Use of camera traps in parametric and non-parametric home range and utilization distribution estimation of tiger (*Panthera tigris tigris* Linn).

A.O. Varghese[1], Vishal Patil[2], Arun S. Suryavanshi[1], Rao Y.L.P.[3]
[1]Regional Remote Sensing Centre – Central, NRSC, Nagpur, India.
[2] Kalparatna Society, Navi Mumbai, India
[3] Van Bhavan, Forest Department Maharashtra, Nagpur, India

(Received on 30 October 2024; In final Form on 20 January 2025)

***DOI**: https://doi.org/10.58825/jog.2025.19.1.195*

Abstract: Each wild animal possesses a home range specific to their trophic level, characterizing that home range provides valuable insight into the animal's habits, social structure, and lifestyle. Camera trapping is one of the methods for analyzing the home ranges of some wildlife species where the individual species can be identified through the stripes or spot characteristics. This method offers essential insights about the target species while minimizing animal disturbance. It operates continuously, silently, and cost-effectively. In the present study, the utilization of camera traps in deriving the home ranges of tigers was analyzed using parametric and non-parametric home range estimators like Minimum Convex Polygon (MCP), Kernel Density Estimator (KDE), Autocorrelated KDE (AKDE) and Low Convex Hull (LoCoH) methods. Melghat Tiger Reserve, Maharashtra, India, was taken as a study site with the camera trap information derived from CaTRAT (Camera Trap Data Repository and Analysis Tool) and ExtractCompare (pattern recognition program). LoCoH is constructed using the k-1 nearest neighbors of each data point. To obtain a utilization distribution in KDE, probability contours were derived as 0.95 as the outer layer. LoCoH hulls were ordered from the smallest to the largest to get the utilization distribution, where the smallest hulls indicate frequently used areas. The average size of the home range of tigers in tropical dry deciduous forests of India derived from MCP, KDE, AKDE, and LoCoH were 51± SD 24, 87± SD 36, 111± SD 33, and 45 ± SD 21km^2 in that order. Average male tiger territory for the above home range estimators recorded were 80±15, 131±29, 146±23, 71±11 km^2 and 40±15, 71±22, 97±26 & 36±15 km^2 for females. In MCP and LoCoH methods, the outer boundary exactly matches the camera trap locations where it is recorded, but in real scenarios, this may be extended further up to some more areas that could not be captured in MCP and LoCoH methods. Moreover, the different hulls generated using LoCoH methods are not continuous in nature and do not give a clear picture of the utilization distribution. Data derived from camera traps with realistic and autocorrelated movement, KDE, MCP, and LoCoH underestimate home range substantially. So, considering these facts, it is concluded that AKDE with 95% probability contours appears to be the best method for home range estimation of tigers using camera traps where the sample size is small.

Keywords –Tiger, Home range, Minimum Convex Polygon, Kernel Density Estimator, Low Convex Hull

1. Introduction

As per IUCN (2001), the tiger is categorized as an endangered species. Although India has the most significant number of tigers, with an average number of 3682 as per the 2022 tiger census, individual populations are dispersed and generally small. Despite all the protection efforts focused on them, tigers continue to be endangered due to the depletion of their prey base, extensive habitat devastation, hunting for commercial drives, and pests and diseases. Geospatial technology is an ideal tool for generating inputs for conserving threatened species (Mani & Varghese, 2018; Varghese et al., 2010; Varghese et al., 2015).

Camera trapping is a method used to capture images of wild animals without disturbing them. It operates silently and continuously, providing proof of the species present in an area. This method provides evidence for management and policy decisions and is a cost-effective monitoring tool compared to extensive field surveys. One of the benefits of camera traps in tiger research is the identification of individual tigers from their stripes and the use of this information to estimate the home ranges of individual tigers in a landscape. An animal's home range is where it lives and moves regularly, and it is interrelated to the notion of an animal's territory, the aggressively defended area. Burt (1943) introduced the concept of a home range (HR); he depicted maps showing where the animal had been observed at different times. The home range, assessed in a spatial dimension, is vital information required for the conservation and management of species populations and, thus, by the ecosystem in which it thrives. The extent of territories and home ranges is normally based on prey base, water accessibility, and animal density, so it can also be defined as the smallest range that encompasses all the necessities of animal requirements. (Harestad and Bunnel 1979).

The standard method of drawing the HR is to create the minimum possible convex polygon in the peripheral regions in the presence of data gathered. However, this inclines to overemphasize the range size in some cases. There are many approaches available to estimate the extent of a home range and the oldest and most common method is the polygon method (Varghese et al., 2022). In this method the home ranges are derived from peripheral points or distances between points furthest apart. The minimum area polygon or Minimum convex-polygon (MCP) method is an example of a polygon method (Mohr, 1947), and the second category is called the center of activity approach. In the center of activity approach, home range is a derivative of the assumption of a parametric form for the utilization distribution (UD) function. This form ultimately fits the activity databases center or ambits. This technique mainly relies on the fact that most wild species do not use their full HR similarly, and some zones are inclined to be used more profoundly than others. So, the center of activity is the terrestrial area inside the HR, which signifies most of the activity of the animal concerned. Kernel density estimators (KDE) and Autocorrelated KDE (AKDE) are good examples of the center of activity Method (Worton, 1989). The third type of method is called the nonparametric estimators. Nonparametric estimators result from estimating the UD function using robust density estimators derived from radio collar/GPS tracking or camera-trapped locations' geographic locations. Low Convex hull (LoCoH) is a nonparametric method that falls under this category (Getz et al., 2007). In the nonparametric method, an animal’s area of UD function will also be considered its activity center. The activity radius is the distance from the activity center to radio collar/GPS tracking or camera-trapped locations' geographic locations. All these methods yield different kinds of home range areas and utilization distributions.

The present study was designed to derive individual home ranges of some of the tigers in the Melghat tiger reserve (MTR) using camera trap information with various home range analysis methods to find the best Method to adopt for home range and utilization distribution in the central Indian region.

2. Study Site

The location of the study area, MTR, comes in the Satpura hill ranges in the Maharashtra State, bordering Madhya Pradesh in the North and East have three divisions, i.e., Sipna, Gugamal and Akot (Figure1). MTR is spread over a vast area that covers 2027 km2, and most of the forest is dry deciduous (Yadav et al., 2023). This tract's forest is comprised mainly of *Tectona grandis* and *Dendrocalamus strictus* species as dominant and with other sub species like *Madhuca latifolia*, *Diospyrous melanoxylon*, etc. Vegetation and climate are interdependent; climate determines the vegetation type in the reserve, i.e., dry deciduous forest. Summer has an extreme temperature of 48˚C and winter with the lowest temperature of 4˚C. Rainfall of this tract fluctuates from 950 mm to 1400 mm during the monsoon months. The hills and valleys of the study area have constant abrupt variations in aspect and gradient; the height above sea level ranges between 381 meters to 1100 meters, with nearly eight to ten percent of the area of steep escarpment.

3. Materials and Methods

The Maharashtra Forest Department provided camera trap information used in the present study during 2017-2020. Moultrie Deercam cuddeyback ambush color trail cameras, which use physical movement and temperature sensing of the animals, are used by the Maharashtra Forest Department. Two cameras were installed opposite each other to take both side flank pictures of tiger because both side stripe patterns are different, giving accurate identification of each tiger. Camera traps were systematically distributed within the sampling area by 2 superimposing a 2 km grid and deploying at least one pair of cameras within each grid.

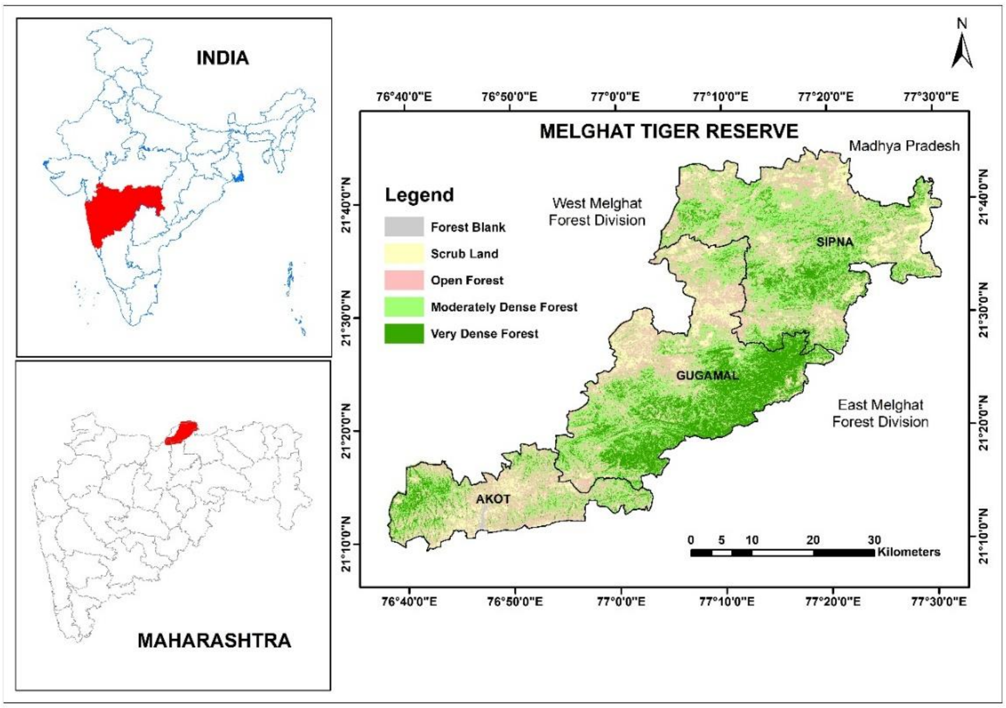

Figure 1. Location map of the study area

The cameras were placed in the best possible location to maximize photo-captures of tigers, identified through extensive search during sign surveys. An image processing software known as CaTRAT (Camera Trap Data Repository and Analysis Tool) was used for organizing and geotagging (tagging individual pictures with the location of the camera trap site) of photo captures obtained from the field. Individual identification is carried out using the pattern recognition program ExtractCompare (Hiby et al., 2009) for tigers. Once individual tigers were identified, a matrix of spatial capture history for each tiger was developed for each site with camera trap IDs, their coordinates, and the deployment and operation history of each camera. Data based on a camera trap with a GPS tag was used to assess the approximate home range of tigers in the reserve. Locations of all camera traps (latitude/longitude) are converted into spatial form, and by analyzing the sight of each tiger recorded in the camera, the ID of that tiger is assigned and tagged to that camera trap attribute. A total of seven hundred and fifty-one cameras are installed in MTR and spread all over the reserve to capture the movement of the wildlife. The present study selected a database of 11 tigers for the home range analysis, out of which three are male (T22, T34, and T80). Tigers with complete data spanning all four years, whose home ranges are located well within the study area, and with a fair representation of females, were selected for the study.

The present study has taken MCP, KDE, AKDE, and LoCoH home range estimators for the home range analysis with the commonly used packages like adehabitatHR (Calenge et al., 2011) and ctmm (Calabrese et al., 2016). KDE uses locational data to create a utilization distribution, which describes the probability that an animal can be found in a given location (Worton, 1989). In KDE, a kernel distribution, a three-dimensional hill or kernel, is placed on each telemetry location. The two most frequently used KDE are adaptive kernel and fixed kernel. The difference between the two is related to the smoothing parameter (SP, also called the bandwidth), with the SP fixed across the dataset in a fixed kernel and the SP varying depending on the density of the data points in the adoptive kernel (Worton, 1989). The bandwidth of the distribution determines the height of the hill. Choosing the right bandwidth is critical and can have a greater effect than the shape of the kernels themselves (Silverman, 1986). A small bandwidth creates a distribution with numerous peaks surrounding each cluster of recorded locations. In contrast, a large bandwidth smooths these peaks, resulting in a more dispersed distribution (Worton, 1989). KDE assumes that the input animal tracking data are independent and identically distributed. However, these data are inherently autocorrelated and violate this vital assumption. The conventional KDE results in unacceptably underestimated home ranges, and they proposed an AKDE method to use autocorrelated data. The present study used autocorrelated Gaussian reference function bandwidth with a debiased area.

The LoCoH method is a generalization of the minimum convex polygon (MCP) method and is a nonparametric kernel method (Getz and Wilmers, 2004). LoCoH applies the MCP construction to a subset of data localized in space, and the local convex polygon (i.e., local hull) is constructed using the k-1 nearest neighbors of each data point, thereby producing a set of nonparametric kernels whose union is the utilization distribution. Thus, LoCoH uses kernels with forms arising directly out of the data, unlike parametric kernels with a form specified by a one-parameter function in most cases. To obtain a utilization distribution, the hulls are ordered from the smallest to the largest, where the smallest hulls indicate frequently used areas. By gradually combining the data points from the smallest values upwards until approximately x% of the points are included (allowing for some rounding error), the boundaries of the resulting union will represent the x% isopleth of the densest cluster of points within the utilization distribution. Depending on the convention, the home ranges can be defined as the area bounded by the 100% isopleth of the utilization distribution or, for purposes of comparison, the 95% isopleth which is the one most commonly used for utilization distribution s constructed from more traditional, particularly noncompact, kernels such as the symmetric bivariate Gaussian.

4. Results and discussion

The tiger's extensive geographical range suggests a significant adaptability to various environmental conditions. The key factors for its survival include sufficient vegetation, access to water, and a healthy prey population. To assess the home ranges of tigers, biotelemetry is a precise and effective technique; however, its utility is limited to specific individuals. An alternative method for estimating home ranges is camera trapping, which is especially valuable for monitoring small home ranges and a diverse array of species and activities. The limitation of camera trapping is that it generates data only from fixed-point camera stations. HRs of twelve tigers of the study area were estimated from the 751 cameras deployed in the study area using MCP, KDE, AKDE, and LoCoH methods. The area-wise occurrence of tigers in the reserve discloses that tigers exist more in the divisions of Akot and Gugamal. Likewise, the Chikaldara and Dhargad ranges exhibit a more significant population of tigers per the camera trap information. IUCN (1994) recommended a minimum convex polygon (also called a convex hull) to measure habitat area. MCP is the minimum polygon with no interior angle exceeding 180 degrees. MCPs are constructed around the most extreme points in space; area estimates derived from them may be sensitive to errors in location. In the present study, the MCP of the 11 tigers was derived (Figure 2), and the MCP was calculated for a 0.95 fraction of points (distance from the center). For calculating MCP for 0.95 fractions of points, a fixed mean of points of locations was used. MCP for 0.95 fraction of points is the same as MCP in all the cases except for the tiger T22, where it is deviated because of some outlier point. The minimum and maximum home range areas registered using the MCP method are 14.33 km^2 and 91.20, respectively, with an average home range size of 50.77 km^2 (Table 1). The home range size reported from other regions of India using MCP method for adult male tigers are 188.6 km^2 in Panna (Chundawat et al., 2002), 25.7 km^2

in Nagarhole (Karanth and Sunquist, 2000), 102 km^2 in Sariska (Sankar et al., 2010), 46.1 km^2 in Rathanbore (Chakravarty, 2009) and 55.1 km^2 in Pench (Jhala et al., 2010). HRs of three collared Bengal tigers of different sexes and ages in Pench Tiger Reserve, Madhya Pradesh, using 100% MCP were 43 km^2 (adult female), 55.1 km^2 (adult male), and 52.2 km^2 (sub-adult male) (Majumder, 2012). In a study reported by Huai Kha Khaeng Wildlife Sanctuary, Thailand, male tigers' average HR extent was estimated using 95 and 100% MCPs, which were 267 and 294 km^2, respectively. The average female HR area for the same study site was 70 km^2 for 95% MCP and 84 km^2 for 100% MCP (Simcharoen et al., 2014). MCP is the simplest method to use and is very easy to calculate. However, it cannot estimate the intensity of occupation or the utilization pattern of a home range.

Table 1. Estimated home range size of tigers using different methods

Sl No	Tiger ID	MCP	KDE	AKDE	LoCOH
1	T1	50.63	69	90	44.48
2	T11	40.54	72	88	40.54
3	T12	49.83	82	136	39.86
4	T22	91.2	100	122	68.24
5	T24	14.33	28	42	14.06
6	T25	66.79	103	117	66.79
7	T34	58.75	124	138	58.73
8	T52	36.63	96	109	30.87
9	T67	27.66	60	104	23.88
10	T71	30.95	59	92	27.61
11	T80	91.19	170	178	86.00

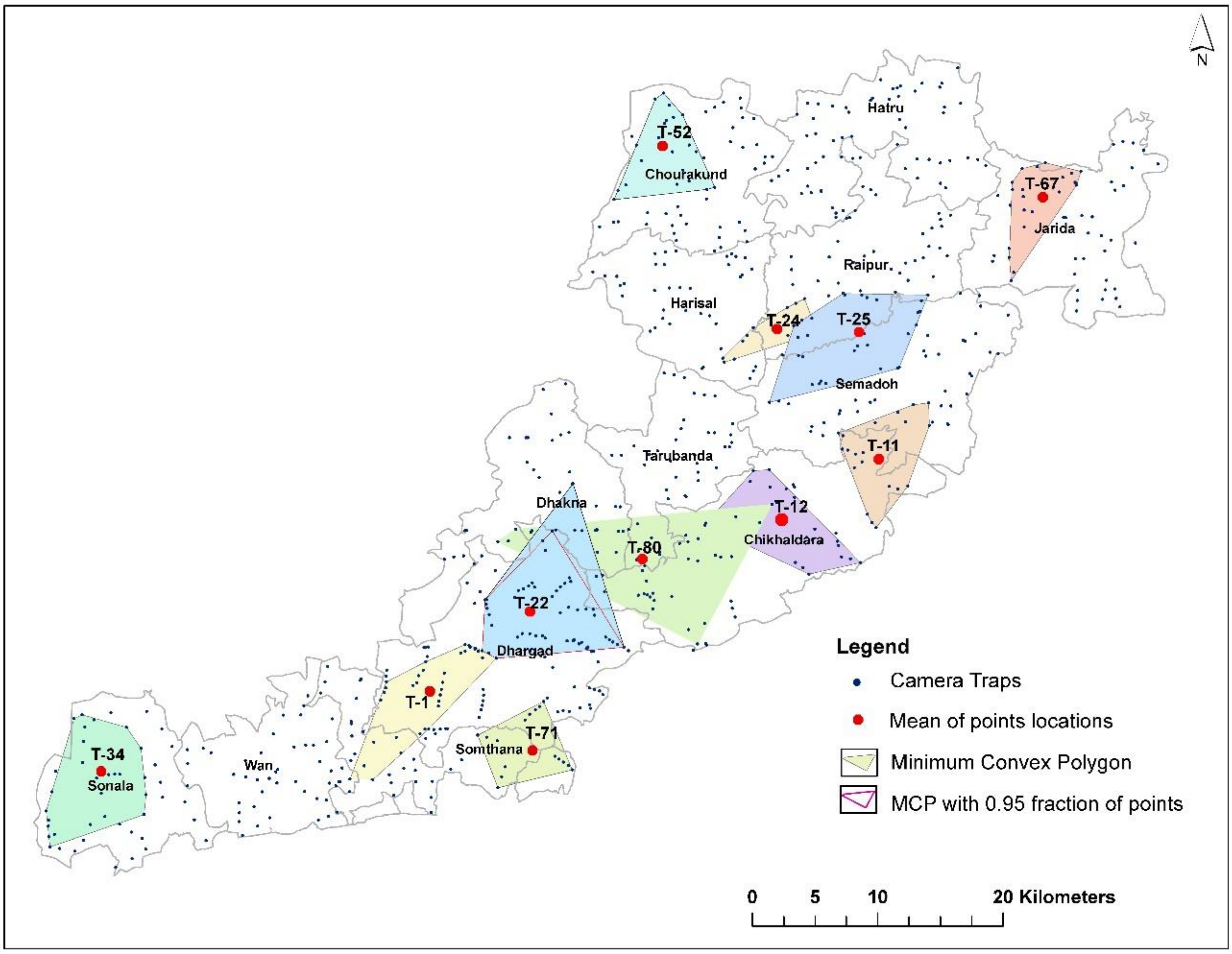

Figure 2. Home ranges of tigers in MTR estimated using MCP method

The KDE-derived home ranges of the tigers of MTR denote that the average home range size is 87 km^2 with a minimum range size of 28 km^2 and a maximum size of 170 km^2 (Table 1). HRs of three collared Bengal tigers of different sexes and ages in Pench Tiger Reserve, Madhya Pradesh using 95% fixed Kernel, were 32.1km^2 (adult female), 64.1 km^2 (adult female), and 19.1 km^2 (sub-adult male) (Majumder, 2012). The KDE HR assessment process eliminates the convex polygon's limitation, including unused zones in the estimation. Still, the KDE method derives more spaces inside the HRs (Getz and Wilmers, 2004) and overrates the size of HRs, irrespective of the chosen bandwidth (Blundell et al., 2001, Downs and Horner, 2008). Besides, KDE assesses the presence locational information as stationary, independent events, but these data are inherently autocorrelated and violate this critical assumption. It is reported and proven that with realistic and autocorrelated movement data, KDEs underestimate the home range (Swihart and Slade 1985, Hansteen et al. 1997). Moreover, autocorrelation-influenced underestimation of HR is predominantly noticeable when the sample size is small, as in the case of the present study. So, the present study utilized the AKDE method, which gives a minimum home range size of 42 and a maximum of 178 with an average home range of 111 km^2. Home ranges of one tiger and one tigress are given in figure 3, showing that the dark contour line demarcates the area of 95 percent HR. As can be seen in the figure, the other two lines in grey shade exhibit the 95 percent confidence range area of the HR.

The density estimate is shown in blue shading with location locational distribution in red dots. KDE is relatively straightforward to compute, is widely used in current literature, and provides a clear representation of home range utilization patterns. Nevertheless, it assumes there are no barriers to movement. LoCoH technique is fundamentally a form of the MCP method with some post-processing, i.e., amalgamation of the hulls generated. Three diverse approaches are there to describe the neighborhood of a point to create the local hulls, as per Getz et al. (2007). The first one is adaptive LoCoH, which uses all those points inside the sum distance of the center point for the local convex hull where the sum of the distance between the points and the center point is lesser than the distance. The second method, k-nearest neighbor, uses all k adjacent points from the center point. The third method is a radius-based approach utilizing all points within a circle of radius r from the center point to shape the local convex hull (Getz et al., 2007). The present study used the k-nearest neighbor approach, initiated by building the convex hull related to an individual point (the root) and its k-1 adjacent neighbors. The combination of all these hulls is finite and was used to characterize the HR of the targeted animal, with the outer boundary as a hundred percent cover hull. To get a utilization distribution function of the concerned animal, the hulls are arranged from the minimum to the maximum, where the lowest hulls represent the recurrently utilized parts. (Figure 4). For graphical representation, all the hulls are colored into five based on the density values irrespective of the number of hulls.

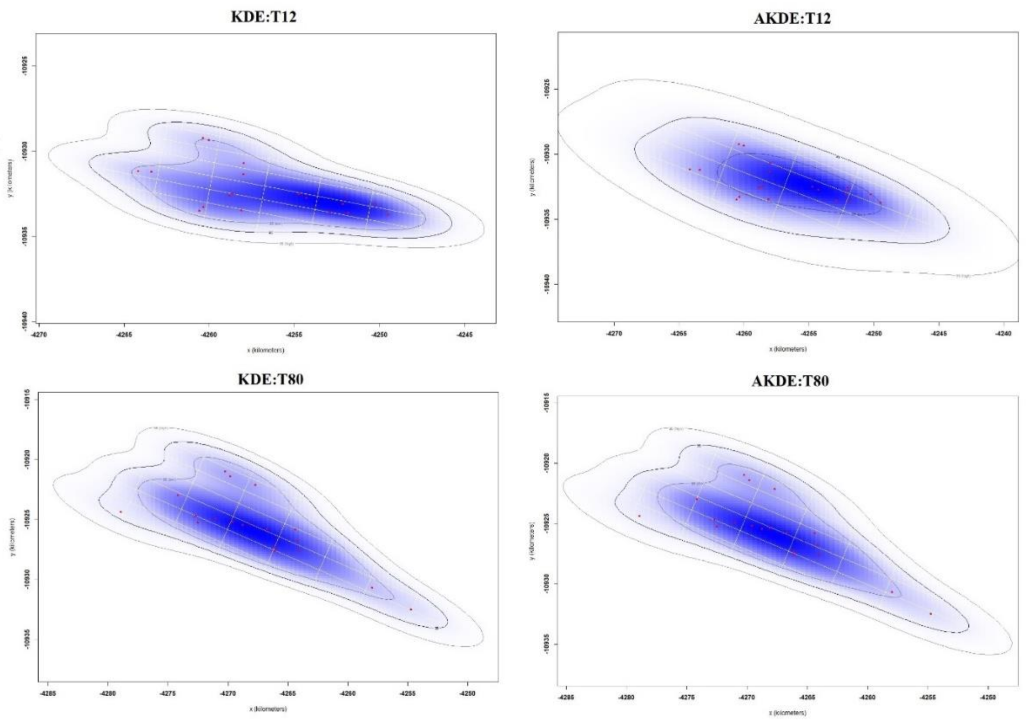

Figure 3. Home ranges of tigers in MTR estimated using KDE and AKDE method

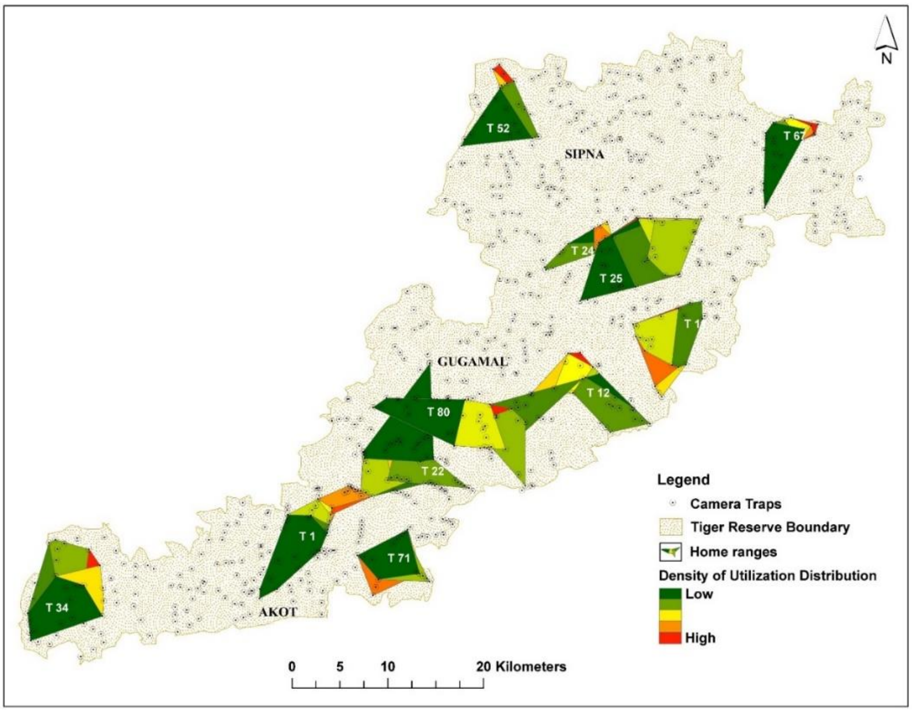

Figure 4. Home ranges of tigers in MTR estimated using LoCoH method

Home ranges derived from the LoCoH method denote that the average size of the home range for tigers in MTR is 45.55 km2, with the smallest being 14.06 km2 and the highest being 86.00 km2. LoCoH takes rigid boundaries into account, making it a more complex method that requires more time to implement. The estimates produced can be somewhat subjective, depending on the chosen parameters, and a large sample size of GPS points is necessary for accurate results. In MCP and LoCoH methods, the outer boundary matches the camera traps where the particular tiger is registered. In a real scenario, this may be extended to more areas that could not be captured in MCP and LoCoH methods because of the stationary, independent points of camera traps based on presence data. Moreover, the different hulls generated using LoCoH methods are not continuous and do not give a clear picture of the utilization distribution. The present study registered male tigers' average home range size for the above home range estimators as 80, 131, 146, and 71 km^2, and that of females was 40, 71,97, and 36 km^2. As can be seen from the figures, the HRs of tigers in this sanctuary overlap in some cases, especially in the case of T80, a male tiger. Tigers are solitary animals within their home range, but the HRs of male tiger's interconnect with the tigress of the adjoining areas. A male's HR generally intersects with one to several females' home range(s). That is the reason for the elevated home range size of male tigers. The AKDE with 95% probability contours is the best method for home range estimation of tigers using camera traps when considering the abovementioned factors.

The specific home ranges of each tiger in a protected area can provide valuable insights into their interactions over space and time, daily activities, and social behaviours related to gender. This information is crucial for various conservation efforts, including the reintroduction of tigers into vacant ranges, managing spill over areas, prey augmentation plans, and identifying essential resources such as waterholes and salt licks. Additionally, data from camera traps can be utilized for monitoring invasive species, developing tourism guidelines, facilitating village relocations, tracking illegal poaching and logging activities, and mitigating human-wildlife conflicts. Using camera traps will greatly enhance the accuracy of locating tigers and determining their home ranges. Previous methods, which relied on sighting, scat, scratches, and pugmarks, often led to inaccurate estimates of tiger locations and individual identification.

The HRs of tigers are primarily influenced by factors such as gender, habitat, prey availability, and subspecies. For Amur (Siberian) tigers (*Panthera tigris altaica*), snow tracking has estimated an average HR of 1,385 km^2 for males and 390 km^2 for females in the Sikhote-Alin Biosphere Reserve in Russia (John, 2010). In Southwestern Primorski, the HRs are estimated to be between 800-1,000 km^2 for males and 200-400 km^2 for females (Matyushkin, 1979). Other studies in the Sikhote-Alin Biosphere Reserve found HRs of 500-600 km^2 for males and 190-250 km^2 for females (Poddubnaya and Kovalev, 1993). In contrast, the HRs of Bengal tigers (*Panthera tigris tigris*) estimated through tracking and observation show an average of 65 km^2 for males and 78 km^2 for females (Schaller, 1967). Utilizing radiotelemetry, the estimates in Panna National Park, Madhya Pradesh, India, were found to be 243 km^2 for males and 27 km^2 for females. For Sumatran tigers (*Panthera tigris sondaica*), research using camera traps indicated that the HRs are approximately 116 km^2 for males and between 49-70 km^2 for females in Sumatra, Indonesia (Franklin, 1999).

5. Conclusion

Many methods are available for home range analysis of wildlife species targeted for conservation and management. The utility, shape, and area derived will vary differently among these methods. So, these techniques must be used by the targeted species, sample size, and region to which the species belongs. The present study compared and analyzed camera traps in parametric and non-parametric home range estimation of tigers using 100% MCP, KDE, AKDE, and LoCoH k-nearest neighbor approaches. The average size of the home range of tigers in tropical dry deciduous forests of India derived from MCP, KDE, and LoCoH were 51, 87, 111, and 45 km2 in that order. The average male tiger territory for the above home range estimators recorded were 80, 131, 146, 71 km2 and 40, 71,97, and 36 km2 for females. Male tigers have more extensive home ranges because of their overlapping ranges with adjoining females. In MCP and LoCoH methods, the outer boundary matches the camera trap locations where it is recorded. However, in the actual scenario, this may be extended to more areas that could not be captured in MCP and LoCoH methods. Moreover, the different hulls generated using LoCoH methods are not continuous in nature and do not give a clear picture of the utilization distribution. When compared to the reported home ranges of similar habitats and analysis of the overlapping home ranges in the present study and the inherent autocorrelated nature of the data, it is suggested that the AKDE method with 95% probability contour as the outer layer is the best. Advancements in the latest technology in GPS real movement data with much finer resolution will tend to result in longer-lasting autocorrelations. So, in these circumstances, the AKDE method provides an accurate estimate of home ranges, as mentioned in the present study.

References

Blundell G.M., J. A. K. Maier and E. M. Debevec (2001). Linear home ranges: effects of smoothing, sample size, and autocorrelation on kernel estimates. *Ecological Monographs* 71: 469–489.

Burt W. H. (1943). Territoriality and Home Range Concepts as Applied to Mammals, *Journal of Mammalogy* 24(3):346-352.

Calabrese J.M., C. H. Fleming and E. Gurarie (2016). Ctmm: An R package for analyzing animal relocation data as a continuous-time stochastic process. *Methods in Ecology and Evolution* 7(9) :1124-1132.

Calenge C. (2011). Home range estimation in R: the adehabitatHR package. Office national de la classe et de la faune sauvage: Saint Benoist, Auffargis, France.

Chakravarty P. P. J., (2009). Ranging patterns of tigers in Ranthambhore Tiger Reserve, Rajasthan. Abstract. 23rd Annual Research Seminar, Wildlife Institute of India, Dehra Dun, India (http://www.wii.gov.in/research/abstracts/irs_abstracts_2009.pdf).

Chundawat R.S., N. Gogate and P. K. Malik (2002). Understanding tiger ecology in the tropical dry forest of Panna Tiger Reserve. WII (1996–2002) Technical report. p.105.

doi:10.2461/wbp.2012.8.4

Downs J. A. and M. W. Horner (2007). Network-based home range analysis using Delaunay Triangulation. In Proceedings of the Fourth International Symposium on Voronoi Diagrams in Science and Engineering (ISVD 2007), Pontypridd, Wales: 255– 9.

Franklin N., S. Bastonio, D. Siswomartono, J. Manansang and R. Tilson (1999). Last of the Indonesian tigers: A cause for optimism. In: J. Seidensticker, S. Christie, and P. Jackson, (eds.) Riding the tiger: tiger conservation in human-dominated landscapes Cambridge University Press, Cambridge, United Kingdom, Pp. 130–147.

Getz W.M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan et al, (2007). LoCoH: Nonparameteric Kernel Methods for Constructing Home Ranges and Utilization Distributions. *PLoS ONE* 2(2): e207. doi:10.1371/journal.pone.0000207.

Getz W. M. and C. C. Wilmers (2004). A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. *Ecography* 27: 489–505.

Hansteen T. L., H. P. Andreassen and R. A. Ims. (1997). Effects of spatiotemporal scale on autocorrelation and home range estimators. *Journal of Wildlife Management* 61:280–290.

Harestad A. S. and F. L. Bunnel (1979). Home Range and Body Weight-A Revaluation, *Ecology* 60(2):389-402.

Hiby L., P. Lovell, N. Patil, N. S. Kumar, S. G. Gopalaswamy and K. U. Karanth (2009). A tiger cannot change its stripes: using a three-dimensional model to match images of living tigers and tiger skins. *Biology Letters* 5: 383 - 386.

IUCN (1994). IUCN Red List Categories. Gland, Switzerland: International Union for the Conservation of Nature, Species Survival Commission.

IUCN (2001). IUCN Red List Categories. Version 3.1. Gland, Switzerland: International Union for the Conservation of Nature, Species Survival Commission.

Jhala Y.V., Q. Qureshi, R. Gopal and P. R. Sinha (2010). Status of tigers, co–predators and prey in India. National Tiger Conservation Authority, Govt., of India, New Delhi and Wildlife Institute of India, Dehradun. Technical report 11/003 p.302.

John M., Goodrich, D. G. Miquelle, E. N. Smirnov, L. L. Kerley, H. B. Quigley and M. G. Hornocker (2010). Spatial structure of Amur (Siberian) tigers (*Panthera tigris altaica*) on Sikhote-Alin Biosphere Zapovednik, Russia. *Journal of Mammalogy* 91 (3): 737–748, https://doi.org/10.1644/09-MAMM-A-293.1.

Karanth K. U. and M. E. Sunquist (2000). Behavioural correlates of predation by tiger (Panthera tigris), leopard (Panthera pardus) and dhole (Cuon alpinus) in Nagarahole, India. *Journal of Zoolology* 250: 255–265. DOI:10.1111/j.1469-7998.2000.tb01076.x

Majumder A., S. Basu, K. Sankar, Q. Qureshi, Y.V. Jhala, P. Nigam and R. Gopal (2012). Home ranges of Bengal tiger (*Panthera tigris tigris* L.) in Pench Tiger Reserve, Madhya Pradesh, Central India. *Wildlife Biology in Practice* 8(1):36-49.

Mani J. K. and A. O. Varghese (2018). Remote Sensing and GIS in Agriculture and Forest Resource Monitoring. In: Reddy, G., Singh, S. (eds) Geospatial Technologies in Land Resources Mapping, Monitoring and Management. Geotechnologies and the Environment, vol 21. Springer, Cham. https://doi.org/10.1007/978-3-319-78711-4_19.

Matyushkin E. N. (1978). Characteristic features of distribution and ecology of the Amur tiger as a geographical form of a species adapted to an extreme environment. International Tiger Symposium, Leipzig Zoological Garden 1:23–32.

Mohr Carl O. (1947). Table of Equivalent Populations of North Americ an Small Mammals. *American Mid-land Naturalist* 37: 223–249.

Poddubnaya N. J. A. and V. A. Kovalev (1993). The tiger in the Ussuriysky Zapovednik: Status and prospects for preservation. Bulletin Moscovsky Obschestva Ispytateley Prirody 98:54–61.

Sankar K., Q. Qureshi, P. Nigam, P. K. Malik, P. R. Sinha, R. N. Mehrotra, R. Gopal, S. Bhattacharjee, K. Mondal and S. Gupta (2010). Monitoring of reintroduced tigers in Sariska Tiger Reserve, Western India: preliminary findings on home range, prey selection and food habits. *Tropical Conservation Science* 3: 301–318.

Schaller G. B. (1967). The deer and the tiger. University of Chicago Press, Chicago, Illinois.

Silverman B.W. (1986). Density estimation for statistics and data analysis. London: Chapman and Hall.

Simcharoen A., T. Savini, G. Gale, S. Simcharoen, S. Duangchantrasiri, S. Pakpien and J. Smith (2014). Female tiger *Panthera tigris* home range size and prey abundance: Important metrics for management. *Oryx* 48(3): 370-377. doi:10.1017/S0030605312001408.

Swihart R. K. and N. A. Slade. (1985). Testing for independence of observations in animal movements. *Ecology* 66: 1176–1184.

Varghese A.O., A. K. Joshi and Y. V. N. Krishna Murthy (2010). Mapping of Realized and Fundamental Niches of Threatened tree Species Using Geoinformatics: A Species Level Approach for Sustaining Biodiversity, Special issue on Biodiversity and Landscape Ecology of *Journal of Indian Society of Remote Sensing* 38 (3): 523-534.

Varghese A.O., V. B. Sawarkar, Y. L. P. Rao and A. K. Joshi (2015). Habitat Suitability Assessment of *Ardeotis nigriceps* (Vigors) in Great Indian Bustard Sanctuary, Maharashtra (India) Using Remote Sensing and GIS. *Journal of the Indian Society of Remote Sensing* DOI: 10.1007/s12524-015-0486-9.

Varghese A.O., A. S. Suryavanshi and C. S. Jha (2022). Geospatial Applications in Wildlife Conservation and Management. In: Jha C.S., Pandey, A., Chowdary, V., Singh, V. (eds) Geospatial Technologies for Resources Planning and Management. Water Science and Technology Library, vol 115. Springer, Cham. https://doi.org/10.1007/978-3-030-98981-1_31.

Wildl. Biol. Pract., 2012 June 8(1): 36-49

Worton B.J. (1989). Kernel Methods for Estimating the Utilization Distribution in Home-Range Studies. *Ecology* 70(1): 164-168. https://doi.org/10.2307/1938423.

Yadav S.P., V. R. Tiwari, A. Mallick, R. Garawad, G. Talukdar, S. Sultan, N. A. Ansari, K. Banerjee and A. Das (2023). Management Effectiveness Evaluation of Tiger Reserves in India, Fifth Cycle, 2022. Wildlife Institute of India, Dehradun and National Tiger Conservation Authority, Government of India.