FACTORS GOVERNING THE SPATIAL DISTRIBUTION AND DENSITY OF ASIATIC LIONS (*Panthera leo persica*) IN GIR PROTECTED AREA

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By
Keshab Gogoi
XIV MSc, Wildlife Sciences
Wildlife Institute of India

Under the supervision of:
Dr. Y.V. Jhala and Shree Qamar Qureshi

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Certificate

This is to certify that **Mr. Keshab Gogoi** has carried out original research titled ***"Factors governing the spatial distribution and density of Asiatic lion (Panthera leo persica) in Gir Protected Area"*** in partial fulfilment of Master's Degree in Wildlife Science from Saurashtra University, Rajkot. The study was carried out under our supervision from December 2014 to June 2015. We hereby certify that this work has not been submitted for any other degree to any other university.

Jhala

(Yadvendradev V. Jhala)
Scientist-G
Sr. Professor
Supervisor

(Qamar Qureshi)
Scientist-F
Professor
Co-Supervisor

Dated : 13th June 2015

Place : Dehradun

पत्रपेटी सं0 18, चन्द्रबनी, देहरादून – 248001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun – 248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स : +91-135-2640111 से 2640115 फैक्स : 0135-2640117
EPABX : +91-135-2640111 to 2640115; **Fax :** 0135-2640117;
ई–मेल / **E-mail:** wii@wii.gov.in, वेब / **website:** www.wii.gov.in

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Summary:

Understanding the mechanisms governing distribution and abundance of organisms have been a key challenge for ecological studies. Large carnivores which act as surrogate for assessing ecosystem conditions are often used as focal species (indicator, umbrella, flagship or keystone) in conservation strategies and their monitoring serves to assess the status of the ecosystem as a whole. Asiatic lions (*Panthera leo persica*) serve as the umbrella and flagship for the Gir ecosystem. Current monitoring techniques use either total counts or capture-mark-recapture (CMR) based on whisker patterns to arrive at population estimates. However, neither provides a spatial context to density which is vital for lion management. Herein I use CMR on individually identified lions in a spatially explicit sampling design and analysis to infer spatial densities of lions in Western Gir. I sampled 29 grids of 25 km^2 by 10 visits (occasions) to each grid to search and identify individual lions. The search resulted in 360 lion sightings of 67 adult individual lions (28 males and 39 females). The best model selected based on AIC has a constant detection probability (g0) between the genders but with males having higher movement than female lions (sigma) (i.e. model Density ~g0-1; sigma~sex). Overall adult lion density in Western Gir was 8.78 (SE 1.10) per 100 km^2, with males having 3.12 (SE 0.60) per 100 km^2 and females having a density of 5.66 (SE 0.92) per 100 km^2. I subsequently analysed my lion sighting data using SECR polygon search method. To understand the factors that likely govern lion distribution I assessed the prey base by DISTANCE sampling on 38 line transects with two transects in each lion search grid. I modelled spatial lion density as a function a) wild prey, b) human disturbance, c) habitat features (water, elevation, vegetation) and d) tourism hot spots (attractants to lions) using general linear models.

Spatial lion density was not correlated with either chital or sambar distribution but was highly correlated with tourism "hot spots", water availability and elevation. My results show the positive influence tourism management practice shows on lion distribution and density. This artificially inflated density can have serious impacts on local prey populations as well as social organization of lions in Western Gir.

1. Introduction

Understanding the mechanisms governing distribution and abundance of organism have been the key challenge of ecological studies since decades (Krebs 1994).Various factors like accessibility to an area (dispersal), resource selection (behaviour), presence of other species and other physico-chemical factors plays an important role, whose complex interactions drives the distribution and abundance of an organism in the ecosystem (Krebs 1994). As well as anthropogenic activities are found to have immense influence in these ecological processes. Shifts in biotic community dynamics through the loss of native species, introduction of novel species or artificially enhanced populations of native generalists, habitat alteration and overexploitation of natural resources are some of the well-known examples of anthropogenic induced alteration of natural system (Smith et al 2015). Likewise behaviour-mediated interactions like artificial feeding of wild animal etc. are found to have substantial impacts on animal distribution and density than purely numerical mechanisms. These behavioural responses are considered to be cryptic but they are powerful driving forces of ecological changes (Blumstein and Fernandez, 2004). On the other hand, a species of high trophic status whose activities exert a disproportionate influence on the pattern of species diversity in a community, plays a very important role in local community diversity, distribution and abundance (Paine 1966, Davic 2003) due to its top-down effect on succeeding species and competition. This effect is largely related to its biomass dominance within a functional group (Davic 2003). So, the number of individuals of a keystone species holds a strong reflection of the ecosystem's health and functionality, which in terms expresses as the density, abundance, and distribution of the species in that ecosystem.

Large carnivores on the other hand are widely recognized to be sensitive to human disturbances owing to slow life cycles, large space requirements, direct persecution by humans and subsequent avoidance of human-dominated areas, often resulting in their decline or extirpation. Carnivores' sensitivity to human density appears to vary between regions as well as between species (Woodroffe, 2000) which might be caused by phenotypic variation among carnivores, people's willingness to tolerate predators, as well as cultural ethics and livelihood practices. For example, Cheetahs were tolerated or even prized in India until the arrival of British colonists, who not only hunted them, but introduced local noblemen to the sport (Divyabahnusinh, 1995). Such cultural differences were also apparent in other parts of the world, in 19th century Cape Province, lions persisted some 30 years longer in black homelands than in white dominated areas, despite higher human densities (Skead, 1987). Therefore top predators act as useful surrogates for assessing ecosystem conditions (Gittleman 1996), and often used as focal species (indicator, umbrella, flagship or keystone) in conservation strategies aiming at a broad objective of conserving the whole ecosystem. Regular and systematic monitoring of these top carnivores keeps a check on the overall status of its ecosystem.

About 20% of large mammal species in India are likely to face extinction in near future, while several species have already disappeared from more than 90% of their original range (Madhusudan and Mishra 2003). Fear of extinction is more to large predators as they require larger inviolate space with intact prey communities and are more prone to conflicts with humans (Woodroffe, 2000). As a result they becomes the first species to disappear from a landscape often with strong cascading effect on ecosystem structure and functionality (Estes *et al* 2011). Negative interactions between carnivores and humans have strong influence on local carnivore population and it also acts as a limiting factor for carnivore meta-population viability as well as a cause of anti-wildlife conservation sentiment (Sillero-Zubiri and Laurenson, 2001). Areas adjacent to protected areas often experience high human-carnivore conflict and carnivore killing, acting as significant population sinks (Loveridge *et al* 2010; Balme *et al* 2010). So it is vital to develop effective large carnivore conservation strategies both within and beyond the boundaries of protected areas.

The cause of the majestic Asiatic lions is not an exception to these cultural shift and human offensiveness. Once Asiatic lions had a wide range through the northern Indo-gangetic basin in North and Central India (Fenton 1908; Pocock 1930; Dalvi 1969). But due to intense hunting and habitat degradation (Kinnear 1920; Fenton 1924) their number and range declined towards the early ninetinth century and confined within the Gir forest of Gujarat with about 50 individuals left in the wild. With the timely and stringent protection by the Rulers of Junagadh and subsequently by the State-run forest department, Gir lions have revived to about 411 individuals in the wild and dispersed into a large tract of about 22,000 km^2 agro-pastoral landscape adjoining the Gir forests (Gir Forest Department 2015). Globally, lions occupied a range in Africa of over 22,211, 900 km^2 which has been currently reduced to less than 3,802,873 km^2 - a reduction of 83% (Ray *et al.* 2005). Simultaneously, lion numbers declined from little less than 100,000 in 1990 (Nowell and Jackson 1996) to a current estimates of continent-wide numbers ranging from 23,000 (Bauer and Van Der Merwe 2004) to 39,000 (Chardonnet 2002).

The population of Asiatic lions in Gir Protected area, being endangered and top predator, has its own unique functional role and importance in the ecosystem and rightly bear the flagship title for the biodiversity of the region (Jhala *et al.* 2004). Hence, it has great conservational value for the ecosystem and its components. Therefore, systematic monitoring of the lion population is required for assessing status of the species as well as the ecosystem it belongs to. But, unlike some of the top carnivore, population level monitoring of lions are somewhat difficult than the use of conventional tools and methods. Remote camera trappings as a tool of wildlife monitoring has been very widely used for other conspecific predators like tiger and leopard. Population size by these method are then estimated in a multiple capture-recapture framework, based on the uniquely identifiable natural marks on the body (Karanth *et al.* 1995, Karanth and Nichols 1998, 2000; Jhala *et al* 2008). While in case of lions, difference in whisker patterns are used to identify individuals (Jhala *et al.* 1999, 2004, 2006, 2011) by taking photographs with handheld still cameras. This technique has been very widely used in a mark recapture framework (Pennycuik and Rudnai 1970; Jhala *et al.* 1999, 2004, 2006, 2011; Ogutu *et al.* 2006; Banerjee *et al.* 2010). This technique gives more reliable estimation than total count (Banerjee and Jhala2012), but it is often very difficult and huge manpower is involved. All the mark recapture techniques are inherently spatial in nature but conventional mark recapture framework does not give any spatial reference of the distribution and abundance of the species (Borchers 2009), which is one of the major component of any ecological studies. Recent advancements in the mark recapture framework and coupled with other tools and technologies, it has become possible to get the spatial arrangement of the species in a geographical area and coupled with other ecological covariate it has now possible to answer some of the ecological questions related to the spatial distribution and abundance of the species. But there has not been any standard protocol developed for lions. In the recent years many studies on Asiatic lion's demography, home range, resource utilisation (Banerjee and Jhala2012), breeding behaviour (Meena 2009), population status (Jhala *et al.* 1999, 2004, 2006, 2011; Banerjee *et al.* 2010; Banerjee and Jhala2012) and conflict (Meena *et al.* 2014) have given enormous understanding about the ecology of the species but a gape in these studies about the spatial abundance pattern of the population as a response to the varying gradients of the environmental factors would be worth meaningful for the conservation and management of the species, which was not very clear till now. This study will be an important addition to the ongoing studies on Asiatic lions in Gir protected area. Therefore, it is imperative to develop a robust yet easily applicable technique to come up with reliable estimates of lion numbers and related ecological processes associated with their distribution and abundance in the landscape.

2. Literature review:

Space plays a vital role in almost all ecological processes (Tilman and Kareiva, 1997; Hanski, 1999; Clobert *et al.*, 2001). The spatial arrangement of habitat can influence movement patterns during dispersal, habitat selection, and survival. The distance between an organism and its competitors and prey can influence activity patterns and foraging behavior. Further, understanding distribution and spatial variation in abundance is important for the conservation and management of wildlife populations (Royle *et al.* 2014). Therefor understanding the spatial ecology is fundamental to effective management of large, wide-ranging carnivores like lion, leopard and tiger in comparatively large and heterogeneous landscapes.

2.1 Factors influence lion abundance

Ecological studies on lions have found strong numerical responses towards both intrinsic and extrinsic factors, leaving profound impact over the density and distribution of the species (Celesia *et al.* 2009; Ogutu 2004). Lion pride size and composition were found to be independent of lion density (Celesia *et al.* 2009); whereas lion density was inversely related with home range size (Schaller 1972; Bertram 1978; Mills *et al.* 1978; Van Orsdol *et al.* 1985; Funston *et al.* 2001; Ogutu and Dublin 2004), while home range size of lion is found to be larger in areas with less prey compared to high density prey area in Gir protected area landscape (Banerjee *et al.* 2012). Relationship between home range size and food availability have widely been reported for other mammalian carnivores as well (Gittleman and Harvey 1982; Van Orsdol *et al.* 1985; Viljoen 1993; Adams 2001), which explains a complex ecological process governing the spatial abundance of the animals.

Climatic conditions are also found to have significant influence on regional variation on lion density (Makacha and Schaller 1969; Schaller 1972; Mills *et al.* 1978; Hanby Bygott and Packer 1995; Funston 2001; Stander 2005). Lion density was positively correlated with rainfall, soil nutrients, prey biomass (Coe *et al.* 1976; Var Orsdol 1984; Stander 1991; Snclair 1995; Ogutu and Dublin 2002, 2004; Hayward et al. 2007). In reality rainfall don't not directly affect the density but exerts an influence via primary productivity and prey biomass (Marker & Dickman 2005).

Habitat heterogeneity and landscape features have strong influence over herbivore biomass and hence on lion density non-linearly (Ogutu and Dublin 2004, Hayward et al. 2007). Recent study on leopards (*Panther pardus fusca*) in Sariska Tiger reserve showed that probability of occurrence of this large carnivore is higher in habitats with moderate cover, high wild prey base and availability of water resources (Mondal et al. 2012).

Anthropogenic pressure on carnivores are always found detrimental (Ogada *et al.* 2003; Inskip, Zimmerman 2009), however, recent studies in Gir landscape have found positive influence on lion density and distribution (Banerjee and Jhala 2012). The semi nomadic pastoral community "Maldharis" living inside the protected area, due to their tolerance and strong ethical beliefs on nature lives a win-win life with Asiatic lions for centuries. This co-existence is only possible because of the timely and efficient compensation scheme of the forest department along with the tolerance of the Maldhari people (Banerjee and Jhala 2012) as well as the surrounding inhabitants of the lion habitat. Nevertheless the situation is not same in other parts of the country with large carnivore existence. In Namibia, large predators, such as lions (*Panthera leo*) and spotted hyenas (*Crocuta crocuta*) have been extirpated from the farmlands to reduce livestock depredation but leaving leopards and cheetahs (*Acinonyx jubatus*) as such, which acts as the functional top predators in those areas (Marker & Dickman, 2005). But, in Gir forest of Gujarat, the semi nomadic forest dwelling pastoral community "Maldharis" are found to have occurred peacefully with both Asiatic lions, leopards since decades (Banerjee et al. 2012). Human cultural ethics and traditional practices exerts remarkable impacts on the distribution and abundance of carnivores and other wildlife. Therefore timely and systematic monitoring of these large carnivores are very essential to keep a check on the functionality of the ecosystem.

2.2. Population estimation of lion

The population size of large carnivores is a good indicator of varying ecological factors, but estimating the population size of large terrestrial carnivores are often difficult and depends on the recognition of individuals and groups (Schaller 1961; Whyte and Dearlove 1977). Owing to their low density and wide ranging cryptic nature, assessments often demands extreme high resources and time requirements (Garshelis 1992). Nevertheless, several approaches have been tried for estimating large carnivore numbers. These include:

1. Total counts without correcting for detection bias (Choudhury 1970; Panwar 1980; Fuller 1989; Gore *et al.* 1993; Smallwood and Fitzbugh 1995),
2. Indices for relative abundance (Knowlton and Tzilkowski 1979; Palomares *et al.* 1996; Stander 1998; Houser *et al.* 2009; Funston *et al.* 2010),
3. Indirect methods of scaling and predicting (Carbone and Gittleman 2002; Karanth *et al.* 2004; Hayward *et al.* 2007) and
4. Modern approaches to abundance estimation incorporating detection probabilities (Karanth 1995; Karanth and Nichols 1998; Jhala *et al.* 2004; Kelly *et al.* 2008; Mondol *et al.* 2009; Sharma *et al.* 2010).

Techniques used to date for abundance estimation of lions includes:

1. Total count without correcting for detection bias.
2. Playback surveys (Ogutu and Dublin 1998; Mills *et al.* 2001; Ogutu *et al.* 2005)
3. Faecal DNA sampling (Tende *et al.* 2010) and
4. Helicopter surveys (Packer 2006).
5. Mark recapture (Smuts 1976; Jhala *et al.* 1999, 2004; Ogutu *et al.* 2006; Banerjee *et al.* 2010) through individual lion identification by vibrissae pattern (Pennycuick and Rudnai 1970).

The methods for estimating endangered carnivores need to be practical and cost effective. Total count gives a fair idea about the population but associated with huge observability bias. But, in large areas this method might incorporate higher biases. Playback survey are also based on total count of lions gathered around the call stations and found to have limitations as a sampling technique (Whitman, 2006) because it is found that: (i) females are less responsive than males, (ii) response is very sensitive to the distance of the speaker from the lions and (iii) location of the speaker within the pride's territory has direct effect on their response (Brink 2012).Faecal DNA sampling could give more reliable estimates if direct counting is combined with DNA-based individual identification. But this is an expensive method and possibility of errors is very high considering the quality of DNA extracted from scat and precautions followed for the analysis.Similarly, helicopter surveys are expensive and cannot be applicable for lion population estimation in the Gir landscape (Banerjee *et al.* 2010), due to the heterogeneity of the habitat and intact dry deciduous forest cover.Population estimation by mark recapture framework is very widely accepted and gives more reliable estimate than the above. It is used for many carnivores around the world including lions (Smuts 1976; Jhala *et al.* 1999, 2004; Ogutu *et al.* 2006; Banerjee *et al.* 2010).

Since 1963, the Gujarat Forest Department has censuses lions about every five years by a labour-intensive method using live baits for three days, until 1995 when this met with social and ethical opposition (Singh 2007). But the total count of lions obtained by the management using buffalo baits was lower than the mark-recapture population estimate (Singh 1997; Jhala *et al.* 1999). This suggests that total count of lion were likely underestimates and associated with biases of observability that varies, in turn, with vegetation cover, activity schedule, body size, group size and population size of the vertebrates (Seber 1982). Therefore the combination of individual identification by standardized protocols based on vibrissae patterns and permanent natural markings (Jhala *et al.* 1999, 2004), in a capture-recapture framework (Pollock *et al.* 1990) if done during the exercise of total counts, would estimate the lion population in a more robust manner (Banerjee *et al.* 2012).

Use of vibrissae pattern to individually identify lions (Pennycuik and Rudnai 1970) has been utilised for the monitoring of Asiatic lions in Gir protected area (Jhala *et al.* 1999, 2004) along with specialised monitoring with GPS and radio tagged animals to understand their ranging pattern, resource utilisation and demographic structure (Banerjee thesis 2013; Banerjee, Jhala and Pathak 2010). Coupling with these studies emphasising management importance,tracing the responses of the population as a whole towards different ecological factors would give enormous input into their ecology and effective conservation practices for the management authorities, as well as development of a robust study design for such study would be worth meaningful for the study of other such species too.

2.3 Mark-recapture

Observing animals in the wilderness at first hand is one of the most rewarding aspects of being a wildlife biologist or a natural resource manager (Keys *et al.* 2008). Unfortunately, wildlife sightings are too few and far between to address modern scientific and conservation issues. For these purposes we need large data sets documenting the pattern of their density and abundance. Recent developments in the field of scientific monitoring and survey methodologies have gained considerable success in survey designs. Among other wildlife survey tools and techniques, use of remote detectors as a mean to sample cryptic and rare species have gained much familiarity and considered reliable. Amongst capture–recapture is the primary indirect method and has a central place in the ecological toolkit (Efford & Fewster 2012). New technology that exploits natural marks, individual variation in microsatellite DNA or individual pelage patterns captured on automatic cameras, has removed the need for physical capture in many situations, so capture–recapture methods are now applied to a greater range of species than ever before (Efford & Fewster 2012). As a method for estimating abundance, some of the earliest work that relates to the use of camera trapping (proximity detector) data in capture-recapture framework originate from Karanth (1995) and Karanth and Nichols (1998, 2000) . In camera trapping studies, cameras are often situated along trails or at baited stations, and individual animals are photographed and subsequently identified either manually by a person sitting behind a computer, or using specialized identification softwares. Than the generated data are processed with different models and analytical platforms.

Capture-recapture methods have been used to estimate the size of animal populations for many years, about 35 years ago the first software package for analysis of this kind of data, CAPTURE (Otis *et al* 1978) was developed. Though useful the approach is often considered bias. Rigorous sampling of animal populations to estimate or index density raises the problem of incomplete detection (Burnham, 1981; MacKenzie & Kendall, 2002; Pollock *et al.*, 2002; Rosenstock et al., 2002; Thompson, 2002). Detection probability generally has been described by a single parameter p. An estimate of p may be used to obtain a population estimate N from a count C

(Lincoln-Peterson closed population estimation).

$$N=C/p$$

If detections relate to a known area a then population density may be calculated as:

$$D=N/a$$

But the area in most of the cases is unknown and according to the above assumptions the sampling area should be closed, but this is not ideal in the real field situations. Rare, secretive and highly mobile species with small number and movement on and off study sites exerts these problems in defining the effective area occupied. Traditionally ½ MMDM method was used to add a buffer around minimum convex polygon (MCP) of animal capture locations. Half MMDM was not reliable and spatial methods to ascertain probable area occupied by captured population solved the ambiguity of defining effective sampling area (Efford 2004).

2.4 Introduction to Spatially Explicit Capture Recapture (SECR)

Most capture-recapture studies are inherently spatial in nature, with capture probabilities depending on the location of traps relative to animals (Borcher 2010). The need for a spatial component in models arises from the fact that animals located closer to traps are more likely to be captured and animals sufficiently far from the traps will certainly not be captured (Borcher 2010, Borcher & Efford 2012). Spatially explicit capture–recapture models were first proposed by Murray Efford in 2004 based on inverse prediction. Spatially explicit capture–recapture (SECR) is a set of methods for modelling animal capture-recapture data collected with an array of 'detectors' (Efford 2015). The methods are developed primarily to estimate population density, but they are also advantageous over non-spatial methods in terms of estimating population size (Efford and Fewster 2013). SECR methods overcome edge effects that are problematic in conventional capture–recapture estimation of animal populations (Otis *et al.* 1978). In SECR detectors may be live-capture traps, with animals uniquely tagged, sticky traps or snags that passively sample hair, from which individuals are distinguished by their microsatellite DNA, or cameras that take photographs from which individuals are recognized by their natural marks. Advanced developments have also extended the concept of detector to area (polygons) or transects that are searched for animals or their sign.

In SECR, the spatial detection histories are fitted with a spatial model of the population and a spatial model of the detection process. Therefore the resulting estimates of population density are unbiased by edge effects and incomplete detection (Efford 2014). Inverse prediction (IP SECR) and maximum likelihood (ML SECR) are alternative methods for fitting the spatial detection model (Efford 2004, Borchers and Efford 2008). Of these, the maximum likelihood approach is considered to be more flexible, with a caveat for data from single-catch traps (Efford 2004, 2015, Borchers and Efford 2008). Data augmentation and Markov chain Monte Carlo (MCMC) methods have also been used for SECR (Royle and Young 2008, Royle *et al.* 2009, Singh *et al.* 2010, Royle and Gardner 2011), but this approach is much slower than ML SECR (Efford 2015). In general SECR models, population density D is considered as the intensity of a Poisson spatial point process for home range centers, which are assumed to be fixed. The process may be homogeneous (D constant) or inhomogeneous (expected value D(X) where / is a vector of parameters for a model relating density to location, X, specified by a vector of coordinates x, y). The data comprise a set of detection histories x*i* for the n observed individuals; the elements of x*i* represent the detections of individual *i* on S successive occasions at a set of K detectors

SECR methods have found to utilise in a wide range of studies. These include cage-trapping of possums (Efford *et al.* 2005), mist-netting birds (Efford *et al.* 2004; Borchers and Efford 2008), acoustic "trapping" of cetaceans from their vocalizations (Marques et al. 2010), acoustic "trapping" of birds from their song (Efford *et al.* 2009b; Dawson and Efford 2009), use of hair snares for stoats and bears together with individual identification via DNA analysis (Efford *et al.* 2009a; Obbard *et al.* 2010), visual capture-recapture of lizards (Royle and Young 2008), and camera-trapping of tigers with visual individual identification (Royle *et al.* 2009a, b; Royle and Dorazio 2008), carnivore density from unstructured spatial sampling of Scat using detector dogs (Thompson *et al.* 2012), estimating abundance of mountain lions from unstructured spatial sampling (Russell *et al.* 2012).

3.5 Comparison between conventional mark-recapture and SECR method

3.5.1 Conventional mark recapture

In conventional mark-recapture studies the basic parameter of estimation is the population size rather than the density of the animals. But, most of the times density is more important from the point of ecology and management than just population size of the species. The fundamental concept of density estimate is to know the size of the area from where the animals are being sampled, which is generally unknown in most of the conventional sampling framework (Royle *et al.* 2009; O'Brien and Kinnaird 2011, Rich *et al.* 2014). Therefore the density estimation is ad hoc, adding a buffer area around the trap array (Wilson and Anderson 1985; Karanth and Nichols 1998; Parmenter *et al.* 2003). But the scale to define the width of that buffer vary; thus, the reliable definition of the effective trapping area is generally uncertain (Borchers and Efford 2008; O'Brien and Kinnaird 2011) and density estimates are somewhat arbitrary (Rich *et al.* 2014).

Another important ecological limitation of conventional mark-recapture studies is that the spatial component of detectors is not directly incorporated into the analytical framework (Gopalaswamy *et al.* 2012). The geographic location of the detectors are important because an individual's probability of being captured or recaptured depends on the overlap of its home range with the trap array (Efford 2004; Royle et al. 2009). In traditional practices of photographic capture–recapture techniques the species must be identifiable to the individual level (Rich et al. 2014).

2.5.2 Spatially explicit capture recapture

Spatially explicit capture-recapture (SECR) models (Efford 2004; Borchers and Efford 2008; Royle *et al.* 2009) were developed to address these limitations of traditional capture–recapture techniques (Rich *et al.* 2014). SECR modelling is a set of methods for modelling animal capture-recapture data collected with an array of 'detectors' (Efford 2014) with reference to specific geographical locations. A hierarchy of models is used in secr to estimate spatial density of animals. The probability of detection is modelled as a function of the distance between camera-trap locations and an animal's activity centre, and density is estimated using a point process model (Efford 2004; Royle *et al.* 2009) based on their activity centre (Russel *et al.* 2014). The actual location of activity centres is unknown, but the spatial coordinates of the traps where individual animals were photographed provide some information about this location (Borchers and Efford 2008; Royle *et al.* 2009). In practical terms, SECR methods are also advantageous over non-spatial methods because their less dependencies on the spatial setup of the camera stations (Noss *et al.* 2012; Sollmann *et al.* 2012) and incorporate different spatial sampling design. Thus, with SECR modeling, a standardized trapping design can be used to estimate the density of a single species or multiple, sympatric species (O'Brien and Kinnaird 2011) along with different environmental covariates. SECR models, however, still require that all photographed animals be uniquely identifiable. In SECR, a spatial model of the population and a spatial model of the detection process are fitted to the spatial detection histories. The resulting estimates of population density are unbiased by edge effects and incomplete detection (Efford, 2014, 2015). Therefore SECR methods overcome edge effects that are biased in terms of effective trapping area in conventional capture recapture estimation of animal populations (Otis *et al.* 1978). Different kinds of detectors can be used which may be live traps, sticky traps for hair sample, from which individuals are distinguished by their microsatellite DNA, or camera traps, where individuals are recognise based on their unique natural patterns of their body. Resent development in secr have extended the concept of detectors to area (polygons) or transects that are searched for animals or their sign (Efford 2014, Thompson *et al.* 2012, Russel *et al.* 2012). Which has now become possible to study animals which were otherwise not possible with conventional sampling designs of mark recapture platforms.

The primary data required for SECR are (i) the locations of the detectors, and (ii) detections of known individuals on sampling occasions (i.e. their detection histories). In SECR, the basic population parameter is density (D), rather than population size (N). The detection process is represented by a mathematical function that describes an animal's declining probability of being detected as its home range centre gets further from a detector. A simple detection function has the parameters g0 (intercept) and σ (spatial scale). The model is used to obtain estimates of D, g0 and σ. Population size N may be estimated as a derived parameter.

1.5.3 The effective sampling area problem

In conventional mark-recapture studies density is derived by converting the abundance with reference to the effective trapping area generated post hoc by using available data on animal movements that account for movements on and off the trapping array (Thompson *et al.* 2012). Which is generally added as a buffer half of the home range size or half the mean maximum distance moved, if the movement data is available (Karanth and Nichols 1998). But size of the sampling area from where the animals are being captured is generally unknown in most of the conventional sampling framework (Royle *et al.* 2009; O'Brien and Kinnaird 2011, Rich *et al.* 2014). Therefore the density estimation is ad hoc (Wilson and Anderson 1985; Karanth and Nichols 1998; Parmenter *et al.* 2003), as well as the scale to define the width of that buffer vary; thus, the reliable definition of the effective trapping area is generally uncertain (Borchers and Efford 2008; O'Brien and Kinnaird 2011) and density estimates are somewhat arbitrary (Rich *et al.* 2014). But incorporating spatial point process models into capture-recapture frameworks using SECR analytical platform can directly estimate density by combining the location data provided by trap or capture coordinates with individual encounter histories (Thompson *et al.* 2012).

2.5.4 State and observation models

SECR combines a state model and an observation model (Efford 2015). The state model describes the distribution of animal home ranges in the landscape, and the observation model (a spatial detection model) relates the probability of detecting an individual at a particular detector to the distance of the detector from a central point in each animal's home range.

2.6 Major type of detectors widely used in SECR

- *Multi-catch traps*: These are traps which can hold any number of animals and in which captured animals are stuck for the duration of a trapping occasion, and as a consequence, animals can only be caught in one trap on any one occasion. Mist-nets are an example.
- *Single-catch traps*: These are traps that can hold only one animal and which are therefore unavailable to catch other animals once they have caught one. Cage-traps are an example.
- *Proximity detectors*: These are ''traps'' that record an individual's presence but leave the animal free to be detected by other detectors within any occasion. Multiple animals may be recorded at each detector. Examples are hair snares, camera traps and acoustic detectors. (See Efford et al. 2009a for some discussion of other kinds of detector.)
- *Count detectors*: The 'proximity' detector type allows at most one detection of each individual at a particular detector on any occasion. Detectors that allow repeat detections are called 'count' detectors in secr. Count data can result from devices such as automatic cameras, or from collapsing data collected over many occasions (Efford et al. 2009). Count data are input by repeating each line in the capture data the required number of times.
- *Polygon detector*: In this kind of detectors are used when the task is to search an area intensively for any kind of indirect sign or direct detection of individuals. This particular sampling methodology is considered somewhat complex but biologically more realistic (Royale 2014). A brief description is hereby provided below.
- *Transect detector*: Here counts are made from searching one or more transects and the overall data collection is somewhat like conventional distance sampling practices but they do not include distances from the route to the location of the individual (Efford 2014). A route may be searched multiple times, and a dataset may include multiple routes.

2.7 Polygon search method

The 'polygon' detector type is used for data that need searches of one or more areas (polygons). This area search differ from other modes of detection in that each detection may have different coordinates, and the coordinates are random rather than fixed by the field design (Efford 2014). The method may be used with individually identifiable cues (e.g., faeces) as well as for direct observations of individuals (Thompson *et al* 2012, Russell *et al* 2012, Efford 2014). Importance of these kind of detection is that both the trap and individuals are mobile *i.e.* the detector would be the person or any other means which actively searches for the individuals within the sampling grids, therefore the geographical location of the detected individuals are independent of any fixed trap array and represents the actual sites of encounter in each detection. Hence, unlike the conventional detection history, instead of trap id, the "capture file" would bear the actual geographical locations of the individuals represented within each of the grid cells. Whereas the "trap file" would consist the geographical coordinates of the polygon vertices representing each of the search polygons. This particular sampling methodology is considered somewhat complex but biologically more realistic (Royale 2014).

Polygons may be independent (detector type 'polygon') or exclusive (detector type 'polygonX'). Exclusivity is a specific type of dependence in which an animal may be detected at no more than one polygon on each occasion (Efford 2014, 2015). Efford has given the technical background of fitting polygon search data in models of spatially explicit capture-recapture by maximum likelihood.

These models are useful in situations where the locations of individuals, say u_{ik} for individuals i and sample occasions k, are observed directly by searching space (often delineated by a polygon) in some fashion, rather than fixed trap locations. The search encounter models are slightly more complicated, and more biologically realistic (Royal 2014). In arrays of fixed trap locations, the movement process is completely confounded with the encounter process because the potential observation locations are prescribed a priori, and independent of any underlying movement process.

There are two designs mentioned by Royale (2014) of search encounter method:

1. Fixed search path:

In this particular survey design the observer has to lay some fixed search paths a prior to the sampling occasions which are assumed to be independent of the animals activity centres and has to repeatedly search the paths for the animals.

2. Uniform search intensity:

Here we should have one or more well defined sampling area (polygon) or may be just the areas are uniformly searched so that the encounter probability is constant for all the individuals within the search area.

2.8 Detection probability

Like distance sampling the basic premise of SECR models is that each animal has a home-range centre and the probability of detection reduces as we move away from the centre. Which can be modelled in halfnormal, hazard rate etc. Detection probability in search encounter or polygon search method is modelled as a function of an animal being detected in different grids or polygons, rather than detection from visiting the same grids in different occasions (Russell *et al* 2012). Royale et al. (2012) have modelled the detection probability as a function of distance between the locations of the detected animals and line of search. Another study by Thompson *et al.* (2012) on unstructured spatial sampling of scats using detector dogs were taking the search efforts as the covariate of detection probability. An assumption of all these models is that an individual's capture probability is greater at locations that are closer to a core area i.e., activity centre. Collectively the activity centres are considered as a realization of a point process, and spatial capture–recapture models estimate the number of such points in any well-defined spatial region in proximity to the sampled region (Efford 2012; Royale 2014). The number of activity centres in any spatial region is the population size of individuals in that region. In maximum likelihood framework, for stationary detector, detection probability is modeled as a decreasing function of the distance between the animal's home range center and the detector. Whereas in polygon detector. the probability of detection is a function of the quantitative overlap between the home range and the polygon (i.e., the instantaneous probability that an animal is within the polygon) (Efford 2011).

2.9 Distance sampling

Distance sampling allows the estimation of absolute density and abundance of wild animals (Thomas *et. al.* 2010) by adjusting counts for detectability. The key to distance sampling is to use the distribution of the observed distances to estimate the "detection function," g(y), the probability of detecting an animal at distance y. This function can then be used to estimate the average probability of detecting an animal given that it is within w (Effective strip width) of the line. During sampling the following information were collected from field:

- Date and time of sighting,
- Species ID
- Group size
- Sighting distance
- Animal bearing and walk bearing
- Major Habitat type
- Terrain Type –Flat, undulating and very undulating
- The beginning and ending Global Positioning System (GPS) points.
- Geographic coordinates of animal or animal group sighted on thetransects.
- Ground based covariates.

2.10 Density Surface Modelling (DSM)

Density surface modelling (DSM) allows to model the spatial arrangement of herbivores based on data collected in line transects as described by Hedley and Buckland (2004). These allow animal density to be related to topographical, environmental, habitat, and other spatial variables, helping wildlife managers and ecologist to identify the factors that affect abundance and distribution. They also enable estimation of abundance for any area of interest within the surveyed region. The concept underlying density surface modelling is that a response variable is modelled as a function of predictor variables. However, the response variable for our purposes can be a count, an estimated density, or an estimated abundance within each transect segment.

3. Objectives:

1. To estimate the density of Asiatic lions (*Panthera leo persica*) using advanced statistical tools and formulate a standard survey protocol for lion estimation.
2. To generate a density surface model of lion distribution.
3. To find out the factors governing the distribution and abundance of lions.

4. Hypothesis:

Lion Density is likely to be a function of a) prey density distribution, b) human disturbance, c) habitat features and d) management practices e.g. attractants for tourism. I test these hypothesis by correlating spatial density surface of lions with variable that estimate the above five factors and their combinations.

3. Methods

3.1. Area description

Gir National Park and Wildlife Sanctuary lies between 210 20' N to 200 40' N and 700 30' E 710 15' E. The total area under protection as sanctuary (1153.42 km2) and National Park (258.71 km2) which was created in 1978 by relocating all human settlements and livestock from within it (Singh & Kamboj 1996), is 1412.13 km2. Additionally the Chachai-Pania wildlife sanctuary (39.64 km2) at the northern boundary, a buffer of reserved forest (245.90 km2), protected forest (107.51 km2) and unclassed forest (77.19 km2) comprising of grasslands and forests (Pathak et al. 2002) are also included as Gir conservation unit (Banerjee PhD thesis 2012). The Gir PA is divided into three managerial zones viz. Sanctuary west (tourism zone), Sanctuary East and National Park. Due to a rainfall gradient increasing from east to west, these three zones differ ecologically, which can be clearly seen in the vegetation compositions of the areas (Qureshi and Shah 2004) and associated productivity (Banerjee PhD thesis 2012).

3.1.2. Topography

The terrain of Gir includes undulating surface with rolling hills of low to moderate height traversed with six major perennial rivers, namely Hiran, Singawada, Machhundri, Jatardi, Ghodawadi and Rawal. The altitude ranges from 100 m MSL to 648 m (Sarakala hill on the northern boundary of Gir PA. Central part of Gir has a more hilly terrain when compared to the rest of the park. The terrain has been classified into the following categories (Chellam 1993): flat plain; gentle slope; steep slope; hill top; river bed; and reservoir bed.

3.1.3. Geology

The chief geological formation of the Gir is Deccan trap occurring as acidic and basic dyke formations. The formation of the hills consists of traps (basalt) of varying composition associated with granite and gneiss, overlaid by beds of calcareous sandstones, which in part assumes the nature of limestone (Santapau and Raizada 1956). Soil ranges from lateritic in the northern and eastern parts to black cotton in the southeast and along many of the plains (Wynter-Blyth 1949; Puri et al. 1983).

3.1.4. Climatic conditions

The area falls under 'Tropical Savanna' climate (Koppen's 1931). The Gir Forest experiences three distinct seasons, cold season (November–February), hot season (March–June) and rainy season (July–October). Average minimum and maximum temperature varies between 9 ∘C and 42 ∘C respectively (Singh & Kamboj 1996). Rainfall is brought by south-westerly winds from the Arabian Sea during monsoon season between June and September. There is a distinct dry spell in winter but pretty heavy dewfall is common. The precipitation in the western part of Gir sanctuary was 89 ± 2 cm/y; Central, National Park and adjacent areas was 80 ± 5 cm/y and the eastern part of Gir sanctuary was 56 ± 2 cm/y (Singh & Kamboj 1996).

3.1.5. Flora and Fauna

Gir lies within the Afro tropical realm (Singh and Kamboj 1996) of Gujrat Rajputana biotic province 4B according to the Biogeographic Classification of India (Rodgers and Panwar 1988). The Gir Forest is largely composed of dry deciduous vegetation, which is classified as 5A/C1b biogeographic subtype (Champion & Seth 1968). Gir vegetation was classified into three broad classes namely Moist Mixed vegetation, Thorn forests and Hill forests which were further divided into eight types (Qureshi and Shah 2004). Moist Mixed Forest, mixed Forest, teak-acacia-zizyphus, acacia (teak)-anogeissus, acacia-lannea-boswelia, thorn forest, scrublands, savannah and agriculture/open forest (Qureshi and Shah 2004). Wild ungulate species of Gir are chital (*Axis axis)*, sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*, Pallas), four-horned antelope (*Tetracerus quadricornis*, Blainville), chinkara (*Gazella bennettii*, Sykes) and wild pig (*Sus scrofa*, Linnaeus). In Gir, chital constitute 91% in terms of density and 78% of the wild ungulate community biomass (Dave 2008). Among the carnivores Lion being the top predator is found throughout the area including agro-pastoral landscapes outside the boundaries of the protected area. Other carnivores found in the area includes leopard, striped hyena, golden jackal, Indian fox, ratel, jungle cat, rusty spotted cat, small Indian civet, ruddy mongoose, common Indian mongoose etc.

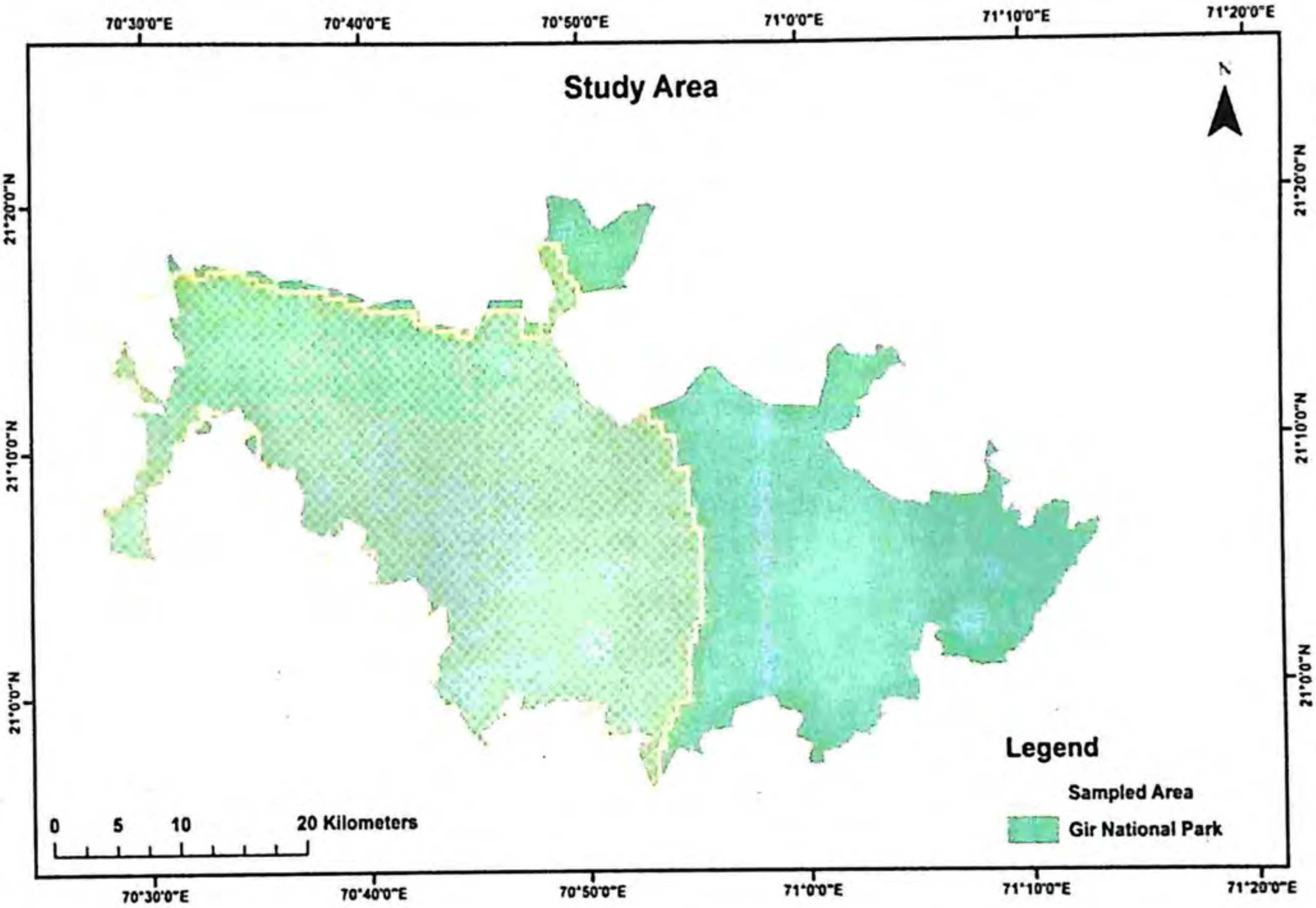


Fig 1: Study area map

3.2. Sampling design

3.2.1. Field survey design for lion

SECR demands a well design sampling setup to generate spatially referenced ecological information about the detections and other detection related processes. Lions on one hand are not possible to individually identify like tiger or leopards with stationary setup of camera traps. As they don't possess any distinct natural marks on body which makes them almost unidentifiable individually on the camera trap images. Therefore a standard protocol of sampling design has to be formularised based on the recently developed spatially explicit polygon search method (Efford 2011).

The study area of about 725 sq km was divided into grids of 25 sq km, which is half of the size of an average home range of female lion i.e. 48.2 sq km (100 MCP home range) ((Jhala et al. 2009), so that missing of an animal within the grids during search would be minimum. Each grid was searched for lions on 10 different occasions. Search for lions was done by professional lion trackers that relied on signs, roars, alarm calls of herbivores, crow assemblage in particular area and suitable lion habitats. That means the search was not random but optimized. Track logs of all search paths were maintained by a handheld GPS unit so as to quantify search efforts. The overlaid grids gives a reference of the area of search and makes the searches systematic for analytical needs. Plotting of track logs in the grids also allow us to estimate the per grid survey effort. It is a crucial component of covariate in search encounter methods, as detection probability is modelled on it (Thompson et al. 2012, Royale et al. 2014). Search effort in each of the grids generated by a handheld unit of GPS during each of the search.

Search for lions were made within the boundaries of the designated grids, keeping a track of survey paths walked or moved in GPS. Grids were visited only once in each of the occasion, swiping from one end of the study area to the other. Once every grid are being sampled the sampling is again repeated from that particular grid where the previous sampling was started. Likewise there were 10 sampling occasions at an area of about 725 sq km. Exploratory data analysis by plotting number of new lions being added with occasions provided a guide for estimating sample size required for precise estimates.

3.2.2. Data collection

The search for lions were done during their high activity period, i.e. during the morning and evening hours (Banerjee et al. 2012). Once located the lions were followed till they rest somewhere, so that photographs of the lion can be taken in a particular fashion to identify them individually. A method developed by Pennycuick and Rudnai in 1970 to identify individual lion based on difference in vibrissae pattern was used to individually identify the lions. He used the upper two rows for individual identifications. This method was later adopted and modified by Dr. Jhala in 2004, where he added another row of the whisker, row "C"and other permanent body marks like ear notch, scars on face, permanent injuries etc. in addition to the patterns of vibrissae to identify lions. Lions were approached within 10-30m to get clear photographs of the vibrissae and other features with a canon HX 50, mega zoom camera. Photographs of the whiskers were taken at right angle (90^0) to the face. The time, date, geographic coordinates, age, sex, associated animals, activity at that particular time and associated habitat covariates were noted for each of the photographed individuals. Later the data were entered into a standard format of excel sheet for further analysis and keep the information in lion database software.

3.2.3. Individual identification of lions:

Lions have different patterns of whisker and unique body marks, based on which it becomes easier to individually identify them, provided with good observation or nice photographs of them. For individual identification the top three rows of whiskers on the upper lip are taken into account (Jhala et al 1999), namely A, B and C. Whisker dots were counted from the nose to the eye direction. The row 'B' is used as a referenced segment to define the position of whiskers on row 'A' and 'C'. Row B used to have around 5-9 whiskers most of the time but row A and C have very less whiskers appears at different combination in relation to the row B. There are around 17 possible positions of row A and C in reference to row B.

Fig 2: Unique rows of whisker

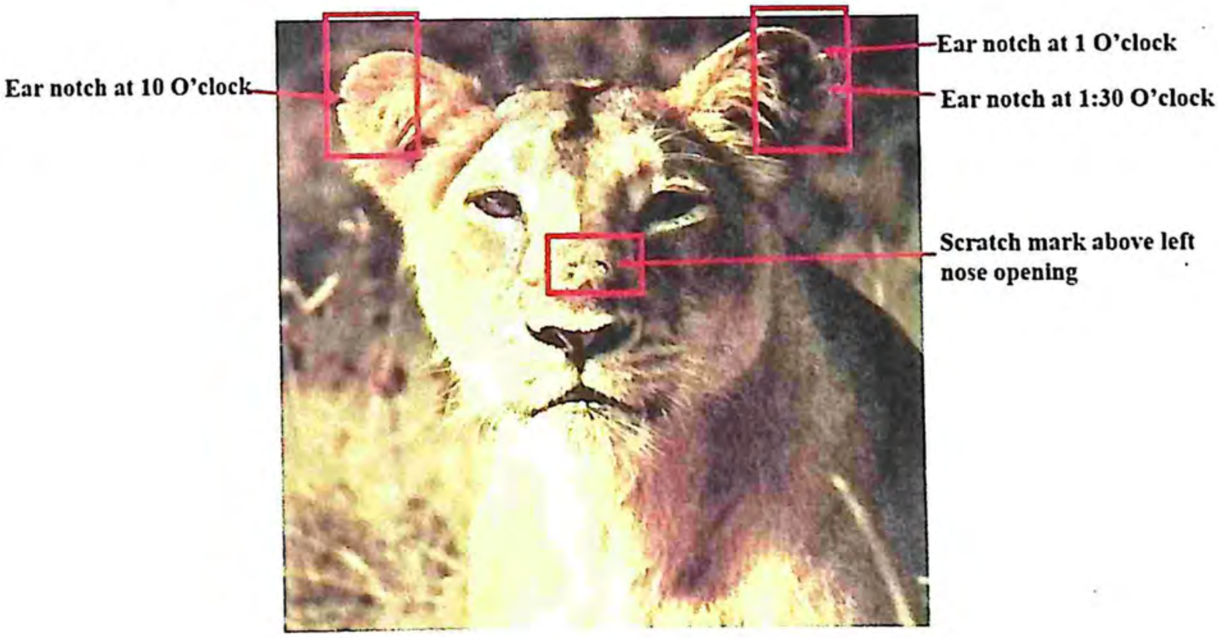
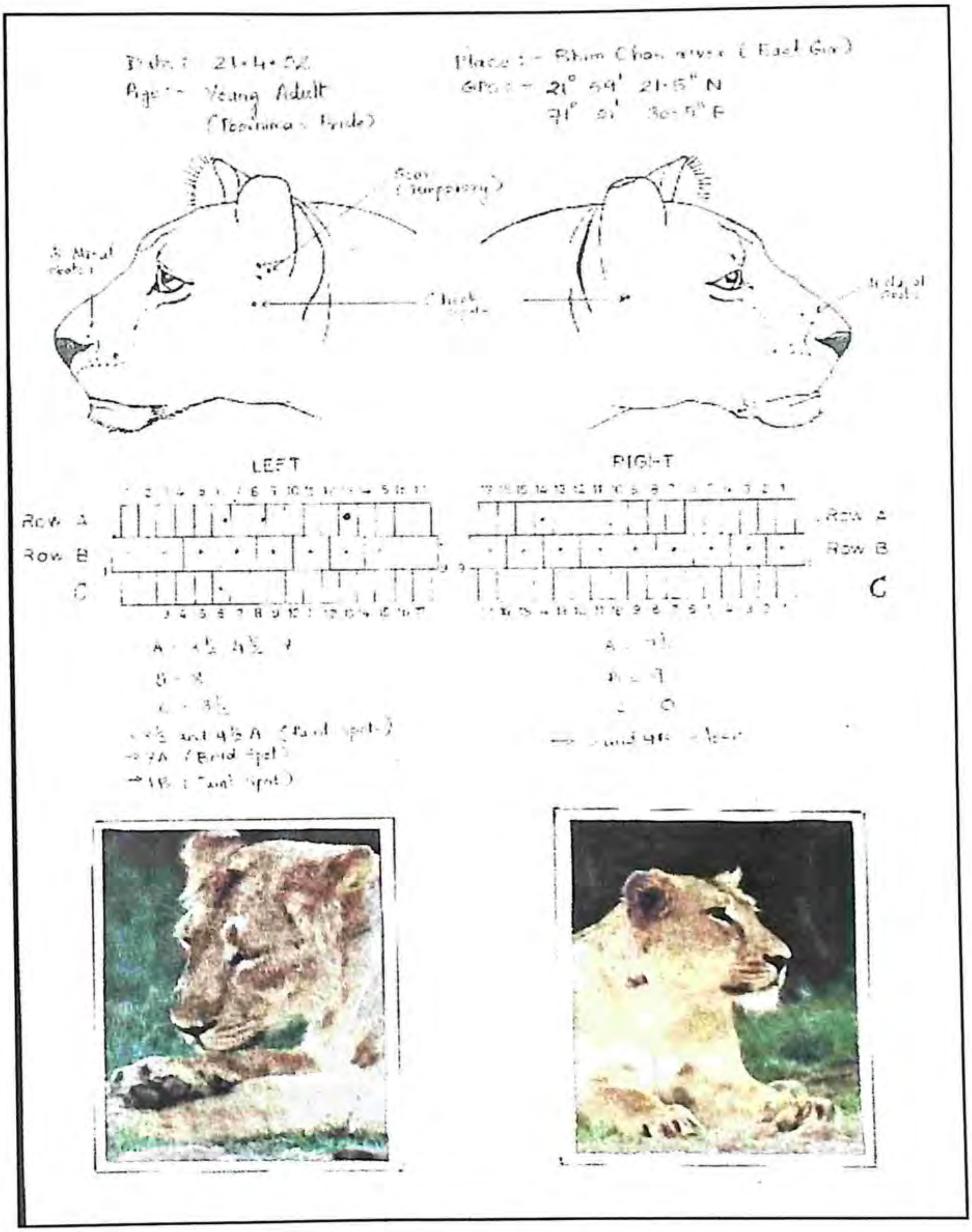


Fig 3: Permanent body marks used for lion identification



Date :- 21·4·02
Age :- Young Adult
(Topiwala Pride)

Place :- Bhim Chas river (East Gir)
GPS :- 21° 59' 21·5" N
71° 01' 30·5" E

A – 4½, 4½, 7
B – 8
C – 3½
→ 4½ and 4½ A (Faint spot)
→ 7A (Bold spot)
→ 1B (Faint spot)

A – 7½
B – 9
C – 0
→ [illegible]

Fig 4: Standard data sheet

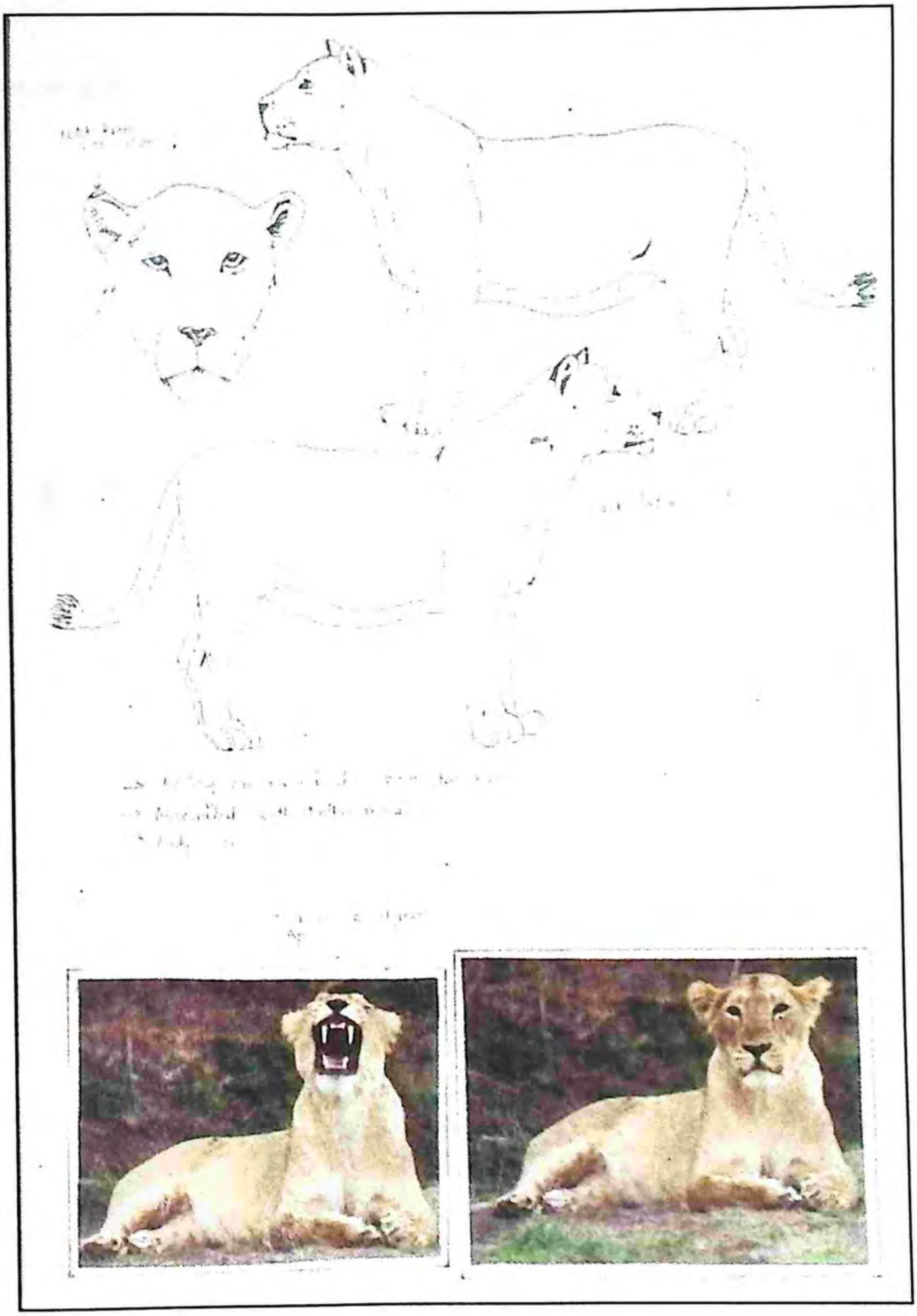


Fig 5: Standard data sheet

3.2.4. Data analysis

Sampling adequacy was ascertained by plotting the number of unique lions sighted against cumulative lion sightings and on examining if they reached an asymptote. The capture histories of individual lions generated from the sample survey were used to make the matrixes for SECR polygon search method (Efford 2011). The field results of 10 occasions were summarised which represents a single session. Data were analysed in SECR platform using hybrid mixture models within the maximum likelihood capture recapture framework. 'Hybrid' refers to a flexible combination of latent classes (as in a finite mixture) and known classes (cf groups or sessions). A hybrid mixture model includes a parameter 'pmix' for the mixing proportion and optionally allows detection parameters to be modelled as class-specific (~ h2). This is particularly useful for modelling sex ratio and sex differences in detection, and matches the Bayesian sex-specific model of Gardner et al. (2010) (Efford 2014).The argument hcov in secr.fit is used to fit a hybrid mixture model. hcov identifies a single individual covariate (the class covariate) that should be a factor with two levels, or contain character values that will be coerced to a factor (e.g., 'f', 'm'). Missing values (NA) are used for individuals of unknown class (Efford 2014).A hybrid mixture model is fitted whenever hcov is not NULL. Mixture models include a parameter 'pmix', the mixing proportion. If the covariate identified by hcov is missing ('' or NA) for all individuals and a mixture term (h2 or h3) appears in the detection model (e.g., g0 ~ h2) then a conventional finite mixture model is fitted (cf Pledger 2000, Borchers & Efford 2008, Efford 2014). As with finite mixture models, any detection parameter (g0, sigma etc.) may be modelled as depending on mixture class by model specifications such as (g0 ~ h2, sigma ~ h2) (Efford 2014).

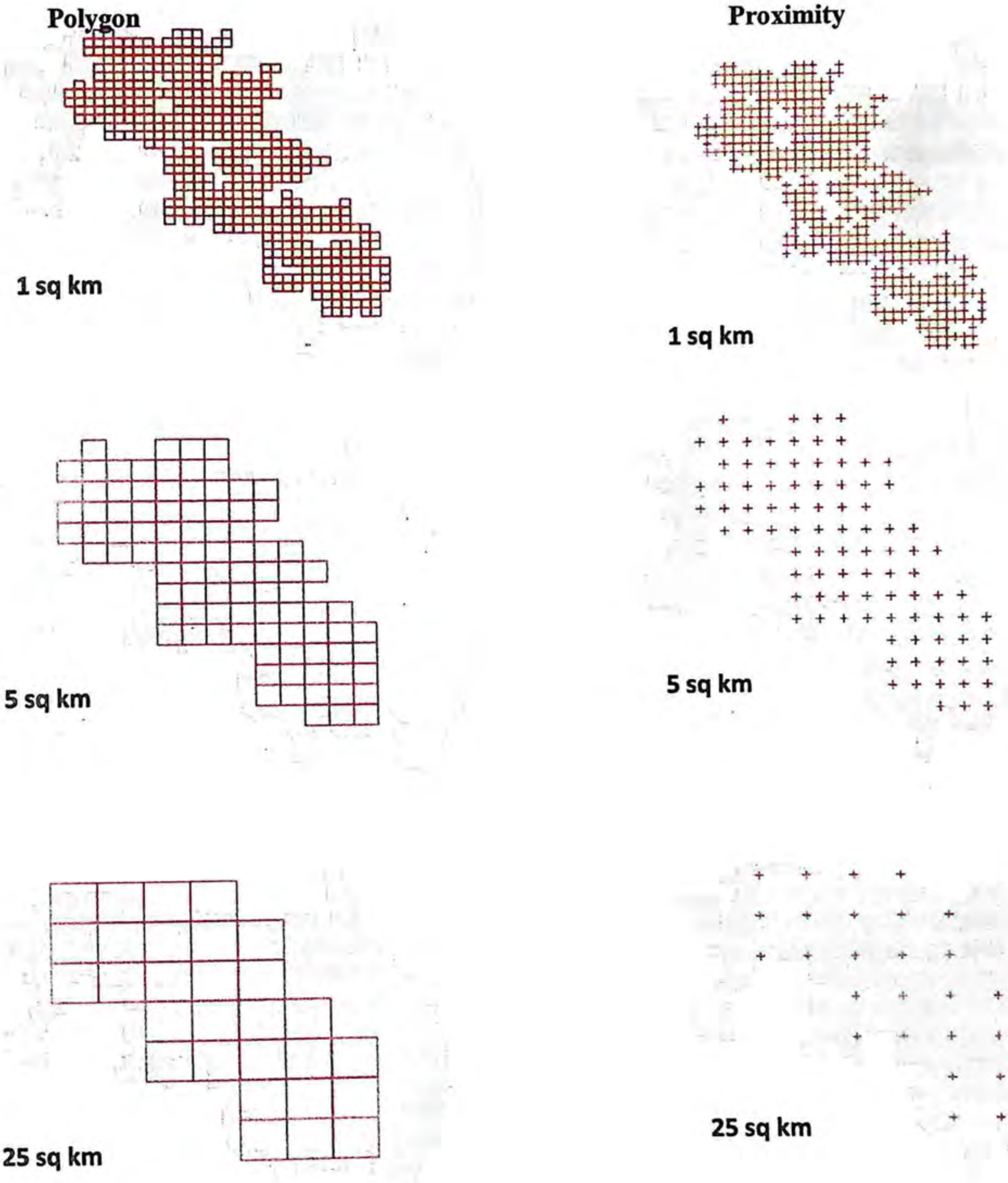


Fig 6. : Simulation across different grid size and detector type

3.3. Field data collection for herbivores

3.3.1. Line transect

Line transects (Burnham et al. 1980) were laid across the study area in a stratification of 2 transects per 25sq km grids, which we were using for lion survey, irrespective of any habitat or terrain, so that it covers all the available habitats as well as represent a good surface modelling of herbivore abundance. Transects were between 2.5 to 4 km long. On the transect information about the detected species were noted down along with GPS coordinates, date, time, radial distance, sighting angle, transect bearing, age, sex, group size, group composition and types of habitats.

3.3.2. Analysis

The line transect data are then subjected to stratified distance sampling, which allow us to see transect wise density estimates of individual species in different habitats. The so obtained densities are then attached to the centroids of the transects and kriged in Arc Gis domain to get a density surface of the herbivores. The spatial information of the herbivores are then extracted into grids of 500 by 500 m along with other environmental covariates at the same scale in which spatial density modelling of lions is done. The overall framework is prepared where we can get correlation between the density of lion and herbivores. Basic frame work for spatial modelling is based on GLM generalized linear modelling. These allow flexible functional forms to be fitted to the response variable (often the number, or estimated number, of animals in some relatively small effort segment, but alternatively the distance between successive sightings) these modelling can be performed by using DSM (Density surface modelling) engine in Distance Software which also provide platform to run this analysis using Program R .

From the ecological prospective of carnivores I hypothesised that lion density is likely to respond to a) Food, b) Human disturbance, c) Water availability, or d) topography/habitat. I tested these hypothesis and their combinations using General linear models. The ecologically most relevant model having the lowest AIC was considered to explain lion abundance distribution in space.

4. Results:

4.1 Population estimation of Asiatic lions:

Sampling adequacy was obtained by plotting the capture history against the successive sampling occasions. Out of 10 sampling occasions, i.e. 100 field days, 360 individual sightings of 67 adult lions were obtained. Out of which 39 individuals were females and 28 individuals were male. Individuals below the age of 1 were not counted for the population estimation.

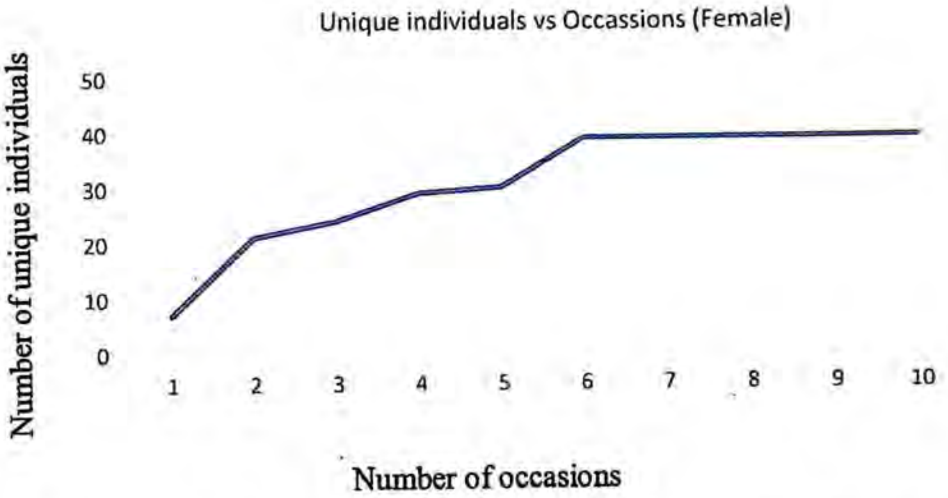


Fig 7 : Cumulative plot of unique female lions plotted against sampling occasions

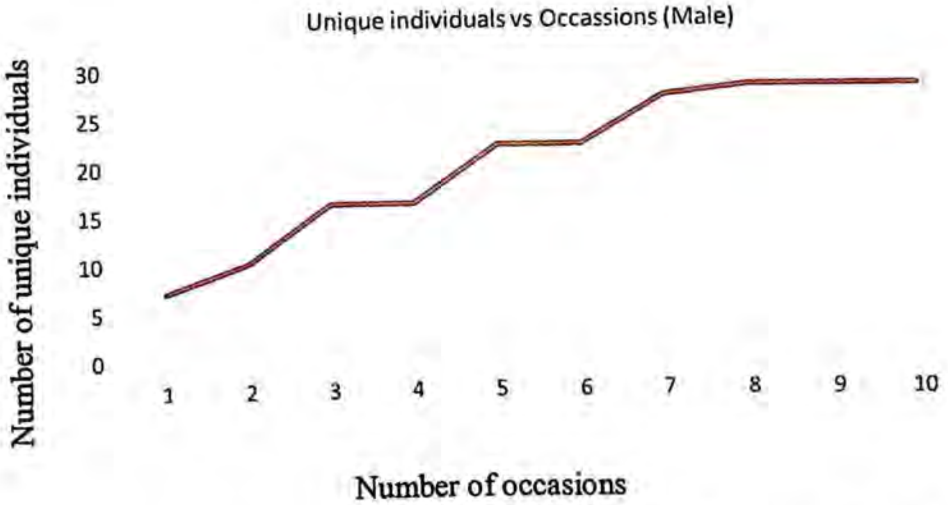


Fig 8: Cumulative plot of unique female lions plotted against sampling occasions

4.1.1 Population estimation of Asiatic lions by conventional mark-recapture:

Population estimates by the conventional mark recapture Huggins models is 71.49 (SE 3.02), with M(t+1): 67 and population density is 9.87 (SE 3.02) individuals per 100 sq km. Number of female is 42.36 (SE 2.72) and number of male is 29.13 (SE 1.31) in an area of 725 sq km. Densities were calculated dividing the number of population by the total area of the polygons.

4.1.2 Density of Asiatic lions by SECR polygon search method:

The SECR density estimates of male and female is found to be 3.12 (SE 0.60) and 5.66 (SE 0.92) simultaneously and an overall density of 8.78 (SE 1.10) individuals per 100 sq km was found, according to the best fit model **g0~1,sigma~sex (Table:);** with detection probability at the homerange centre **g0** is (9.25E-01) for females and (9.25E-01) for male and the movement parameter **sigma** is (2.64E+03) for females and (5.03E+03) for males. Models with behavioural and temporal response were not used as they are ecologically not relevant, individual behavioural response to trap search and observe and time did not play a significant role.

Summary of the estimates with different grid size and analytical approaches are given below:

Table1: Model selection and parameter estimates using likelihood based Spatially explicit capture recapture of lions in Western Gir by Polygon detector method at 1sq km grid size

Grid/detector	Sex	D	SE	lcl	ucl	Models	pmix	detectfn	npar	logLik	AIC	dAIC	g0	g0(SE)	sigma	sigma(SE)
1sq_polygon	D	8.78	1.10	6.89	11.2	g0~1,sigma~sex	pmix~h2	halfnormal	4	-1526.50	3061.01	0				
	F	5.66	0.92	4.13	7.76		pmix~h2	halfnormal	4				9.25E-01	0.07	2.64E+03	151.22
	M	3.12	0.60	2.16	4.53		pmix~h2	halfnormal	4				9.25E-01	0.07	5.03E+03	279.19
1sq_polygon	D	8.28	1.02	6.51	10.5	g0~sex,sigma~1	pmix~h2	halfnormal	4	-1550.29	3108.59	47.579				
	F	4.84	0.78	3.53	6.63		pmix~h2	halfnormal	4				1.04E+00	0.10	4.10E+03	175.56
	M	3.44	0.66	2.38	4.98		pmix~h2	halfnormal	4				1.11E+00	0.11	4.10E+03	175.5
1sq_polygon	D	8.99	1.12	7.05	11.5	g0~sex,sigma~sex	pmix~h2	halfnormal	5	-4164.22	8338.45	5277.44				
	F	5.88	0.95	4.29	8.05		pmix~h2	halfnormal	5				7.21E-01	0.06	2.48E+03	130.21
	M	3.11	0.60	2.14	4.51		pmix~h2	halfnormal	5				1.47E+00	0.18	5.67E+03	400.66
1sq_polygon	D	8.48	1.05	6.66	10.8	g0~1,sigma~1	pmix~h2	halfnormal	3	-4209.65	8425.30	5364.285				
	F	4.94	0.80	3.61	6.76		pmix~h2	halfnormal	3				1.07E+00	0.08	4.10E+03	175.66
	M	3.55	0.67	2.45	5.13		pmix~h2	halfnormal	3				1.07E+00	0.081	4.10E+03	175.66

Table2: Model selection and parameter estimates using likelihood based Spatially explicit capture recapture of lions in Western Gir by Polygon detector method at 5sq km grid size

Grid/detector	Sex	D	SE	lcl	ucl	Models	pmix	detectfn	npar	logLik	AIC	dAIC	g0	g0(SE)	sigma	sigma(SE)
5sq_polygon	D	8.69	1.08	6.82	11.1	g0~hsex,sigma~sex	pmix~h2	halfnormal	5	-4336.82	8683.65	0.00				
	F	5.61	0.902	4.1	7.67		pmix~h2	halfnormal	5	-4336.82	8683.65	0.00	5.54E-01	0.06	2.34E+03	130.21
	M	3.08	0.589	2.13	4.47		pmix~h2	halfnormal	5	-4336.82	8683.65	0.00	1.03E+00	0.18	5.41E+03	400.66
5sq_polygon	D	8.80	1.08	6.92	11.2	g0~1,sigma~sex	pmix~h2	halfnormal	4	-4345.26	8698.52	14.87				
	F	5.41	0.87	3.96	7.4		pmix~h2	halfnormal	4	-4345.26	8698.52	14.87	6.80E-01	0.06	2.42E+03	279.19
	M	3.39	0.643	2.34	4.9		pmix~h2	halfnormal	4	-4345.26	8698.52	14.87	6.80E-01	0.06	4.89E+03	130.21
5sq_polygon	D	8.31	1.03	6.53	10.6	g0~1,sigma~1	pmix~h2	halfnormal	3	-4394.47	8794.94	111.30				
	F	4.84	0.779	3.54	6.62		pmix~h2	halfnormal	3	-4394.47	8794.94	111.30	7.68E-01	0.08	3.92E+03	175.66
	M	3.47	0.659	2.4	5.02		pmix~h2	halfnormal	3	-4394.47	8794.94	111.30	7.68E-01	0.08	3.92E+03	175.66
5sq_polygon	D	8.32	1.03	6.54	10.6	g0~sex,sigma~1	pmix~h2	halfnormal	4	-4393.71	8795.42	111.77				
	F	4.88	0.787	3.56	6.68		pmix~h2	halfnormal	4	-4393.71	8795.42	111.77	7.33E-01	0.10	3.91E+03	175.56
	M	3.45	0.655	2.38	4.98		pmix~h2	halfnormal	4	-4393.71	8795.42	111.77	8.09E-01	0.11	3.91E+03	175.56

Table3: Model selection and parameter estimates using likelihood based Spatially explicit capture recapture of lions in Western Gir by Polygon detector method at 25 sq km grid size

Grid/detector	Sex	D	SE	lcl	ucl	Models	pmix	detectfn	npar	logLik	AIC	dAIC	g0	g0(SE)	sigma	sigma(SE)
25sq_polygon	D	7.92	0.976	6.22	10.1	g0~sex, sigma~sex	pmix~h2	halfnormal	5	-4336.823	8683.645	0				
	F	4.99	0.803	3.65	6.83		pmix~h3	halfnormal	5	-4336.823	8683.645	0	7.21E-01	6.32E-02	2.48E+03	1.30E+02
	M	2.92	0.555	2.02	4.23		pmix~h4	halfnormal	5	-4336.823	8683.645	0	1.47E+00	1.82E-01	5.67E+03	4.01E+02
25sq_polygon	D	8.78	1.1	6.89	11.2	g0~1, sigma~sex	pmix~h5	halfnormal	4	-4345.258	8698.515	14.87				
	F	4.86	0.78	4.13	7.76		pmix~h6	halfnormal	4	-4345.258	8698.515	14.87	9.25E-01	6.55E-02	2.64E+03	1.51E+02
	M	3.13	0.593	2.16	4.53		pmix~h7	halfnormal	4	-4345.258	8698.515	14.87	9.25E-01	6.55E-02	5.03E+03	2.79E+02
25sq_polygon	D	8.48	1.05	6.66	10.8	g0~1, sigma~1	pmix~h8	halfnormal	3	-4394.471	8794.941	111.296				
	F	4.94	0.797	3.61	6.76		pmix~h9	halfnormal	3	-4394.471	8794.941	111.296	1.07E+00	8.16E-02	4.10E+03	1.76E+02
	M	3.55	0.674	2.45	5.13		pmix~h10	halfnormal	3	-4394.471	8794.941	111.296	1.07E+00	8.16E-02	4.10E+03	1.76E+02
25sq_polygon	D	8.28	1.02	6.51	10.5	g0~sex, sigma~1	pmix~h11	halfnormal	4	-4393.707	8795.415	111.77				
	F	4.52	0.727	7.72E+08	8.41E+08		pmix~h12	halfnormal	4	-4393.707	8795.415	111.77	1.04E+00	1.04E-01	4.10E+03	1.76E+02
	M	3.17	0.601	7.81E+08	8.47E+08		pmix~h13	halfnormal	4	-4393.707	8795.415	111.77	1.11E+00	1.14E-01	4.10E+03	1.76E+02

Table4: Model selection and parameter estimates using likelihood based Spatially explicit capture recapture of lions in Western Gir by Proximity detector method at 1 sq km grid size

Grid/detector	Sex	D	SE	lcl	ucl	Models	pmix	detectfn	npar	logLik	AIC	dAIC	g0	g0(SE)	sigma	sigma(SE)
Prox_1sqkm	D	8.74	1.09	6.86	11.1	g0~sex,sigma~sex	pmix~h2	halfnormal	5	-1515.35	3040.709	0				
	F	5.65	0.913	4.12	7.74		pmix~h2	halfnormal	5	-1515.354	3040.709	0	1.64E-02	1.78E-03	2.80E+03	1.48E+02
	M	3.09	0.591	2.13	4.48		pmix~h2	halfnormal	5	-1515.354	3040.709	0	7.71E-03	9.07E-04	5.64E+03	3.72E+02
Prox_1sqkm	D	8.78	1.1	6.89	11.2	g0~1,sigma~sex	pmix~h2	halfnormal	4	-1526.509	3061.018	20.309				
	F	5.66	0.919	4.13	7.76		pmix~h2	halfnormal	4	-1526.509	3061.018	20.309	1.12E-02	8.95E-04	3.16E+03	1.64E+02
	M	3.12	0.596	2.16	4.53		pmix~h2	halfnormal	4	-1526.509	3061.018	20.309	1.12E-02	8.95E-04	5.03E+03	2.73E+02
Prox_1sqkm	D	8.27	1.02	6.5	10.5	g0~1,sigma~1	pmix~h2	halfnormal	3	-1550.401	3106.803	66.094				
	F	4.82	0.776	3.52	6.59		pmix~h2	halfnormal	3	-1550.401	3106.803	66.094	6.40E-01	8.06E-04	3.74E+03	1.75E+02
	M	3.46	0.657	2.39	5		pmix~h2	halfnormal	3	-1550.401	3106.803	66.094	6.40E-01	8.06E-04	3.74E+03	1.75E+02
Prox_1sqkm	D	8.28	1.02	6.51	10.5	g0~sex,sigma~1	pmix~h2	halfnormal	4	-1550.298	3108.597	67.888				
	F	4.84	0.782	3.53	6.63		pmix~h2	halfnormal	4	-1550.298	3108.597	67.888	9.92E-03	9.98E-04	4.28E+03	1.75E+02
	M	3.44	0.655	2.38	4.98		pmix~h2	halfnormal	4	-1550.298	3108.597	67.888	1.05E-02	0.0010814	4.28E+03	175.43178

Table5: Model selection and parameter estimates using likelihood based Spatially explicit capture recapture of lions in Western Gir by Proximity detector method at 5 sq km grid size

Grid/detector	Sex	D	SE	lcl	ucl	Models	pmix	detectfn	npar	logLik	AIC	dAIC	g0	g0(SE)	sigma	sigma(SE)
Prox_5sqkm	D	8.17	1.01	6.36	10.4	g0~sex,sigma~sex	pmix~h2	halfnormal	5	-1110.648	2231.297	0				
	F	5.18	0.837	7.03E+08	7.69E+08		pmix~h2	halfnormal	5	-1110.648	2231.297	0	4.99E-01	5.67E-03	2.25E+03	1.77E+02
	M	2.99	0.57	9.48E+08	1.05E+09		pmix~h2	halfnormal	5	-1110.648	2231.297	0	8.57E-01	4.63E-03	5.20E+03	5.11E+02
Prox_5sqkm	D	8.80	1.08	7.88E+08	8.47E+08	g0~1,sigma~sex	pmix~h2	halfnormal	4	-1120.526	2249.053	17.756				
	F	5.17	0.839	7.17E+08	7.93E+08		pmix~h2	halfnormal	4	-1120.526	2249.053	17.756	5.98E-01	3.41E-03	3.66E+03	1.88E+02
	M	3.02	0.576	8.83E+08	9.71E+08		pmix~h2	halfnormal	4	-1120.526	2249.053	17.756	5.98E-01	3.41E-03	4.82E+03	2.96E+02
Prox_5sqkm	D	7.86	0.972	8.22E+08	8.83E+08	g0~1,sigma~1	pmix~h2	halfnormal	3	-1136.761	2279.521	48.224				
	F	5.17	0.839	8.22E+08	8.83E+08		pmix~h2	halfnormal	3	-1136.761	2279.521	48.224	6.40E-01	3.19E-03	3.74E+03	1.96E+02
	M	3.02	0.576	8.22E+08	8.83E+08		pmix~h2	halfnormal	3	-1136.761	2279.521	48.224	6.40E-01	3.19E-03	3.74E+03	1.96E+02
Prox_5sqkm	D	8.28	1.02	6.51	10.5	g0~sex,sigma~1	pmix~h2	halfnormal	4	-4393.707	8795.415	6564.118				
	F	4.84	0.782	3.53	6.63		pmix~h2	halfnormal	4	-4393.707	8795.415	6564.118	5.99E-01	3.93E-03	3.74E+03	1.96E+02
	D	3.44	0.655	2.38	4.98		pmix~h2	halfnormal	4	-4393.707	8795.415	6564.118	6.96E-01	4.19E-03	3.74E+03	1.96E+02

Table6: Model selection and parameter estimates using likelihood based Spatially explicit capture recapture of lions in Western Gir by Proximity detector method at 25 sq km grid size

Grid/detector	Sex	D	SE	lcl	ucl	Models	pmix	detectfn	npar	logLik	AIC	dAIC	g0	g0(SE)	sigma	sigma(SE)
Prox_25sqkm	D	8.69	0.967	6.16	9.98	g0~sex,sigma~sex	pmix~h2	halfnormal	5	-649.3187	1308.637	0				
	F	5.61	0.975	6.19	10	g0~sex,sigma~sex	pmix~h2	halfnormal	5	-649.3187	1308.637	0	3.14E-01	3.41E-02	2.61E+03	1.18E+02
	M	3.08	0.925	5.92	9.56	g0~sex,sigma~sex	pmix~h2	halfnormal	5	-649.3187	1308.637	0	1.29E-01	1.51E-02	5.43E+03	3.30E+02
Prox_25sqkm	D	8.80	0.975	6.19	10	g0~1,sigma~sex	pmix~h2	halfnormal	4	-664.9171	1337.834	29.197				
	F	5.41	0.967	6.16	9.98	g0~1,sigma~sex	pmix~h2	halfnormal	4	-664.9171	1337.834	29.197	1.97E-01	1.58E-02	3.01E+03	2.27E+02
	M	3.39	0.975	6.19	10	g0~1,sigma~sex	pmix~h2	halfnormal	4	-664.9171	1337.834	29.197	1.97E-01	1.58E-02	4.74E+03	1.18E+02
Prox_25sqkm	D	7.52	0.927	5.91	9.57	g0~eft, sigma~1	pmix~h2	halfnormal	4	-672.4646	1352.929	44.292	2.10E-01	2.10E-02	3.89E+03	1.51E+02
Prox_25sqkm	D	8.31	0.925	5.92	9.56	g0~1,sigma~1	pmix~h2	halfnormal	3	-696.993	1399.986	91.349				
	F	4.84	0.975	6.19	10	g0~1,sigma~1	pmix~h2	halfnormal	3	-696.993	1399.986	91.349	1.71E-01	1.35E-02	4.11E+03	1.61E+02
	M	3.47	0.967	6.16	9.98	g0~1,sigma~1	pmix~h2	halfnormal	3	-696.993	1399.986	91.349	1.71E-01	1.35E-02	4.11E+03	1.61E+02
Prox_25sqkm	D	8.32	0.975	6.19	10	g0~sex,sigma~1	pmix~h2	halfnormal	4	-695.8666	1399.733	91.096				
	F	4.88	0.925	5.92	9.56	g0~sex,sigma~1	pmix~h2	halfnormal	4	-695.8666	1399.733	91.096	1.58E-01	1.51E-02	4.10E+03	1.61E+02
	M	3.45	0.975	6.19	10	g0~sex,sigma~1	pmix~h2	halfnormal	4	-695.8666	1399.733	91.096	1.88E-01	1.92E-02	4.10E+03	1.59E+02

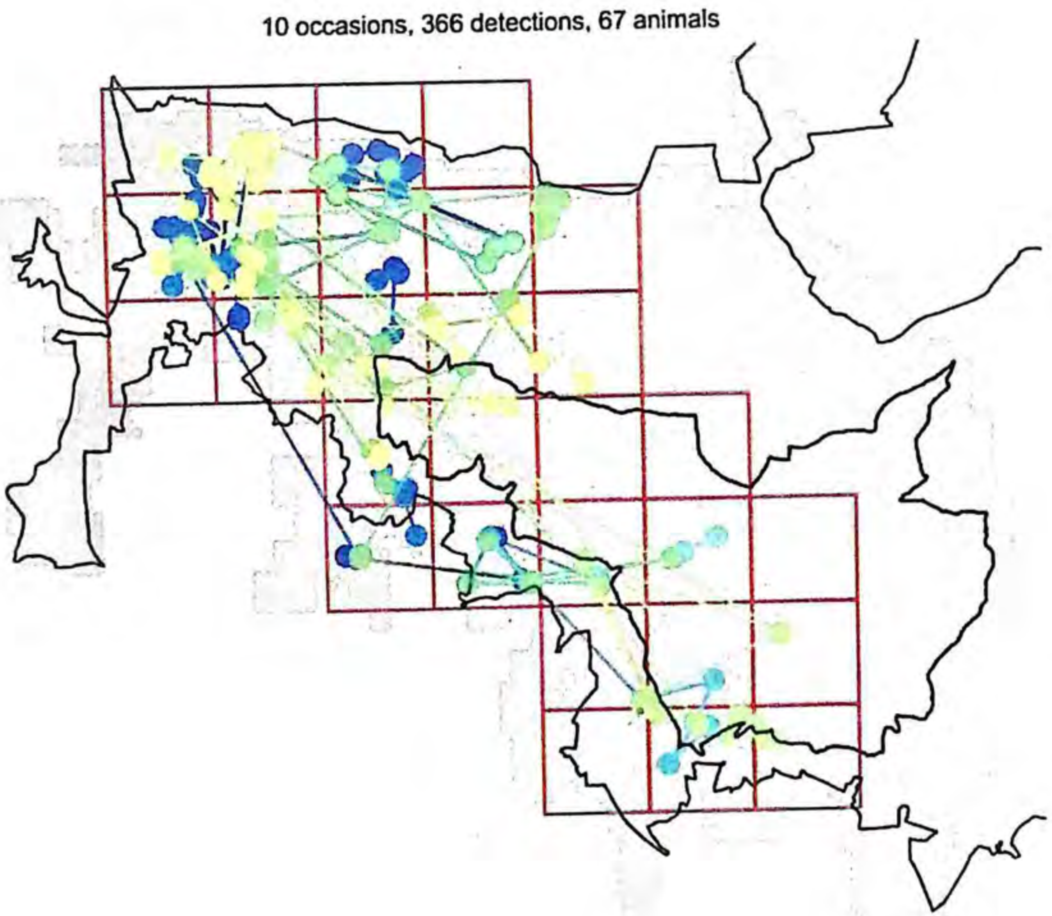


Fig 9: Study area showing the search grids and locations of lion captures.

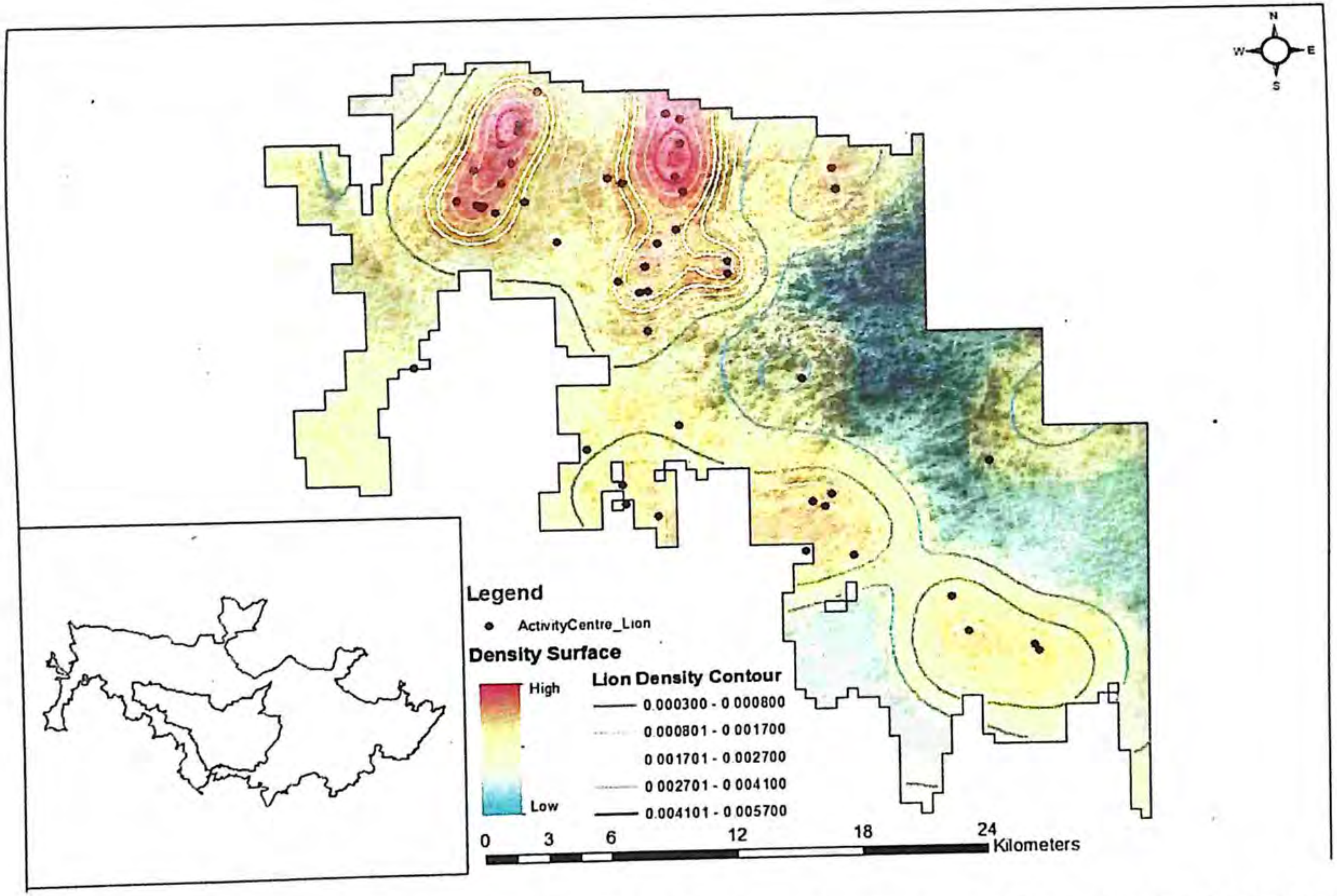


Fig 10: Spatially explicit density of Asiatic lions (*Panthera leo persica*) in western Gir as estimated by the best model (g0~1, sigma~sex) in 1sq km polygon search method

4.1.3 Population structure of Asiatic lions:

Average group size	**2.84 (SE 0.33)**
Typical group size	**2.06**
Average Adult group size	**2.20 (SE 0.26)**
Average Female group size	**3.6 (SE 0.61)**
Average Male group size	**2.14 (SE 0.33)**
% of male	**36.36%**
% female	**40.90%**
%cubs	**22.72%**

Sightings of 31 unique groups consisting of 88 lions (including cubs) were obtained, each of which were given unique id for field and analytical verifications. There were 15 groups of single and coalition male and16 groups of female in 725 sq km of the study area. Average group size including all gender and age classes is found to be 2.84 (SE 0.33). Adult group size excluding the cubs is 2.20 (SE 0.26); average female group size is 3.6 (SE 0.61) and average male group size is 2.14 (SE 0.33). Typical group size of all lions was 2.06 while male typical group size was 1.68 and female typical group size was 2.26.

Age wise contribution of different age class individuals to the population have shown an increasing pattern of population of Asiatic lions with a recruitment group of size 68.18% of the total population. There were few old animals 7.96%. Among most of the sex classes % contribution of females were found higher than the males.

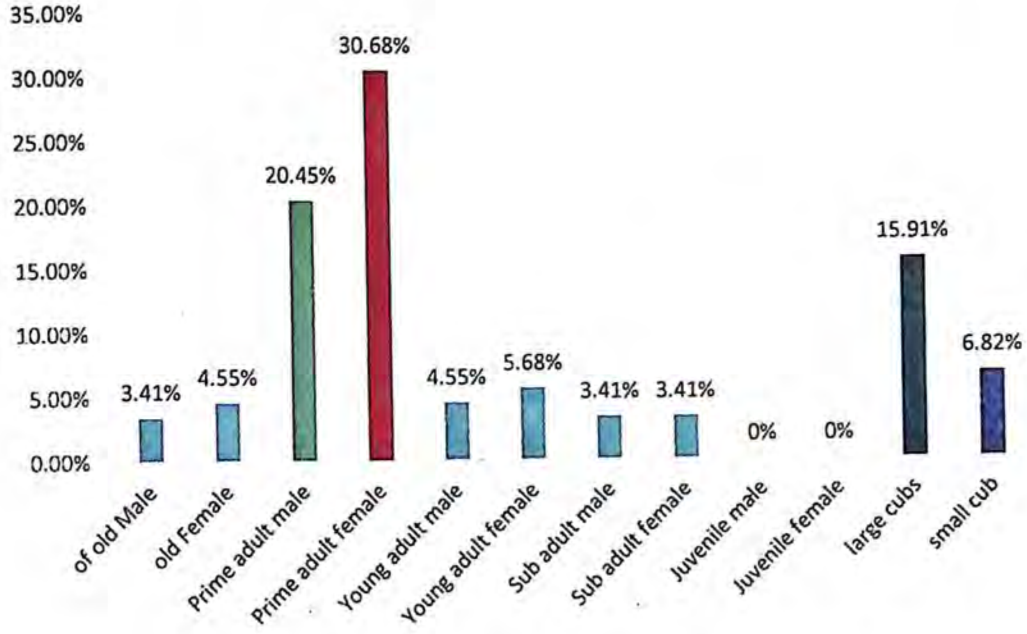


Fig 11: Demographic classes of Asiatic lions in Western Gir (N=88 individual lions)

4.2 Herbivore abundance:

Herbivore abundance was estimates by line transect distance sampling method (Buckland et al. 2001). Transects were laid with the same structural design, that was used for lion abundance estimation. Each of the grids were laid two transects, irrespective and habitat or terrain, so as to cover all the habitats and terrain falling within the sampling grids. Only morning hours were selected for walking transects, to avoid detection bias of some species due to differential temporal activity pattern. Total 111.93 km of effort was put to sample 38 spatial transect, which were around 2.5 to 4 km in length.

Detections of herbivores were noted down on datasheet during the walk. Which were later on analysed using software, Distance 6.02. There were detections of chital and sambar >20 times fulfilling the minimum detection requirement for distance (Backland 2001). There were 100 detections of Chital (*Axix axix*) and it is found to be the most abundant prey in the region with a detection probability of 0.75 (SE 0.04), density 57.77 (SE 16.39) per sq km, with a chi square P value of 0.94. Comparatively sambar had less detection, around 25 and density 3.48 (SE 28.78), with a chi-square P value 0.98. Nilgai had only 4 detections and density is 1.02 (SE 50.26) with a chi square P value 0.92. Peafowl had 24 detections and density is 7.80 (SE 34.93) with a chi square value of 0.63. Other pre species had very less detection to get a reliable estimate from the analysis. A detailed table of abundance estimate has been attached below.

Using density surface modelling a density surface map of the two major prey of lions has been plotted against the densities of lions. And a generalised linear modelling of different environmental covariates along with the density surface of major prey has been done to see the most contributing factors governing the spatial density of lions.

Table7 : Estimation of herbivore abundance by line transect

Species	Total Effort (km)	Observation	ESW	SE (ESW)	Detection Probability P	SE (p)	Model Fit	Chi-square p-value	Mean Cluster Size (MCS)	SE (MCS)	Group Densit (Ds)	SE(Ds)	Individual Density (D)	SE (D)
Chital	111.93	100.00	64.80	3.43	0.75	0.04	Hazard Rate/Simple polynomial	**0.94**	8.38	0.84	6.89	12.99	**57.77**	16.39
Sambar	111.93	25.00	56.41	8.45	0.72	0.11	Hazard Rate/Simple polynomial	**0.98**	1.76	0.19	1.98	26.59	**3.48**	28.78
Nilgai	111.93	4.00	54.46	7.33	0.61	0.09	Hazard Rate/Simple polynomial	**0.92**	1.5	0.29	0.68	46.43	**1.02**	50.26
Peafowl	111.93	24.00	46.42	3.22	0.54	0.04	uniform/Cosine	**0.63**	3.38	0.6	2.31	30.15	**7.80**	34.93
Langur	111.93	33	29.00	4.64	0.37	0.061	Half-normal/Cosine	**0.63**	5.88	0.82	5.09	1.32	**21.18**	6.47

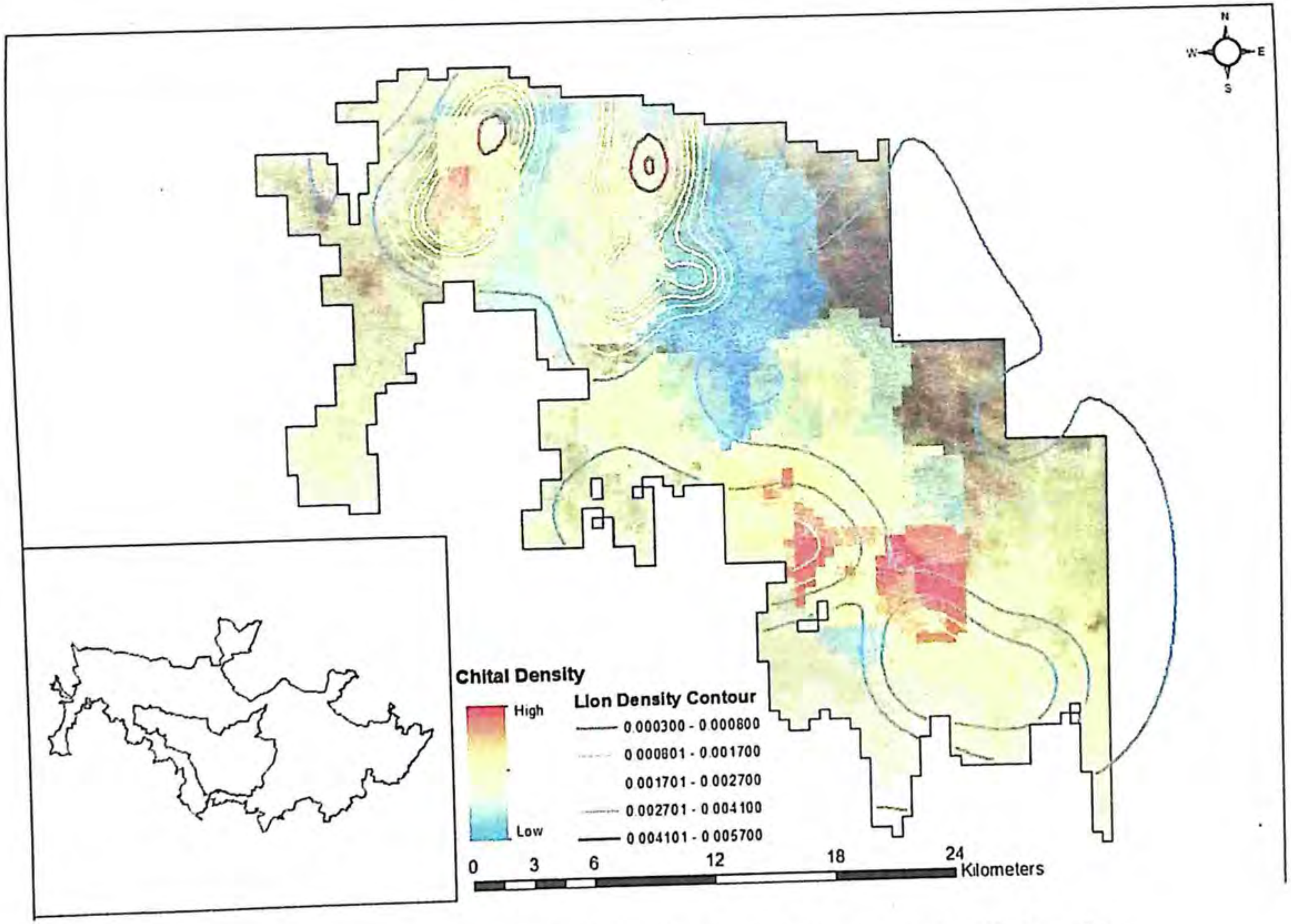


Fig 12: Density surface map of chital with lion density contours in Western Gir

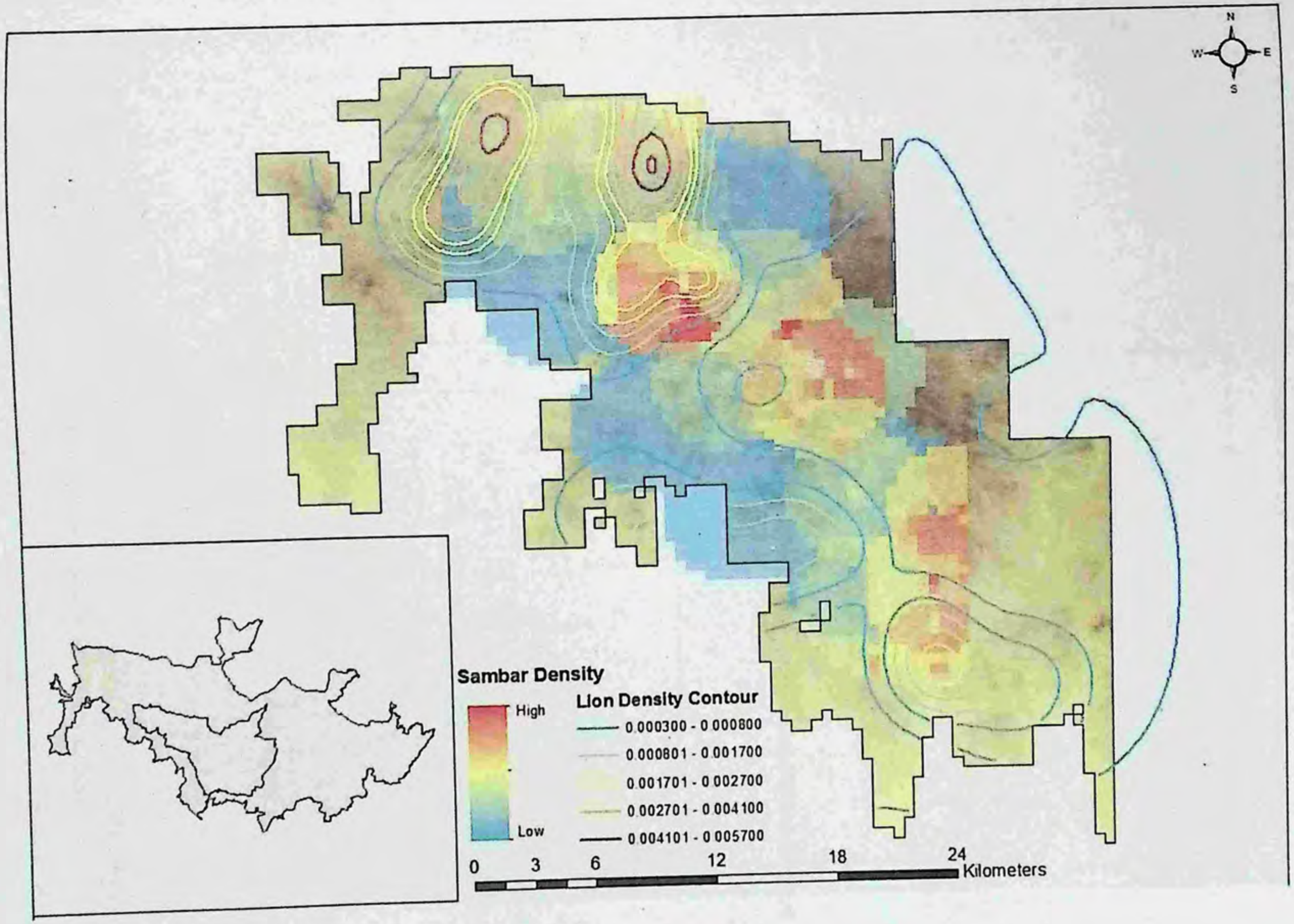


Fig 13: Density surface map of sambar with lion density contours in Western Gir

Influence of Grid Size on Density, Sigma and g0

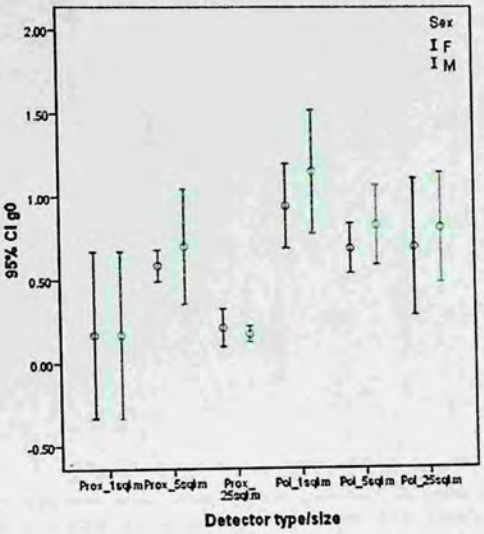


Fig 14: Error bar of g0 (Male and female) vs polygon size and detector type

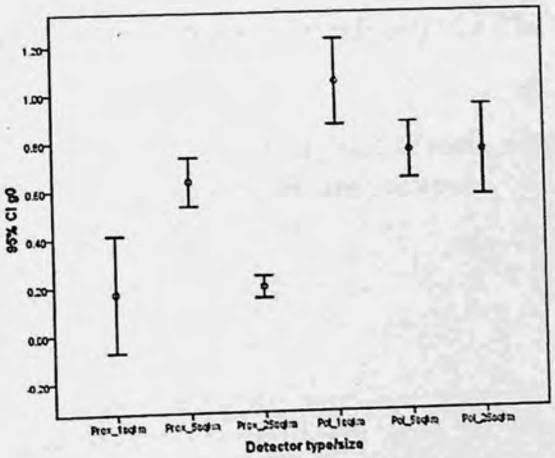


Fig 15: Error bar of g0 vs polygon size and detector type

With proximity detector the value of g0 is seen decreasing significantly with the increase of grid size. But in polygon search, there is not such significant difference is noticed.

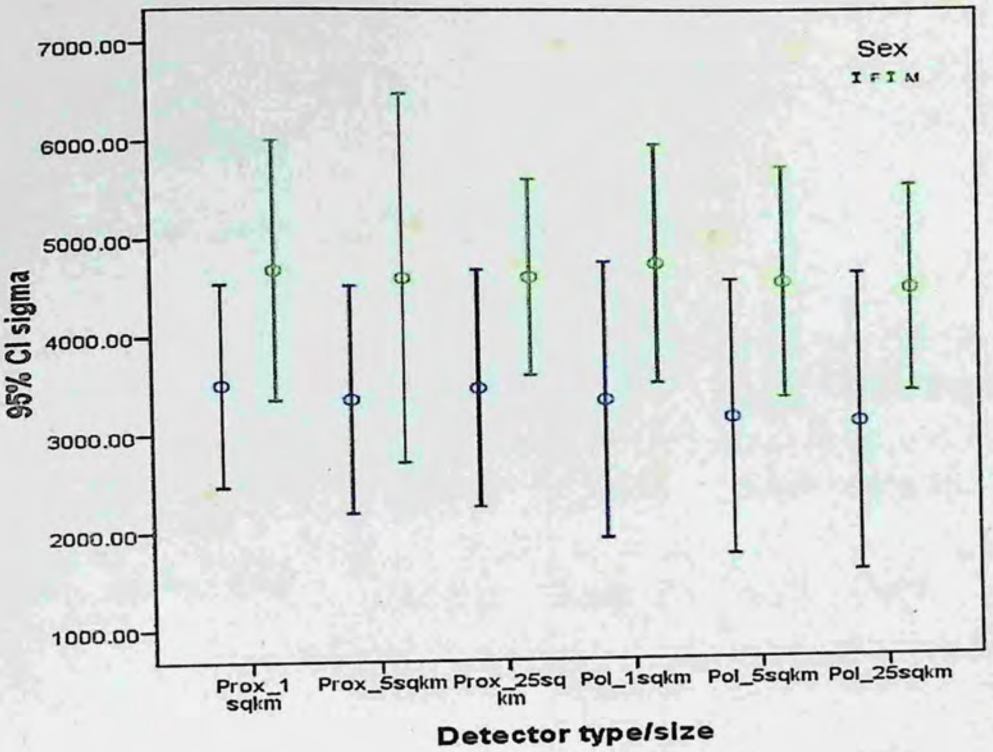


Fig 16: Error bar of sigma (Male and female) vs polygon size and detector type

The Scaling parameter sigma is found to be higher in case of male, whereas we didn't find any significant difference of sigma across different grid size and types.

Model selection in GLM:

Table 8: Univariate models tested for lion density modelling:

Model no	Model	Estimate	Standard error	t value	Significance	AIC	dAIC
1	lion~ distance from tourism hotspot	-3.37E-04	5.54E-05	-6.083	6.64E-09	-2154	3.6
2	lion~ distance from water	-1.03E-04	6.02E-05	-1.717	0.0876	-2122.9	34.7
3	lion~ Elevation	-9.51E-05	6.02E-05	-1.578	0.116	-2122.4	35.2
4	lion~ Sambar density	-6.66E-05	1.24E-04	-0.536	0.594	-858.27	1299.33
5	lion~ Chital density	-7.31E-06	1.27E-04	-0.058	0.954	-835.62	1321.98

Table 9: Table showing the hierarchical order of factors effecting spatial distribution of Asiatic lions (*Panthera leo persica*).

model no	model	estimate	standard error	t value	significance	AIC	dAIC
1	lion~ Distance to water+ distance from Tourism hotspot					-2157.6	0
2	lion~ Distance to water+ distance from Tourism hotspot + DEM					-2157.3	0.3
3	lion~ DEM + distance from Tourism hotspot					-2154.8	2.8
4	lion~ distance from tourism hotspot	-3.37E-04	5.54E-05	-6.083	6.64E-09	-2154	3.6
5	lion~ distance from water	-1.03E-04	6.02E-05	-1.717	0.0876	-2122.9	34.7
6	lion~ Distance to water+ DEM					-2122.6	35
7	lion~ Elevation	-9.51E-05	6.02E-05	-1.578	0.116	-2122.4	35.2
8	lion~ human footprint	5.71E-05	6.05E-05	0.943	0.347	-2120.8	36.8
9	lion~ Sambar density	-6.66E-05	1.24E-04	-0.536	0.594	-858.27	1299.33
10	lion~ Chital density	-7.31E-06	1.27E-04	-0.058	0.954	-835.62	1321.98

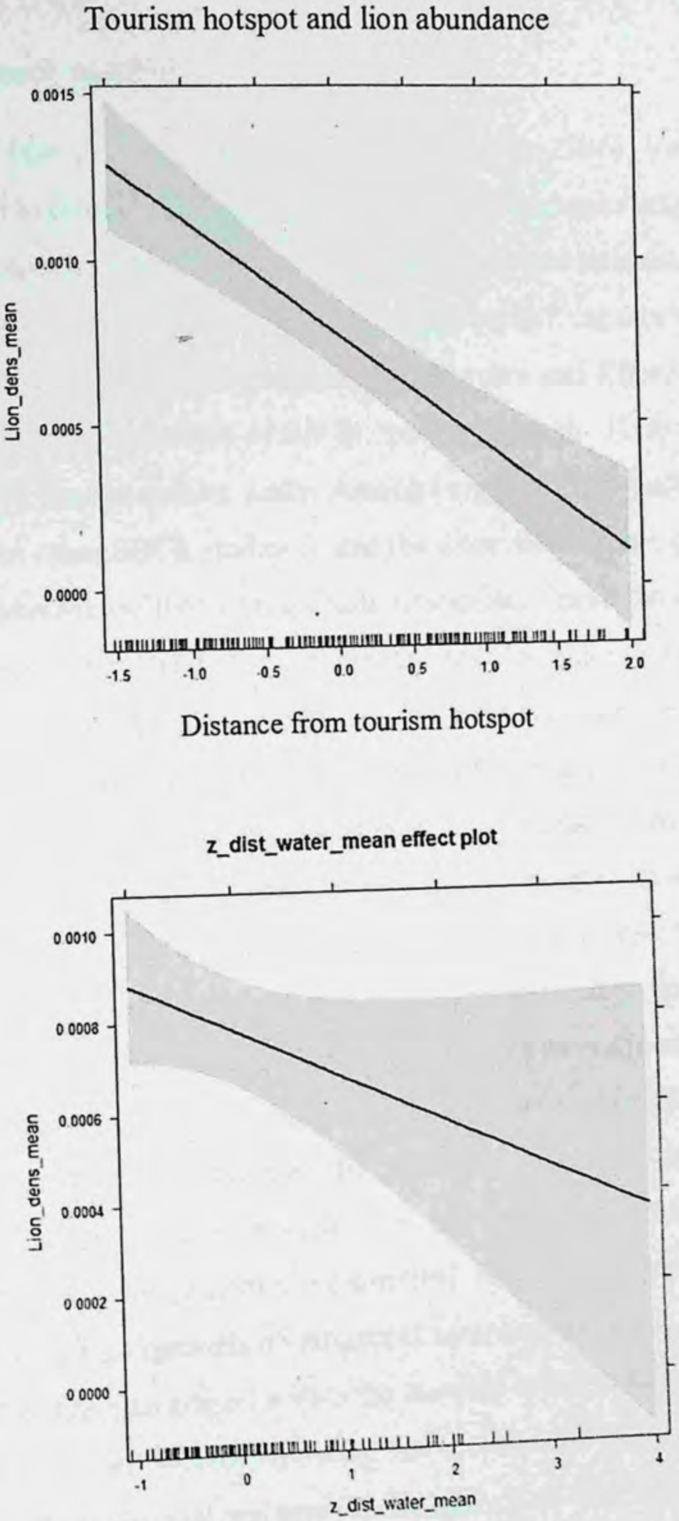


Fig17: Regression plot showing the relationship of tourism hotspot and distance to water with lion

5 Discussion

5.1. SECR polygon search method

Density estimation of lion is always been a challenge (Ogutu 2006). Various methodological approach has been used to estimate lion density. But none has been regarded as ecologically robust. Conventional mark recapture methods are useful tool for population estimation but associated with some bias (Efford 2009; Royale 2012). Whereas spatially explicit capture recapture methods are considered more robust and ecologically meaningful (Borcher and Efford 2008; Royale 2011). Therefore a recently developed method of SECR "polygon search" (Efford 2011, Royale *et al.* 2011) has been adopted for the current study. Among various SECR methods the current study design is different from other SECR studies in that the detections are not dependent on arrays of fixed traps. Both the detector and the target animals are mobile. Unlike the stationary camera traps the detectors here are not static. The mobile detector i.e., the observer actively searches for animals in a targeted area. Detections are also associated with a covariate of search effort. Each of the searches are hence incorporated with a tracklog from a GPS unit that records the path and distance moved within the sampling area. Another addition to the existing method is the framework of structured sampling design. Where systematic collection of samples is done with a predefined structural design. Other such studies, like the "unstructured spatial sampling of mountain lions" by Russell et al. 2012, where after each encounter of signs and tracks, the observer followed for the track to get a tissue sample of the individual, which did not have a predefined structural design of sample collection. But in my case the sampling area is equally divided into polygons of 25 sq km to ensure equal chance of being sampled. Each of which acts as an individual sampling unit. The sampling occasions were designed in such a way that each of the grids must be searched once in every occasions and the adjacent grids were searched simultaneously one after another until all the grids are sampled. This approach of structural sampling ensures, sampling adequacy and minimises chance of missing an animal within the trapping array. Additionally it allows for non-spatial CMR analysis as well thereby allowing for a comparative estimate of population and density estimation by the traditional and new SECR appears as well. Importantly, grid cells must be larger enough to be ecologically meaningful to explain the heterogeneity in presence or absence across the landscape (Russell *et al.* 2012). It must be based on a combination of the ecology and movement capacity of the target species, local topography or other landscape features, and logistics (Thompson *et al.* 2012).

Search effort is believed to be acted upon detection probability at the level of grid cells. That means each grid cell has a relative encounter probability based upon the search effort. So it was hypothesise that more the number of efforts, more would be the detection of lions in the grids. But in reality, the effort was only intense when there was no detection of lions in the respective grids. Once found there were no need of putting further effort for more search. Searching time and expertise in locating lions in the field also plays equally important role.

One of the important advantage of polygon search method within maximum likelihood framework is that if we get multiple captures of the same individual within the grid at the same occasion there is no need for repeated searches because the model accepts within occasion ''recaptures'' (Efford *et al*. 2009b, 2011).

Drawback in polygon search method is that the analysis takes too much computational time. Thompson et al. (2012) has mentioned about 3-9 days per grid cell size but in my case with effort and polygon as a detector, taking around 5-25 days, in different grid sizes.

Thought results didn't vary substantially across different range of grid size and analytical design (polygon/proximity), simultaneous decrease in density is noticed as the grid size increases. Cause behind this could be the decreasing function of g0 with the increase of grid size. In case of proximity detector, instead of having the same number of detections, due to the analytical decrease in detector number and pulled detections to the centroid of the grids, the resultant g0 and sigma is becoming significantly smaller as the grid size increases.

5.1.2. Population estimation of lions

In SECR population density D is defined as the intensity of a Poisson spatial point process for home range centres, which are assumed to be fixed. The data comprise a set of detection histories (x*i*) for the n observed individuals; the elements of detection histories represent the detections of individual (*i*) on S successive occasions at a set of K detectors. Therefore the probability of observing a particular individual depends on a vector of detection parameters Θ and on X*i* (Efford 2011). For polygon search data, each element of detection histories comprises both the binary or integer number of detections of individual (*i*) on a particular occasion, and a vector of corresponding x-y coordinates equal in length to the number of detections, which may be zero (Efford 2011). Whereas the conventional capture-recapture assumes an area around the minimum convex polygon of trapping locations based on the half MMDM.

Population estimates by the conventional mark recapture Huggins models is 71.49 (SE 3.02), with M(t+1): 67 and density is 9.87 (SE 3.02) individuals per 100 sq km. Number of female is 42.36 (SE 2.72) and number of male is 29.13 (SE 1.31) in an area of 725 sq km.

We ran the SECR models in different grid sizes with both polygon (Efford 2011) and proximity detectors (Thompson et al. 2012; Russell et al. 2012). The original grids of 25 sq km were further subdivided into smaller grids of 5 sq km and 1 sq km. Search effort in each of the grids were intersected based on the grid size and assigned to its respective grid numbers in Arc map 10.2. Now each of the grid is having a covariate of effort and individual locations of detection with gender, since sex of the animals were known.

Data of this kind is very much advantageous, apart from just density estimation we can also model sex wise detection probability and sex wise densities. Combination of individual sex, movement and detection probability at homerange centre if modelled we can get a range of gender wise density estimates. Which are then selected based on AIC values. This model is known as the hybrid mixture model in SECR terms (Efford 2009).

The best fir model in 1sq km polygon search method, **(g0~1, sigma~sex)** has given an density estimate of **8.74** (SE 1.09) individuals per 100 sq km. Among which density of female is **5.65 (SE** 9.13) with a sigma of 2.80E+03, whereas density of male is **3.09** (SE5.91E-05) with a sigma of (5.64E+03), which is significantly higher than female and it is ecologically very true. Because in Asiatic lions unlike the African cousins males don't live with the group instead, they form coalition of 2 or 3 male and actively defend many such female groups. Whereas females tends to guard the resources, with relatively smaller home ranges than the males.

5.1.3. Change in g0 with different detector and grid sizes

Density estimation is almost similar across different grid and detector types but g0 is found to be significantly higher in 1 sq km polygon search method than the others. As the size of the grids are increasing there is a decreasing trend of g0 in all the grids irrespective of detector type but the changes in g0 is very significant in grids with proximity detectors. The cause behind this could be the scale at which detections are made. More the area of search less would be the probability of capture at its homerange centre, moreover if we reduce the number of detectors and keep increasing the sampling area, the detection at homerange centre would be significantly reduced. This is what happening in the current simulations. As we are pulling all the detections to the centre of the grids for proximity detector, the relative area of search compared to the number of detector is larger. So, though we are increasing the grid sizes from 1sq km to 25 sq km but the number of detectors within them remains the same. That is why there is significant decrease of g0 in proximity detector.

But in polygon detector the decreasing trend of g0 is not significant. This is because of the inherent property of area search method, where the detector actively searches for animal within the search grids, so effect of area in comparison to the traps would be less. Another cause in polygon is that the polygon itself works as a trap, within which detections area made by actively searching the area. So, there would be less effect of area on detections unlike the proximity detectors.

For lion, this fine scale spatial information is meaningful to infer the underlying processes governing their density and abundance. Due to its spatial integrity and finer ecological information it would be meaningful to use the density estimates and generate density surfaces of lions. Which can be later extracted to desired scales.

As mentioned conventional mark-recapture methods always have a biasness towards the estimation of density, because of edge effects. The SECR models very well tackle this problem, due to its inherent property of incorporating space along with the individual detections. Lions on the other hand were always challenging to estimate their population size by the conventional methods of capture-recapture, as it was difficult to incorporate them within the array of detectors like stationary camera traps, as well as the structural integrity of the sampling design. The polygon search method in SECR not only providing the ecological information but also incorporating a structural design of sample collection for such studies.

5.1.4. Change of sigma with different detector and grid size

Unlike the g0 there is not any significant difference in sigma across different grid sizes and detector type. As we know sigma is the movement/scale parameter that depicts how far the animal is being detected from g0. The current grid size were designed based on half of the average homerange size of a female lions. Which is around 48.2 sq km (100 MCP home range) (Jhala *et al.* 2009). So logically the animals must cove more than 1 grid and their detections will also be generalised based on their captures in those particular grids and ultimately the resultant scale of movement would be the same. Nevertheless, if the compared grid sizes would bigger than their home ranges than we could see some pattern of changes in the scale of sigma.

5.2. Herbivore density

Line transects (Buckland *et al.* 2001, 2004) were laid for herbivore abundance estimation. Transects were stratified to get a good coverage of the sampling area to generate a density surface model of the herbivores, which were latter compared with the density of lions to a comparative index of their interactions.

Ungulates are the major source of carnivore diet in various forests (Schaller 1967; Johnsingh 1983; Karanth and Sunquist 1995; Biswas and Sankar 2002; Bagchi *et al.* 2003; Acharya *et al.* 2007; Andheria *et al.* 2007; Edgaonkar 2008; Ramesh 2010), understanding herbivore abundance therefore forms the basis for predator ecology studies. It is further supported by the fact that any effort towards conservation of large carnivore is preceded by an equal scale study on ungulate density estimation (Jhala *et al.* 2008). It may also help in determining the capacity and suitability of different habitats to support the large carnivore.

Density of herbivores were analysed using Distance software and density surface models were created by stratified density of herbivores per transect which were then kriged in Arc GIS and the information were extracted on 500m by 500m grid. Various models were run to estimate the density of herbivore, which are then categorised based on AIC values. Hazard rate is found to be the best fit model in all the detections. During the line transect there were very less detection close to the transects, which is due to the openness of the habitat with higher visibility of the herbivores as well as related disturbance of dry teak leaves on the transect. When we walked the transects there used to be some amount of disturbance, because of which animals often used to move out from the line before we can detect them. That is why most of the detection were after some intervals from the line transect. Though the sampling area is less than what earlier used for herbivore abundance estimation seems to be constant with the previous estimates. With a relatively higher density of chital 57.77 (SE 19.39) per sq km, which has enormous contribution as the principal prey to the diet of lions i.e. 80% of lions diet within the Gir protected area (Meena et al. 2010). Current study have shown a positive relationship of chital density with lion density. The cause behind this could inherently be the higher density of chital, with higher encounter rate and preference of similar habitat type by both of the animal i.e. moist mixed forest (Jhala et al. 2009, Singh 2007, Khan et al. 1990, Mishra 1982). The total biomass of chital is around 1732.8 kg. There were comparatively less detections of sambar 25 individuals, which are mostly found in the hilly terrains of Gir PA. Nilgai had only 4 detections, which is then analysed with a global detection function with sambar. The density of nilgai in the sampled area is 1.02 (SE 50.26). They were mostly found in the periphery of the forest with moderate disturbance. Other prey detected on the survey were chinkara, four horned antelope, langur, peafowl and hare.

5.3. Factors governing the spatial distribution of lion

(i) Distribution of prey

Lions preferred prey are sambar while principal prey are chital (Meena et al. 2010; Banerjee et al. 2012). However, lion spatial density was not explained by spatial density of either chital or sambar. I believe this was because my sampling was restricted to the protected area where lion density and distribution was not limited by food resources but more by social organisation, other features like terrain and aggregation caused due to attractants provided for promotion of lion tourism.

(ii) Tourism hot-spots:

Tourism hot spots tends to localise and habituate wildlife species to facilitate their observation. Lucrative attractants are provided to localize target specis around these areas, which is found to have significant ecological impact on the spatial distribution and habitat selection of wild animals (Masse et al. 2014). These animals are found to restrict their movements around these hotspots regardless of environmental conditions, habitat type or quality. These places are also found to have higher densities than naturally possible which might exceed their social carrying capacity and result in social strife (Masse et al. 2014). At tourism "hot-spots" in Western Gir, lions are often baited at specific locations. These bait locations were found to have the highest influence in determining the spatial density distribution of lions in the region. This distribution pattern caused by baiting overrides the influence of natural prey and other ecological factors suggesting high local densities beyond what is ecologically possible at the site. These would enhance tourist viewing but have serious implications on social organization of lions as well as enhanced predation pressure on wild prey in small pockets of artificially enhanced lion density.

(iii) Elevation:

For a heavy large predator like the lion it is energetically more costly to live in terrain that is steep. Besides for this bulky predator such high elevation terrain makes predation difficult. It is for this reason lions prefer less elevation areas and moderately undulating to flat terrain. Their socio-biology and evolutionary adaptations in this regards plays a major role in resource selection. In Gir PA lion densities have a negative response with elevation or hilly terrain and that is why they occur at low density within the core areas of the National Park which is primarily hilly steep terrain.

(iv) Euclidean distance from water

In arid and semi-arid savannas, large herbivores congregate more in the vicinity of waterholes (Redfern et al. 2003, Valeix et al. 2009) as they need to drink regularly, which is advantageous for carnivores and predation increases in the vegetation surrounding these water sources (Hopcraft et al. 2005). Hence, it is very likely that lions spend more time in the vicinity of waterholes and explore these areas thoroughly to maximize their encounter rate with potential prey in areas where prey are relatively more abundant and accessible.

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Appendix I- Detection Curves of the Lion Prey

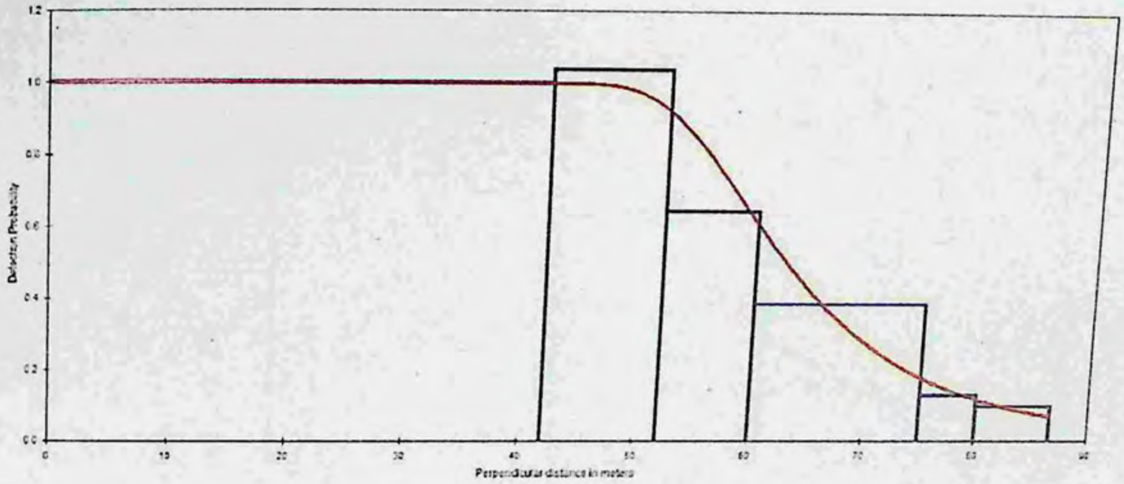

Figure 1 Detection curve for Chital

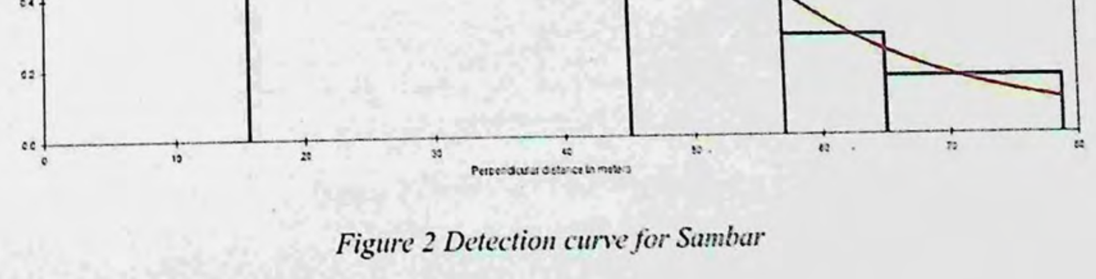

Figure 2 Detection curve for Sambar

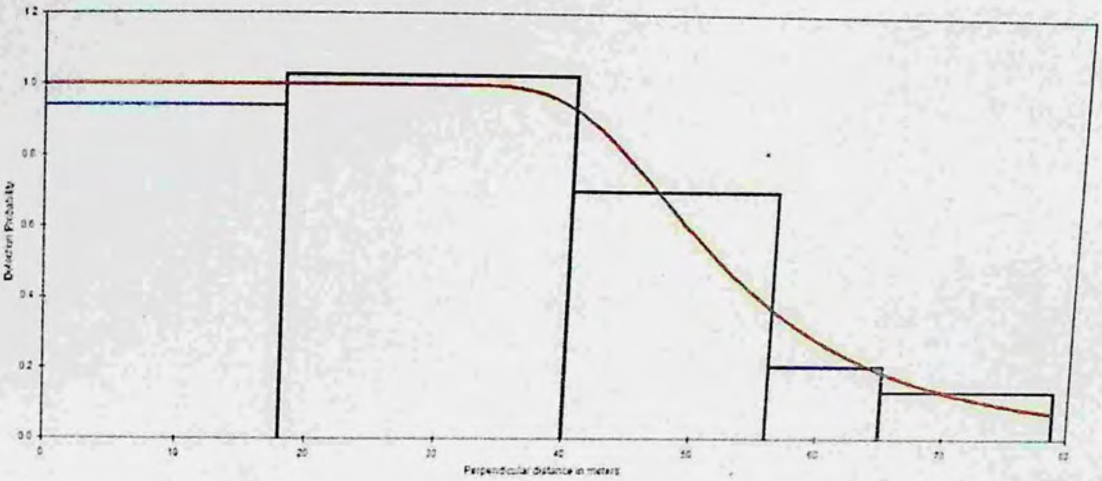

Figure 3 Detection Curve for Nilgai

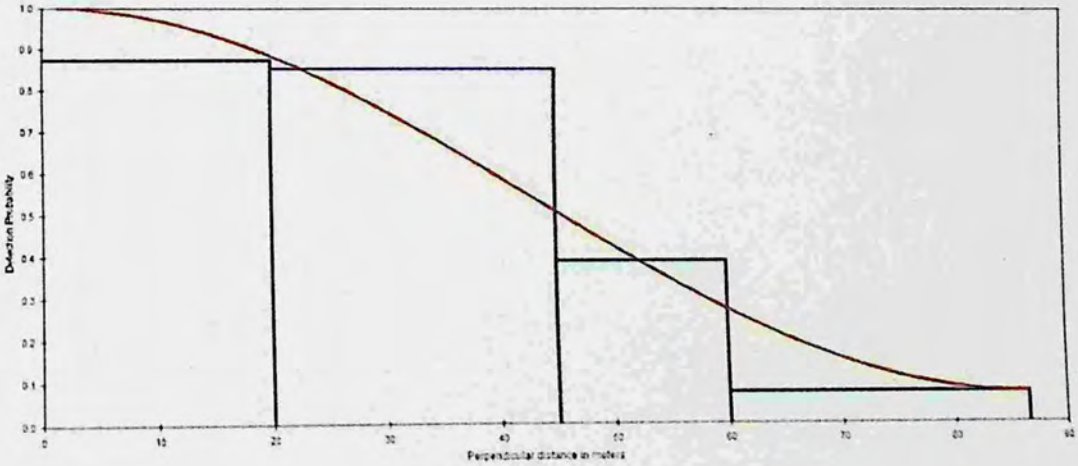

Figure 4 Detection Curve for Peafowl