JULY
2023

TIGER POPULATION ESTIMATION

IN WAYANAD LANDSCAPE

PARAMBIKULAM
TIGER RESERVE
PALAKKAD, KERALA, INDIA

PARAMBIKULAM
TIGER CONSERVATION
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TIGER POPULATION ESTIMATION IN WAYANAD LANDSCAPE, KERALA – 2023

KERALA FORESTS AND WILDLIFE DEPARTMENT
THIRUVANANTHAPURAM

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ACKNOWLEDGEMENT

In the context of widespread propaganda spread among the public that the number of tigers in Wayanad Landsacpe has exceeded its carrying capacity, Hon'ble Minister for Forest and Wildlife, Government of Kerala, **Shri. A.K. Saseendran** announced in the Assembly (15th Legislative Assembly in its 8th Session during February 2023) that the tiger population in Wayanad Landscape would be carried out to find out the exact situation. Accordingly, the Kerala Forests and Wildlife Department carried out the tiger population estimation in Wayanad Landscape from 10th April to 25th May 2023 with the help of Parambikulam Tiger Conservation Foundation and experts. We wholeheartedly acknowledge the guidance given on this by the Hon'ble Minister for Forest and Wildlife.

ABBREVIATIONS

AITE - All India Tiger Estimation

AKTE - All Kerala Tiger Estimation

APCCF - Additional Principal Chief Conservator of Forests

CCF - Chief Conservator of Forests

CF - Conservator of Forests

CT - Camera Trap

EDC - Ecodevelopment Committee

FD - Forest Division

GOI - Government of India

GOK - Government of Kerala

ITL - Inter-state Tiger Landscape

LS - Landscape

MSL - Mean Sea Level

Non-PA - Non-Protected Area

NP - National Park

NTCA - National Tiger Conservation Authority

PA - Protected Area

PCCF - Principal Chief Conservator of Forests

RF - Reserved Forest

TR - Tiger Reserve

WG - Western Ghats

WII - Wildlife Institute of India

WLD - Wildlife Division

WLS - Wildlife Sanctuary

WP - Working Plan

DEFINITIONS

Abundance - Total number of individuals or items of interest in some defined area and time period; also known as absolute abundance.

Age-category in tiger population - The tiger population in the wild include individuals of both sexes with various age-classes viz., **cub** (< 12 month-old), **juvenile** (12-24 month-old pre-dispersal tiger), **transient floaters** (>24 month-old, dispersing tiger that do not breed or hold stable home range) and **resident breeder** (tiger that maintain stable range and reproduce). During their wanderings, the transient floaters move several kilometers and range across many breeder territories, constantly looking for vacancies to settle down. The presence of floaters appears to be tolerated to some extent by their mothers, and by the specific individual male tigers that sired them. When a breeder becomes old, weak or injured, its tenure is ended by a more vigorous rival (either a neighbour or a transient floater) who takes over its range. A small segment of the transient population may also comprise of evicted breeders, although such animals may be short-lived.

Bias - A persistent statistical error associated with parameter estimates whose source is not random chance. More precisely, bias is the difference between the expected value of a parameter estimate and the true value of the parameter. For example, a negatively biased estimator produces estimates that, on average, are smaller than the true quantity being estimated.

Closed population - A fixed group of individuals within a defined area and time period, i.e., there are no births, deaths, immigration and emigration on the area for the period of interest.

Coefficient of variation (CV) - Ratio of a standard error of a parameter estimate to the parameter estimate. The coefficient of variation is used in computing sample sizes and as a measure of relative precision when comparing degree of variation among different estimates or sets of data.

Confidence interval (CI) - An interval around a parameter estimate that provides a measure of confidence regarding how close a sampled-based estimate is to the true parameter. The usual two-sided symmetrical confidence interval around the parameter estimate is generated by adding and subtracting the quantity computed from the product of the standard error and the t value or z value corresponding to the pre-specified (1-K) % confidence level (K is frequently set at 0.05). For example, a 95% confidence interval will contain on average, the true parameter of interest 95 of 100 times if 100 such intervals were calculated in a like manner. That is, confidence refers to the procedure of obtaining an interval rather than the interval itself. There is not a 95% probability that the true parameter occurs in the interval; either a parameter is in the interval or it is not.

Cub - Refer age-category

Density - Total number of individuals or objects of interest per unit area (also known as absolute density). Sometimes, the concept is broadened to mean number of animals per unit resource, where resource could be suitable habitat, food abundance, etc.

Home Range - A home range is described as an area (where it spends its time encompassing all the resources the animal required to survive and reproduce), spanned by animals during their normal activities of foraging, mating, and caring for the young (Burt. 1943). Competition for food and other

		resources influences how animals are distributed in space.
Interstate Tiger Reserves	-	The series of Tiger Reserves and Protected Areas located in Western Ghats such as Nagerhole-Bandipur-Wayanad-Mudumalai-Sathyamangalam-Biligirirangan Thittu that spread across the states of Karnataka, Kerala and Tamil Nadu all together known as 'Interstate Tiger Landscape'. These areas have a contiguous tiger population with ample connectivity, which is important for long- term survival of tiger populations. Also, these areas hold the highest population of wild tigers in the world as well as one of the four source populations in India which have the required population size for long term survival without immigration.
Juvenile	-	Refer age-category
Potential Home Range Centre	-	In SPACECAP analyses, the surveyed area containing the camera trap array combined with an extended area surrounding it, known as the "state-space" of the underlying point process (S), which is represented by a large number of equally spaced points in the form of a very fine mesh. These points are visualized as representing all possible potential activity centers (or home range centers) of all the animals in the animal population being surveyed (Pallavi Singh et. al., 2010).
Resident Breeder	-	Refer age-category
Sample	-	A group of sampling units selected during a survey.
Spatial distribution	-	A geographical range of locations or areas occupied by a species.
Standard deviation (SD)	-	Square root of variance of individual items in a probability distribution. In this case, □distribution□ refers to either the true or population distribution, such as the distribution of all plot abundances, N_i (called the

population standard deviation), or the distribution within a single sample, such as the distribution of items within a single plot sample (called the sample standard deviation or just standard deviation).

Standard error (SE) - Square root of variance; the standard deviation of a sampling distribution of sample estimates. The population standard error describes this measure for a sampling distribution of all possible sample estimates. An estimator of this quantity, called the sample standard error (or just standard error), may be obtained from a single sample and, for infinite populations, is equal to the sample standard deviation divided by the square root of sample size. The standard error is especially useful for computing a confidence interval for a parameter estimate.

State-Space - Refer Potential Home Range Centre

Territory vs Home Range - A territory of an individual provides a safe place for young to be raised and usually contains a breeding site at its centre. A territory can be marked out using movements (displays), sound (calling) or smell (scent). A territory is a defended area which can be as small as the space around the individual. A home range, in contrast, is simply the area where an individual spends its time. An animal's home range is usually much larger than its territory. Unlike territories, a home range is not actively defended and home ranges may overlap. A tigress home range size is governed by prey density (varies between regions from 20 km^2 in Indian sub-continent to over 400 km^2 in Russian Far East). Male home range size is dependent on female density and only indirectly on prey, and hence varies much more. (50–300 km^2 in tropical habitats to over 2000 km^2 in temperate forests in Russia). Male territories tend to completely overlap from one to four female territories.

Transient Floater	-	Refer age-category
Trend	-	A change in average status of some quantity or attribute over a defined time period.
Variance	-	A measure of precision; average of squared differences between a set of values and the mean of the distribution of those values.
Wayanad Landscape	-	Wayanad landscape, consisting of territorial Forest Divisions (Wayanad North, Wayanad South FDs and part of Kannur FD) and PAs (such as Aralam, Kottiyur and Wayanad WLSs), is a contiguous habitat in Kerala side and lying adjacent to Brahmagiri WLS, Nagerhole and Bandipur Tiger Reserves in Karnataka and Mudumalai Tiger Reserve in Tamil Nadu.
Western Ghats Landscape Complex	-	The Western Ghats Landscape Complex consist of two Clusters viz., (i) Sahyadri TR, Protected areas of Goa (Mhadei WLS, Bhagawan Mahavir (Mollem) NP, Netravali WLS, Cotigaon WLS), Dandeli-Anshi TR, Bhadra TR, Bandipur TR, Nagarhole TR, Biligiri Ranganatha Temple TR (BRT), Sathyamangalam TR and Mudumalai TR. This landscape has both high and low-density areas; (ii) Parambikulam TR, Anamalai TR, Periyar TR, Kalakad-Mundanthurai TR (KMTR) which has low density of tigers.

EXECUTIVE SUMMARY

Globally, 93% of historical tiger lands have disappeared due to expansion of human activities. In India tiger habitats have declined by 41% in the past 17 years (IUCN). In spite of this enormous depletion of habitats, the largest remaining wild tiger population in the world occurs in India, though in fragmented landscapes.

The 'Interstate Tiger Landscape' (ITL) consisting of a cluster of TRs/PAs such as Nagerhole-Bandipur-Wayanad-Mudumalai-Sathyamangalam-Biligirirangan Thittu (spread across the states of Karnataka, Kerala and Tamilnadu) has a viable source population with the required numbers (724) for long term survival.

An important component of this ITL on the Kerala side is Wayanad Landscape (LS) consisting of PAs of Wayanad, Aralam and Kottiyur WLSs and adjoining territorial forest divisions (FDs) of Kannur, Wayanad North and South. A population assessment has been carried out exclusively for Wayanad LS for effective management of its tiger population.

The photographic mark-recapture method, which depends on identification of each tiger based on its unique stripe patterns, has been used to estimate the tiger numbers. The spatial distribution and density of tiger were assessed through deployment of camera traps in Wayanad LS during the period between 10th April to 25th May 2023.

A total of 297 camera trap (CT) stations were setup in the entire Wayanad LS that included 247 CT stations within the grids identified during 'All India Tiger Estimation' and 50 CT stations outside the grids but within the landscape to understand the movement of tigers to other areas of Wayanad LS. All the CTs were operated for 45 days totalling a sampling effort of 13,365 trap nights. Tigers were captured in camera traps deployed in all FDs except in Kannur FD and all WLSs except Aralam WLS. Of the total 297 CT stations, tigers were captured in 160 stations (53.87%) and a total of 84 unique individual adult tigers were identified. Out of these 84 individuals, 82.14% (69 numbers) of individuals were from Wayanad WLS, eight individuals (9.52%) from Wayanad North and seven individuals (8.34%) from Wayanad South FDs. One individual captured from Kottiyur WLS was already captured in Wayanad North FD.

Out of 84 unique individuals, 46% were newly captured during 2023 and the remaining 54% were captured during the previous estimations. Out of 54% that were already captured, 17% were during 2016, eight percent in 2018 and 29% during 2021-22. Out of 84 individuals, the gender of eight

tigers could not be ascertained. A total of 29 males and 47 females were classified which yielded a male to female sex-ratio of 1:1.62 in Wayanad LS during 2023.

The last survey (carried out during 2018) identified 120 unique tigers in the Wayanad LS, whereas the 2023 survey photographed only 84 unique individuals in the region. A decline in the density estimation of tigers is also observed in Wayanad LS. During 2018, the tiger density was estimated to be 9.33 (SE 0.86) per 100 km^2, the 2023 estimate shows 7.7 individuals (95% CI 6.6 - 8.7) per 100 km^2. Hence, the population of tigers in Wayanad LS has shown reduction.

The fluctuation of tiger population as estimated through counts by different agencies over the years is expected as most of the tigers captured in the Wayanad LS are floaters or having major part of their home ranges in the adjoining TRs in Karnataka and Tamil Nadu. The estimated resident tigers in Wayanad LS are much less (30 to 40 individuals) than the actually captured individuals (84 during 2023). This is evident from the data on the past capture history of individuals photographed during 2023. Out of 84 individuals, 46% is newly captured. Out of the remaining 54%, individuals that are regularly captured since 2016 and 2018 (14 and 7 individuals respectively) could certainly be the resident individuals. The 24 individuals that were also captured during 2021-22 could be partially resident.

According to the summary report of AITE-2022, tiger populations in Nagerhole and Bandipur TRs have increased but reduced in Wayanad LS. Some tigers in Wayanad LS might have moved to these PAs which are located adjacent to Wayanad LS. Moreover, the fire incidents during 2022 were also reported to be much less in Nagerhole and Bandipur TRs as there were rains during the first week of April itself. The reduction in the population and density in Wayanad LS could also be attributed to the prevailing factors (human-dominated landscape) and habitat attributes (infestation of exotic weeds such as Lantana, Eupatorium, Mikania and Senna) and inadequate maintenance of marshy meadows (*vayals*). Incidents of livestock grazing on the forest fringe area close to human habitations is also found to be a factor for decrease in number of wild herbivores which are the naturally preferred prey of carnivores.

Removal of exotic weed species and other woody species from the marshy grasslands is already proven to be effective elsewhere in the State as evidenced by enhanced fodder availability as well as significant utilization of such maintained habitats by wild herbivores. Hence, it is of paramount importance that maintenance of these *vayals* needs to be carried out regularly to confine the herbivore population within the available habitat. In addition, control of livestock grazing in the forest is also important to sustain wild animals within the forest and reduce human-wildlife conflict.

TIGER POPULATION ESTIMATION IN WAYANAD LANDSCAPE, KERALA – 2023

1. PRELUDE

Tiger (*Panthera tigris*), representing the world's largest cat species, plays a pivotal role in the health and diversity of an ecosystem and functions as a flagship species generating significant public and government support for their conservation. It is a top predator, being at the apex of the food chain keeps the population of wild ungulates in check, thereby maintaining the balance between prey herbivores and the vegetation upon which they feed. The role of top predators in an ecosystem in maintaining biodiversity has been highlighted by several food web modelling studies, highlighting those additional extinctions which are triggered by extermination of top predators (Borrvall and Ebenman, 2006; Chesson and Kuang, 2008). Therefore, they can also be considered as keystone species critical to maintain ecosystem processes.

The presence of tiger in an area directly benefits the conservation of all biodiversity that coexists within their habitat. Healthy tiger habitats help mitigate climate change, provide fresh water to animals and people, reduce the impact of natural disasters and improve the health of local people. Further, the tigers also function as a good umbrella species for conservation as they are habitat generalists with large spatial requirements ranging from the colder climates of Siberia in Russia to the dry and hot semi-arid regions of western India and parts of peninsular India.

Tiger habitats are home to far more animals than just the iconic big cat. More than 30% of Asian elephant populations live within tiger landscapes in Asia including India. That means protecting tiger habitats is important for elephants, too. Where tigers thrive, so do other diverse plants and animals. When we invest in wild tigers, we can help save many other species. Hundreds of millions of people depend on water from places where tigers roam, hence protecting tigers means protecting vital fresh water sources and functions. Unfortunately, tiger range has plummeted by 95%, leaving populations fragmented and isolated in the remaining forests of Asia. The remaining range for wild tigers is at risk of getting reduced by nearly half due to unsustainable agriculture expansion and urbanization. If tigers are to survive this century and beyond, their home range urgently needs protection and restoration. This requires sustained support from governments, stakeholders and communities.

Conservation decisions about any species require knowledge of their population size and the trend over the years. Such knowledge can be obtained only through application of rigorous scientific methods of data collection and this knowledge can be used for effectively implementing the conservation efforts. Population estimation of tigers is difficult due to their large ranges, low densities

and cryptic nature. Earlier in India, methods such as 'Pugmark Census' were used to estimate the population abundance of tigers (Panwar, 1979; Riordan, 1998); but this method appeared to have very high percentage of error (Karanth, 1987 & 1988) and thus the estimates obtained by this method were not very reliable. Although the pugmark census technique has provided some insight into felid ecology, diet, behaviour and some index of relative abundance, this has not been successful in estimating population size or density of tigers with high or relative accuracy. The mark-recapture framework using camera traps (Karanth, 1995; Karanth and Nichols, 1998; Nochols and Karanth, 2002) is found to be a more precise and scientific approach for estimating the population of tigers and other cryptic carnivores.

The photographic mark-recapture method depends on the concept of identifying each tiger based on its unique stripe patterns (Karanth *et al*., 2004). Digital camera traps, installed to capture images of wildlife with as little human interference as possible, are increasingly used in wildlife research because they allow species inventories, population estimates, and behavior or activity observations (Long et. al., 2008). Besides individual identification or population estimation, camera trapping can also provide other biologically relevant information such as temporal variation, distance of travel, mortality, natality etc., if continuously carried out in a given area. The camera trapping technique has been successfully employed to estimate the tiger densities in various parts of the country (Karanth, 1995; Karanth and Nichols, 1998; Carbone *et al*., 2001; Karanth *et al*., 2004; Wegge *et al*., 2004; Jhala *et al*., 2008; Jhala *et al*., 2011; Jhala *et al*., 2015; Jhala *et al*., 2020). The 'capture-recapture' model is widely used to estimate the sizes of populations and has a good statistical database (Karanth and Nichols, 2002, Otis et. al., 1978). Recent developments in the use of camera traps demonstrate that they can be both more effective and more cost efficient than any other labour-intensive survey methods. Hence this study entirely used camera trap technique for achieving the objectives.

Since 2006, the stock of tiger population in the country is being taken by National Tiger Conservation Authority (NTCA) with technical backstopping of Wildlife Institute of India (WII) at every four-year interval as part of the country-wide programme on 'All India Tiger Estimation' (AITE) using the state-of-the-art technology involving remotely sensed data, geographical information system and camera traps besides extensive ground surveys.

The highest wild tiger population in the world exist in India with more than 75 percent and the largest population exist in the Western Ghats (WG) (824 unique tigers recorded during 2022 as per AITE-2022 (Qureshi, *et. al.,* 2023) in southern India which is a critical biodiversity hotspot and hosting

source populations of several threatened species including tiger and elephant. The WG Landscape has the highest number of Protected Areas (PAs) that run in a series along the slopes of the Mountain range. Wayanad Wildlife Sanctuary (WLS) is one of the PAs in the cluster on Kerala side. This PA along with the adjoining territorial forest divisions in Kerala hold a good population of tigers (as per All India Tiger Estimation 2018 estimation, there were 120 individuals in Kerala side). As part of effective management of the tiger population in Wayanad LS, a population assessment has been proposed.

2. GOAL AND OBJECTIVES

Since the very survival of tigers is dependent on conservation and management efforts taken by the forest department, it is highly crucial to gauge the success of those conservation efforts to guide the management inputs needed for their long-term survival. Evaluation of the success rate of conservation efforts thus requires precise estimation of the tiger population and information on where the tigers are and how many are there. Another main goal of continuous scientific monitoring of tiger population is to help in developing a body of empirical and the theoretical knowledge that can potentially improve our predictive capacity to deal with the new situations such as ever-increasing human-wildlife conflict. Continuous monitoring at regular interval through camera trap exercise would yield information on population dynamics of a target species including emigration (or mortality), immigration (or natality), fecundity, etc. The outcome of this exercise would be crucial for the effective management of tiger population in all tiger-bearing forests of Wayanad LS and also to take appropriate actions in addressing issues of human wildlife conflict. Hence, a tiger population assessment was initiated in Wayanad LS during 2023 with the following objectives:

a. To document and map the spatial distribution of tigers in Wayanad LS.
b. To estimate the number and density of tigers using spatially explicit capture recapture method.
c. To identify individual tigers currently operating in Wayanad LS and create/update the database maintained at State-level for future monitoring.

This report is an outcome of the Tiger Monitoring Programme carried out in Wayanad LS during April-May, 2023.

3. STUDY AREA

3.1. Description of Wayanad Landscape (LS)

The Wayanad Landscape (Fig. 1) is part of the WG LS (delineated for tiger estimation by AITE) that consist of a series of interstate TRs and PAs (Fig. 2). The TRs/PAs such as Nagerhole-Bandipur-Wayanad-Mudumalai-Sathyamangalam-Biligirirangan Thittu (all together known as 'Interstate Tiger

Landscape') are located in the WG LS and spread across the states of Karnataka, Kerala and Tamilnadu. This is one of the four source populations in India which have the required population size for long term survival without immigration (Jhala *et. al.,* 2020)

Wayanad LS (Fig. 1) consists of territorial Forest Divisions (FD) (such as part of Kannur, Wayanad North and Wayanad South FDs) and PAs (such as entire Aralam, Kottiyur and Wayanad WLSs). The Kannur FD is located on the northern part of the landscape. The forest area in this division is highly fragmented and linear all along the interstate boundary of Kerala and Karnataka. But a compact forest is found on the southern side of Kannur FD which is contiguous towards east with forest areas in Brahmagiri WLS in Karnataka and forests of Aralam and Kottiyur WLS in Kerala. On the south of Kannur FD, the forest is continuous to Aralam WLS. The Aralam WLD consist of Aralam WLS (with an extent of 55 km^2) and Kottiyur WLS (with an extent of 30.38 km^2) which are bordered on the north by Brahmagiri WLS located in Kodagu (Coorg) district, Karnataka and north west by Kannur FD in Kerala. The forest of Aralam and Kottiyur WLSs is further contiguous towards east with Begur Range of Wayanad North FD. The forest in Begur Range is found to be a potential dispersal habitat or area for spillover population of tigers from Wayanad Wildlife Sanctuary (WLS) (Tholpetty Range is located on east of this forests). Part of territorial FDs such as Wayanad North and Wayanad South and entire Wayanad WLS are considered to be the most important areas in Wayanad LS. The Wayanad WLS (Fig. 1), with an extent of 344.44 km^2, is located on the south-eastern side of Wayanad LS and is the key habitat in the entire Wayanad LS as this PA is contiguous to other 'Interstate Tiger Landscape in WG Landscape' (Fig. 2).

The terrain in Wayanad LS is moderately undulating with altitudes ranging from 600m to 1400m above MSL (Fig. 3). The terrain along the interstate boundary between Karnataka and Kerala in the norther part is highly undulating with small hills interspersed with many swampy valleys. The boundary between Karnataka and Kerala along the Forest Divisions of Kannur and Aralam WLS are elevated with hillocks. The Wayanad WLS as well as adjoining TRs in Karnataka and Tamil Nadu have almost flat terrain.

Several perennial streams drain the Wayanad LS (Fig. 4). Wayanad WLS, being a wetter region in the entire Interstate landscape and holds a lot of waterbodies and perennial streams (Fig. 5), attracts all animals especially larger herbivores and carnivores from the adjoining TRs particularly during summer season. During summer, mostly all larger animals congregate at Wayanad WLS due to dryness and fires in the adjoining TRs. Water is a serious limiting factor inducing the movement of wildlife from the area of scarcity to the zones of availability. Such sporadic movement often lead to serious conflict between human and wildlife. The existing waterholes and perennial streams in Wayanad WLS sustain the populations of prey and predators existing in WLS as well as population moving in from the adjoining areas especially during peak summer season.

Fig. 1: Protected Areas and Territorial Forest Divisions in Wayanad Landscape

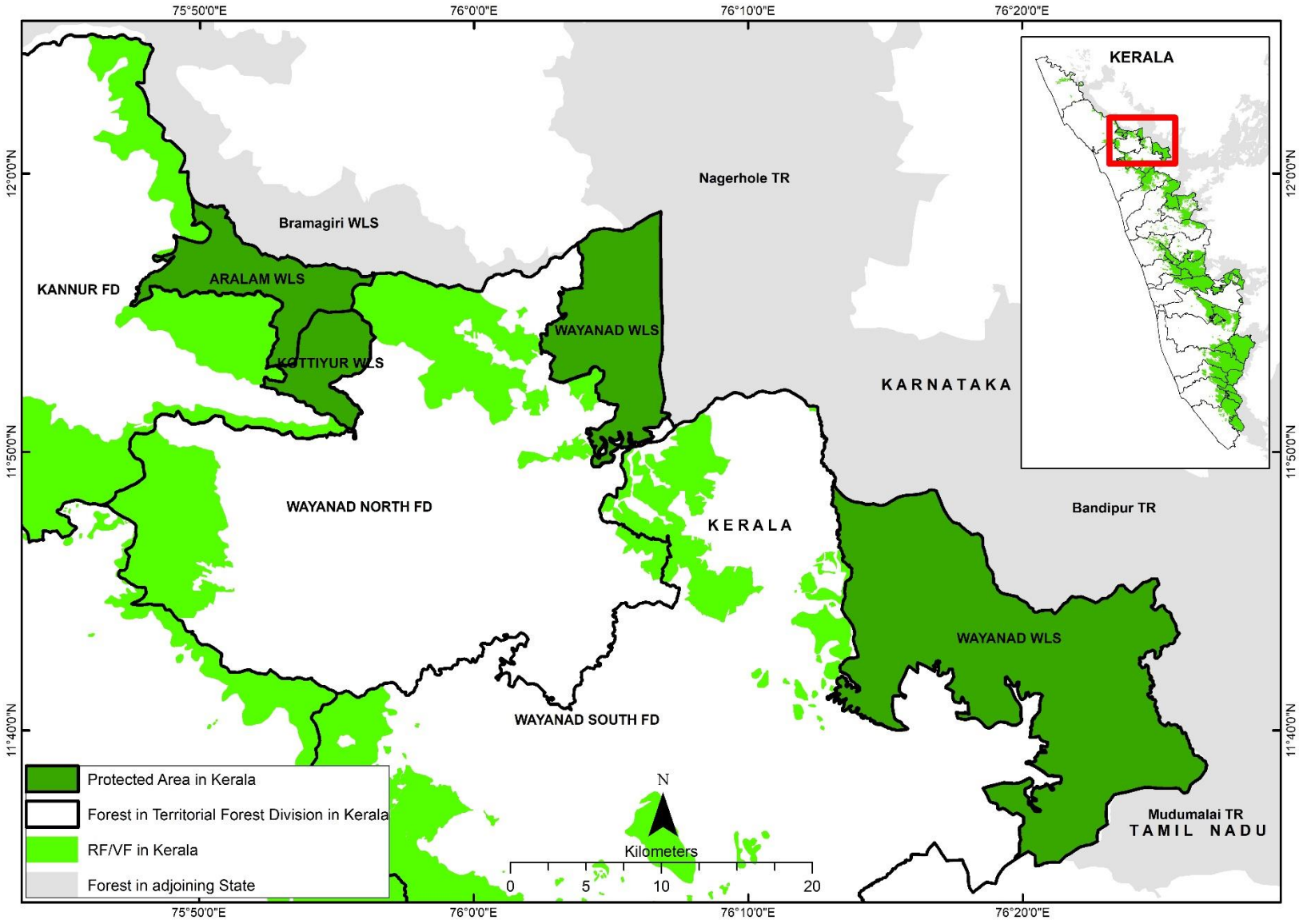


Fig. 2: The Tiger Reserves and Protected Areas in the WG Landscape

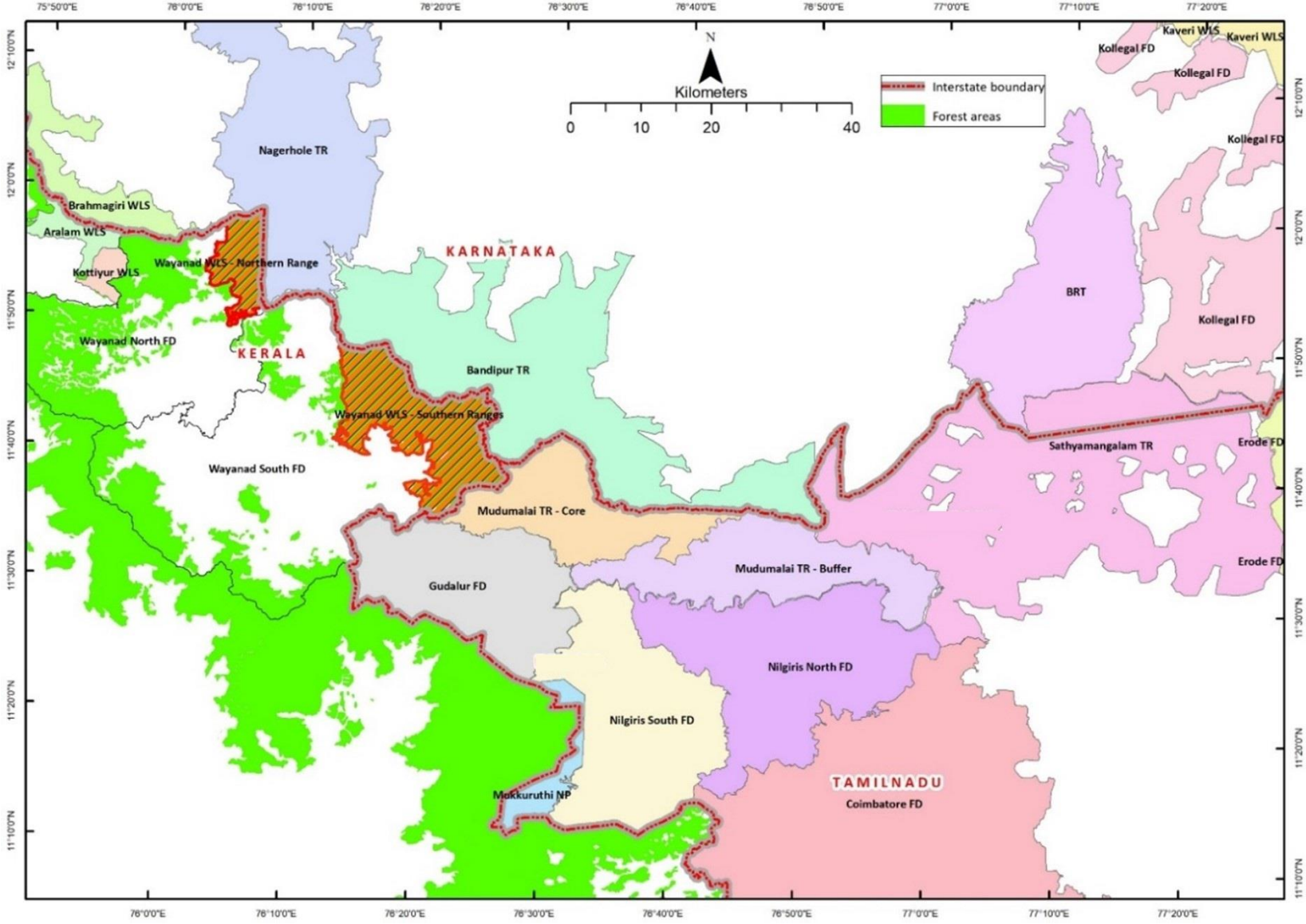


Fig. 3: Terrain with altitude in Wayanad LS

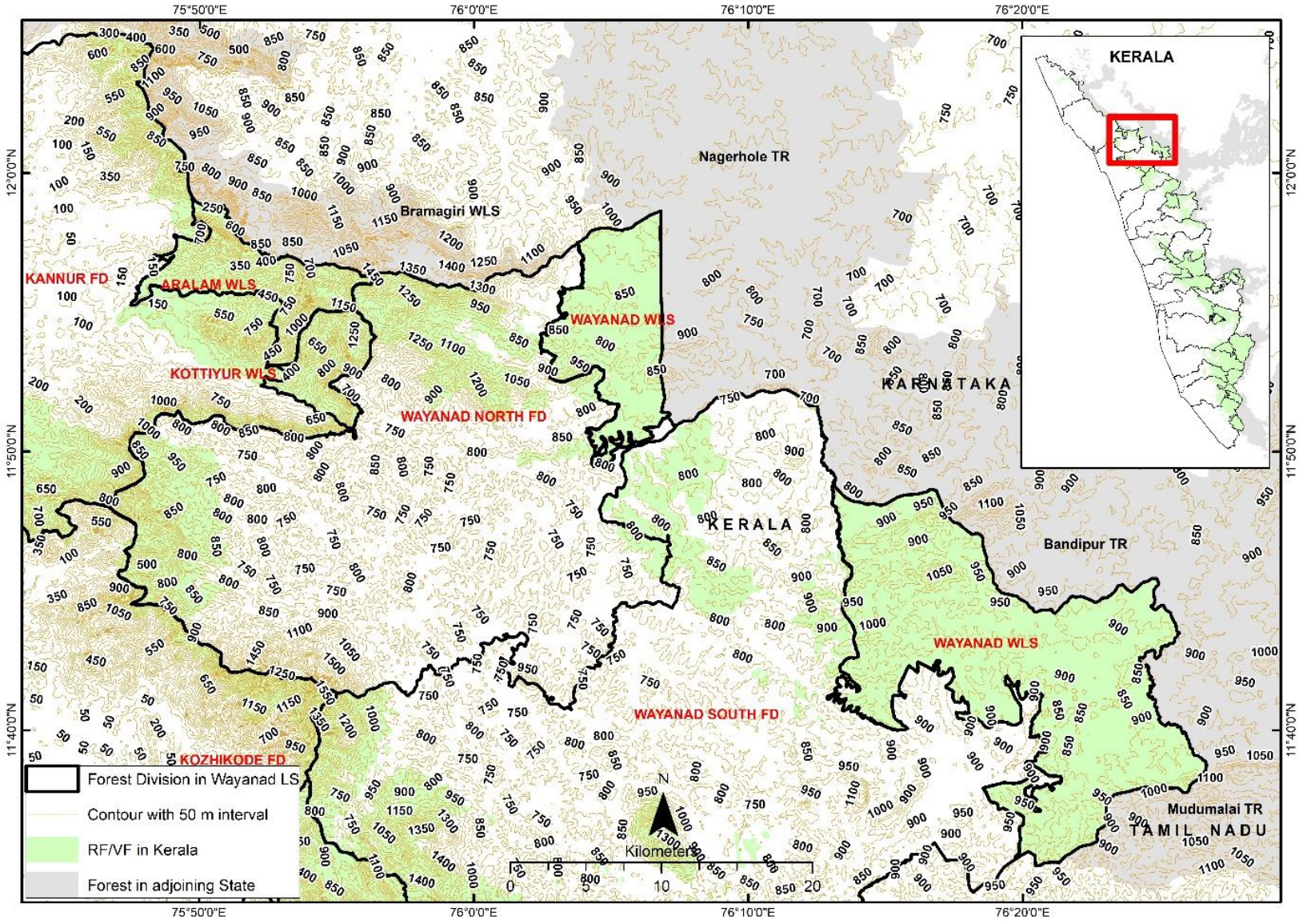


Fig. 4: Perennial water sources in Wayanad LS

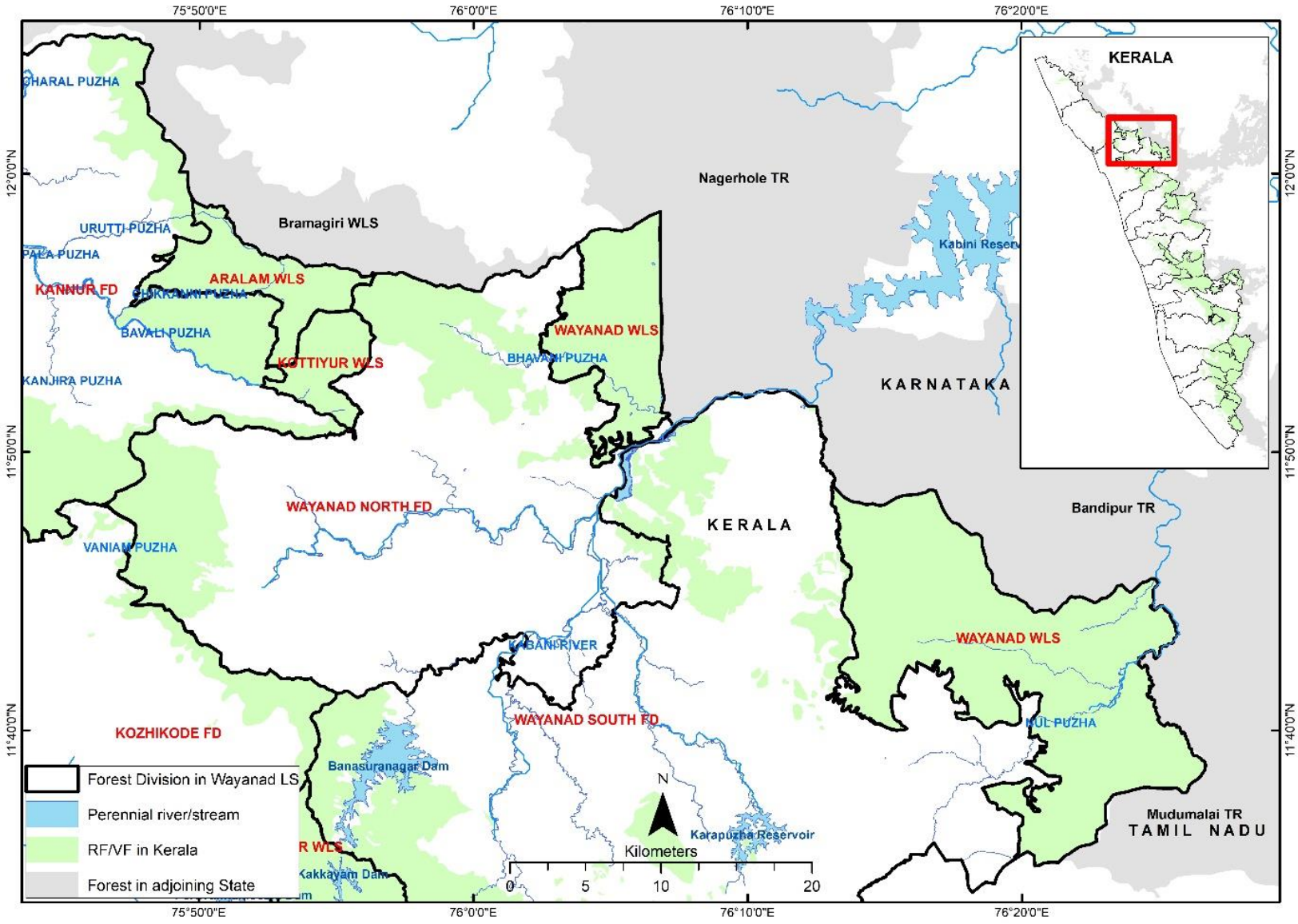
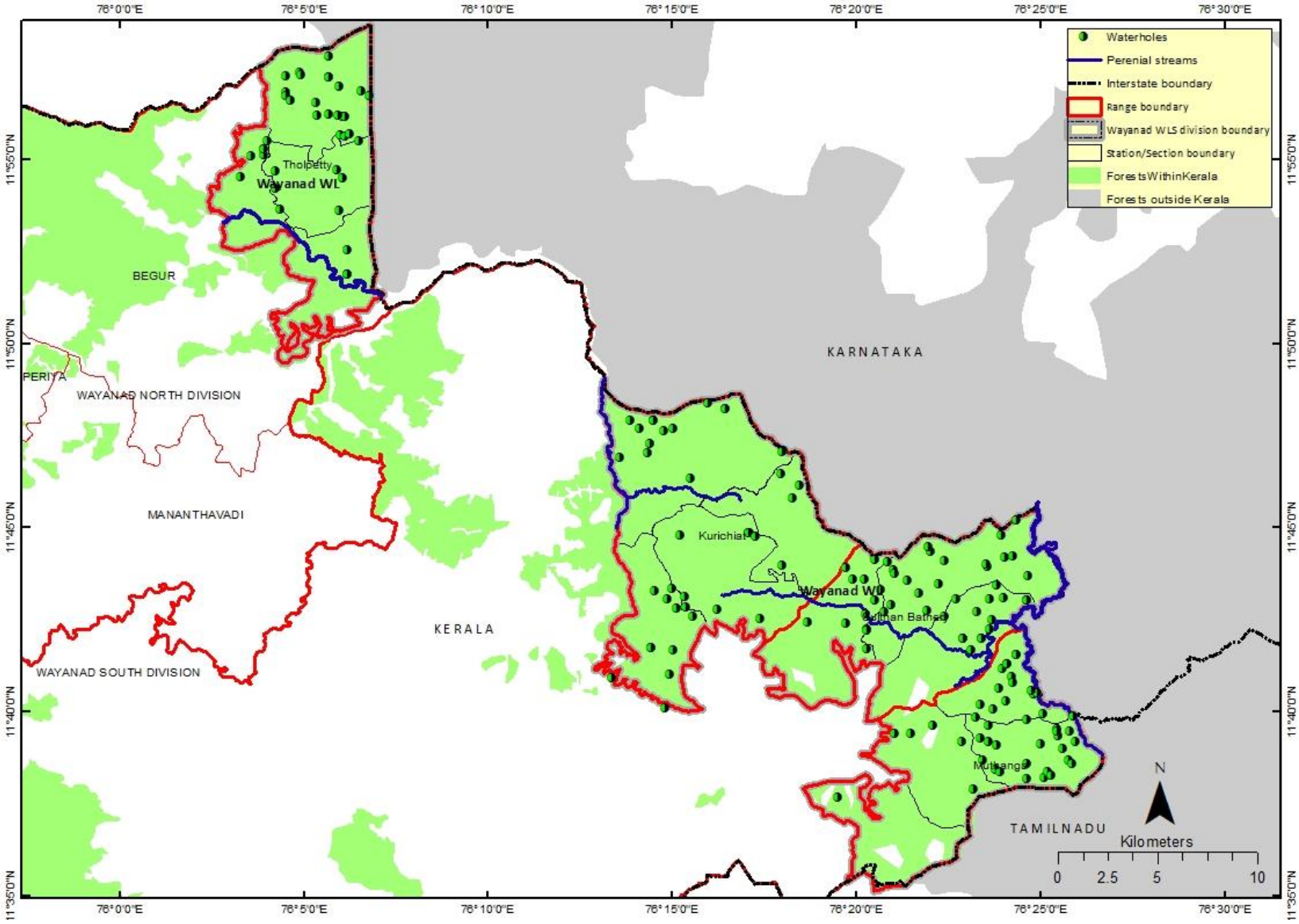


Fig. 5: Locations of waterholes and perennial streams in Wayanad WLS



Wayanad receives fairly high rainfall of 3000 mm to 4000 mm annually, mostly from the south-west monsoon. The slightly higher elevations are fairly cold during the winter (November-December).

The dominant vegetation in part of Kannur FD and Aralam and Kottiyur WLSs is mainly of evergreen to semi-evergreen (Champion and Seth, 1968) with high-elevation grasslands on top of the hill ridges (along the interstate boundary of Kerala and Karnataka) (Fig. 6). These grasslands, though smaller in extent, are the potential habitats for the herbivore populations (including elephants and other prey base of mega carnivores such as tiger and leopard) found in this region. Bamboos are well represented in the evergreen and semi-evergreen forests which harbour significant arboreal wildlife. The parts of Wayanad North and South FDs that constitute the Wayanad LS and connect the Wayanad WLS is mainly of moist deciduous forests (Champion and Seth, 1968) with monocultures (predominantly teak plantations). Almost the entire area of Tholpetty Range of Wayanad WLS consists of moist deciduous forests with teak plantations. The southern Ranges (Muthanga, Bathery and Kurichiat) of Wayanad WLS consist of dry deciduous forests (Champion and Seth, 1968) along the interstate boundary and certain parts on the western side have teak plantation and moist deciduous forests. The dry deciduous forest in this part is highly productive and support a good population of herbivores as well as carnivores. The Wayanad WLS and territorial FDs such as Wayanad North and South in Wayanad LS are characterized by large number of low-lying marshy grass lands called '*Vayals*' which form prime feeding grounds of the herbivore populations. Wayanad WLS is characterized by large number of *vayals* which form prime feeding grounds of herbivore populations even during summer season since water exists throughout the year in the *vayals*. A total of about 120 *Vayals* were identified in Wayanad WLS having an extent of 1477 ha is given in Fig. 7.

Wayanad LS also has its share of problems and the management is facing multitude of the challenges in protecting wildlife and its habitat. The *vayals* are often invaded with the weed '*Rhynchospora corymbosa*', which is an unpalatable sedge affecting the natural fodder species of the area. Vayals are also dominated by wood vegetation as well as other unpalatable exotic weeds like Lantana, Eupatorium and Mikania that suppress the growth of fodder species especially the grass species.

Apart from these species, *Senna spectabilis* which is an exotic weed species belonging to the family Fabaceae is also invading into parts of Wayanad WLS as well as Wayanad North and South FDs (Fig. 7). The spread of this invasive alien plant is posing serious threat to wildlife and indigenous plants in the forest areas of the Nilgiri Biosphere Reserve, including the Wayanad WLS, a major habitat of tiger as well as Asiatic elephants in the country. Nearly 300 km^2 stretch of forests in the landscape, including the Wayanad WLS, North and South Wayanad Forest Divisions and the adjacent Mudumalai, Bandipur and Nagarhole Tiger Reserves, have been infested by this invasive plant.

Fig. 6: Vegetation in Wayanad LS and adjoining forests

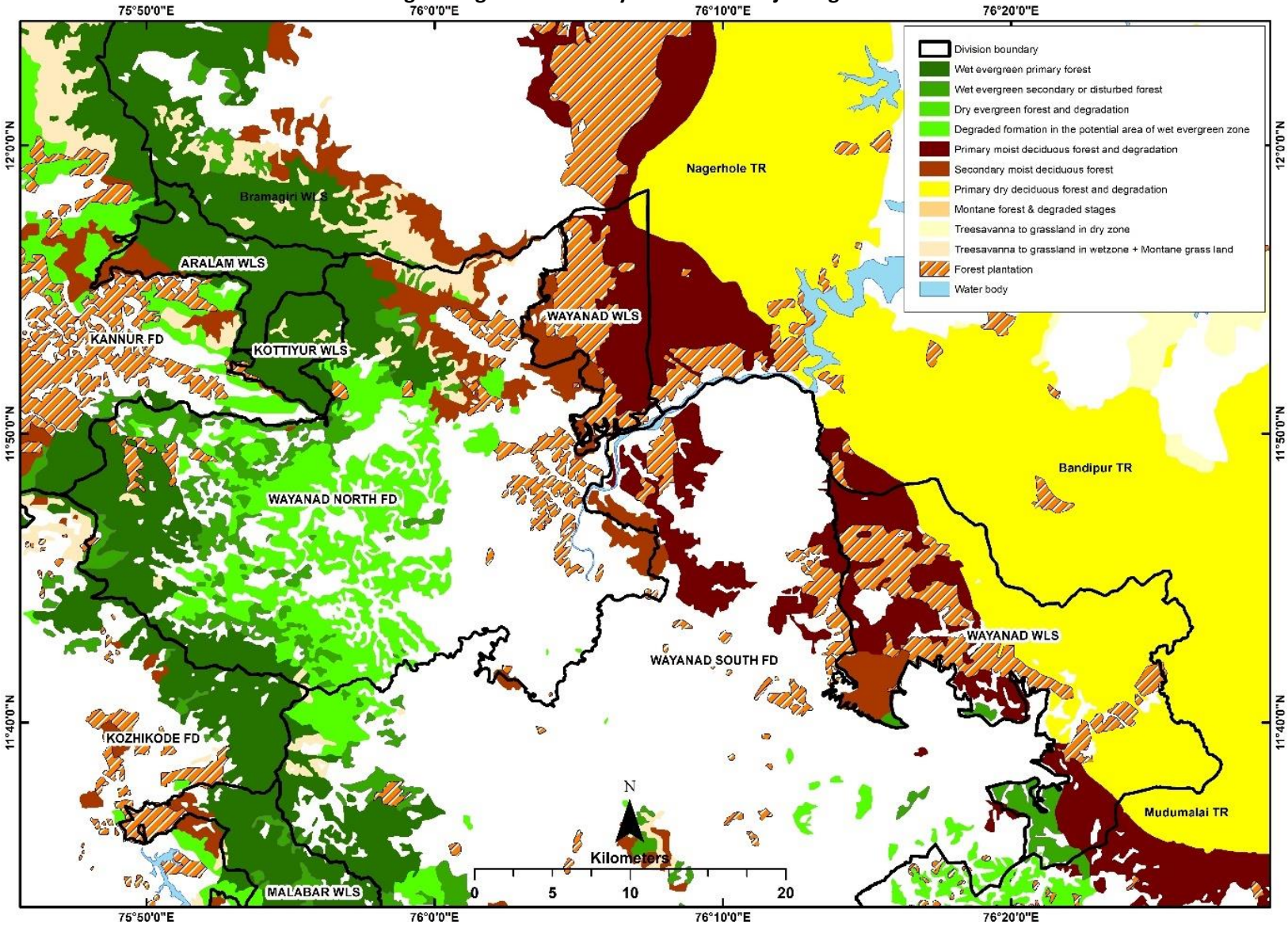
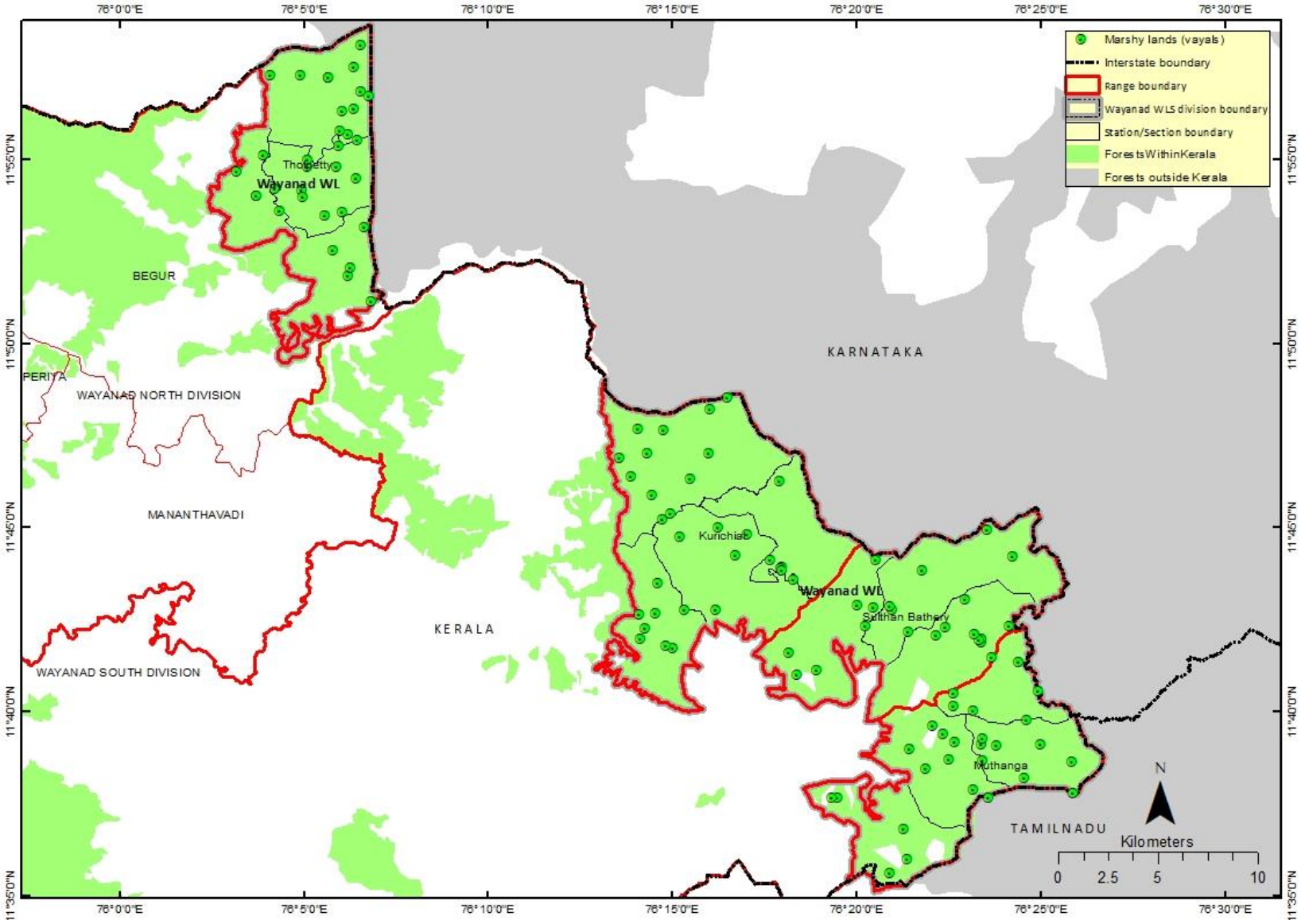


Fig. 7: Distribution of marshy lands (*vayals*) in Wayanad WLS



A preliminary survey conducted by the Wildlife Trust of India (WTI), in association with the Kerala Forests and Wildlife Department revealed that the plant is widely distributed in Muthanga and Tholpetty Forest Ranges and certain areas in Sulthan Battery and Kurichiat Ranges of Wayanad WLS. The study carried out during 2013-14 documented that an extent of 47.6 km^2 has been infested with Senna (Range-wise detail is tabulated in Table 1 and the locations are shown in Fig. 8). The recent study carried out by Vinayan (2023) reveals that about 35% of the WLS is presently infested with Senna. This shows that Senna is spreading very fast in the Wayanad LS.

Table 1: Extent of *Senna spectabilis* invaded region in Wayanad WLS

SN	Range	Location	Extent (ha)
1	Muthanga	Karadimuda block	1988.22
2		Vengoor block	508.75
3	Sulthan Battery	Ponkuzhy block	298.62
4	Kurichiat	Pachady block	294.57
5		5th mile block	183.23
6	Tholpetty	Cheriyanaikatty block	1076.11
7		Camproad block 1	47.77
8		Camproad block 2	148.41
9		Karamadu block	214.18
		Total	**4759.86**

Human habitations in Kannur FD and, Aralam and Kottiyur WLSs are mostly restricted in the periphery of forest areas. However, Aralam Farm is located on the western side of Aralam WLS which experience high human-elephant conflict in the recent days (Fig. 9). Human enclosers are found in large extent in Wayanad WLS, Wayanad North and South FDs. Wayanad WLS is highly fragmented and has a large human population living inside (Fig. 9). The latest management plan (Anon, 2022) of Wayanad WLS reveals that there are 55 enclosures amidst the forests with a population of 11,433 individuals living in an area of 4.96 km^2. In addition to this, 44 settlements are located on the forest fringe with a population of 6,056 individuals (Anon, 2022).

3.2. Tiger Distribution in the 'Interstate Tiger Landscape' and Wayanad LS

Qureshi, et. al. (2023) reveals that the minimum estimated tiger population in the country is 3167 during 2022. This 'Interstate Tiger Landscape' is the source population in the WG Tiger Conservation Unit (with an extent of about 4000 km^2) and it has an estimated tiger population of 824 tigers (recorded during AITE-2022 Qureshi, *et. al.,* 2023) constituting the single largest wild population of tigers in the world (Jhala et.al., 2015; Jhala et.al., 2020; Qureshi, *et. al.,* 2023). This 'Interstate Tiger Landscape' is a fine example of managing Interstate TRs for the long-term conservation of source

population of tigers. Hence, the Wayanad LS comprising of Wayanad WLS and parts of adjoining territorial FDs (Wayanad North and South FDs, and part of Kannur FD) and other PAs (Aralam and Kottiyur WLSs) in Kerala side becomes a vital component of the 'Interstate Tiger Landscape' in the WG as it possesses part of the world's largest tiger population.

Wayanad WLS is located on the south-east part of Wayanad LS. This PA, together with the adjoining TRs and PAs of Karnataka and Tamil Nadu, is home to the largest tiger and elephant population in the world. During 2018, a total of 312 pairs of Camera Traps (CT) were deployed in Wayanad LS as part of AITE and reported to have captured 120 unique tigers (adults) from Wayanad LS (Jhala *et al*., 2020). Jhala *et al*. (2020) also reported that Wayanad LS had a tiger density as 9.33 adults / 100 km^2 estimated during 2018. Figure 10 depicts the CT layout grids supplied by WII and the locations of CTs deployed during 2018.

4. METHODS

The spatial distribution and density of tiger were assessed through deployment of camera traps in the Forest Divisions falling under Wayanad LS. The placement of camera traps in Wayanad LS was decided based on the previous knowledge of camera trapping (carried out during 2016, 2018 and 2022) in the landscape.

Deployment of camera traps in the identified locations started with a detailed one-day training programme at division-level. Trainings were imparted in two locations *viz*., (i) Tholpety (for the staff of Aralam and Kottiyur WLSs, Kannur FD, Wayanad North FD and Tholpetty Range of Wayanad WLS) and (ii) Sulthan Bathery (for the staff of Wayanad South FD and Muthanga, S.Bathery and Kurichiat Ranges of Wayanad WLS). The trainings were imparted for the frontline staff and watchers by the professionals of PaTCoF.

During training, presentations were made on the importance of monitoring tigers, various techniques involved in the monitoring, setting up of camera traps, subsequent monitoring of camera traps in the field and data retrieval from the camera traps. Subsequently, field demonstrations were made in the nearby forest region regarding setting up of camera traps including fixing date, time, flash, height at which the instrument to be fixed and periodic monitoring. It was ensured that each member in the team understands the process of setting up of camera trap in the field and all doubts were cleared during field demonstration. Field demonstration included setting data and time equally in both cameras in a pair, setting up of flash, placement height, distance between cameras, subsequent checking of cameras, filling up of datasheets, etc.

Fig. 8: Invasion of *Senna spectabilis* in Wayanad WLS

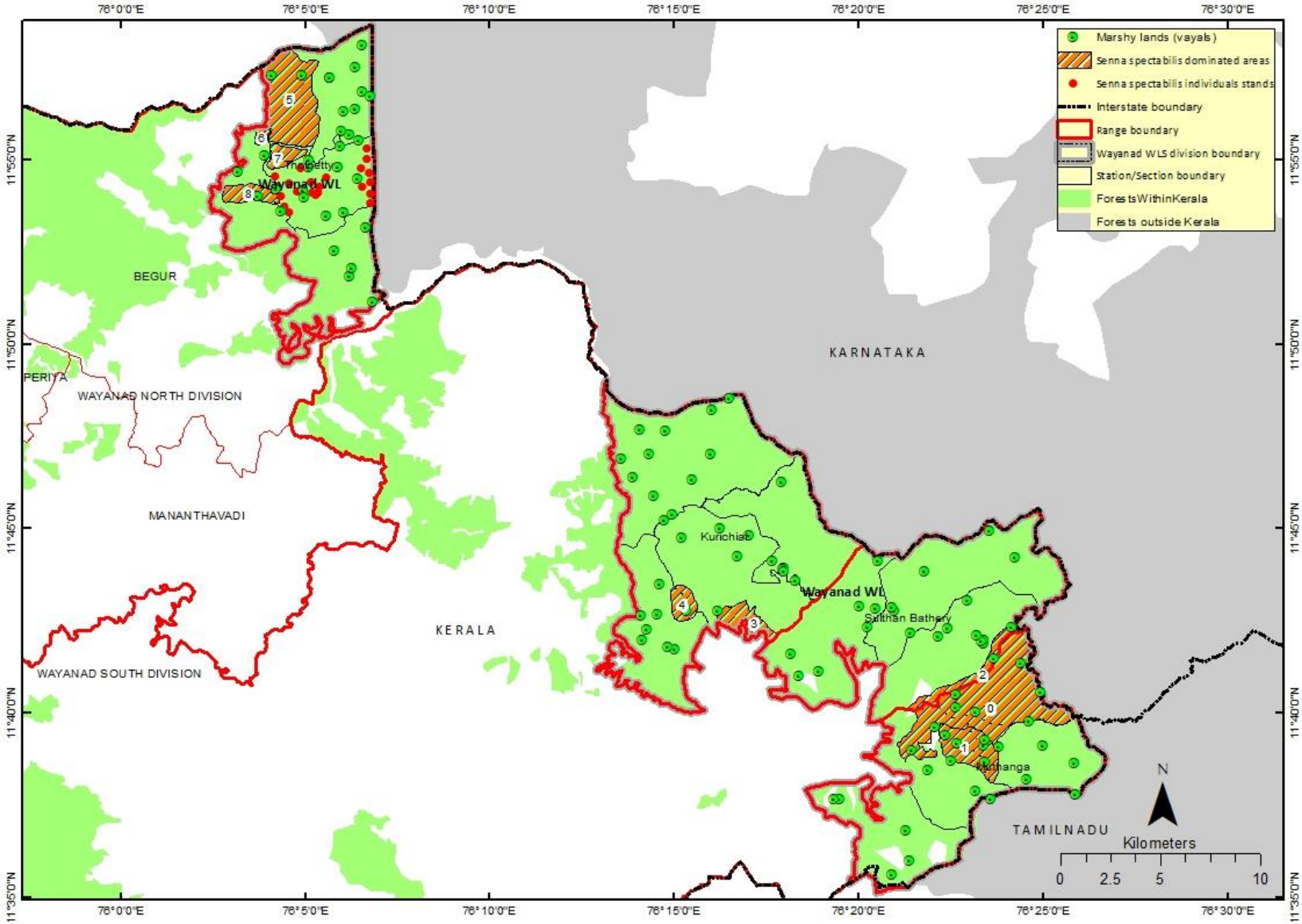


Fig. 9: Human enclosures within the forests in Wayanad LS

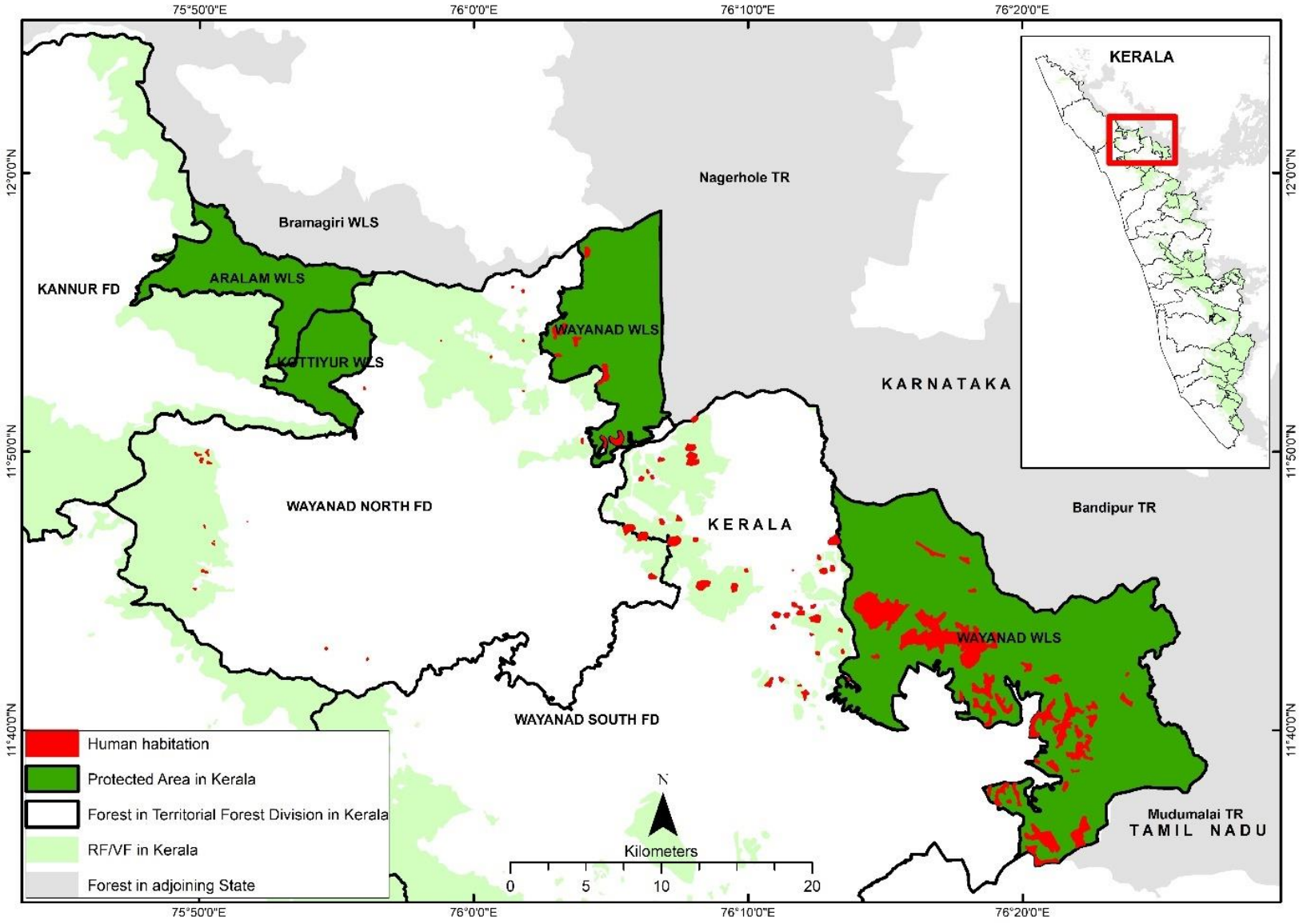
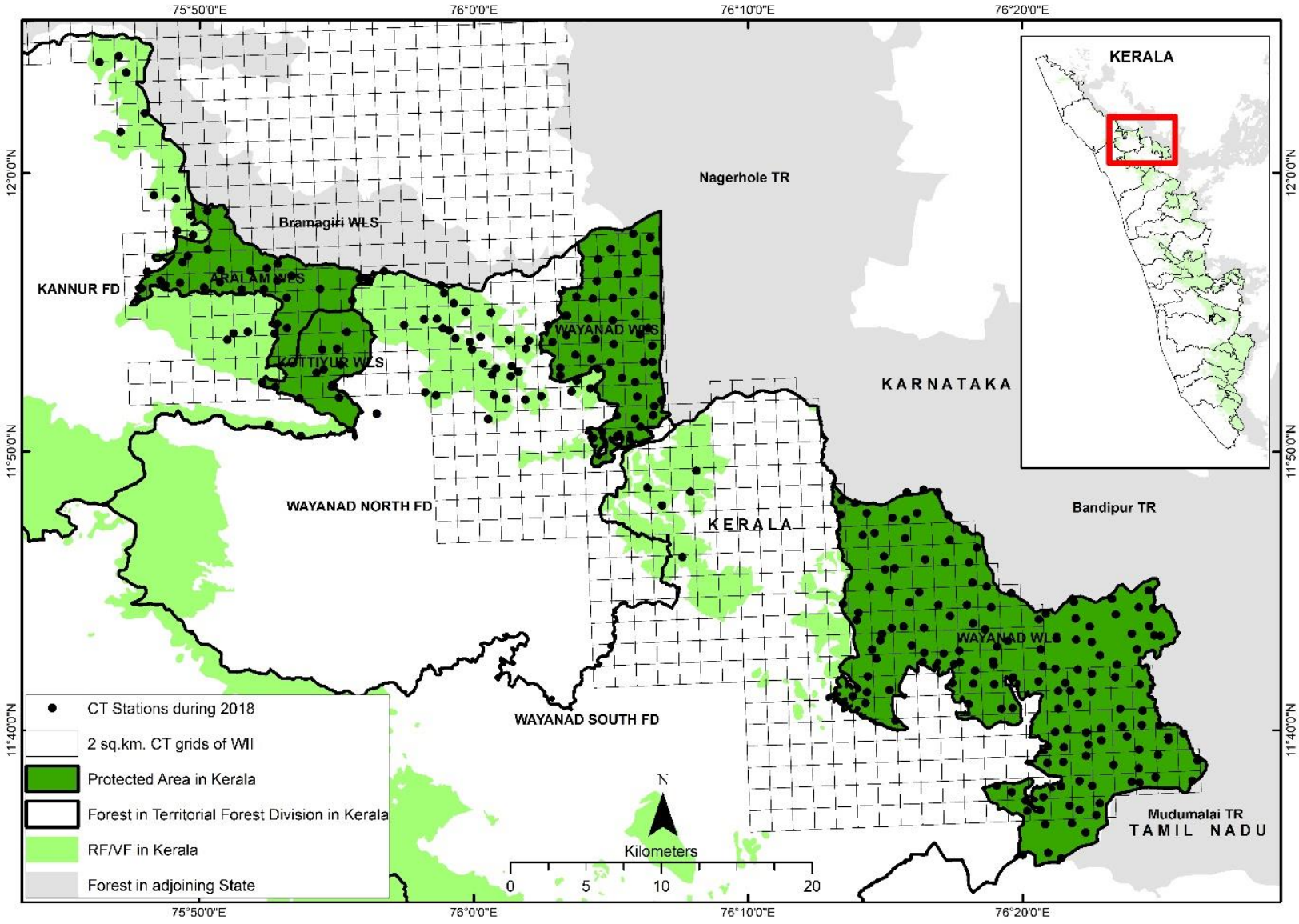


Fig. 10: CT layout grids supplied by WII and the locations of CTs deployed during 2018



Subsequent to the trainings, camera traps with other accessories along with data sheets were supplied to each team. The teams started deployment of camera traps in the field from the very next day of the trainings and completed the deployment by 9th April, 2023. On completion of camera traps deployment, the designated teams monitored the functioning the camera traps in the field as frequent as possible and ensured each camera trap's performance and battery status at least once in three days.

Camera traps were kept in the field for 45 consecutive days (from 10th April to 25th May, 2023) at each camera trap location. Digital camera traps (Cuddeback C1) were used in the estimation. When an animal passes in front of the camera, motion is detected by the sensor and the camera is triggered to take photographs. Camera traps were setup along trek paths, forest roads, traditional routes of animals, roads etc. In order to get photographs of both flanks of the animal for accurate identification, a pair of camera traps were deployed on either side of the trail with a distance of 3.5 to 5.0m from the centre of the trail.

Deploying two cameras at a station would also reduce the risk of loss of trap-nights through camera failure. However, if the camera failed to take pictures due to various reasons, the non-functioning period of camera traps were worked out and appropriately used for analysis. Camera traps were fixed on trees at a height of 40 to 50cm. While deploying the camera traps, data and time were checked. All the camera traps were programmed to run continuously for 24 hours and on activation they take three snaps with an interval of less than five seconds delay before next activation. While mounting the camera traps, they were tested to ensure that a target would be detected and photographed while passing the camera station.

Following the theoretical assumption of capture-recapture model that all the individuals in the population have a non-zero capture probability, the camera traps were spaced in such a way to ensure that no individual's home range lies between cameras (Karanth and Nichols, 1998; Wang and Macdonal, 2009). Hence, the trap stations were spaced 1.0 to 2.5km apart, close enough to each other such that the capture probability of every tiger within the study area was more than zero.

After 45 days from the date of deployment all cameras were removed from the field and brought to PaTCoF and the images were downloaded.

Individual tigers have been identified from the photographs using their unique stripe pattern. Photographs that were difficult to identify due to distortion or underexposure were matched after image processing. Photographs that could not be used for identification of individuals were discarded

from the analysis. All identified tigers were sexed from external genitalia (males), presence of cubs (females) and general appearance (body size, plump muzzle, wider chest etc.). All identified tigers were given unique IDs.

The number of individuals captured in the camera traps were given as 'minimum number of individuals' captured in the camera traps from the division.

The spatially explicit modelling approach was used to analyse the camera trap survey data using R package 'SPACECAP' version 1.1.0. The density of tiger was estimated using SPACECAP that directly estimates animal density by explicitly using the information on capture histories in combination with spatial locations of captures under a unified Bayesian Modelling Framework. The Bayesian SECR model is a hierarchical model comprising two components *viz*., (i) a point process model describing the distribution of individuals in space, and (ii) capture process model describing the observation of individuals in traps, offers advantage of dealing with problems posed by individual heterogeneity in capture probabilities and non-asymptotic inferences (Royle *et al*., 2009). Details of models and analysis of this approach for camera trapping data is available in Royle *et al.* (2009) and the methods have been described by Singh *et al*. (2010).

For performing the statistical analysis for density estimation of tigers in Wayanad LS, three types of input files *viz*., (i) animal capture details, (ii) trap deployment details, and (iii) state-space details were prepared to analyse data in the SPACECAP package. All the files were saved in ASCII comma separated format (.csv) as required by SPACECAP package. Since, Wayanad WLS is a key habitat within Wayanad LS, analysis were carried out separately for Wayanad LS as well as Wayanad WLS.

The animal capture details file consists of location ID (unique identification number given to each location), the animal ID (unique identification number to each identified tiger) and the sampling occasion number (unique occasion number given to each sampling day starting from 1). The trap deployment file consists of trap location ID and spatial location of trap IDs in X and Y Coordinates (in Universal Transverse Mercator (UTM) projection system) along with information on the occasions when each camera trap location was operational during the survey. The trap deployment data were organized in a two-dimensional matrix of camera trap locations and sampling occasions in a binary, 1s and 0s, indicating a particular camera trap station was or was not operational on a particular sampling occasion.

The potential home range centre (or activity centre) files for Wayanad LS and Wayanad WLS (Fig. 11 and Fig. 12 respectively) were prepared. These files are represented by a large number of

equally spaced points (500m between the points or area of habitat pixel was 0.25 km^2) in the form of a very fine mesh in the surveyed area containing the camera trap array with an extended buffer surrounding it, known as 'state-space' of the underlying point process (Singh *et al*., 2010). These points represent all possible potential activity centres (or home range centres) of all the individuals in a population being surveyed. The mesh of points (potential home range centre) was generated using QGIS (v.3.6.1) with 10 km buffer around the camera trapped locations. The potential home range centre file consists of X and Y Coordinates of all the potential activity centres in the UTM Projection System, and habitat suitability indicator indicating with 1s or 0s representing the potential activity centres lies within suitable habitat or not.

The SPACECAP package uses the Markov-Chain Monte Carlo (MCMC) simulation algorithm written in Program R to estimate the parameters of the Spatially Explicit Capture Recapture Models (Royle *et al*., 2009). For MCMC simulation, values of 52000 iterations, 20000 burn in values (number of initial values to be discarded during the MCMC analysis) and 'one' as thinning. The number of individual tigers captured and used for analysis were multiplied with 'five' and the figure was used as data augmentation value. Only iteration numbers defined by the thinning rate are stored during the analysis (Singh *et al*., 2010).

5. RESULTS

A total of 297 camera trap (CT) stations were setup in the entire Wayanad LS that include 247 CT stations within the grid supplied by WII and 50 CT stations outside the grid but within the landscape (Fig. 13). All the CTs were operated for 45 days occasions (10th April to 25th May, 2023) constituting a sampling effort of 13,365 trap nights in Wayanad LS.

Out of 297 locations, 170 locations fall in Wayanad WLS, 49 in Wayanad North FD, 50 in Wayanad South FD and 14 locations in Aralam and Kottiyur WLSs and 14 locations in Kannur FD. Tigers were captured in camera traps in all FDs except in Kannur FD.

Of the total 297 CT stations, tigers were captured in 160 stations (53.87%), of which more than one individual was captured in camera traps in 91 locations (Fig. 14). Two individuals were identified from 45 locations, three in 31 locations and four individuals were in 12 locations. Five individual tigers were captured in three locations.

All the locations that recorded more than two individuals mostly fall within Wayanad WLS (Fig. 15).

Fig. 11: State-space (with 10 km buffer) of Wayanad LS used in SPACECAP analysis

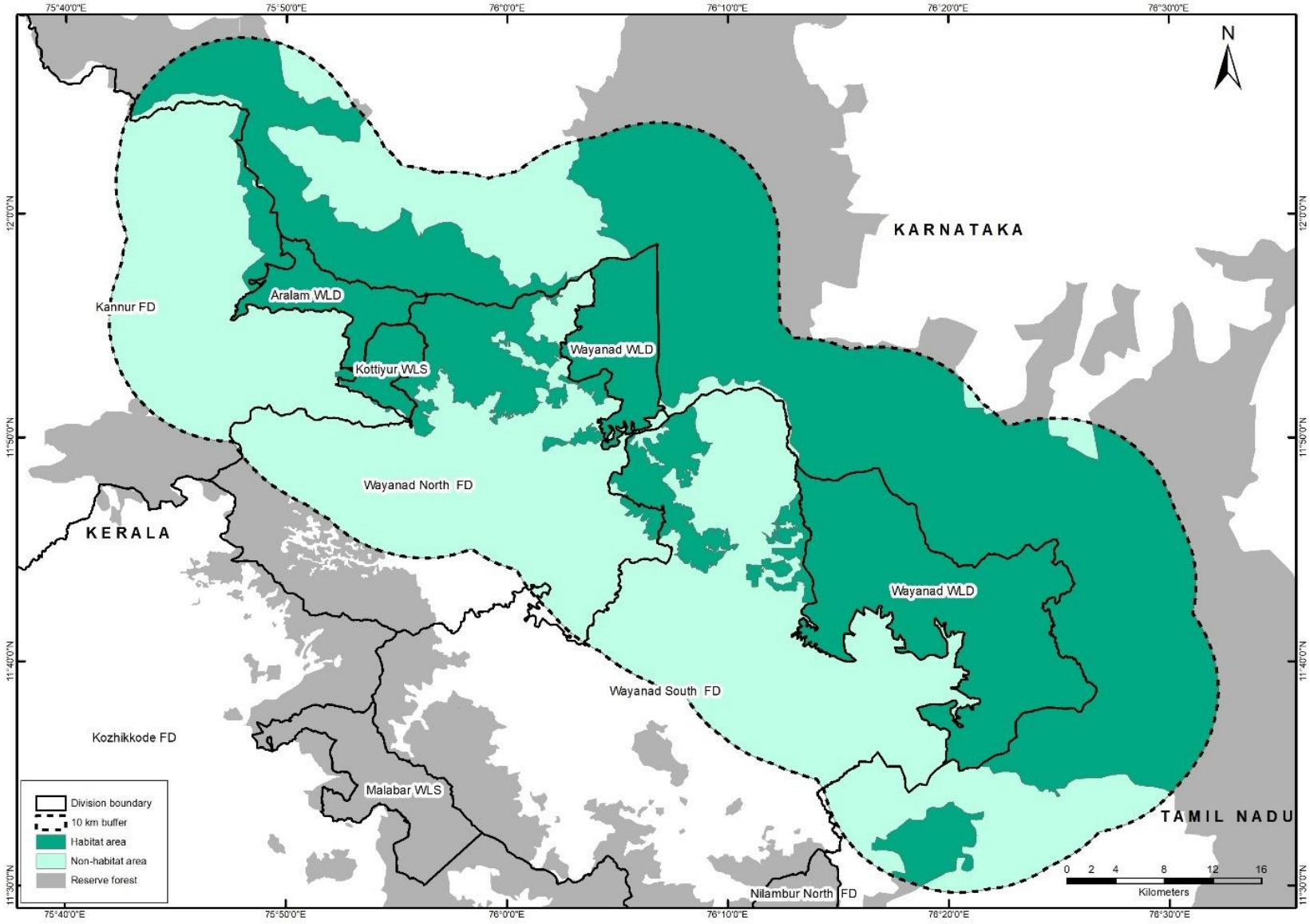


Fig. 12: State-space (with 10 km buffer) of Wayanad WLS used in SPACECAP analysis

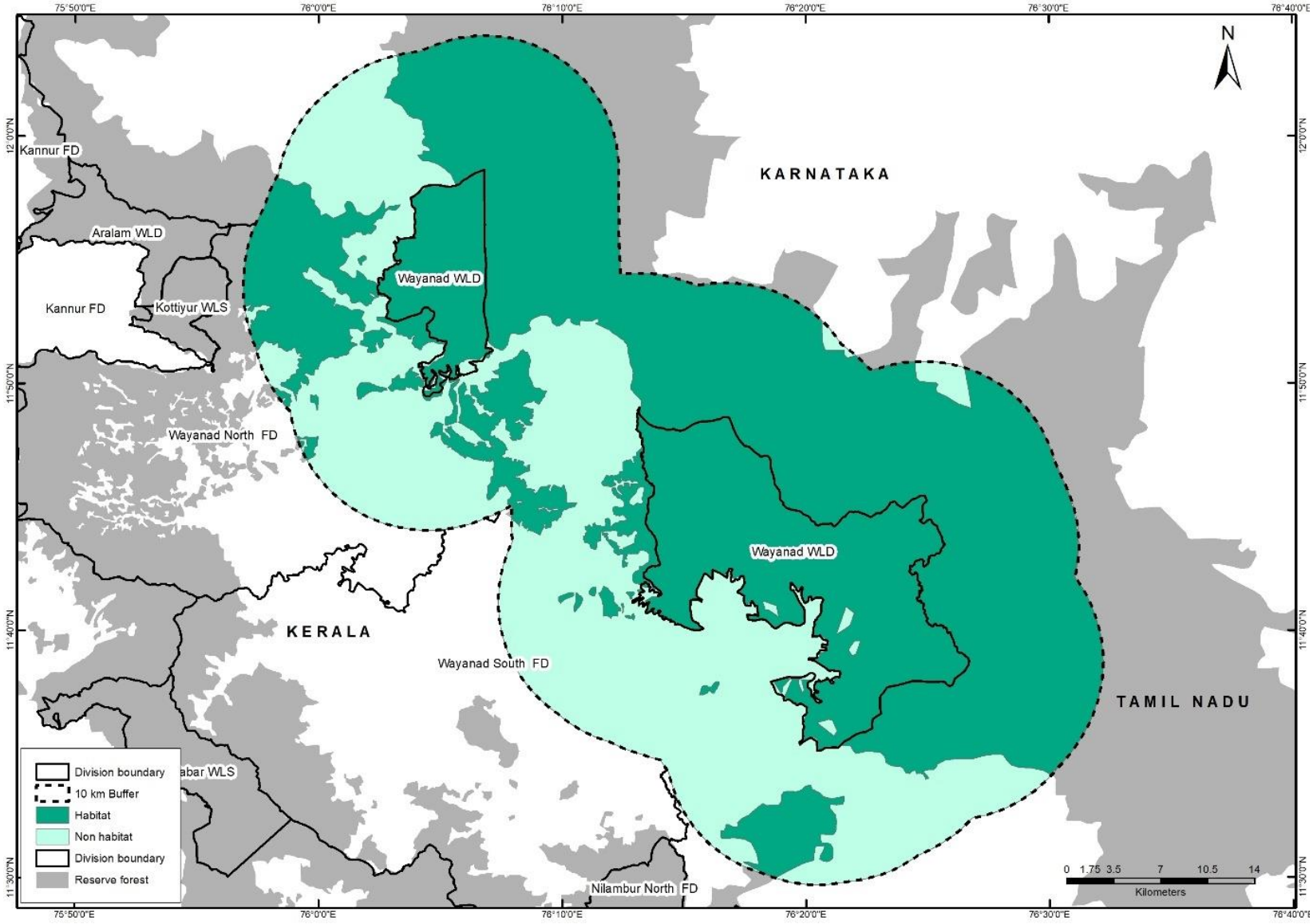


Fig. 13: Stations deployed with CTs during 2023 in Wayanad LS

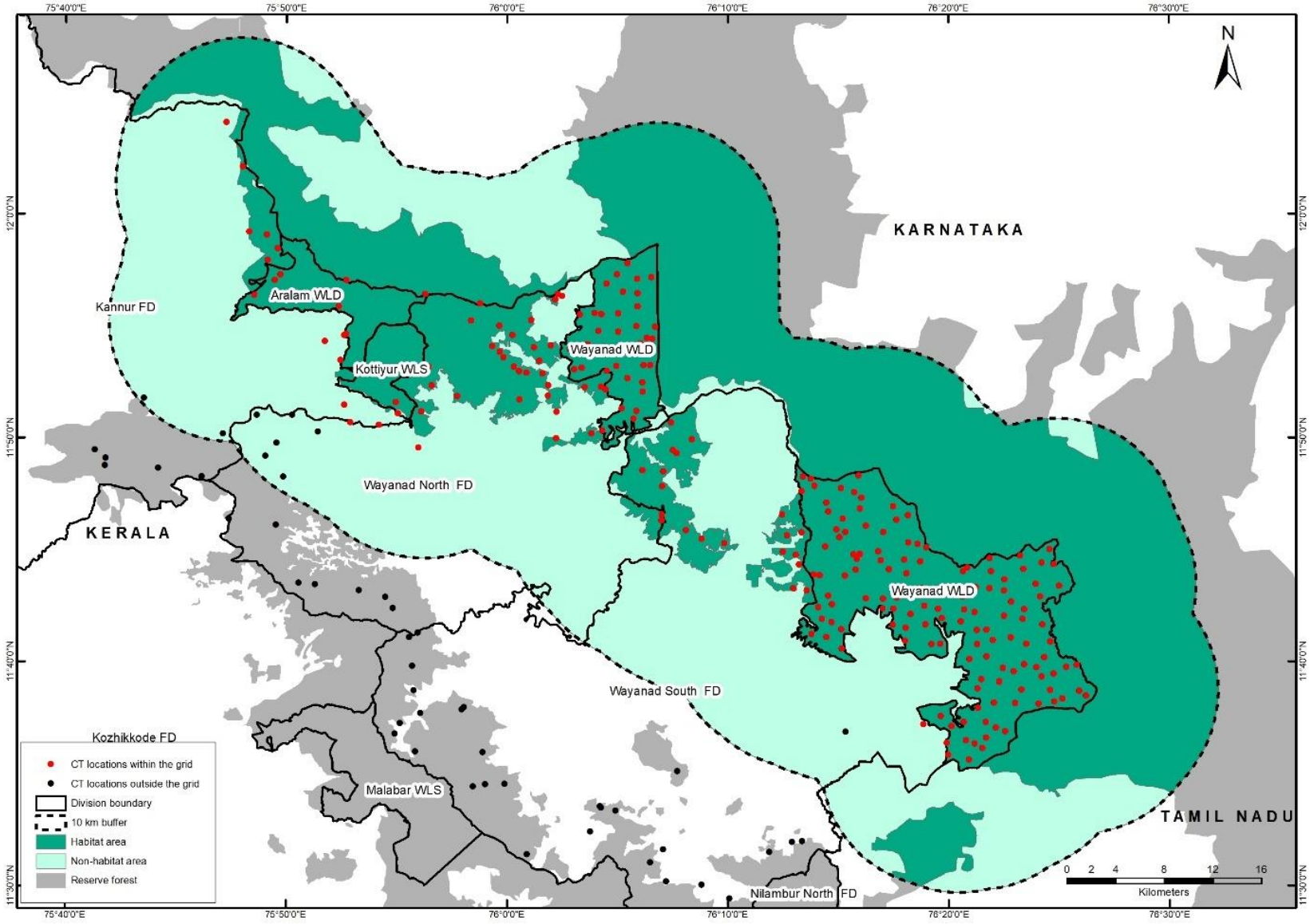


Fig. 15: Map showing CT stations with number of tigers captured

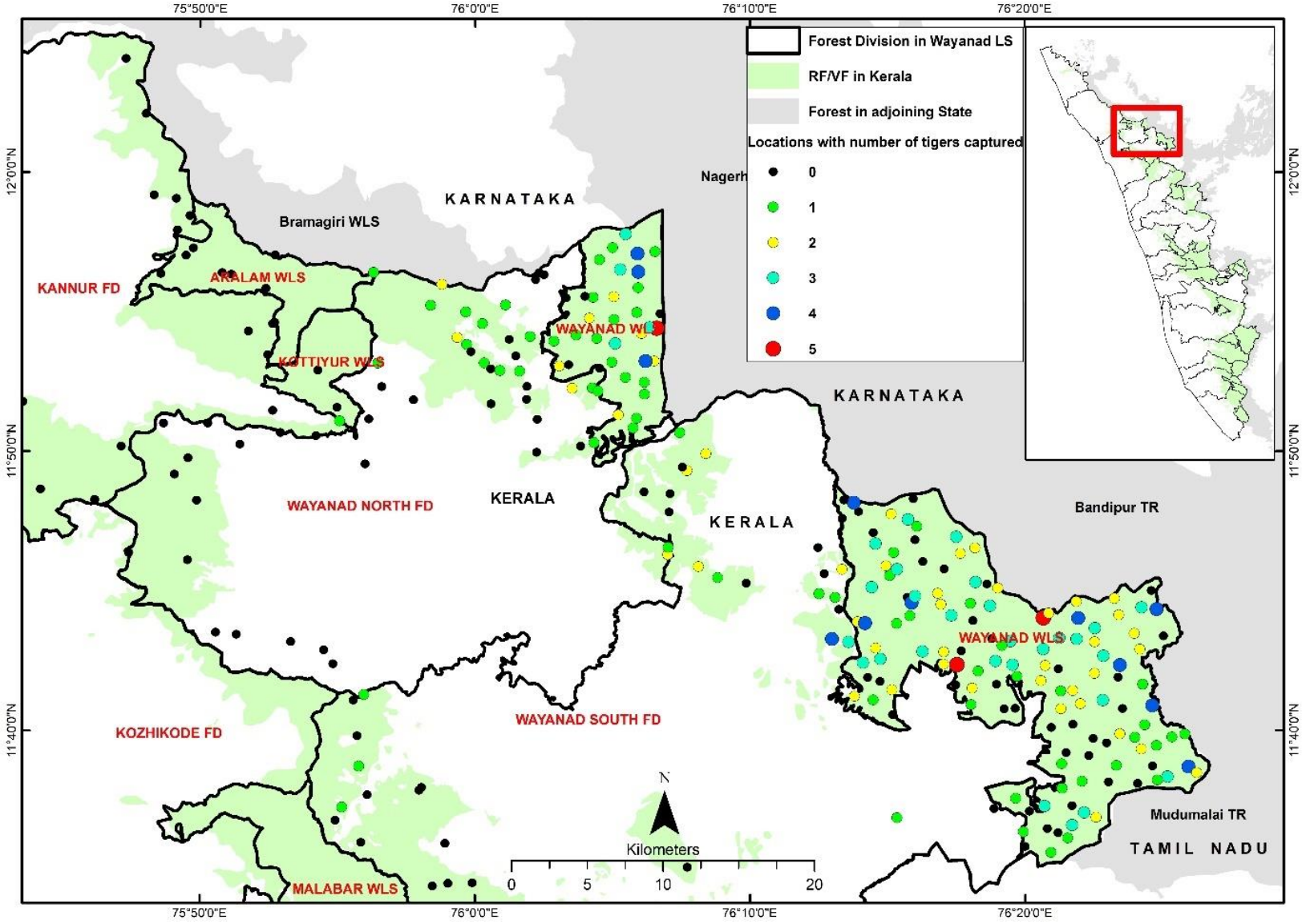
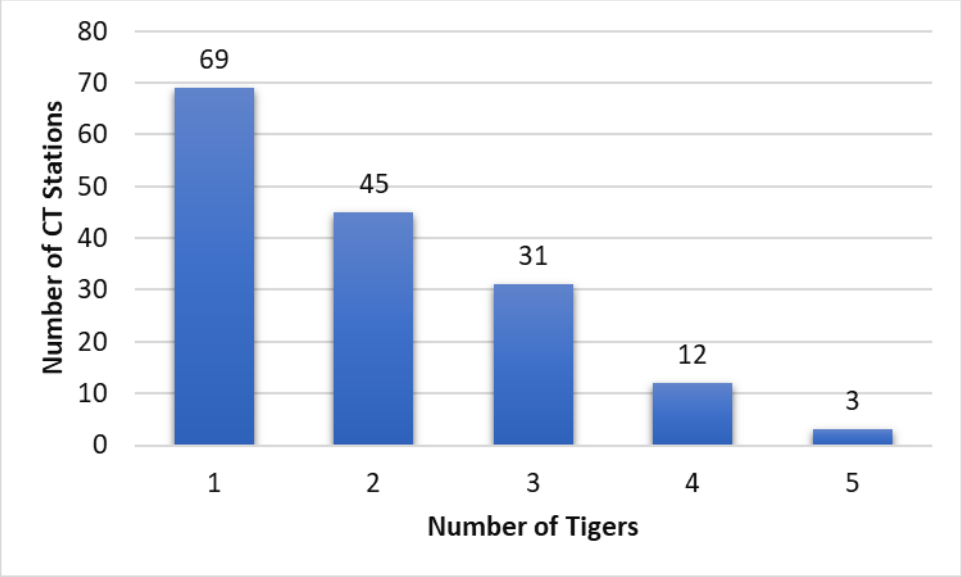


Fig. 14: Number of CT Stations with number of individual tigers recorded



From the 160 CT stations having tiger capture, a total of 84 unique individual adult tigers were identified. In addition, one cub was also captured in the camera trap in 2023. Out of the 84 unique individual tigers identified from the LS during 2023, 82.14% (69 numbers) of individuals were from Wayanad WLS, eight individuals (9.52%) from Wayanad North and seven individuals (8.34%) from Wayanad South FDs.

Some tigers captured in Wayanad WLS during 2023 were also captured in the adjoining territorial FDs. Tigers captured at division-level reveals that a total of 69 individuals were captured from Wayanad WLS, 9 individuals from Wayanad North FD, 12 individuals from Wayanad South FD and one individual from Kottiyur WLS (Annexure 1).

Each individual adult tiger captured during 2023 was assigned with a unique ID at Division-level and attached as Annexure 2. The past capture history of these identified individuals is also given in the same Annexure.

Out of 84 unique individuals, 46% were of newly captured during 2023 and the remaining 54% were captured during the previous estimations. Out of 54% that were already captured, 17% were during 2016, eight percent in 2018 and about 29% during 2021-22 (Fig. 16).

Table 2 reveals the gender categories of the unique tigers captured in Wayanad LS during 2023. Out of 84 individuals, the gender of eight tigers could not be ascertained. A total of 29 males and 47 females were classified which yielded a male to female sex-ratio of 1 : 1.62 in Wayanad LS during 2023.

Fig. 16: Tiger captured during 2023 with past capture details

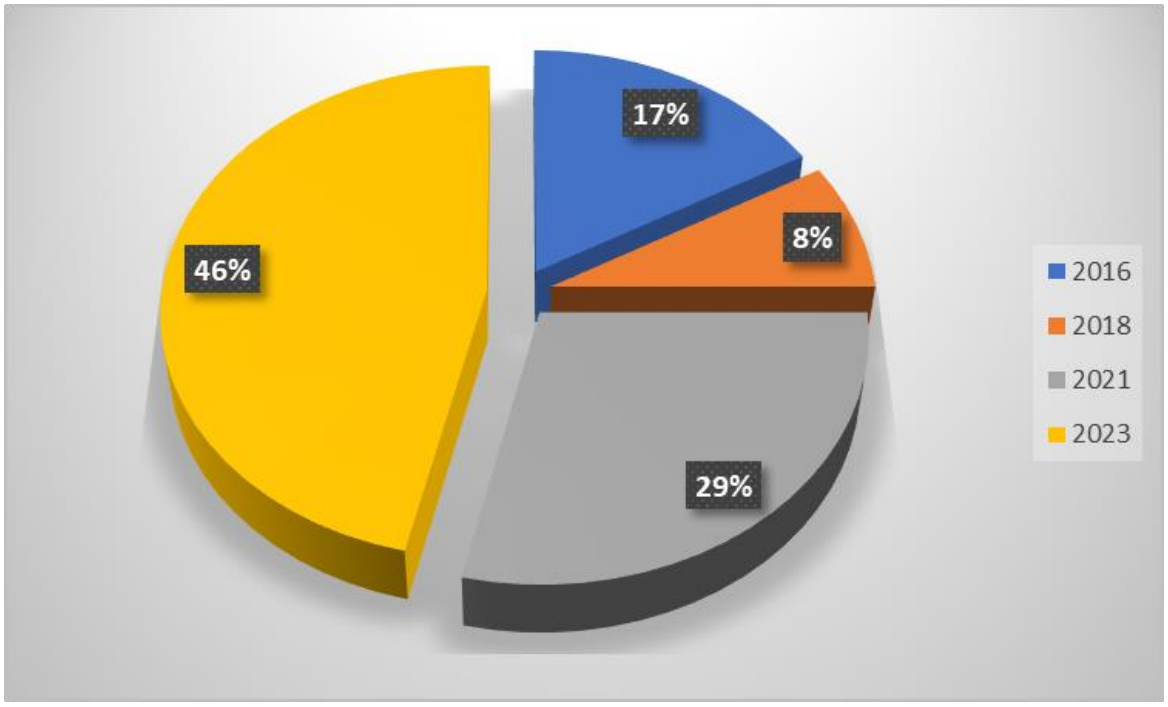


Table 2: Gender categories of tiger captured in Wayanad LS during 2023

Forest Division	Male	Female	Unidentified	Total
Wayanad WLS	22	40	7	**69**
Wayanad North FD	2	6	0	**8**
Wayanad South FD	5	1	1	**7**
Total	**29**	**47**	**8**	**84**

5.1. Population and density estimation of tigers using SPACECAP Program

5.1.1. Population and density estimation in Wayanad LS

In order to estimate the tiger density, the CT stations that fall within the specified grids suggested by WII has been considered. Thus, a total of 247 CT Stations (Fig. 17) and 80 individual unique tigers captured from these CT stations were included in the analysis.

The tiger population (N) estimated in the Wayanad LS using the SPACECAP programme for the entire state-space (with an extent of 2576 km^2 that include areas of Tiger Reserves in the adjoining States) is 132 (95% posterior CI 113-149). The estimated tiger density for Wayanad LS from Bayesian SECR analysis is 7.7 (95% posterior CI 6.6-8.7) tigers/100 km^2. The summary of model parameters of tiger estimation carried out during 2023 in Wayanad LS is given in Table 3.

Fig. 17: Stations deployed with CTs during 2023 in Wayanad LS

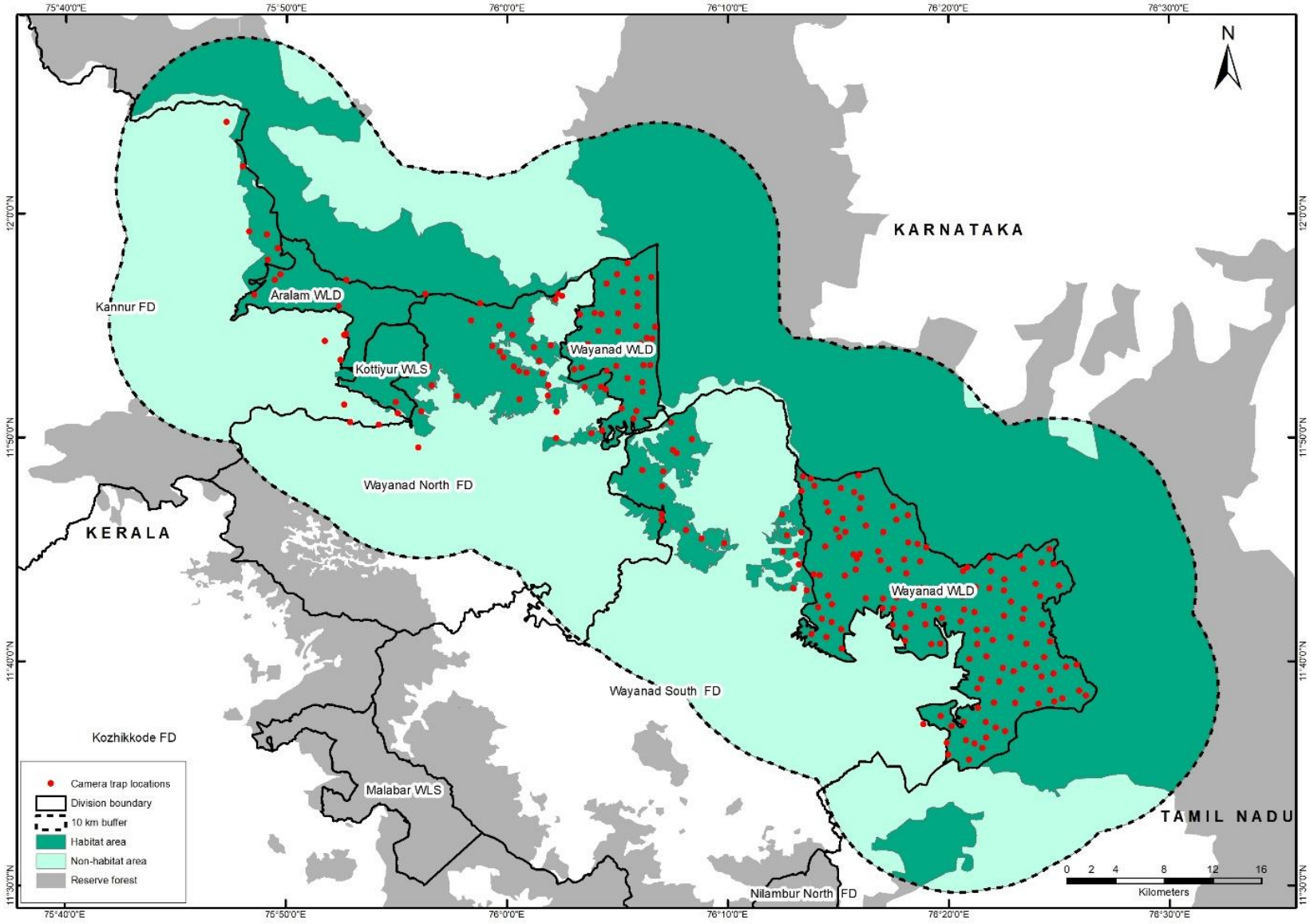


Table 3: Summary of model parameters of tiger estimation from the camera trapping survey (SPACECAP analysis) in Wayanad LS during 2023

Parameters	Posterior Mean (SD)	95% Lower and Upper HPD Level
sigma	**2575.75 (72.92)**	**2435.28-2713.21**
lam0	0.02 (0)	0.02-0.03
psi	0.27 (0.03)	0.22-0.33
Nsuper	**132 (9.40)**	**113-149**
Density/100 sq.km	**7.7 (0.006)**	**6.6-8.7**
p1 & P2	0.023 (0.001)	0.020-0.026

** sigma is the range parameter of an animal or encounter probability; lam0 is the expected encounter rate of an individual "i" in trap location "j" at sampling occasion "k", whose home-range centre is exactly at the trap location; Psi is the ratio of the number of animals actually present within S to the maximum allowable number or data augmentation parameter; Density, D = N/S where S is the area of the state-space; Nsuper is the population size of individuals – the number of activity centres location in S; p1 & p2 are the probability of capture and probability of recapture respectively.*

The map depicting pixel-wise estimates of tiger density for Wayanad LS shows high tiger concentration in Wayanad WLS though large extents of human habitations exist (Fig. 18). However, potential home range centres of tigers exist in Bandipur and Nagerhole TRs in Karnataka and in Mudumalai TR in Tamil Nadu.

5.1.2. Population and density estimation in Wayanad WLS

A total of 170 CT Stations (Fig. 19) and 68 individual unique tigers captured in the CT stations of Wayanad WLS were included in the analysis. The tiger population (N) estimated in the Wayanad WLS using the SPACECAP programme for the entire state-space including areas of Tiger Reserves in the adjoining States (with an extent of 2603 km^2) is 124 (95% posterior CI 103-144). The estimated tiger density for Wayanad LS from Bayesian SECR analysis is 7.9 (95% posterior CI 6.6-9.2) tigers/100 km^2. The summary of model parameters of tiger estimation carried out during 2023 in Wayanad WLS is given in Table 4.

Table 4: Summary of model parameters of tiger estimation from the camera trapping survey (SPACECAP analysis) in Wayanad WLS during 2023

Parameters	Posterior Mean (SD)	95% Lower and Upper HPD Level
sigma	**2602.73 (77.12)**	**2463.45-2753.78**
lam0	0.03 (0)	0.02-0.03
psi	0.30 (0.03)	0.24-0.37
Nsuper	**124 (10.65)**	**103-144**
Density/100 sq.km	**7.9 (0.007)**	**6.6-9.2**
p1 & P2	0.028 (0.002)	0.025-0.032

The map depicting pixel-wise estimates of tiger density for Wayanad WLS shows high tiger concentration within the Sanctuary though large extents of human habitations exist (Fig. 20). However, potential home range centres of tigers exist in Bandipur and Nagerhole TRs in Karnataka and in Mudumalai TR in Tamil Nadu.

Fig. 18: Map depicting pixel-wise density estimates/potential home range centres of tigers in Wayanad LS

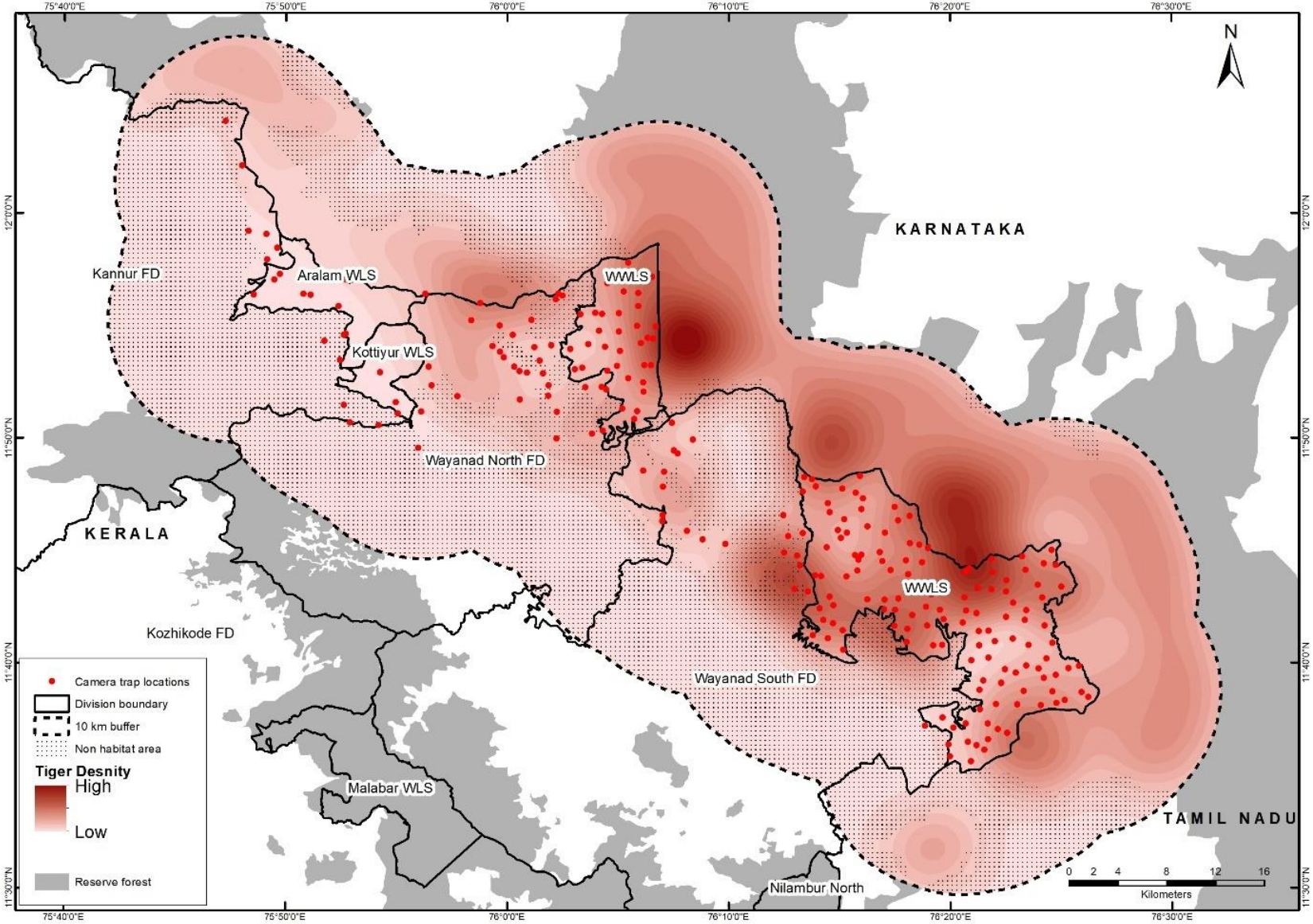


Fig. 19: Stations deployed with CTs during 2023 in Wayanad WLS

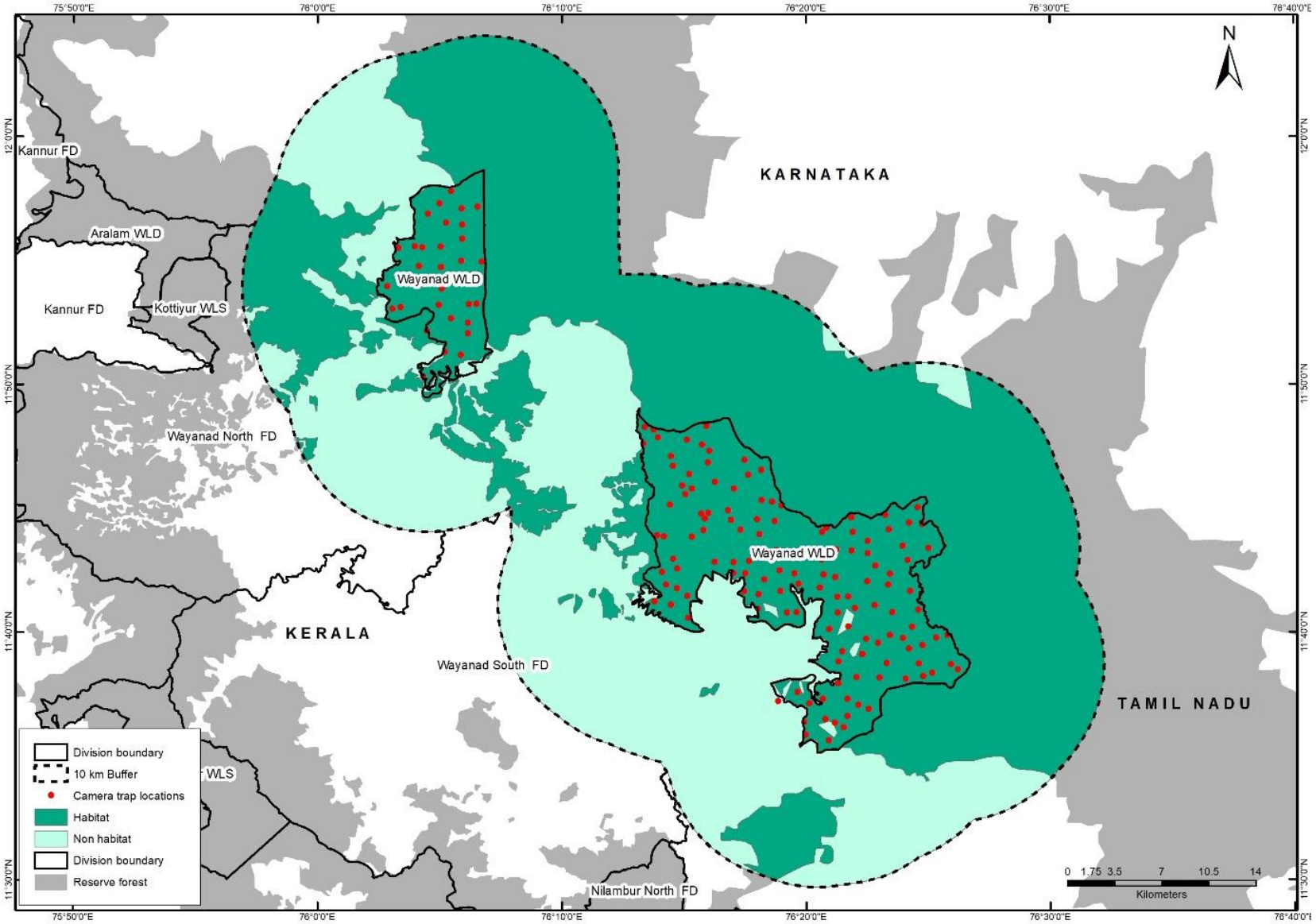
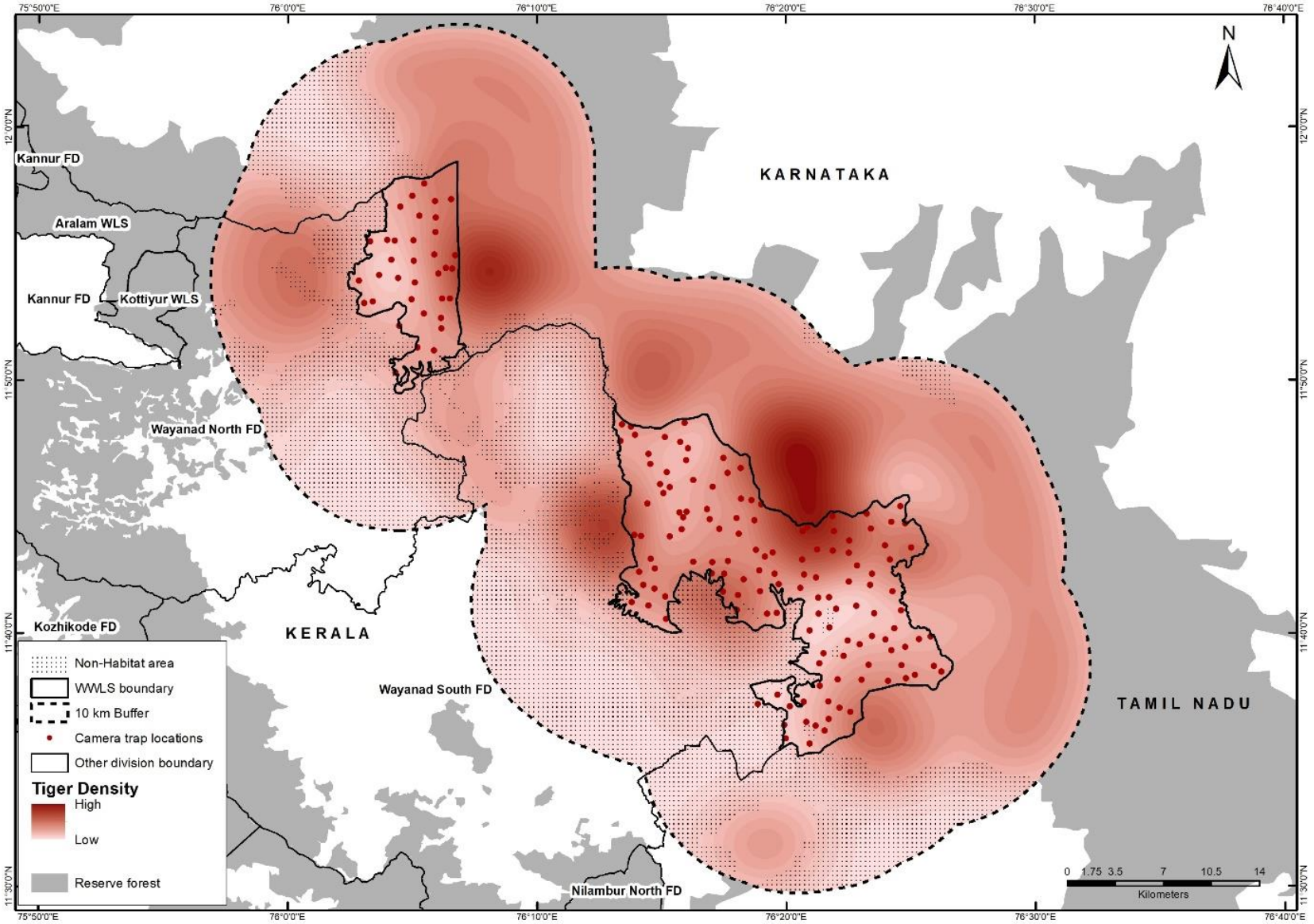


Fig. 20: Map depicting pixel-wise density estimates/potential home range centres of tigers in Wayanad WLS



6. DISCUSSION

Wayanad LS gains great significance with respect to conservation of the apex predator, the tiger, since it is a part of a large forest complex (Nagerhole-Bandipur-Wayanad-Mudumalai-Sathyamangalam-BRT) of about 12,134 km^2 holding the single largest meta population of tiger in India (estimate 724, 95% CI 635 – 813 during 2018).

6.1. Comparison of population and density estimations of tiger

The present survey carried out in Wayanad Landscape during April-May 2023 reports a total of 84 unique individual tigers. The last survey (carried out during 2018) estimated tiger numbers in the Wayanad LS at 120, whereas the 2023 survey photographed only 84 unique individuals in the region. A decline in the density estimation of tigers is also observed in Wayanad LS. During 2018, the tiger density was estimated to be 9.33 (SE 0.86) per 100 km^2 (Jhala *et. al.*, 2020), the 2023 estimate shows 7.7 individuals (95% CI 6.6 8.7) per 100 km^2. Hence, the population as well as density of tigers in Wayanad LS has reduced.

The past tiger estimations carried out in Wayanad LS before 2016 were limited to Wayanad WLS. All those estimations show fluctuations in the tiger population in Wayanad WLS. The first systematic study was carried out by WWF-India using camera trap method during October 2011 to January 2012 (Narasimen, 2013). They used a 44-day subset (so as to adhere to an accepted criterion of closure period – 30-45 days) of this larger data set collected over a period of 4 months to analyse density of tigers for Southern Ranges (Muthanga, S.Bathery and Kurichiat Ranges of Wayanad WLS) and reported a density of 11.21 individuals (SD=1.49) per 100 km^2 from the 49 individuals captured during the study period. Since the Northern Range (Tholpetty Range of Wayanad WLS) was a small area, they didn't analyse the tiger photo capture data for density or abundance estimation, and the minimum numbers of individuals identified during the entire period (26 numbers) was reported. Densities that were estimated using Maximum Likelihood or Bayesian methods were very similar. The 'secr' estimate yielded a tiger density of 11.2 ± 1.7 SE (95% C.I 8.3-15.2) per 100km^2, whereas SPACECAP estimated density per 100 km^2 was 11.3 ± 1.5 SE (95% C.I 8.3-14.1) (Table 5).

Table 5: Estimated tiger densities by various agencies in Wayanad WLS

Agency carried out the study & year	Location	No. of individuals captured in CTs	Posterior Mean (SD)	95% Lower and Upper HPD Level
WWF (2011-2012)[#]	SR	49	11.33 (1.49)	8.35-14.14
	NR	26	NA	NA
WCS (2013)[##]	SR*	33	10.28 (0.82)	NA
	NR**	12	11.09 (0.91)	NA

Agency carried out the study & year	Location	No. of individuals captured in CTs	Posterior Mean (SD)	95% Lower and Upper HPD Level
WWF (2014)[##]	SR	50	10.33 (1.5)	NA
WCS (2014-2015)[###]	SR*	46	12.6	NA
	NR**	19		
KFD (2017)[####]	SR	59	13.07 (1.26)	10.56-15.42
	NR	16	11.21 (2.31)	6.95-15.73
NTCA (2018)[#####]	Wayanad LS	120	9.33 (SE 0.86)	NA
NTCA (2022)[$]	Results awaited as on 26th June 2023			
KFD (2023)[$$]	Wayanad LS	84	7.7 (SE 0.6)	(6.6 8.7)

SR = Southern Ranges with an extent of 266.77 km^2; NR = Northern Ranges with an extent of 77.67 km^2
Narasimen, 2013; ## Jhala *et.al.,* 2015; ### Karanth & Kumar, 2015; #### KFD, 2019; ##### NTCA (Jhala *et.al.,* 2020); $ NTCA (Qureshi, *et.al.,* 2023); $$ Present study
** The data from Southern Ranges was pooled with data from Bandipur TR and analysed by WCS-India.*
*** The data from Northern Range was pooled with data from Nagerhole and analysed by WCS-India.*

The study by WWF-India was continued during 2014 from 8th March to 12th May 2014 with a total of 71 camera trap stations and sampled simultaneously over 32 occasions accounting for cumulative sampling effort of 2272 trap nights with a minimum bounding polygon of 180 km^2. During this study they have identified 50 individuals (Table 5) and estimated tiger density, using Maximum Likelihood based Spatially Explicit Capture Recapture (*ML SECR*) method, as 10.33 individuals per 100^2 (1.5 SE) (Jhala *et.al*., 2015).

During 2013, the WCS-India has carried out a pilot study on tiger density estimation using camera trap method in Wayanad WLS along with landscape-level estimation (including Nagerhole and Bandipur TRs). WCS-India carried out camera trap field survey in Northern Range from 8th March to 12th May 2013 along with Nagerhole TR while the areas of Southern Ranges were deployed with camera traps during 11th March to 13th May 2013 along with Bandipur TR. A total of 20 camera traps (in a trap area of 52.41 km^2) locations were sampled over 30 sampling occasions, accounting for cumulative sampling effort of 540 trap nights in the Northern Range while 51 camera traps (in a trap area of 143.78 km^2) locations were sampled over 30 sampling occasions, accounting for cumulative sampling effort of 1530 trap nights in the Southern Ranges. The data from Northern Range was analysed along with data from Nagerhole TR while the data from Southern Ranges were analysed with data from Bandipur TR. The number of tigers estimated from the 12 individuals identified in Northern Range was 11.09 individuals per 100^2 (SE=0.91) and the number of tigers estimated from the 33 individuals identified in Southern Ranges was 10.28 individuals per 100^2 (SE=0.82) (Table 5).

During 2014-15, WCS-India carried out camera trap survey in the entire Wayanad WLS with a total of 84 trap locations. Camera trap field surveys were carried out from 26th November 2014 to 13th

January 2015 at Northern Range along with Nagarahole TR. A total of 26 camera trap stations covering the Northern Range were sampled over 49 sampling occasions, together accounting for a cumulative sampling effort of 1274 trap nights. In Southern Ranges, camera trap field surveys were carried out from 22nd January to 2nd March 2015 along with Bandipur TR. A total of 58 camera trap stations covering the Southern Ranges were sampled over 41 sampling occasions, together accounting for a cumulative sampling effort of 2378 trap nights. The overall tiger population density in Wayanad WLS derived from these abundance estimates was 12.6 tigers per 100 km^2 (Table 5).

During 2016-17, as part Pan-Kerala Tiger Monitoring Study carried out by Kerala Forests and Wildlife Department, camera traps were deployed in Wayanad, Aralam and Kottiyur WLSs along with areas of Wayanad North & South and Kannur FDs (present Wayanad LS). In Wayanad WLS alone a total of 82 traps locations were selected and camera traps were deployed simultaneously over 30 sampling occasions during the period between 14th October to 18th November 2016 accounting for a cumulative sampling effort of 2460 trap nights. Though statistical analysis (using statistical package SPACECAP V.1.1.0 in R domain – Gopalaswamy *et.al.*, 2012) for the density estimation should not be carried out for Northern Range (being a smaller region for statistical analysis), just for the purpose of management, analysis was carried out as followed by other studies in Wayanad WLS. A total of 59 individuals were identified from Southern Ranges which resulted a population density of 13.07 individuals (varying between 10.56 and 15.42 individuals) while from the 16 individuals identified from Northern Range resulted a population density of 11.21 individuals (varying between 6.95 and 15.73 individuals) (Table 5).

During 2018, as part of AITE-2018 (Jhala *et. al.,* 2020), a total of 312 camera traps were deployed in Wayanad LS yielding 1,380 tiger detections (including 29 images of cubs) from which 120 individual tigers were identified. Density of tigers in Wayanad WLS was estimated to be 9.33 (SE 0.86) per 100 km^2. The results of AITE-2022 in Wayanad LS is awaited while writing this report.

The study by WCS-India during 2013 indicates that the total tiger population within Southern Ranges is 32±6 resident individuals and 10±3 resident individuals in Northern Range of Wayanad WLS (Jhala *et.al.,* 2015). Whereas the study carried out by KDF during 2016 indicates that the total tiger population within Southern Ranges is 34±3 resident individuals and 10±3 resident individuals in Northern Range of Wayanad WLS (KFD, 2019). The present study carried out reveals that the total tiger population in Wayanad WLS is 26±3.

From the above, it can be inferred that the tiger population and density in Wayanad WLS is highly fluctuating and the worked-out densities by various agencies over a period of ten-years were also fluctuating.

6.2. Possible reasons for fluctuation of population of tiger in Wayanad LS

The fluctuation of tiger population as estimated through counts by different agencies over the years is expected as most of the tigers captured in the Wayanad LS are floaters or having major part of home range in the adjoining TRs in Karnataka and Tamil Nadu. The estimated resident tigers in Wayanad LS are much less (30 to 40 individuals) from among the actually captured individuals (84 during 2023). This is evident from the data on the past capture history of individuals photographed during 2023. Out of 84 individuals, 46% is newly captured. Out of the remaining 54%, individuals that are regularly captured since 2016 and 2018 (14 and 7 individuals respectively) could certainly be the resident individuals. The 24 individuals that were also captured during 2021-22 could be partially resident. Most of the individuals that were newly captured during 2023 could be having major part of their home range in the adjoining TRs or even be floaters. Qureshi *et.al.* (2023) in the summary report of AITE-2022 reveals that the tiger populations in Nagerhole and Bandipur TRs have increased but reduced in Wayanad LS. Some tigers in Wayanad LS might have moved to these PAs which are located on the boundary of Wayanad LS. Moreover, the fire incidents during 2022 were also reported to be much less in Nagerhole and Bandipur TRs as there were rains during the first week of April itself (https://www.thehindu.com/news/national/karnataka/rains-in-bandipur-nagarahole-abate-forest-fire-threat/article65320784.ece).

The fluctuation in the population and density in Wayanad LS could also be attributed to the prevailing environmental factors and habitat attributes mainly of Wayanad WLS. There are large number of human settlements within the Wayanad WLS which is the key habitat for the tigers of 'interstate tiger landscape' as majority of tigers (69 individuals) were photographed from Wayanad WLS during 2023. In addition, Wayanad WLS faces a major and unique management problem due to invasion of *Senna spectabilis*. *S. spectabilis* is believed to have been planted in various parts of Wayanad District (especially in small townships and human habitation adjoining forests) as an ornamental tree in the past. Of late, *S. spectabilis* has garnered the attention of foresters and conservationists due to its rapid invasion. The invasion would have started around 25 years ago and has now become a critical management issue. Many of the important potential (productive) habitats of Wayanad WLS have been invaded by this species critically lowering the quality of ecosystem services and functionality. The study carried out during 2013-14 reveals that an extent of 47.6 km^2 was infested with *S. spectabilis.* The area has tripled over a period of ten years from 47.6 km^2 to 123.86 km^2 (> 35 % of the WLS) (Vinayan, 2023) (Fig. 21a and b). The study also pointed out that the degree of invasion was very high in Tholpetty and Muthanga ranges of the sanctuary. The species is unpalatable for herbivores and does allow any other species to grow underneath. The herbivores don't

use these areas even for resting. Arresting further invasion and eradication of *Senna* from the already invaded areas are of prime importance to restore the habitat health of Wayanad WLS and retain the population of prey species and reduce the human-wildlife conflict.

Fig. 21a: Senna Distribution in Wayanad WLS during 2013-14

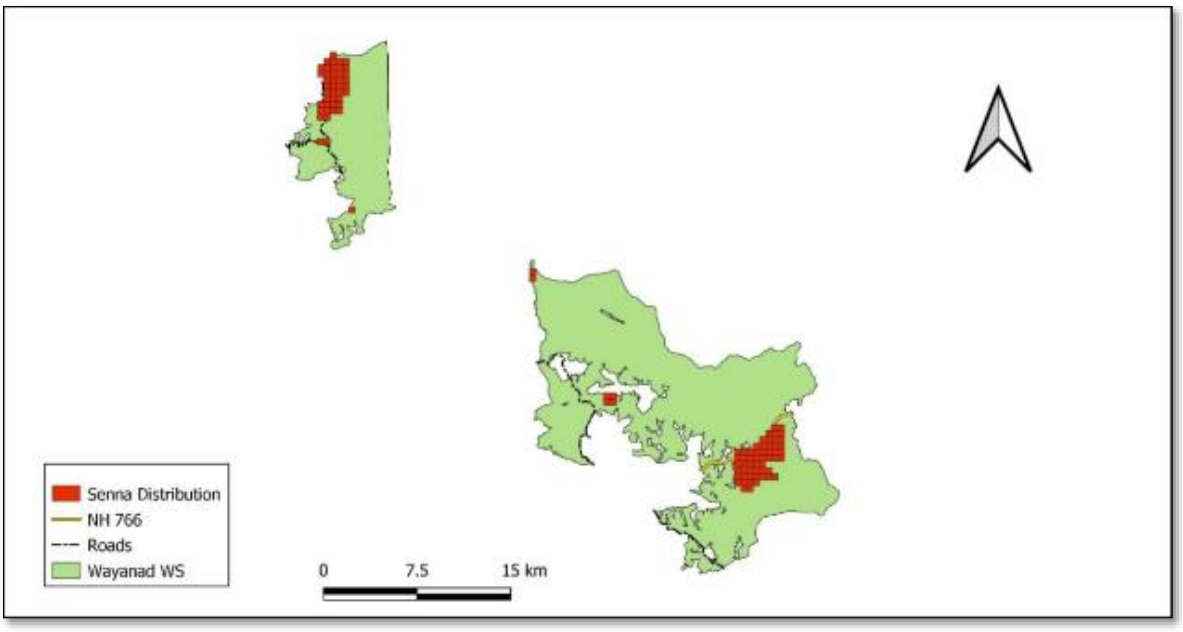
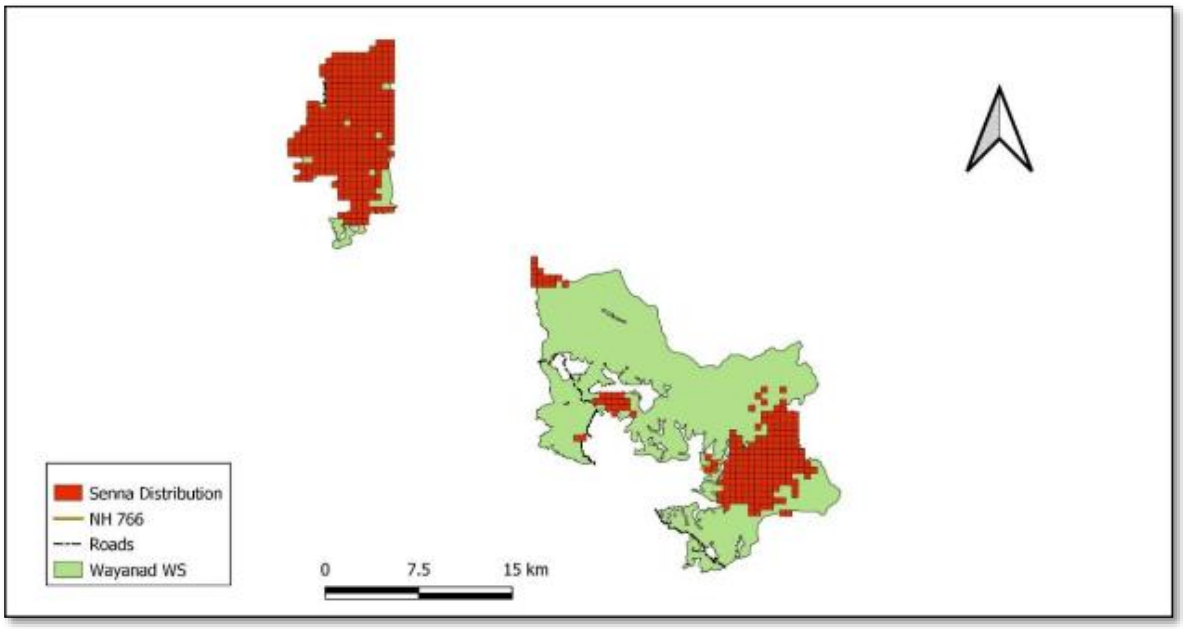


Fig. 21b: Senna Distribution in Wayanad WLS during 2022-23



Wayanad WLS is bestowed with extensive marshy meadows/grasslands that are the key micro-habitat for the sustenance of herbivore population in the Sanctuary. The marshy meadows (*vayals*) with an extent of 1477 ha. face degradation due to infestation of weeds and woody species. The

vayals are often invaded with the weed '*Rhynchospora corymbosa*', which is an unpalatable sedge affecting the natural fodder species of the area. *Vayals* are also dominated by wood vegetation as well as other unpalatable exotic weeds like Lantana, Eupatorium and Mikania that suppress the growth of fodder species especially the grass species. Management of these *Vayals* are crucial for managing and maintaining the herbivore populations. However, only a fraction of these key habitats (Table 6) is being managed every year due to paucity of fund. Lack of maintenance of this crucial habitat is also found to be accountable for increased HWC.

Table 6: Extent of *vayals* marshy meadows being managed (weeding) in Wayanad WLS

Year	Extent (ha) managed
2020-21	193.40
2021-22	171.50
2022-23	127.00

There is evidence that cattle grazing in forests limits big cat abundance. There is livestock grazing occurring along the fringes of human settlements in Wayanad WLS. These cattle directly compete for resources with the wild ungulates that constitute the prey-base of mega carnivores. Moreover, the cattle grazing inside the forests or found in the vicinity of forests are being lifted by tiger. The tigers that are injured, aged or incapable of hunting in the wild often come out from the forest and cause panic in the human habitations.

The present survey documented the adult male to female ratio as 1: 1.62. The generally accepted the best male to female ratio is 1: 2 or 1:3. The 2018 estimation revealed that the detection corrected tiger male to female sex ratio in Wayanad WLS was 0.47:0.53. Hence, the present sex-ratio is considered as healthy and acceptable.

7. RECOMMENDATIONS

Continuous monitoring at regular interval through camera trap exercise would yield information on population dynamics of a target species including emigration (or mortality), immigration (or natality), fecundity, etc. The outcome of such exercise is highly crucial for effective management of tiger population in all tiger-bearing forests especially outside the PAs and also for taking appropriate actions in addressing issues of human-wildlife conflict. The study needs to be continued at least once in two years to;

- Understand population density, abundance and demographic structure of different sub-populations tigers and co-predators within Kerala and the relationship with variations in prey abundance.

- Estimate the survival, recruitment, temporary emigration, dispersal and mortality rates of tigers which are vital for understanding the population dynamics for assessing the viability of sub-populations of tigers.
- Understand connectivity and potential movement corridor, as well as movement pattern of individuals among tiger sub-populations.
- Provide a clear perspective of population dynamics of large predators like tiger to the general public.

Removal of exotic weeds species and other woody species from the marshy grasslands is already proven to be effective elsewhere in the State as evidenced by enhanced fodder availability as well as significant utilization of such maintained habitats by wild herbivores. Hence, it is of paramount importance that maintenance of these *vayals* needs to be carried out every year to confine the herbivore population within the Wildlife Sanctuary and other tiger-bearing habitats. In addition, control of cattle grazing in the forest is also of prime importance to sustain the wild animals within the forests itself and reduce human-wildlife conflict.

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Annexure 1

Unique tigers identified in Wayanad WLS


WWL-25


WWL-27


WWL-28


WWL-31


WWL-38


WWL-39


WWL-45


WWL-50


WWL-56


WWL-60


WWL-72


WWL-76


WWL-77


WWL-79


WWL-80


WWL-84


WWL-85


WWL-87


WWL-89


WWL-90

WWL-95

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WWL-136

WWL-137

WWL-138

WWL-139

WWL-140

WWL-141

WWL-142

WWL-143

WYS-07

WYS-09

Tigers in Wayanad North FD

WYN-5

WYN-6

WYN-7

WYN-12

WYN-13

WYN-01

WYN-21

WYN-22

WWL-118

Tigers in Wayanad South FD

WYS-05

WYS-07

WYS-15

WYS-16

WYS-17

WYS-18

WYS-19

WYS-20

WWL-39

WWL-102

WWL-136

WWL-140

Annexure 2

Tigers captured during 2023 with their past capture history

Wayanad WLS			Wayanad North			Wayanad South			Aralam & Kottiyur WLSs		
Year of first capture	Gender	Division-level ID	Year of first capture	Gender	Division-level ID	Year of first capture	Gender	Division-level ID	Year of first capture	Gender	Division-level ID
2016	M	WWL-025	2016	F	WYN-005	2021	F	WYS-005	2021	M	WYS-018
2016	F	WWL-027	2018	F	WYN-006	2021	F	WYS-007			
2016	F	WWL-028	2018	F	WYN-007	2023	M	WYS-015			
2016	F	WWL-031	2018	M	WYN-012	2023	M	WYS-016			
2016	F	WWL-038	2018	F	WYN-013	2023	M	WYS-017			
2016	F	WWL-039	2021	M	WYN-018	2023	M	WYS-018			
2016	M	WWL-045	2021	F	WYN-021	2023	M	WYS-019			
2016	M	WWL-050	2023	F	WYN-022	2023	U	WYS-020			
2016	F	WWL-056	2021	M	WWL-TR-41	2016	F	WWL-039			
2018	M	WWL-060				2023	M	WWL-102			
2018	F	WWL-072				2023	F	WWL-124			
2021	F	WWL-076				2023	M	WWL-127			
2021	F	WWL-077									
2021	F	WWL-079									
2021	M	WWL-080									
2021	F	WWL-084									
2021	F	WWL-085									
2021	F	WWL-087									
2021	M	WWL-089									
2021	M	WWL-090									
2021	F	WWL-095									
2023	F	WWL-098									
2023	F	WWL-099									
2023	F	WWL-100									
2023	F	WWL-101									
2023	M	WWL-102									
2023	F	WWL-103									
2023	F	WWL-104									
2023	F	WWL-105									
2023	M	WWL-106									
2023	F	WWL-107									
2023	F	WWL-108									
2023	M	WWL-109									
2023	F	WWL-110									
2023	M	WWL-111									
2023	M	WWL-112									
2023	U	WWL-113									
2023	M	WWL-114									
2023	M	WWL-115									
2023	F	WWL-116									
2021	F	WWL-TR-35									
2021	M	WWL-TR-41									
2016	F	WWL-TR-05									
2023	U	WWL-117									

Wayanad WLS			Wayanad North			Wayanad South			Aralam & Kottiyur WLSs		
Year of first capture	Gender	Division-level ID	Year of first capture	Gender	Division-level ID	Year of first capture	Gender	Division-level ID	Year of first capture	Gender	Division-level ID
2018	M	WWL-TR-17									
2023	F	WWL-118									
2021	M	WWL-TR-34									
2023	U	WWL-119									
2016	U	WWL-TR-12									
2016	F	WWL-TR-03									
2023	M	WWL-120									
2023	M	WWL-121									
2021	F	WWL-TR-40									
2021	M	WWL-TR-31									
2021	F	WWL-TR-42									
2023	F	WWL-122									
2023	F	WWL-123									
2021	F	WWL-TR-36									
2016	F	WWL-TR-02									
2023	F	WWL-124									
2021	F	WWL-TR-37									
2023	U	WWL-125									
2023	U	WWL-126									
2023	M	WWL-127									
2023	F	WWL-128									
2021	F	WWL-TR-39									
2023	U	WWL-129									
2021	F	WYS-07									
2021	M	WYS-09									

M = Male; F = Female; U = Unidentified