiger showed a bimodal activity pattern with a minor and major peak. The major peak of tiger activity was observed after midnight 0:00 to 3:00 h and the minor peak was between 18:00 to 21:00 h. The leopard activity was found very low after midnight between 0:00 to 3:00 h, when tiger was most active. The mean peak activity time of leopard was 20:57 and 22:35 h before and after tiger release respectively (Watson's U^2 test: P<0.005), while mean peak activity time of tiger was 03:02 h (Table 2).

DISCUSSION

After the extermination of tigers from Sariska in 2004, leopard occupied the entire Sariska National Park area (present study area), which was previously occupied by tigers. Sankar et al. (2009) also recorded comparatively

high density of leopard (10.7/100 km^2) in the study area before tiger release. The present study showed that there was a significant (P = 0.0002) decline in leopard population after the reintroduction of tigers in the study area. In regions of high tiger density, tigers are known to out-compete leopards (McDougal, 1988; Schaller, 1967). Radio-tracking studies on tiger and leopard indicate that leopards avoid areas frequented by tigers and occupy the periphery of parks near human settlements (Seidensticker, 1976). In the present study, photo capture rate of leopard and tiger showed that leopard avoided valley habitats which were frequented by tigers. Leopard largely occupied the peripheral hilly areas which are less frequented by tigers in the study area. In two occasions, re-introduced tigers killed two leopards in the study area due to confrontation between 2009 and 2010. A number of studies reported that, one species may occupy areas that do not overlap with the competitor species' home ranges, or they may use different habitats (Fuller and Keith, 1981; Major and Sherburne, 1987; Voigt and Earle, 1983). Red foxes (*Vulpes vulpes*) have been reported using the periphery of coyote (*Canis latrans*) home ranges or different habitats from coyotes where they occur sympatrically and coyotes have been recorded as using areas between wolf (*Canis lupus*) home ranges (Dekker, 1989; Harrison et al., 1989; Sargeant et al., 1987). European genets (*Genetta genetta*) and Egyptian mongooses (*Herpestes ichneumon*) avoid suitable habitats where densities of Iberian lynx (*Lynx pardinus*) are high (Palomares et al., 1996), as do wild dogs and cheetahs (*Acinonyx jubatus*) where lions are common (Durant, 1998; Mills and Gorman, 1997).

Based on photo capture time, it was found that leopard changed their mean peak activity period from 20.57 h before tiger release to 22:35 h after tiger release. Leopards became more active in the late evening in between two tiger activity peaks, which reflects a temporal segregation between these two sympatric large cats. Temporal segregation is a mechanism that ecologically similar species can use to avoid competition (Kronfeld-Schor and Dayan, 2003; Hayward and Slotow, 2009). Examination of our data suggests that temporal niche segregation may occur between leopard and tiger. One species may adjust its activity patterns to reduce encounters with competitor species (Litvaitis, 1992; Johnson et al., 1996). For example, in Kruger National Park, lions became active mainly at night, wild dogs in early morning, and cheetahs around the middle of the day (Mills and Biggs, 1993). Rudzinski et al. (1982) found that the activity of arctic foxes (*Vulpes lagopus*) decreased when red foxes were present. Nevertheless, clear temporal segregation has been found rarely in studies of resource partitioning between sympatric and potentially interacting carnivores (Litvaitis and Harrison, 1989; Major and Sherburne, 1987; Saleni et al., 2007).

The present study suggested that there is segregation along the spatial and temporal axis between these two carnivores. The dietary segregations between leopard and tiger were observed in many study sites (Hayward et al., 2006, 2012), but in the present study area, both leopard and tiger utilized and preferred wild prey species (sambar and chital) in similar manner (Mondal et al., 2011; Sankar et al., 2010). Leopard responded to tiger presence in terms of (a) space (detection probability of leopard is 0.36 when tiger is not present and detection probability of leopard is 0.07 when tiger is present; similarly site utilization of leopard reduced from 0.75 to 0.55 after tiger release) and (b) time (peak activity period is shifted from 20:19 to 22:53 h to 21:02 to 01:25 h). The results reflected that there is inter-specific competition between leopards and re-introduced tigers in Sariska. The reintroduction efforts for carnivores should routinely include assessment of the potential effects of inter-specific competition, as Gusset et al. (2008) assessed the effects of re-introduction of wild dogs in South Africa. Inter-specific social dominance can confer the right of first choice in food and space. The tiger, through inter-specific interactions, can reduce the abundance of leopards and in effect substitute ability in utilization of resources (MacArthur, 1972), and thereby secure a wider potential resource base (Schaller, 1967). The leopard, as subordinate, can derive no benefit from inter-specific competition with the tiger. For the leopard to co-exist with the larger cat in many areas of range overlap, it must have the ability to exist within a decreased niche breadth or else shift to areas where the tiger is absent. Selection pressure on the leopard is directed both towards specialization by reducing overlap with the tiger in use of resources and expansion of the fundamental niche in terms of areas and habitats it occupies (Eisenberg and Lokhart, 1972; Schaller, 1972; Seidensticker, 1976). In Kanha Tiger Reserve, leopards were resident only in areas where the tiger was absent. This inter-specific competition can have strong effects on the distribution and abundance of carnivores and should be an important consideration in their conservation. Studies of an ecologically and phylogenetically broad set of carnivore species show that the effects of competition on carnivore populations are sometimes difficult to predict (Creel et al., 2001; Palomares and Caro, 1999). The spatial and temporal factors, which can modify the effect of competition among carnivores, sometimes in ways are counter-intuitive under classical competition theory (Creel et al., 2001). At present, there are only five re-introduced tigers in Sariska TR. With the increase of number of re-introduced tigers, it is expected to get a clear picture of co-existence of tiger and leopard in Sariska TR.

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Prey selection, food habits and dietary overlap between leopard Panthera pardus (Mammalia: Carnivora) and re-introduced tiger Panthera tigris (Mammalia: Carnivora) in a semi-arid forest of Sariska Tiger Reserve, Western India

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Abstract
After the extermination of tigers in Sariska Tiger Reserve, Western India in 2004, three tigers were re-introduced in Sariska during 2008–2009. The present study examined the prey selection and dietary overlap between leopard and tiger after re-introduction of tiger in the study area. Scat analysis revealed the presence of nine prey species in leopard scat (n = 90 scats) and five prey species in tiger scats (n = 103 scats). Percentage frequency of occurrence of sambar (45.5%) was found to be the highest followed by chital (15.2%) > nilgai (8.9%) > cattle (7.1%) > common langur (6.3%) > peafowl (6.3%) > rodent (5.4%) > wild pig (2.7%) and hare (2.7%) in leopard diet. In the diet of tiger, sambar contributed maximum (41.7%) followed by chital (26.2%), cattle (19.4%), nilgai (10.7%) and common langur (1.9%). The present study revealed that both the predator utilized and preferred prey species in similar way, though there was difference in selection of prey species in terms of sex and age class as observed by kill records. The dietary overlap between leopard and tiger was found to be 94%. The results suggested considerable overlap between the two carnivores along diet axis.

Keywords: *Distance sampling, leopard, niche breadth, scat analysis, tiger*

Introduction

The survival of any predator is directly related to its habitat, presence of other competitor species and quality and quantity of its diet (Melville 2004). Prey selection of a predator determines spacing patterns, population growth rate and distribution of the species. The key factors that determine large carnivore habitats are prey abundance, less disturbance, water availability and forest continuity. The acquirement of food is a fundamental component for every predator's existence. Hence, prey selection is critical for understanding life history strategies of any carnivore (Miquelle et al. 1996).

A small population of tigers (10–12 individuals) got exterminated in Sariska due to poaching in 2004 (Sankar et al. 2005). Subsequently, re-introduction of tigers from Ranthambhore Tiger Reserve (Ranthambhore TR) to Sariska Tiger Reserve (Sariska TR) was envisaged by translocating initial population of five tigers (two males and three females), with a supplementation of three tigers (one male and two females) in every two years for a period of six years (Sankar et al. 2005). An adult tiger and adult tigress were translocated from Ranthambhore to Sariska on 28th June and 4th of July, 2008 respectively. There after another tigress was reintroduced to Sariska from Ranthambhore on 25th February 2009. After the tiger extermination in Sariska, leopard took over the entire tiger habitat (Sariska National Park), which was the best habitat available in Sariska and became the top predator (Sankar et al. 2009). Afterwards, the re-introduced tigers again established their territory in the same area of Sariska National Park (Sankar et al. 2010). Several hypotheses have been proposed to explain the prey selection by competitor predators. The hypotheses pertain to ultimate causal factor such as energetic benefits and costs involved (Kruuk 1972; Schaller 1972;

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Griffiths 1975; Stephens & Krebs 1986) and seem to be affected by the change in development prey predator assemblages due to recent extinctions and simultaneous human predation on prey and predator species (Karanth & Sunquist 1995). However, both of these factors were observed to happen in the present study area (Sankar et al. 2005), it is expected that the prey-predator relations and the intra-guild competition between large predators in terms of food will get balanced after the reintroduction of tiger in the study area. In the present study, the prey selection of leopard and re-introduced tiger was studied and dietary overlap between these two top predators was examined between 2008 and 2009. The result was compared with the previous study (Sankar & Johnsingh 2002), when there were 12–16 tigers in the study area. In the present study, the prey selection of leopard was also compared with a previous study (Mondal et al. 2011), when there was no tiger in the study area.

Study area

The study area is the Sariska Tiger Reserve (Sariska TR), Western India. The park lies between Longitude: N27°05' to N27°45' and Latitude: E76°15' to E76°35' and is situated in the Aravalli Hill Range of semi arid part of Rajasthan (Rodgers & Panwar 1988). It became a wildlife sanctuary in 1955 and Tiger Reserve in 1982. The total area of the Tiger Reserve is 881 km^2 (Figure 1), of which 273.8 km^2 is a notified National Park. The altitude of Sariska varies from 540–777 m. Sariska terrain is undulating to hilly in nature and has numerous narrow valleys.

The climate of this tract is subtropical, characterized by a distinct summer, monsoon, post monsoon and winter. The vegetation of Sariska falls under Northern Tropical Dry Deciduous Forests and Northern Tropical Thorn Forest (Champion & Seth 1968). Apart from leopard and tiger, other carnivores present are striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), desert cat (*Felis silvestris*), common mongoose (*Herpestes edwardsi*), small Indian mongoose (*H. auropunctatus*), ruddy mongoose (*H. smithi*) palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*) and ratel (*Mellivora capensis*). Prey species of leopard and tiger in the area include chital (*Axis axis*), sambar

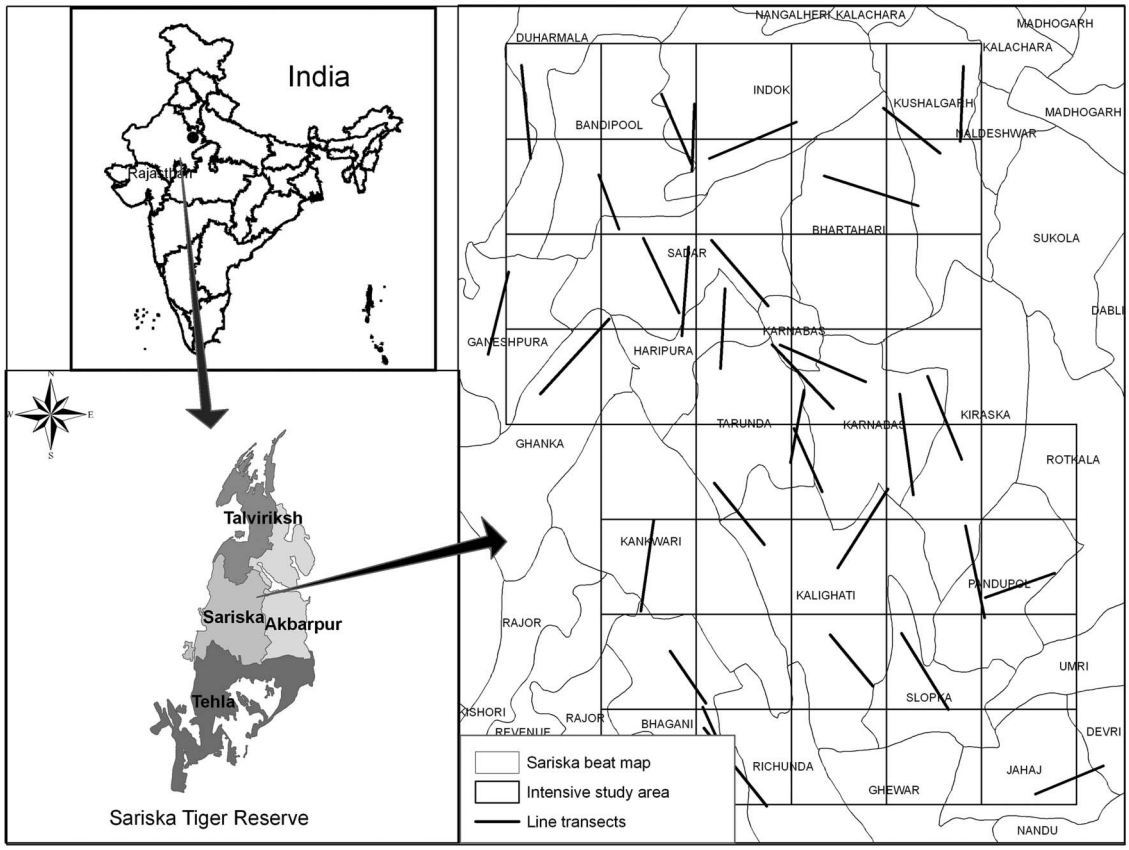

Figure 1. Geographic location of Sariska Tiger Reserve and location of line transects in the intensive study area.

(*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), common langur (*Semnopithecus entellus*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*), porcupine (*Hystrix indica*), rufous tailed hare (*Lepus nigricollis ruficaudatus*) and Indian peafowl (*Pavo cristatus*). The predominant domestic livestock found inside the reserve are buffaloes (*Bubalis bubalis*), brahminy cattle (*Bos indicus*) and goats (*Capra hircus*). There are 10 villages located inside the National Park area which are due for relocation since 1984. The human population is over 1700 in the villages of National Park along with a population 10,000 livestock including buffalo, cow, goat and sheep (Sankar et al. 2009). There are 21 villages located outside the National Park but within the Tiger Reserve. The human population in these villages is around 6000 and the livestock population is more than 20,000 (Sankar et al. 2009).

Materials and methods

Prey species density in the study area was estimated by line transect method under distance sampling technique (Burnham et al. 1980). This method has been widely applied to estimate densities of prey species in different forest in Indian subcontinent (Karanth & Sunquist 1995; Khan et al. 1996; Biswas & Sankar 2002; Sankar & Johnsingh 2002; Bagchi et al. 2003). The study area was divided into 40 grids of 4 km^2 covering 160 km^2 areas. A number of 32 line transects varying in length from 1.6 km to 2 km were laid covering the intensive sampling area of 160 km^2. The total transects length of 60.4 km were walked three times in early morning resulting in total effort of 181.2 km. On each sighting of prey species on line transects, total number of individuals, animal bearing and angular sighting distance were recorded. Program DISTANCE 5 (Laake et al. 2001) was used to estimate the density of prey species. The best model was selected on the basis of the lowest Akaike Information Criterion (AIC) (Burnham et al. 1980; Buckland et al. 1993). The half normal key function with cosine adjustment gave the best fit for all the prey species.

Predators' diets have been found to be precisely studied by scat analysis as opposed to kills in forested habitats (Karanth & Sunquist 1995). Studies based on kills being biased towards large prey, the remains of which are more easily detected than those of small prey (Edgaonkar & Chellam 2002). Diet and food preference of leopard and tiger can be estimated from the scat analysis and as well as from the kills (Mukherjee et al. 1994; Biswas & Sankar 2002; Sankar & Johnsingh 2002; Bagchi et al. 2003; Mondal et al. 2011). Fresh leopard and tiger scats were collected in all seasons whenever encountered during the study period. All the scats were washed, oven dried and subsequently preserved for future analysis. Micro-histological structures of hairs were used to identify the prey species (Johnsingh 1983; Mukherjee et al. 1994; Biswas & Sankar 2002; Sankar & Johnsingh 2002; Bagchi et al. 2003; Mondal et al. 2011). The biomass and number of individuals of the prey consumed by both the carnivores were estimated using Ackerman's equation (Ackerman et al. 1984) to get a more accurate estimate of prey consumption. The assumption for extrapolating of the above equation was that the leopard, tiger and cougar (*Felis concolor*) had similar utilization and digestibility (Karanth & Sunquist 1995). It was also presumed that the scats containing various prey items had similar decay rate and their detection was equally probable and would apply the same formula as mentioned above (Ackerman et al. 1984) to estimate the prey consumption by leopard and tiger.

Each scat yielded the remains of one or more species. It was necessary to know whether the number of scats analyzed reflect an accurate picture of the diet of the leopard and tiger. The following procedure was adopted to find out the adequacy of sample size. After all the scats were analyzed, an observation-area curve (Odum & Keunzler 1955) which is a curve for the percent frequency of occurrence of major prey species represented in the diet was calculated at an interval of every ten scats, after randomizing the order of the results obtained.

Prey selectivity by leopard and tiger was estimated for each prey species by comparing their availability and utilization data. The expected proportion of scats in the environment (i.e. availability) was calculated using the following equation (Karanth & Sunquist 1995): $fi = [(di/dt) * \lambda i]/ \Sigma [(di/dt) * \lambda i]$, where fi= expected scat proportion in the environment, di= density of i th species, dt = sum of density of all species, $\lambda i = X/Y$ = the average number of collectible scats produced by leopard from an individual of i th prey species, X = average body weight of the species and $Y = 1.980 + 0.035\ X$ (Ackerman et al. 1984). Percentage biomass consumption and percentage individual consumption were also estimated using the parameters of percentage occurrence of the prey species in the scats, Ackerman's correction factor and average body weight of the prey species (Karanth & Sunquist 1995; Biswas & Sankar 2002; Mondal et al. 2011). The average body weight of prey species of leopard and tiger required for biomass estimation were taken from Karanth & Sunquist (1995), Sankar & Johnsingh (2002), Ramesh et al. (2008) and Mondal et al. (2011). The prey selection was also

determined by using Ivelev's index (Ivelev 1961), $E = (u - a)/(u + a)$, where, 'u' was observed relative frequency occurrence of prey items in predator scats and 'a' was expected scat proportion in the environment. If a species was preyed relatively more frequently than it exists in the prey population then it was considered preferred, whereas if it was taken less frequently it was avoided.

To assess the dietary overlap between tiger and leopard, the Pianka's niche overlap index was used (Pianka 1973). Where: Pianka index = $(\sum pij^{*}pik)/\{\sum(pij)^2 * \sum(pik)^2\}$. Here, Pij = percentage of prey items i of predator j; Pik = percentage of prey items i of predator k. The index distributes between 0 and 1, the similarity is higher as the index is close to 1. The diet niche breadth of leopard and tiger were assessed using Levins measure (Levins 1968), standardized to a scale of 0–1 following Hurlbert (1978). Levin's Niche breadth $B = 1/\Sigma pi^2$, where pi = Proportion of diet contributed by prey species i; Standardized Niche breadth Bs= (B-1)/(n-1), where n = Total number of prey species.

Results

In the intensive study area (Sariska National Park), estimation of cluster size, group encounter rate and density of different prey species of leopard and tiger was given in the Table I. In program DISTANCE 5, the selected model was half normal with cosine adjustment 2, 3 (P = 0.69783, Chi-square = 0.1507 and degree of freedom = 1). The density of peafowl was found to be the highest (121.4/km^2) followed by goat (54.1/km^2), chital (44.3/km^2), cattle (36.5/km^2), sambar (25.2/km^2), common langur (22.1/km^2), nilgai (18.9/km^2), wild pig (14.9/km^2), hare (3.6/km^2).

Nine prey species were identified in 90 leopard scats and five prey species in 103 tiger scats. Frequency of occurrence and percentage occurrence of prey species of both leopard and tiger are given in Table II. Sambar contributed maximum (45.5%) in leopard's diet followed by chital (15.2%), nilgai (8.9%), cattle (7.1%), common langur (6.3%), peafowl (6.3%), rodent (5.4%), hare (2.7%) and wild pig (2.7%). In tiger's diet, sambar contributed maximum (41.7%) followed by chital (26.2%), cattle (19.4%), nilgai (10.7%) and common langur (1.9%).

To know the required sample size to analyze the food habits of leopard and tiger in the study area, successively ten scats were randomly drawn from the total sample size, which gave the cumulative frequency of occurrence of each species (Figures 2 and 3). The proportion of different prey species in scats got stabilized once a sample 70 scats were analyzed of leopard and 80 scats of tiger. Hence, it is suggested that a minimum of 70–80 scats should be analyzed to understand the food habits of leopard and tiger in the study area. In addition, no new prey species were found after analyzing 70 leopard scats and 80 tiger scats, as shown by diet stabilization curve (Figures 4 and 5).

Estimation of relative biomass contribution of different prey species in the diet of leopard and tiger, using the equation developed by Ackerman et al. (1984) gave an assessment of prey use by both the predators in the study area. Biomass contribution of each prey species in the diet of leopard and tiger is given in Table II. Comparison of observed utilization and expected availability was done using Ivlev's index (Ivlev 1961) to know the prey selection by leopard and tiger in the study area. Sambar ($P < 0.05$) and Chital ($P < 0.05$) were preyed upon by both leopard and tiger in excess of their availability, suggesting

Table I. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2008.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2
		Mean	SE	ER	SE	D	SE	
Chital	64	6.40	0.67	0.37	0.06	44.30	9.26	1993.50
Sambar	71	3.14	0.24	0.44	0.07	25.23	4.83	3153.75
Nilgai	73	2.47	0.21	0.41	0.05	18.91	3.24	3403.80
Wild pig	27	5.44	1.00	0.15	0.03	14.95	4.31	568.10
Peafowl	223	5.35	0.42	1.24	0.10	121.43	15.02	412.86
Cow	38	9.44	1.46	0.21	0.05	36.51	11.51	6571.80
Goat	23	23.13	2.11	0.12	0.03	54.10	16.19	865.60
Hare	27	1.25	0.08	0.15	0.03	3.45	0.92	12.42
Common langur	21	10.33	1.29	0.11	0.02	22.06	6.39	176.48

SE = Standard error; ER = encounter rate; D = Density.

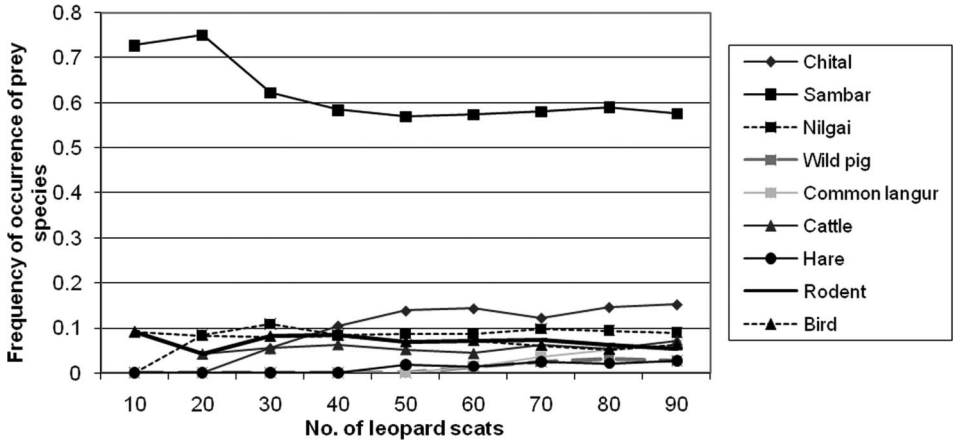

Figure 2. Frequency of occurrence of prey species in leopard diet with increasing number of scats in Sariska Tiger Reserve, Rajasthan, India.

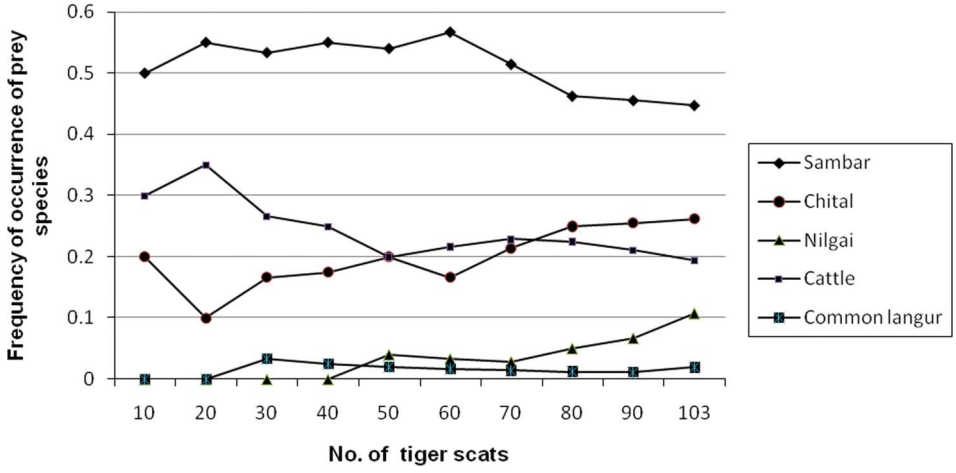

Figure 3. Frequency of occurrence of prey species in tiger diet with increasing number of scats in Sariska Tiger Reserve, Rajasthan, India.

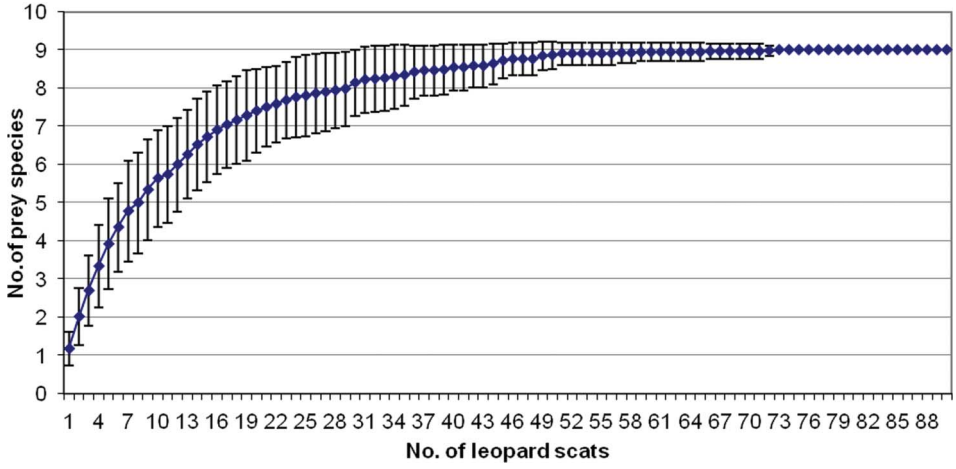

Figure 4. Diet stabilization curve of leopard in Sariska Tiger Reserve, Rajasthan, India.

positive selection or preference, while nilgai ($P < 0.05$) and cattle ($P < 0.05$) were preyed upon less than their availability, suggesting negative selection or rejection. The common langur was preyed upon more than its availability ($P > 0.05$) by leopard but avoided by tiger (Figure 6). The index of prey selection by leopard at individual species level was in the following order: sambar > common langur>

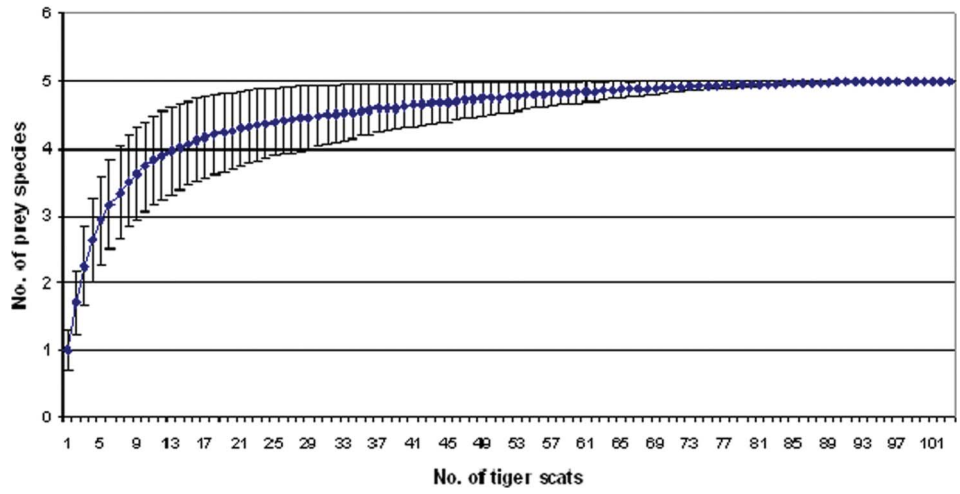

Figure 5. Diet stabilization curve of tiger in Sariska Tiger Reserve, Rajasthan, India.

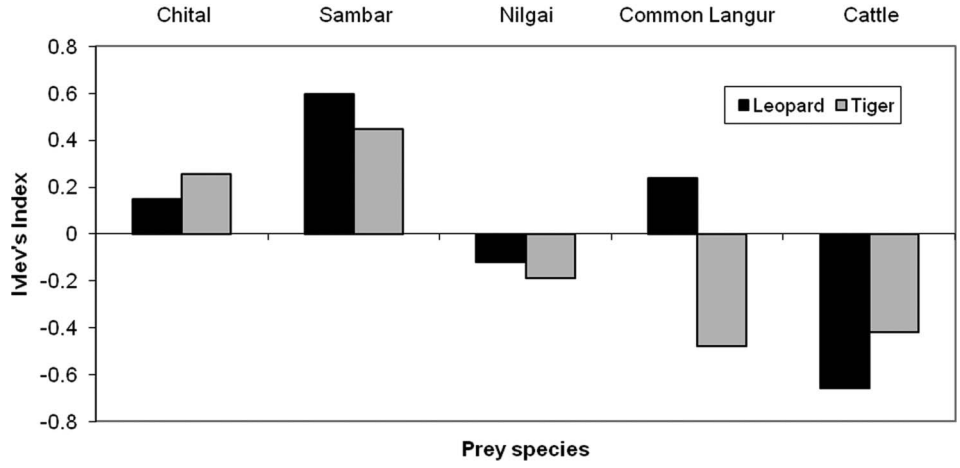

Figure 6. Prey selection of leopard and tiger in the study area of Sariska Tiger Reserve, Rajasthan, India.

Table II. Frequency of occurrence, percentage of occurrence and percentage biomass consumed of different prey species by leopard and tiger as shown by scat analysis.

Species	Frequency of occurrence		Percentage occurrence		(%) Biomass consumed	
	Leopard N = 90	Tiger N = 103	Leopard	Tiger	Leopard	Tiger
Chital	17	27	15.2	26.2	10.1	15.2
Sambar	51	43	45.5	41.7	54.2	43.2
Nilgai	10	11	8.9	10.7	14.1	14.7
Wild pig	3	–	2.7	–	1.7	–
Common langur	7	2	6.3	1.9	2.9	0.8
Cattle	8	20	7.1	19.4	11.1	26.2
Hare	3	–	2.7	–	1.1	–
Porcupine	6	–	5.4	–	2.5	–
Peafowl	7	–	6.3	–	2.5	–

chital > nilgai > cattle (Figure 6) and that of tiger was sambar > chital > nilgai > cattle > common langur (Figure 6).

The dietary overlap between leopard and tiger was calculated to be 94% (Pianka index). The Levin's niche breadth for the diet of leopard in the study area

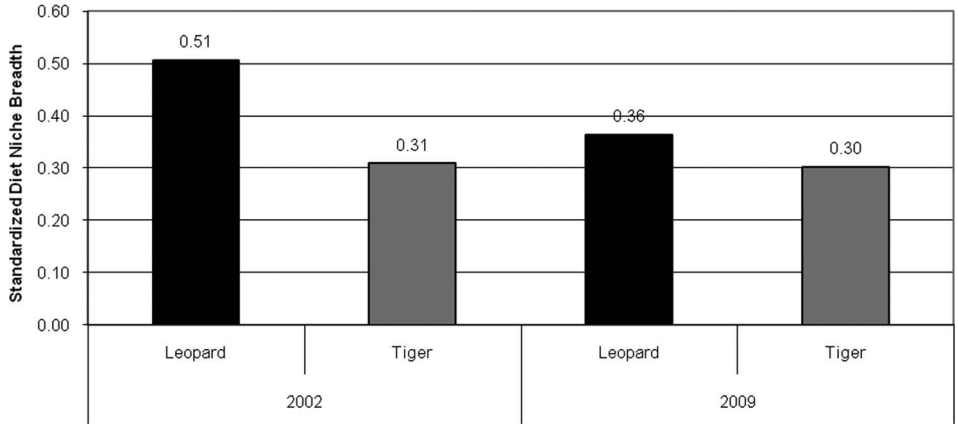

Figure 7. Standardized diet niche breadth of leopard and tiger in the study area in 2002 and 2009.

was 3.91 and that of tiger was 3.41. The standardized diet niche breadths of leopard and tiger in the study area were 0.36 and 0.30 respectively (Figure 7).

Discussion

Leopards hunt by stalking, utilizing their prey opportunistically and mostly at night (Nowell & Jackson 1996; Arivazhagan et al. 2007). The prey of leopards varies in different geographical areas. In Kruger National Park, South Africa, leopards were found to kill mainly medium-sized prey such as Impala (*Aepyceros melampus*), though a wide variety of small animals including hyraxes (*Procavia capensis*), civets (*Civettictis civetta*) and mongooses (*Herpestes* sp.) also formed part of their diet (Bailey 1993). In Tai Natinal Park, Ivory Coast, leopards prey upon 30 species of animals (Hoppe-Dominik 1984). Small prey also constituted a significant proportion of leopard diet in Tsavo, Kenya (Hamilton 1976). Muckenhirn and Eisenberg (1973) reported that in Sri Lanka leopards preyed mainly on chital and wild pig, while also feeding on sambar, common langur, black-naped hare, porcupine and calves of domestic buffalo. In India, Schaller (1967), Johnsingh (1983), Karanth & Sunquist (1995, 2000) studied leopard food habits; the major prey reported were chital, sambar, barking deer, goral and livestock. In Bandipur, Johnsingh (1983) found that 66% of leopard kills were chital. Chellam (1993) found that in Gir, 40% of leopards scats consisted of chital and 25% common langur. In the tropical forest of Nagarhole, Karanth & Sunquist (2000) found that chital constituted the major prey base of leopards. In the present study it was found that leopard and tiger were utilizing prey species in similar manner. Comparing with previous study, it was found that, leopard largely used to prey upon rodents when there was an established population of 12–16 tigers in Sariska TR (Sankar & Johnsingh 2002). During the present study, both leopard and tiger largely preyed on sambar and chital (Table I). The contribution of rodent in leopard's diet was 44.2% in 1990, when the study area was largely occupied by tigers (Sankar & Johnsingh 2002), but after the local extermination of tiger from the study area (2007-08), Mondal et al. (2011) found no contribution of rodent in leopard's diet. Later, after the re-introduction of tiger in the study area (in 2009), the contribution of rodent in leopard's diet raised to 5.4% (Table III). In 1990, chital contributed maximum in tiger diet (57.2%) followed by sambar (18.1%) and in leopard diet, rodent contributed maximum (44.2%) followed by chital (20.2%), sambar (19.4%) and nilgai (7%). But after the local extermination of tiger from the study area, the diet of leopard changed significantly. The contribution of sambar and nilgai in leopard's diet increased to 40.3% and 11.5% respectively in 2007-08, when there was no tiger in the study area (Mondal et al. 2011) (Table III). It was evident that, leopard shifted their diet from lesser prey species

Table III. Percentage occurrence of different prey species of leopard and tiger scats between 1990 and 2009 in Sariska Tiger Reserve, Rajasthan, India.

	1990		2008	2009	
	Leopard	Tiger	Leopard	Leopard	Tiger
Chital	20.2	57.2	22.4	15.2	26.2
Sambar	19.4	18.1	40.3	45.5	41.7
Nilgai	7.0	2.2	11.5	8.9	10.7
Common langur	6.2	17.4	10.4	6.3	1.9
Rodent	44.2	4.3	0	5.4	–
Peafowl	3.1	0.7	1.6	6.3	–
Dietary overlap*	0.54			0.94	

*Pianka Index.

to large ungulates after tiger extermination from Sariska (Sankar et al. 2009; Mondal et al. 2011). In the present study, it was found that, leopard and tiger consumed the prey species in similar way. Both leopard and tiger showed similar preference except for the arboreal prey species common langur, as common langur was preferred by leopard but avoided by tiger due to its less capability to climb tree (Figure 6). Ranathambore Tiger Reserve and Sariska Tiger Reserve both lies in Aravalli hills with similar habitat condition, environmental condition and prey base. The re-introduced tigers in Sariska TR consumed largely sambar (41.7%), chital (26.2%) and nilgai (10.7%), which are very similar to the previous study in Ranathambore Tiger Reserve (original habitat of re-introduced tigers), where tigers found to consume largely chital (45.7%), sambar (36.9%) and nilgai (3.3%) (Bagchi et al. 2003). Because of the presence of around 10,000 livestock population in the study area, the contribution of livestock in tiger diet is higher in Sariska TR (19.4%) than Ranthambore Tiger Reserve (5.5%), as there is no village situated inside Ranathambore Tiger Reserve. A high overlap (94%) was observed between leopard and tiger diet in the present study, though in the previous study the diet overlap was only 54% (Sankar & Johnsingh 2002). The standardized diet niche breadth of leopard (0.51) was observed much higher than tiger (0.31) in the previous study in the study area (Sankar & Johnsingh 2002), as leopard was largely dependent on small to medium sized prey species and had broader prey spectrum. But in the present study, the standardized diet niche breadth of leopard (0.36) and tiger (0.30) are similar (Figure 7).

Leopards have been found to coexist with other large canivores across most of their range. In Asia, it shares its habitat with the tiger, Asiatic lion and dhole (Karanth & Sunquist 1995, 2000). In Zaire, Central Africa, Hart et al. (1996) found the leopard coexisting with the golden cat (*Felis aurata*) by specializing on different prey. In Nagarhole, Karanth & Sunquist (2000) found that the tiger, leopard and dhole selectively killed different prey in terms of species, size and age-sex classes, allowing for the co-existence of all three predators. Leopards are opportunists and are flexible in diet; their ability to feed on both small and large prey, to climb trees and scavenge (Johnsingh 1983) may help them survive in highly disturbed habitat where prey species are scarce. Tigers, on the other hand, are not good climbers, limiting their ability to hunt arboreal prey. Unlike the study of Arivazhagan et al. (2007) and Seidenstickker & Lumpkin (1996), where leopards are more likely to move through open terrain and raid villages for domestic prey and tigers depend upon large ungulate prey (Ramakrishnan et al. 1999), in Sariska both the predators utilized the prey species in same manner and tiger consumed more domestic cattle (19.4%) than leopard (7.1%).

Available studies in India reported high dietary overlap amongst leopard, wild dog and tiger (Johnsingh 1983; Karanth & Sunquist 1995; Ramesh et al. 2008). Similar to present study, the dietary overlap between leopard and tiger was observed 94% in Nagarhole Tiger Reserve (Karanth & Sunquist 1995) and 82% in Mudumalai Tiger Reserve (Ramesh et al. 2008). Evidences suggest that among large sympatric carnivores, the larger carnivores can prey on broader size ranges of prey classes due to

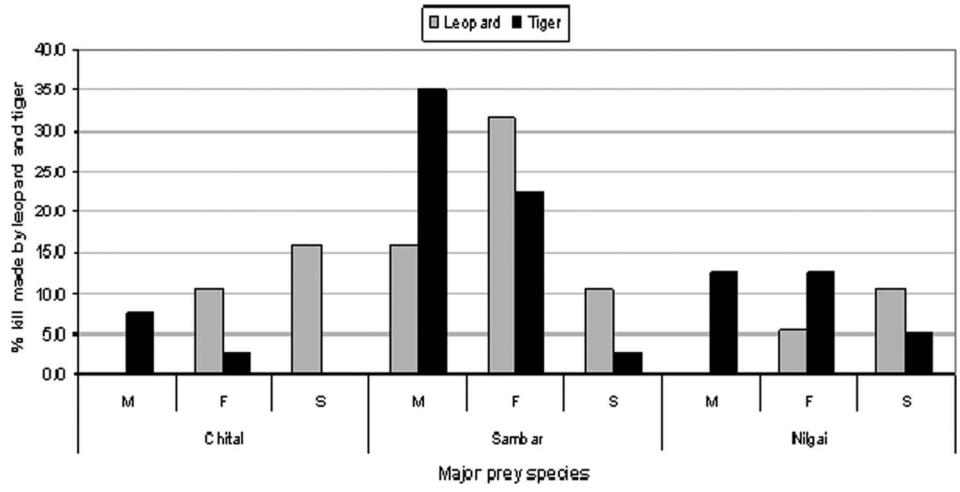

Figure 8. Age and sex classes of large herbivores observed by kill records of leopard (n=29) and tiger (n=40) in Sariska Tiger Reserve, Rajasthan, India. M= Male, F= Female, and S= Subadult.

their prey handling capabilities (Gittleman 1983). In Chitawan National Park where tigers and leopards co-exist, tigers were recorded utilizing a much wider range of prey sizes than leopards (Seidensticker 1976). The wild ungulate density in the intensive study area (102 individuals/km^2) is one of the highest reported density in Indian sub-continent (Mondal 2011) and adequate to support both leopard and re-introduced tiger population in the study area (Sankar et al. 2009). Though leopards and tigers utilized the same prey species in the study area, but there is a difference between the sex and size classes of prey species, as observed by kill records. Present study showed that tiger and leopard killed chital, sambar and nilgai but leopards largely killed females and fawns while tigers largely killed adult males and females (Figure 8). From the present study it was understood that, when there was a large number of tigers (12–16) in the study area (1988–1990), leopard was dependent on lesser bodied prey species and occupied broader diet niche breadth than tiger (Sankar & Johnsingh 2002). But after the extermination of tigers, diet of leopard completely shifted to large bodied ungulates (Mondal et al. 2011). After the re-introduction of tiger in the study area, both the predators utilized the prey species in a similar manner and showed similar preference towards large ungulates. The dietary overlap between leopard and tiger was also increased from 54% (1988–1990) to 94% (present study). There was a noticeable difference observed in the selection of sex and age class of prey species by these two predators, as leopard largely hunted fawns and females of large ungulates, while tiger largely hunted adult males, as observed by kill records (Figure 8). At present, there are only six re-introduced tigers in Sariska TR. With the increase in the number of re-introduced tigers a clearer picture of prey utilization and dietary interaction between these two top predators in the study area is expected.

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