A PROTOCOL ON PHASE-IV MONITORING

(Continuous monitoring of tiger reserves / tiger source areas)

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SECTION-1

SECTION-1

1. BACKGROUND

1.1 The Tiger Task Force constituted by the National Board for Wildlife (2005) has endorsed the revised methodology / approach propounded by the erstwhile Project Tiger Directorate (now the National Tiger Conservation Authority-NTCA) and the Wildlife Institute of India (WII) for country level estimation / monitoring of tiger / prey status and its habitat. The said approach, interalia, comprises of the following:

(a) Country level assessment of tiger, co-predators, prey and habitat in 17 tiger States once in every four years using the double sampling method having three phases (Phase-I: Spatial mapping and monitoring of tigers, prey and habitat; Phase-II: Assimilation of spatial and attribute data; and Phase-III: Estimating the population of tigers and its prey).

(b) Intensive monitoring of tiger source populations in tiger reserves and protected areas in each tiger landscape complex (Phase-IV), and maintenance of a centralized photo-database of tigers at NTCA obtained from camera traps deployed across all tiger reserves.

(c) Routine management-oriented monitoring, which, inter alia, comprises of regular monitoring of tiger signs at beat level, which can potentially be integrated with monitoring of law enforcement and patrolling.

(d) Survey Design (for all tiger reserves except Sundarbans) for spatially explicit mark-recapture study involving research workers / scientists is at Appendix-I.

1.2 The above endorsement of the Tiger Task Force is being implemented and has also been reiterated in the guidelines issued by the NTCA (Technical Document: NTCA/01/07). In a country level meeting of Chief Wildlife Wardens / Field Directors held in May, 2011, it was decided to taken to implement the Phase-IV monitoring from

November, 2011. This was followed by a discussion with experts / NTCA members and a meeting with Chief Wildlife Wardens / Field Directors in October, 2011.

As per the decision taken, the minimum standards for the Phase IV protocols were:-

(1) Camera trap density one pair per 4-5 sq.km.
(2) Minimum trap nights of a 1000 per 100 sq.km. (i.e. 25 pairs of cameras in 100 sq.km. for 40 days)
(3) Minimum area coverage of 400 sq.km.
(4) Closure period of 40 to 60 days
(5) Minimum of 20 spatial replicates of line transects each of a minimum of 2 km length (for the entire reserve)
(6) Entire reserve needs to be sampled. Each sampling occasion should cover minimum area of 400 sq.km (100 pairs of cameras) and in case of larger reserves, the area should be covered by dividing the area into 400 sq.km blocks and camera trapping should be done successively, within the closure period of 60 days.

The objective of the NTCA exercise is to, at the least, obtain a minimum number of tigers in a Tiger Reserve (Section-2), but aims to estimate the tiger population size and prey densities (Section-3) in a reserve using spatially-explicit capture-recapture approaches using software tools such as SPACECAP / DENSITY for estimating tiger population size & DISTANCE for estimating densities of prey.

In brief, the Phase-IV protocol of NTCA contains six components:

(a) Maintaining daily patrolling log (described in Section-2)
(b) Carrying out beat-wise monitoring of sign encounters twice a year (described in Section-2)
(c) Recording from PIP (described in Section-2)
(d) Obtaining minimum tiger number using camera traps (described in Section-2)
(e) Obtaining tiger numbers using camera traps (40-60 days closure period) (described in Section-3)
(f) Obtaining minimum tiger numbers through DNA analysis from Scats (described in Section-3)

The field managers are familiar with some of these components. Under Phase-IV monitoring, emphasis have been given on the use of camera traps for obtaining minimum tiger numbers or preferably, tiger population size estimation and using line transect sampling for estimating prey densities. It must be borne in mind that for data analysis using camera trap data in a mark recapture framework as well as in DISTANCE sampling, the 'detection probability' or 'probability of detecting animals' is important. Further, it is important to note that more animals in an area may not result in enhanced detection probability, since the latter is governed by terrain features, cover, visibility etc. However, more animals in an area may result in more detections on a line transect or more captures during a camera session.

The phrase 'detection probability' is used in line transects, whereas 'proportions of animals captured' is used in the context of camera traps. The 'proportion of capture' or 'capture probability' facilitates estimation of true population size. To illustrate the importance of a detection probability, a simple example is given below:

- 100 spotted deer were introduced in a known area
- The same area was traversed by a team of two persons six times resulting in a count of 62 spotted deer (mean)

- Here, the detection probability = $\hat{p}$ = 62/100 = 0.62
- After a year, the area was again counted along the same trail resulting in a count of 90 spotted deer
- The population estimation is done as below:
  90/0.62 = 145 spotted deer, with the assumption that detection probability has remained constant over the two years.

Thus a generic formula is given for population estimation:

$$\hat{N} = \hat{C} / \hat{P}$$

where, $\hat{N}$ = population
$\hat{C}$ = count / index
$\hat{P}$ = probability of detection

In the above example, the initial figure of 100 spotted deer was known, which is not the situation under wild conditions. Further, two counts / indices can be compared only if we know the probability / estimate the probability of detection. Thus, both in camera trap as well as distance sampling, the analysis part requires estimation of the probability of detection / capture.

> QuickReferenceGuide
>
> Phase IV involves monitoring of Tiger and its prey on annual basis at Tiger Reserve level, while Phase I to III is done at every 4 year interval for country level monitoring. The following needs to be kept in mind while planning the Phase IV:
>
> Carnivore population estimation
> 1) Camera trap density one per 4-5 sq km
> 2) Minimum trap nights of a 1000 per 100 sq km
> 3) Minimum area coverage of 400 sq. km or whatever is the reserve size
> 4) Closure period of 40 to 60 days
> Trap night are number of days of operation multiplied by number of pair of cameras. Closure period is time frame within which animal movement in and out of study area, birth and death are going to have no or negligible effect.

Given the importance of estimating detection probability as outlined above, this concept is central to intensive monitoring under Phase IV, unlike in Phases I, II, and III where ‘encounter rates and indices’ were employed more prominently.

However, since at the reserve or source population level tiger and prey density estimation methods which can rigorously deal with detection probability require substantial scientific expertise to design and deploy, it may not always be possible for reserve managers to have access to and be guided by adequately qualified scientists. Therefore, Phase IV intensive monitoring is being seen as a “ladder process” in which tiger reserves will gradually move up the ladder from routine management oriented monitoring to the intensive scientific monitoring scheme.

States/Reserve managers who do not have ready access to trained scientists with expertise in design and deployment of intensive scientific methods may use the first step of the ladder described here under Section-2, as routine management oriented activities. These routines will involve a wide range activities covered under parts A, B, C, D under Section 2 of this protocol and will be generally helpful in management of reserves. One aim of this is to generate minimum number of tigers in each reserve, each year without violating important closure assumptions described later. This routine management oriented monitoring is described in Section 2 of this document.

The next step in the "ladder process" involves use of rigorous distance sampling (for prey) and capture-recapture sampling (for tigers). These may require collaboration with adequately qualified scientists in survey design, implementation and data analysis stages. Here the goal is to generate valid estimates of population density and population size for tigers and important prey species in each reserve, fully meeting all the minimum standards and approaches described in Section 3 of this document.

Where such intensive scientific monitoring of tiger and prey populations is undertaken as described in Section 3, there may be no need for deploying other kind of line transect or camera trap surveys, to avoid unnecessary duplication of work.

SECTION-2

SECTION-2

PHASE-IV MANAGEMENT-ORIENTED MONITORING

I. For all tiger reserves except Sundarbans

Part-A Maintaining daily patrolling log in patrolling camp / chowki registers

While on regular or targeted patrolling duties the personnel shall record the following information:

1) Each patrolling team shall be equipped with a GPS unit and a digital camera besides the regular equipment (e.g. firearms, wireless, torch, etc).
2) The date, time and GPS coordinates of the beginning of the patrol recorded.
3) Preferably the GPS unit shall be switched on throughout the patrol in a track log mode. However, due to constraints of technical knowhow or other issues if this is not possible then a GPS coordinate recorded and written down in the record form every 30 min or at major deviations from a straight line path.
4) The total number of persons on the patrol are recorded along with number of armed personnel and type of arms. The mode of patrol is also recorded, e.g. on foot, bicycle, motorcycle, 4WD, elephant, boat, etc.
5) A record of all illegal activities is entered in the data sheet along with time, date and coordinate stamp. A photograph is also taken of the site with a time date stamp.
6) A record of signs and sightings or highly endangered species while on Patrol is also maintained by entering the GPS coordinate, date and time of the sighting /sign as well as recording a digital picture of the same if possible.
7) After the end of the Patrol, the GPS track log is either downloaded onto a computer (in MSTrIPES program if this is applicable at the site) or the datasheet with the recorded information deposited at the Range Head Quarters. Data formats for recording Patrol data are provided in Annexure-I.

Part-B Carrying out beat-wise monitoring of signs and encounters of animals/vegetation/habitat disturbances following Phase-I protocols twice a year

The entire tiger reserve would be covered at the beat level, by considering the latter as a sampling unit, as done in Phase-I of the country level assessment by following the standardized eight day protocol (the data collection needs to be done twice a year in the formats provided at Annexures-VII, VIII, IX and X). This would involve beat wise collection of data (in the standardized formats) twice a year relating to tiger / carnivore signs survey, ungulate, encounter rates, habitat status, human presence and pellet / dung counts. Based on such data, beat level maps indicating the spatial presence / relative abundance (index) of prey / predators species should be prepared in the GIS domain for record.

(i) Beat-wise collection of data in the standardized formats of Phase-I country level assessment process.
(ii) The data collection should be done twice a year (summer and winter).

(If the tiger reserve is following advanced protocols as described in Section-3 in collaboration with scientific institutions, then the routine monitoring of prey animal signs/encounters, vegetation features and habitat disturbance features should be carried out along transect lines designed based on protocols described in Part-E of Section-3. There may be no need for laying of transect lines in each beat as per Phase-I protocol.)

Part-C Recording data from ‘pressure impression pads’ (PIP)

As a part of intensive monitoring of source populations of tigers, data will be recorded from pressure impression pads (PIP’s, track plots) in every beat.

- A minimum of 5 PIPs will be permanently maintained in each beat. The dimension of the PIP shall not be less than 6m in length the width of the PIP should equal the foot path, jungle trail or dry nullaha’s width on which the PIP is made. GPS coordinates of all PIP’s need to be recorded.

- The location of the PIPs within the beat should be such that they maximize the possibility of recording carnivore tracks. Minimum distance between any 2 PIPs should be more than 1.5km.
- The PIPs should be cleaned of debris, leaf litter, gravel and covered with fine dust of about 0.5cm depth. After preparing the PIP, data should be recorded the next morning and the PIP cleared of all tracks. The PIPs should be sampled thrice every month during summer and winter. In case a prepared PIP is disturbed due to rain, traffic etc. then it should be set again before data is collected. The topography and forest type should be recorded for each PIP.
- Trails of all carnivore and mega herbivores species should be recorded e.g. tiger one track set, leopard two track sets, several dhole track sets (as it may not be possible to identify individual track sets due to many tracks by a passing dhole pack), one small cat track (as species level identification may not be possible).
- It is important to note that a track set is constituted by one to many pugmarks made by a single animal traversing the track plot (PIP). One need not identify the gender or individual animal (tiger), but if this information is known, it should be entered in the remarks column. If there are more than one track sets of "same" animal eg. a tiger moving up and down the trail several times, they should be recorded as separate track sets. Data sheet for recording are provided in Annexure-III.

Part-D Obtaining the minimum number of tigers in the tiger reserve

(i) Three pairs of camera traps to be deployed per beat and should be left open within a closed period of 40-60 days depending on the reserve.

(ii) The period of leaving the camera traps open (closure period) is important owing to the fundamental assumption of "population closure" (no deaths / births / immigrations / emigrations in the population). Leaving the cameras open for longer duration will lead to over estimation of tiger numbers.

(iii) The photographs obtained from camera trapping should be submitted to NTCA for analysis for fixing individual IDs of tigers.

(iv) A digital camera trap tiger photo database should be prepared for the reserve with location ID, Date and Time Stamps as per format to be provided by NTCA.

(v) The minimum number of tigers should be ascertained based on individual camera photo traps of tigers obtained within the closure period specified to be 45-60 days.

(vi) Details of new captures / missing tigers should be recorded.

(vii) The format for recording the camera trap capture data will be provided by NTCA

SECTION-3

SECTION-3

(Advanced protocol involving scientists)

PHASE-IV INTENSIVE MONITORING OF SOURCE POPULATIONS AND TIGER RESERVES

Part-E Obtaining tiger population size for the reserve using spatially-explicit capture recapture framework and Obtaining prey population size using line transect sampling.

(A) Obtaining tiger population size.

(i) The camera traps deployed as per the survey design in Appendix-1. should be left open for a period of 40-60 days (depending on the areas). Where possible the entire Tiger Reserve must be surveyed. If the survey area is very large, tiger population size can be obtained by sampling a minimum block of 400 square kilometers at a time, but following all other minimum standards in section 3. If deployment of camera traps in an entire reserve or parts of it is not feasible for any reason, fecal DNA samples may be collected over the entire Tiger Reserve for Capture-Recapture analysis. The tiger population size may then be estimated over the entire Tiger Reserve using Mark-recapture methodology.

(ii) The analysis of the data needs to be done in collaboration with a technical expert / scientist conversant with spatially-explicit capture-recapture process / analysis.

(iv) The period of leaving the camera traps open (closure period) is important owing to the fundamental assumption of "population closure" (no deaths / births / immigrations / emigrations in the population). Leaving the cameras open for longer duration may lead to over estimation.

(v) The format for summary record of camera captures and the basics of mark recapture process using camera traps are provided at Annexures-V & VI.

(vi) The analysis of capture data between years (using open population models) should also be done in collaboration with technical experts / scientists/ WII.

(B) Obtaining prey densities

(i) Line transects must be systematically placed with a random start according to the survey design mentioned in Appendix-1 and implemented in program DISTANCE.

(ii) The line transect data should be analysed using the “DISTANCE” software for prey density. The analysis of the data needs to be done in collaboration with a technical expert / scientist conversant with the DISTANCE SAMPLING analysis.

(iii) The format for collecting line transect data to facilitate analysis using “DISTANCE” software and the basics of DISTANCE sampling using line transects are provided at Annexure-II.

Part-F Using scats for DNA analysis to obtain the minimum tiger numbers in reserves where camera trapping is not possible

(i) Collection of tiger scat samples: a) Use disposable surgical gloves to handle scat samples, b) for each scat a new set of gloves should be used to avoid cross contamination, used gloves should be discarded in an environmentally friendly way c) about 20 gms of fresh scat sample should be taken and stored in a vial/tube containing buffer & / or 70% alcohol. Tubes should be prepared in duplicate with GPS coordinates and date clearly recorded on the tube (alcohol erases permanent marking pens).

(ii) Obtaining the minimum number of tigers in the area through DNA analysis of tiger scats involving an institution having the domain expertise.

APPENIDCES

Appendix-I

SURVEY DESIGN (For all tiger reserves except Sundarbans) for spatially explicit mark-recapture study involving research workers / scientists

Minimum Standards for monitoring tiger source populations were: Sampling area: Minimum area of 400 km^2 or entire Tiger Reserve, if area is smaller than 400 km^2.

(i) Tiger monitoring by camera trap sampling:

Camera density = 25 double-sided cameras per 100 km^2.
Sampling effort = 1000 trap nights / 100 km^2.
Closure period = 40-60 days

NOTE: The period of leaving the camera traps open (closure period) is important owing to the fundamental assumption of "population closure" (no deaths / births / immigrations / emigrations in the population). Leaving the cameras open for longer duration may lead to gross over estimation.

(ii) Prey monitoring by line transect sampling:

1) Straight or square line transects will be systematically placed with a random start over the study area. These designs must be generated using program DISTANCE.

2) At least 20 spatial replicates must be laid out.

3. Each transect must be walked at least 4 times during sampling to generate >40 detections for each important prey species.

DESIGN OF SURVEYS ANALYSES OF DATA

(i) The survey design and analysis of these data needs to be done in collaboration with a technical expert / scientist conversant with the advanced open and closed model mark-recapture and advanced distance sampling methodologies.
(ii) The format for recording camera capture data and the basic ideas of the mark-recapture process using camera traps are provided at Annexures-V & VI and in published scientific literature.

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Data Sheet-6

Patrol Form

Name of Guard: ……………………. Date: …………… Forest Division …………….. Range: ……………….…. .

Beat: ……………………………….. No. of Persons on Patrol: ……… Armed ……………. Unarmed ………………….. .

Patrol Type: General Duties, Investigations, Surveillance, Others Patrol Method: Foot, Jeep, Motorbike, Bicycle, Elephant and Others

D t	T m	L			L g			Pl	An m l n	G F n	Ill g l A				An m l M l y R d					
		D g	M	S	D g	M	S				Ty	T m l p l	D t l	A t t k	S	G l (M/F/U)	Ag (Y/A l/U)	C t t	C f l th	S m l t k

M – Male, F – Female, Un – Unknown, Y – Young, Ad – Adult.

<u>Annexure-II</u>

Field formats for data collection in distance sampling

I. Line Transect Data Sheet for monitoring of ungulate population by DISTANCE sampling:

Observer name: .... Start time: .... Date: ....
End time: .... ID no. of line transect: ....Total length: ……km
TR / Forest division: .... Range: .... Beat: ....
Weather condition: Cloudy/Clear sky
Beginning GPS Lat: ....N; Long: ………...........................E
End GPS Lat: ....N; Long: ....E

Sighting No	Time	Species*	Total Nos. (Adults & Young)	Young	Sighting Distance	Compass Bearing	Forest Type	Terrain Type	Remarks
1									
2									
3									
4									
5									
6									
7									
8									

*Species that need to be recorded on the transect: chital, sambar, nilgai, gaur, barking deer, elephant, rhino, wild buffalo, swamp deer, hog deer, chowsingha, blackbuck, chinkara, wild pig, langur, peafowl, hare, cattle (live stock), and other mammalian species seen.

II. Location of transects in relation to Vegetation and Terrain features

Transect No.	Total length (km)	Name	Bearing	GPS location		Vegetation type	Terrain category
				Start	End		
T1							
T2							
T3							
T4							
T5							
T6							
T7							

Annexure-II
(Basic Information)

Assessment of prey using line transects following survey design as described in Part-E of Section-3 and analyzing the data with DISTANCE Software

(i) The use of line transect in estimation of prey density is known as 'line transect sampling'. This technique of abundance estimation is included under 'distance sampling'.

(ii) It provides a direct estimate of density, provided its assumptions are met.

(iii) It also accounts for the probability of detection.

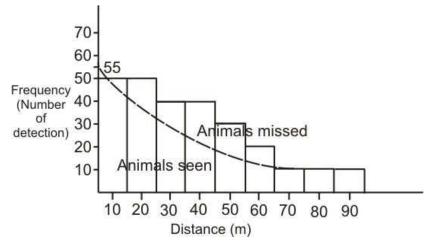
(iv) In 'Distance Sampling', the fact that the 'probability of detection decreases with increasing distance from the observer' is modelled by developing a function, which is used to estimate the 'probability of detection' ($\hat{\beta}$). The density ($\hat{D}$) is estimated as below:

$$\hat{D} = \frac{n}{\alpha\hat{\beta}}$$

where, n= total number of detections
α = total area sampled

(v) The observer travels along a line of length 'L', located randomly in the study area, and counts all the animals which are seen. There is no assumption that all animals are counted, and the counts are assumed to be incomplete. More often, a maximum observation distance 'w', which is perpendicular to the transect line on each side, is established. Beyond this distance, no count is made. In some cases, counting of all animals is done without establishing a distance.

(vi) Let us consider the common approach of establishing the 'maximum observation distance' (w). Here, it is important to estimate the 'detection probability' or the proportion of animals that are actually seen (β). This is required to correct the actual counts.



(Hypothetical from the transect line histogram plot of the number of detections against the distance from the transect line, with a smooth function fit.)

(vii) If the number of detections are plotted against distance from the transect line, a smaller number of detections are seen as the distance increases. The detection function to the observed distances is fitted to estimate the detection probability '$\hat{\beta}$':-

$$\hat{\beta} = \frac{\text{Area under the curve}}{\text{Total area}} = \frac{3500}{4950} = 0.70$$

(viii) Once the detection probability ($\hat{\beta}$) is computed, animal abundance in the survey area can be calculated, as in the case of the strip sampling, using the canonical estimator as before:

$$\hat{N} = \frac{An}{2wL\hat{\beta}}$$

(ix) For animal density ($\hat{D}$), the abundance needs to be divided by area, resulting in:

$$\hat{D} = \frac{n}{2wL\hat{\beta}}$$

(x) The salient features of this estimation technique are as below:-

a. From the transect line, the perpendicular distances (x) to each detected animal of interest are computed by measuring the detecting angles 'M' and detection distances 'r'.
b. This computation is done as x = r sin M.
c. Imagine a situation where 'k' transect lines have been laid

in some randomized design, having lengths l_1............l_k, with a total length 'L'.

d. Further, suppose that 'n' animals are seen at perpendicular distances x_1, x_2...........x_n, and animals beyond a distance (w) from the transect (truncation distance) are not taken into account.

e. In the above situation, the area surveyed (a) is given by : a = 2wL.

f. Say 'n' animals are seen/detected within this area.

g. Estimation of animal density (D) is given by:

$$\hat{D} = \frac{n}{cwLP_a}$$

where, P_a = probability of detection of a randomly chosen animal within the area surveyed;

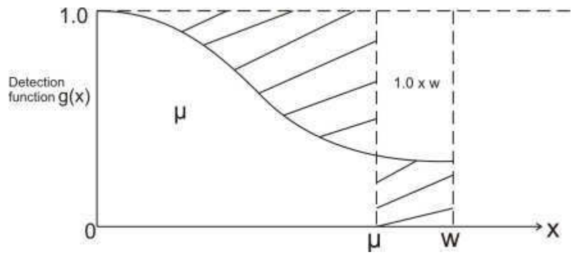
P_a = estimate of P_a

h. Thus, it becomes necessary to give a framework to estimate P_a. In this context, the 'detection function' 'g(x)' is defined as the probability of an animal at distance x from the transect line being detected, given that x is between w and 0 (i.e. $0 \leq x \leq w$). Further, it is also assumed that animals on the transect are certainly detected (i.e. g (0) =1).

i. A new parameter 'μ' is now defined, which is known as the 'effective strip (half) width'. It is the distance from the transect 'for which as many objects as are detected beyond μ as are missed within μ '.

(Defining a detection function g(x), where g(0) = 1; μ = the effective strip width).

j. If the detection function g(x) is plotted against perpendicular distances 'w' as a histogram, a model for g(x) needs to be specified, and fitted to the distance data.

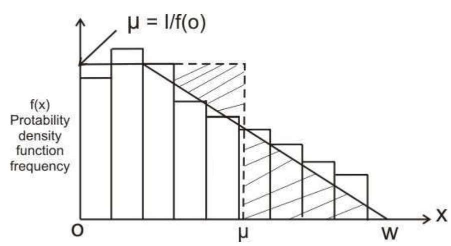


P_a is related to μ. If the definition for $\mu = \int_0^w g(x)dx$, then $P_a = \mu/w$.

$$\text{Thus, } \hat{D} = \frac{n}{aP_a} = \frac{n}{2wL\hat{\mu}/w} = \frac{n}{2\hat{\mu}L}$$

k. Now μ(hat), an estimate of μ is required. For this another function known as the 'probability density function' (pdf) of perpendicular distances f(x) to detected animals is used. This is the rescaled detection function g(x) for integrating into unity; i.e. f(x) = g(x)/ μ. Since it is assumed that g(0) = 1, hence f(0) =1/ μ.

$$\text{Thus, } \hat{D} = \frac{n}{2\mu L} = \frac{n\hat{f}(0)}{2L}$$



[Fitting the probability density function (pdf) to the data. The area under this function is 1].

f(x) is the pdf of perpendicular distance p frequencies, plotted on a histogram of perpendicular distance frequencies. These are scaled so that the area of the histogram is 1. By definition, the area below the curve is unity (1). The two shaded areas in the above curve are equal in six, hence the area of the rectangle, μf(0) is also unity, resulting in μ=1/f(0).

l. Thus the pdf of perpendicular distances are modeled, and the fitted function is evaluated at x=0. The DISTANCE Software address this standard statistical issue. A parametric ‘key’ function is selected. However, if the fit provided by it is not adequate, adjustment are done using polynomial or cosine series, till the fit is judged satisfactory by one or more criteria.

m. Usually, the data are grouped into distance categories before analysis and such grouped data is fitted using standard likelihood methods from the multinomial data.

(xi) The distance software calculates variance and confidence in interval inherently and also besides addressing the estimation of cluster size.

(xii) The data from a line transects includes: (a) number of individual animals / number of individual animals in a cluster, (b) the perpendicular distance of the animal / centre of the cluster from the transect, (c) name / identity of the transect line where count was made / detected, (d) total length of the transect line.

(xiii) The transects should be made in all the beats (at least two line transects of 2 km each per beat).

(xiv) The transect lines may be straight lines or conforming to a continuous shape leading to the starting point. The transects should be randomly laid, separated by at least a distance of 2 to 3 km. and physically marked using GPS for replication.

(xv) The total walks on a transect (total effort) is computed by adding all the walks done on a transects, and totaling up such walks on all the transects laid in the area.

(xvi) For low density areas, more efforts may be required on the transects.

(xvii) Laser range finders and compass should be used for measuring distance and angle respectively.

Assumptions in line transect sampling:

The critical assumptions in line transect sampling, which should be met for a reliable density / abundance estimation are as below:

A. Random location of transect lines with respect to distribution of animals:

This assumption helps in estimating the detection function from the observed distribution of perpendicular distances, leading to the average probability of detection (p). To ensure this assumption, the transect lines should be laid randomly, causing minimum disturbance to the habitat.

B. Detection of animals with certainty on the transect line :

This assumption is fundamental for deriving the density estimator, wherein detection of all objects at 0 perpendicular distance are assumed (i.e. g(o) = 1). The density would be under estimated if objects / animals falling on the transects are missed, since bias is a simple function of g(o). Thus, by missing 15% of the animals on the transect line, the density estimate on an average would be less by 15%.

C. Detection of animals at their initial location:

This assumption can be easily met for stationary objects like plants or dung piles of wild animals, but it is difficult to meet for moving animals. It has been pointed out that movement does not create much problem provided it is not in response to the observer. Further, comparatively faster movement of observers also reduces the problem. However, the observers should move as silently as possible to avoid evasive movement of the animals before detection, while trying to detect them. A considerable evasive movement of animals would lead to under estimation.

D. Exact measurements are made:

Proper field measurements are essential to record reliable measurements. Erroneous recordings relating to animals on transect line from a distance makes analysis difficult.

Apart from the above, the other assumptions include :

(a) Detections are independent events.
(b) Animals should not be counted twice on the same line.

Hypothetical example of distance sampling:

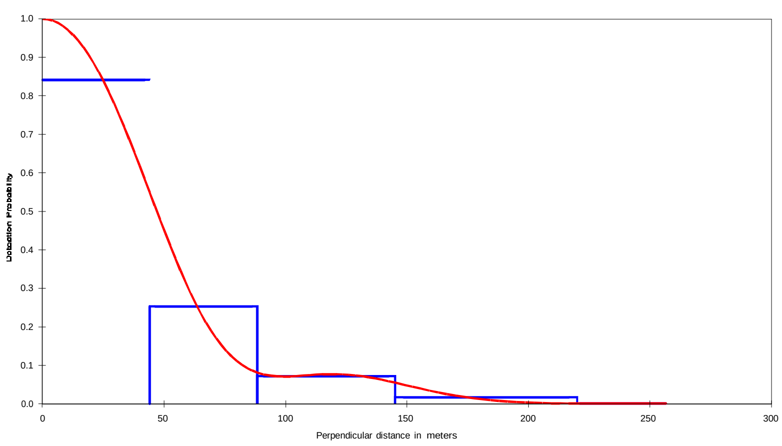
```
Effort         :    126.0000
 # samples     :    42
 Width         :    256.0000
 Left          :       0.0000000
 # observations:   447

 Model
    Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))
    Simple polynomial adjustments of order(s) :  4, 6

             Point         Standard     Percent Coef.       95 Percent
  Parameter  Estimate       Error       of Variation     Confidence Interval
  ---------  -----------  -----------  --------------  ----------------------
    A( 1)      43.57        1.680
    A( 2)     -115.6        34.19
    A( 3)      755.9        242.4
    f(0)     0.18600E-01  0.77638E-03       4.17      0.17136E-01  0.20190E-01
    p        0.21001      0.87661E-02       4.17      0.19348      0.22796
    ESW       53.763       2.2441           4.17       49.531       58.358
  ---------  -----------  -----------  --------------  ----------------------

 Sampling Correlation of Estimated Parameters


         A( 1)   A( 2)   A( 3)
 A( 1)  1.000   0.427  -0.742
 A( 2)  0.427   1.000  -0.886
 A( 3) -0.742  -0.886   1.000
```



Cell i	Cut Points		Observed Values	Expected Values	Chi-square Values
1	0.000	44.2	309	308.43	0.001
2	44.2	88.3	93	93.78	0.007
3	88.3	145.	34	34.07	0.000
4	145.	220.	11	10.67	0.011
5	220.	240.	0	0.05	0.054
6	240.	256.	0	0.01	0.007

Total Chi-square value = 0.08 Degrees of Freedom = 2.00

Probability of a greater chi-square value, P = 0.96098

The program has limited capability for pooling. The user should judge the necessity for pooling and if necessary, do pooling by hand.

There is a need for some pooling to achieve a reliable chi-square test However, the pooling algorithm built into this program would result in no degrees of freedom left. Therefore pooling is left to the user.

One or more expected values is < 1.
Try pooling some some cells by hand to obtain a more reliable test.

Model
    Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))
    Simple polynomial adjustments of order(s) : 4, 6

Parameter	Point Estimate	Standard Error	Percent Coef. of Variation	95% Percent Confidence Interval	
f(0)	0.18600E-01	0.77638E-03	4.17	0.17136E-01	0.20190E-01
p	0.21001	0.87661E-02	4.17	0.19348	0.22796
ESW	53.763	2.2441	4.17	49.531	58.358
n/L	3.5476	0.39480	11.13	2.8355	4.4386
DS	32.993	3.9214	11.89	26.017	41.839
E(S)	3.7964	0.22495	5.93	3.3794	4.2649
D	125.26	16.635	13.28	96.287	162.94
N	125.00	16.601	13.28	96.000	163.00

Measurement Units

Density: Numbers/Sq. kilometers
    ESW: meters

Component Percentages of Var(D)

Detection probability : 9.9
Encounter rate : 70.2
Cluster size : 19.9

Data Sheet-5
Track Plot for Carnivores and Mega Herbivores
(Pressure Impression Pad)

Name of Observer: …………… Date: …………Forest Division …………Range: ………...

Beat: ……………………..........

PIP No.	Forest Type	Terrain Type	Tiger		Leopard		Sloth Bear	Dhole	Hyena	Jackal	Small Cat	Gaur	Elephant	Rhino	Water Buffalo	Others	Others	Deg N	Min N	Sec N	Deg E	Min E	Sec E
			Adult	Cub	Adult	Cub																	
1																							
2																							
3																							
4																							
5																							

If track of young carnivores (eg. tiger cubs) are observed, please mention in remarks.

Remarks: ……………………………………………………………………………………**.**
…………………………………………………………………………………………………

Details of Digital Photographs taken …………………………………………………………..

Annexure-IV

Format for recording camera trap capture data to obtain tiger numbers at the reserve level

1) Place double-sided camera traps at the best locations within a beat to photograph tigers.
2) The distance between camera traps within and between beats should be over 1.5 km.
3) A minimum of 3 camera traps (consisting of double sided cameras) per beat should be deployed. The number of camera trap will increase as the size of the beat increases, keeping the strategy of one pair of camera traps for 4 sq.km. area (2 km x 2 km).
4) The GPS coordinates of each camera location and the dates of deployment should be recorded as given below:

Camera Trap Station ID	Degree, Min, Sec North	Degree, Min, Sec South	Dates deployed	Dates not operating
1 – main Rd nalla				
2- River Junct				
3- temple jnct				
4-.....				

5) Format for daily monitoring of camera traps (beat-wise)

Date	Camera Unit	Camera Trap Station 1			Camera Trap Station 2			Camera Trap Station 3			Remarks*
		Tiger	Leopard	Other	Tiger	Leopard	Other	Tiger	Leopard	Other	
	A – Right Side Camera										
	B – Left Side Camera										
	A – Right Side Camera										
	B – Left Side Camera										
	A – Right Side Camera										
	B – Left Side Camera										
	A – Right Side Camera										
	B – Left Side Camera										

	A – Right Side Camera									
	B – Left Side Camera									
	A – Right Side Camera									
	B – Left Side Camera									
	A – Right Side Camera									
	B – Left Side Camera									
	A – Right Side Camera									
	B – Left Side Camera									

* Non-functioning of camera traps or missing of tiger capture, etc. to be recorded in the Remark column.

6) Photographs of tigers, leopards and all mammal species should be downloaded and saved as folders for each species. Each photograph should have a time and date stamp recorded digitally, the camera trap station identity stored in the file name. An appropriate format is to have a species folder e.g. tiger, sub folder for camera trap station id, within which photographs of each of the cameras (from the double sided camera traps) is stored as separate folders. A CD with the above data (points 4, & 5) should be sent to NTCA every 2 months.
7) All Photographs of tigers and leopards should be printed and compared visually based on their stripe and spot patterns to identify individuals. In case of >15 tigers/leopard captures the need of software assisted identification may become essential.
8) For estimation of the tiger/leopard population after individual identification using closed capture estimators the data needs to be arranged in the format given below:

Trap Occasion (Day)

Tiger / Leopard ID	Day 1	Day 2	Day 3	....	Day 35	....	Day 48....
T-1							
T-2							
T-3							
T-4-.....							

CAMERA TRAP: CAPTURE DATA (Range Level)

Division…………… Range……………………Species: Tiger / Leopard ……………

Sl.No.	Beat Name	Observer Name	Camera ID	Tiger ID / Leopard ID	Date of Capture	Remarks

Annexure-V

(Basic information on mark recapture)

Assessment of tiger population at beat level using photographic mark-recapture camera trapping while analyzing the data with an appropriate softwares like MARK, CAPTURE and CARE. This should result in the preparation of a reserve-level photo-capture database of individual tigers, to be shared with the Chief Wildlife Warden / NTCA / WII.

(I) The capture–recapture methodology is largely derived from the classical Peterson-Lincoln Estimator which is highlighted below:

Peterson Estimate (Lincoln Index)

The mark-recapture methods based on Peterson Estimate constitute the most important pseudo-sample methods. A large number of variations of this basic method have been evolved, which have been further complicated since the technique is simultaneously utilised to measure movement or mortality.

Here the sample of a population is marked after it is caught and then released; subsequently, samples are again taken from the population after recapturing and the proportion of marked individuals are recorded. Using the proportion of marked individuals in the subsequent samples, the total population is estimated. The capture-recapture sampling facilitate estimation of the 'proportion' of animals captured which facilitates estimation of true population size.

The simplest form of the mark-recapture estimator is the Lincoln-Peterson estimator; this is known variously as 'Peterson index', 'Lincoln index' or 'the Peterson estimate'. This method gives an estimate of actual numbers and hence it is a sample census rather than an index. Peterson, in 1896, described this method for fish populations; however it was first applied for wildlife in 1930 by F.C. Lincoln, for populations of waterfowl.

The model can be derived from the ratio: $\frac{M}{\hat{N}} = \frac{m}{n}$

where, M= total number of individuals marked and released during the first capture period;

$\hat{N}$ = estimated population size (unknown);

n = total sample taken during the second capture period;

m = number of individuals captured in the second capture which were marked.

The above ratio can be rewritten as an estimator:

$$\hat{N} = \frac{Mn}{m}$$

Theoretically this is a very elegant and simple method and can be applied to any vertebrate which can be captured, viz. from fish to cats. However, it is time consuming, laborious and costly and becomes impractical for large areas. Apart from this, several critical assumptions of this method act as constraints:—

1. Each animal has an equal chance of being captured.
2. The behaviour of animals is not influenced by marking.
3. No marks are lost.
4. The individuals which are marked mix randomly in the population after release.
5. There are no immigrations or births in the area under study between the first and second trapping seasons.
6. There is no emigration or differential mortality between the marked and unmarked members of the population.
7. The population is closed; if mortality occurs, then the estimate of N is valid for the initial size of the population. If recruitment occurs then N is valid for the time of recapture.
8. The time spent in sampling is small relative to the inter-sampling period.

The model assumptions can be re-written concisely as follows:

Assumption 1. A well defined population of animals having N individuals exists.

Assumption 2. M of these individuals are marked.

Assumption 3. There exists a sample of n 'observations' of animals from the population, having x 'observations' marked animals.

Assumption 4. The average probability $\overline{p_m}$ of observing an animal that is marked is equal to $\bar{p}_u$ which is the average probability of observing an unmarked animal.

i.e. $\bar{p}_m = \bar{p}_u$

The formula $\hat{N} = \frac{nM}{m}$ can be used satisfactorily with appropriate assumptions.

Use of Lincoln-Petersen Sample Estimator in camera trapping of tigers

The sample periods can be aggregated into two groups – viz. in a session of 30 days, the first 15 days can be denoted as 'occasion-1' and the next fortnight as 'occasion-2'.

In general, for photo trapping of tigers, the camera traps are set in the study area, covering the animals so that the tigers in the area can encounter the traps at least once (preventing 'holes' so that tigers are not missed). The traps are set for several days in succession, and each day is considered as a 'sample period'. In large areas, the traps can be 'rotated' over the area as per a prescribed scheme, and the data collected over the number of days taken to cover the entire area defines the sampling period.

The camera trap data is summarised in 'capture-history' data sheets, consisting of rows of 'i' and 'o', which indicate the periods when an animal was camera trapped. Thus, a history of '100101', indicates that a tiger was trapped in periods 1, 4 and 6 of a study having 6 periods.

<u>Example</u>

m_1 = number of tigers, with known identity, trapped on occasion 1
m_2 = number of tigers trapped and released on occasion 2
m = number of tigers recaptured in period 2 (i.e. trapped at both occasions 1 and 2)

1. The unknown quantity of interest (total number of tigers in the sampled population) is defined as 'N'.

2. The model parameters are then defined as:

   p_1 = probability of a tiger exposed to sampling efforts in the sampled area is trapped on occasion i (i = 1, 2)

3. $p=1-(1-p_1)(1-p_2)$ = the probability that a tiger, from the total number of tigers in the sampled population N, is trapped at least once during the study.

4. The 'detection probabilities' for the two sampling periods are estimated, by ascertaining the proportion of tigers which were trapped in one occasion are also trapped in the other occasion. Since the population is "closed", it can be said that the tigers caught during occasion 1 are also present during occasion 2. Thus by "conditioning" tigers trapped in occasion 2, and ascertaining the number of these tigers which were also trapped during occasion 1, p_1 and p_2 can be estimated:

$$\hat{p}_1 = \frac{m}{n_2}, \quad \hat{p}_2 = \frac{m}{n_1}$$

$$\hat{p}=1-(1-\hat{p}_1)(1-\hat{p}_2)$$

The general equation for estimating abundance is:

$$\hat{N} = \frac{C}{\hat{p}},$$

where, $\hat{N}$ = estimate of abundance N (true number of tigers)

C = Number of tigers counted

p = estimate of capture probability 'p' (probability that a tiger exposed to sampling efforts in the sampled area is captured on occasion i (i=1, 2)

For period 1, the following estimator is obtained:

$$\hat{N} = \frac{n_1}{\hat{p}_1} = \frac{n_1}{m/m_2} = \frac{n_1 n_2}{m}$$

For period 2, the following estimator is obtained:

$$\hat{N} = \frac{n_2}{\hat{p}_2} = \frac{n_2}{m/m_1} = \frac{n_1 n_2}{m}$$

The assumptions of the Lincoln-Peterson model are again stated below:-

1. The population is a ‘closed’ one.
2. It is likely that all animals are equally captured in each sample (equal probability of capture).
3. The marks are not overlooked, gained or lost.

A short interval between samples can meet the first assumption. The second assumption is often relaxed, while the last one can be met with proper marking techniques.

<u>Example of Lincoln-Peterson estimate</u>

(camera trapping exercise)

50 camera traps are placed in a tiger habitat along trails, and for two consecutive nights photographs are taken, resulting in the following data:

n_1 = 10 tigers camera trapped during the first night
n_2 = 8 tigers camera trapped during the second night
m = 2 tigers camera were photographed on both the nights

Estimation of capture probabilities and abundance

Capture probabilities of each night (sampling occasion) and for both nights (combined) are calculated as below:

$$p_1 = \frac{2}{8} = 0.25$$

$$p_2 = \frac{2}{10} = 0.20$$

$$\hat{p} = 1-(1- p_1)\ (1- p_2)$$

i.e. $\hat{p} = 1-(1-0.25)\,(1-0.20)$

$= 1-(0.75)\,(0.80)$

$= 0.40$

Using the Chapman estimator for abundance:

$$\hat{N}_c = \frac{(n_1+1)\ (n_2+1)}{(m_2+1)} - 1$$

$$= \frac{(10+1)\ (8+1)}{(2+1)} - 1$$

$= 32.$

The Variance and Standard Error for the estimate are as below:

$$\text{Var}(\hat{N}_c) = \frac{(10+1)\ (8+1)\ (10\text{-}2)\ (8\text{-}2)}{(2+1)^2\,(2+2)}$$

$$= \frac{(11)\ (9)\ (8)\ (6)}{(3)^2\ (4)} = \frac{4752}{36} = 132$$

$= \quad \widehat{SE}(\hat{N}) = \sqrt{132} = 11.49$

Thus, the estimated number of tigers in the sampled area is 32.

An approximate 95% confidence interval for this estimate is given by:

$\hat{N} = \pm 1.96 \; SE(\hat{N}) = 32 \pm 22.52 = (54.52, \; 9.48)$

The above estimate is not precise and is highly uncertain, perhaps owing to small sample size in studies of elusive animals like the tiger.

(II) Broadly, the mark recapture methods have been categorised on the basis of population 'closure' as below:-

(1) Closed Population Models – Where the total number of individuals in a population does not change due to birth, deaths, immigration or emigration. There are no 'gains' or 'losses' in the population between sampling occasions. Hence, these are most suitable for short-time period estimators like abundance estimation.

(2) Open Population Models – Where the population is changing during the study due to births, deaths, immigration or emigration. These gains or losses or both occur between the sampling periods. The time interval between sampling occasions is longer. These models provide scope for estimation of abundance, survival rate and recruitment.

(III) In the Indian context, both models are applicable. The closed population models are good for abundance estimation of tigers and its prey in the country level estimation was carried out after every four years. The open population models are suitable for long term studies (e.g. Phase IV of the new methodology at source sites for monitoring tiger and its prey). In this chapter, the focus would be on the 'closed population model' owing to their relevance in the context of tiger estimation.

Capture-Recapture Models for closed population

Capture-Recapture Data

In the capture-recapture approach, the capture history of the individual animal is maintained as a series of "non-captures" (0's) and "captures" (1's).

Hypothetical Individual Capture history of 10 tigers with four capture (camera trap) occasions

Tiger	Occasion 1	Occasion 2	Occasion 3	Occasion 4
1	1	1	1	1
2	1	1	0	0
3	1	1	1	0
4	1	1	1	1
5	0	1	0	0
6	0	0	1	0
7	0	0	0	1
8	0	0	0	1
9	0	0	1	0
10	0	1	0	0

The first tiger has a capture record of (1111), and was photo captured on all four occasions. The second tiger, having a photo capture record of (1100), was captured on occasions 1 and 2. Rest of the capture history data can be interpreted similarly. Since the capture-recapture data involving a number of animals becomes large, it is usually represented in the form of summary statistics for statistical analysis:-

k = number of capture occasions;
n_j = number of animals captured on the j^{th} occasion (j=1,......k);
u_j = number of unmarked animals captured on the j^{th} occasion (j=1, ...k);
m_j = number of marked animals captured on the j^{th} occasion (j=1, ...k);
M_j = number of district animals captured before the j^{th} occasion (j=1, ...k);
(M_1=0, and M_{k+1} is the total number of distinct animal captured in the exercise);
f_j = number of animals captured exactly j times (j=1, ...k);

The statistics pertaining to the hypothetical capture history data is provided as a summary below:

Summary Statistics for the Capture history of tigers

J	n_j	m_j	u_j	M_j	$f1_j$
1	4	0	4	0	6
2	6	4	2	4	1
3	5	3	2	6	1
4	4	2	2	8	2
				10 (M_5=10)	
TOTAL	19	9	10		10

Description of the statistics:

n_j = column sum for the j^{th} occasion (column) in the capture data (history matrix), with (n_1, n_2,.....n_4).

u_j = first captures out of n_j animals, with (u_1, u_2,.....u_4)=(4,2,2,2).

m_j = recaptures out of n_j animals, with (m_1, m_2,.....m_4)=(0,4,3,2). (u_j + m_j = n_j i.e. 19)

M_j = cumulative number of first recaptures on the first j-1 occasions, thus $M_j = u_1+u_{2+}.....u_{j-1}$) and ($M_1$, M_2,......, M_5)=(0,4,6,8,10); i.e. there is a progressive increase of marked animals in the population from M_1 = 0 to M_5 = 10.

The capture frequency of an animal is denoted by its row sum. Thus (f_1, f_2, ..., f_k) denote the frequency counts of all the animals which were capture (6, 1, 1, 2). Thus, 6 tigers were photo captured once, one tiger photo captured twice, one tiger photo captured thrice and two on all the four occasions.

The number of animals which are never captured is represented by 'f_0', so that $f_1 + f_2 +$ ...., f_k = M and $f_0 + f_1 +$ ...., f_k = N. Thus estimation of population size 'N' becomes equivalent to estimation of f_0, the number of missing animals ($N=M_{t+1} + f_0$).

(IV) There are a number of models to address different sources of variation in capture probabilities, which are available in the software (CAPTURE):

1. M_o: equal probability of capture model
2. M_h: Heterogeneity Model
3. M_{bh}: Behaviour-heterogeneity Model
4. M_t: Time Variation (Schnabel) Model
5. M_{th}: Time-Heterogeneity Model
6. M_{tb}: Time-behavioural Response Model
7. M_h: Heterogeneity Model

(V) Issues relating to survey design (for camera trapping of tigers)

Some general considerations are as below:

1. The sampling time in camera trapping of tigers should be 'short' vis-à-vis the tiger populations turn over for meeting the assumptions relating to 'close models'. It has been stated that four to six weeks of sampling through camera trapping may be needed which may be stretched to eight to twelve weeks. Experience in general indicates that a period of six to eight weeks of sampling may be required.

2. The space should provide scope for every animal in the study area to have some chance of being captured.

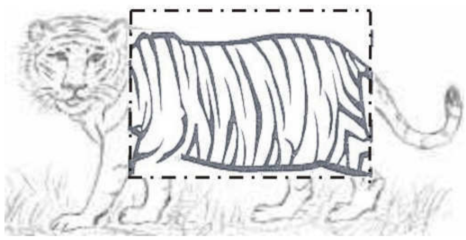
3. The camera traps should be adequately spread through out the study area and should be checked each day during the sampling period to get a good capture history data.

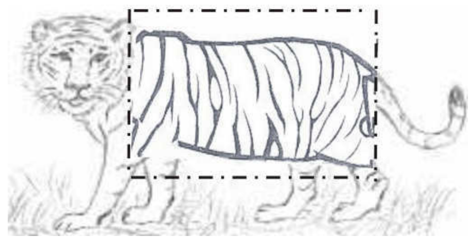
4. The study area may be divided into a number of potential sampling units, whose size should be just sufficient to set up a single camera trap. Each sampling unit can be considered as a 'grid cell' which can be randomly selected to place camera traps at sites which are promising. In the following day, the camera can be moved to other such sites in the grid cell and the process can be repeated between five to thirty days to get a standard capture history data.

5. If the area is difficult or the number of camera traps are not adequate, then smaller portions of the area can be covered (block-wise) for camera trapping for a short period of time before moving successively to other portions. The total number of days used for camera trapping to cover the entire area (all

blocks) is denoted as sample occasion 1. The procedure is repeated to get the capture occasion 2.

The other considerations in camera trapping of tigers include choice of the equipment (camera and the tripping device), choice of sites to set up the traps, spacing of traps and a standard data collection protocol. The tigers are identified visually from photographs using their unique stripe patterns:





Hiby et. al. have used a three dimensional model to match images of living tigers and tiger skins.

The identified individual tigers are numbered and every capture of an individual tiger is assigned to a particular secondary sampling occasions.

The capture history of individual tigers consist from the database in the standard history matrix and are analysed through a suitable computer program CAPTURE or MARK. During analysis, the results are checked to ascertain the violation / non-violation of the closure assumption and finally the statistical tests 'between models' is done to indicate the best fitting model vis-à-vis the data, from which the parameters are obtained. Since tigers are territorial, models which address heterogeneous capture probabilities (like M_h) should be used for tigers.

Hypothetical Data relating to individual capture history of 10 tigers with 6 camera trap (capture) occasions: Analysis with software CAPTURE

Tiger	Occasions
1.	100101
2.	101001

3. 010110
4. 100010
5. 101010
6. 101101
7. 001010
8. 101101
9. 010101
10. 101001

```
Mark-recapture population and density estimation program            Page    1
                  Program version of 16 May 1995        9-Dec-2010
 Input and Errors Listing

 Input---title='rg2'

 Input---task read captures x matrix occasions=6 captures=6

 Input---data='Group 1'

 Input---format='(a6,6f1.0)'

 Input---read input data

        Summary of captures read
               Number of trapping occasions       6
               Number of animals captured        10
               Maximum x grid coordinate        1.0
               Maximum y grid coordinate        1.0

 Input---task model selection

 Input---task population estimate appropriate

 **  Warning ** Appropriate model has been selected,
            but no estimator is available.
             Processing will be attempted.

 ***  ERROR *** Population estimator was not specified.
             Scanning for a new task card.

 Input---task population estimate null

 Input---task population estimate darroch

 Input---task population estimate zippin

 Input---task population estimate jackknife

 Input---task population estimate mh-chao
```

Input---task population estimate mth-chao

rg2

Model selection procedure. See this section of the Monograph for details.
Group 1

Occasion	j=	1	2	3	4	5	6	
Animals caught	n(j)=	7	2	6	5	4	6	
Total caught	M(j)=	0	7	9	10	10	10	10
Newly caught	u(j)=	7	2	1	0	0	0	
Frequencies	f(j)=	0	2	6	2	0	0	

1. Test for heterogeneity of trapping probabilities in population.
Null hypothesis of model M(o) vs. alternate hypothesis of model M(h)

Expected values too small. Test not performed.

2. Test for behavioral response after initial capture.
Null hypothesis of model M(o) vs. alternate hypothesis of model M(b)

Chi-square value = 3.819 degrees of freedom = 1
Probability of larger value = 0.05068

3. Test for time specific variation in trapping probabilities.
Null hypothesis of model M(o) vs. alternate hypothesis of model M(t)

Chi-square value = 8.687 degrees of freedom = 5
Probability of larger value = 0.12223

4. Goodness of fit test of model M(h)
Null hypothesis of model M(h) vs. alternate hypothesis of not model M(h)

Chi-square value = 5.581 degrees of freedom = 5
Probability of larger value = 0.34910

Mark-recapture population and density estimation program Page 3
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rg2

Model selection procedure. See this section of the Monograph for details.
Group 1

5. Goodness of fit test of model M(b)
Null hypothesis of model M(b) vs. alternate hypothesis of not model M(b)

Chi-square value = 7.262 degrees of freedom = 4
Probability of larger value = 0.12265

5a. Contribution of first capture homogeneity across time

Expected values too small. Test not performed.

5b. Contribution of recapture homogeneity across time

Chi-square value = 7.252 degrees of freedom = 4
Probability of larger value = 0.12316

6. Goodness of fit test of model M(t)
Null hypothesis of model M(t) vs. alternate hypothesis of not model M(t)

Expected values too small. Test not performed.

7. Test for behavioral response in presence of heterogeneity.
Null hypothesis of model M(h) vs. alternate hypothesis of model M(bh)

Chi-square value = 0.667 degrees of freedom = 1
Probability of larger value = 0.41422

Model selection criteria. Model selected has maximum value.

Model	M(o)	M(h)	M(b)	M(bh)	M(t)	M(th)	M(tb)	M(tbh)
Criteria	0.89	0.68	0.44	0.91	0.00	0.75	0.43	1.00

Appropriate model probably is M(tbh)
No estimator results from this model.

Mark-recapture population and density estimation program Page 4
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rg2

Population estimation with constant probability of capture.
See model M(o) of the Monograph for details.
Group 1

Number of trapping occasions was 6
Number of animals captured, M(t+1), was 10
Total number of captures, n., was 30

Estimated probability of capture, p-hat = 0.5000

Population estimate is 10 with standard error 0.4189

Approximate 95 percent confidence interval 10 to 10

Profile likelihood interval 10 to 11

Mark-recapture population and density estimation program Page 5
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rg2

Population estimation with time specific changes in probability of capture.
See model M(t) of the Monograph for details.
Group 1

```
Occasion          j=     1    2    3    4    5    6
Animals caught  n(j)=    7    2    6    5    4    6
```

Total animals captured 10

p-hat(j)= 0.70 0.20 0.60 0.50 0.40 0.60

Population estimate is 10 with standard error 0.0053

Approximate 95 percent confidence interval 10 to 10

Profile likelihood interval 10 to 11

Histogram of n(j)

```
Frequency     7    2    6    5    4    6
------------------------------------------
     7        *
     6        *         *         *
     5        *         *    *    *
     4        *         *    *    *    *
     3        *         *    *    *    *
     2        *    *    *    *    *    *
     1        *    *    *    *    *    *
------------------------------------------
```

Mark-recapture population and density estimation program Page 6
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rg2

Population estimation with constant probability removal estimator.
See model M(b) of the Monograph for details.
Group 1

Occasion	j=	1	2	3	4	5	6	
Total caught	M(j)=	0	7	9	10	10	10	10
Newly caught	u(j)=	7	2	1	0	0	0	

Estimated probability of capture, p-hat = 0.714281

Estimated probability of recapture, c-hat = 0.434783

Population estimate is 10 with standard error 0.0751

Approximate 95 percent confidence interval 10 to 10

Profile likelihood interval 10 to 10

Histogram of u(j)

```
Frequency     7    2    1    0    0    0
------------------------------------------
      7       *
      6       *
      5       *
      4       *
      3       *
      2       *    *
      1       *    *    *
------------------------------------------
```

Mark-recapture population and density estimation program Page 7
Program version of 16 May 1995 9-Dec-2010
rg2

Population estimation with variable probability of capture by animal.
See model M(h) of the Monograph for details.
Group 1

Number of trapping occasions was 6
Number of animals captured, M(t+1), was 10

Total number of captures, n., was 30

Frequencies of capture, f(i)

i=	1	2	3	4	5	6
f(i)=	0	2	6	2	0	0

Computed jackknife coefficients

	N(1)	N(2)	N(3)	N(4)	N(5)
1	1.833	2.500	3.000	3.333	3.500
2	1.000	0.467	-0.233	-0.833	-1.167
3	1.000	1.000	1.225	1.542	1.750
4	1.000	1.000	1.000	0.956	0.914
5	1.000	1.000	1.000	1.000	1.001

The results of the jackknife computations

i	N(i)	SE(i)	.95 Conf. Limits		Test of N(i+1) vs. N(i) Chi-square (1 d.f.)
0	10				
1	10.0	0.00	10.0	10.0	2.250
2	8.9	0.00	8.9	8.9	0.002
3	8.9	1.49	6.0	11.8	0.261
4	9.5	2.83	4.0	15.0	0.488
5	10.0	3.57	3.0	17.0	0.000

The data are ill-conditioned. As a best guess, use

Average p-hat = 0.5000

Interpolated population estimate is 10 with standard error 0.4567

Approximate 95 percent confidence interval 10 to 10

Histogram of f(i)

```
Frequency      0    2    6    2    0    0
------------------------------------------
     6                   *
     5                   *
     4                   *
     3                   *
     2              *    *    *
     1              *    *    *
------------------------------------------
```


rg2
Population estimate under individual heterogeneity in capture probabilities.

See model M(h) of Chao (1988).
Group 1

Number of trapping occasions was 6
Number of animals captured, M(t+1), was 10
Total number of captures, n., was 30

Frequencies of capture, f(i)

i=	1	2	3	4	5	6
f(i)=	0	2	6	2	0	0

Average probability of capture = 0.5000

Population estimate is 10 with standard error 0.0000

Approximate 95 percent confidence interval 10 to 10

rg2
Population estimate under time variation and
individual heterogeneity in capture probabilities.
See model M(th) of Chao et al. (1992).
Group 1

Number of trapping occasions was 6
Number of animals captured, M(t+1), was 10
Total number of captures, n., was 30

Frequencies of capture, f(i)

i=	1	2	3	4	5	6
f(i)=	0	2	6	2	0	0

Estimator	Gamma	N-hat	se(N-hat)
1	0.0000	10.00	0.00
2	0.0000	9.74	0.00
3	0.0000	10.34	0.67

p-hat(j) = 0.70 0.20 0.60 0.50 0.40 0.60

Bias-corrected population estimate is 10 with standard error 0.6687

Approximate 95 percent confidence interval 10 to 13

rg2

S u c c e s s f u l E x e c u t i o n

Capture Matrix of the tiger capture data analysed above:

Tiger	Occasions					
	1	2	3	4	5	6
1	1	0	0	1	0	1
2	1	0	1	0	0	1
3	0	1	0	1	1	0
4	1	0	0	0	1	0
5	1	0	1	0	1	0
6	1	0	1	1	0	1
7	0	0	1	0	1	0
8	1	0	1	1	0	1
9	0	1	0	1	0	1
10	1	0	1	0	0	1

(VI) Analysis

- Every tiger captured was given a unique identification number viz. (MT-002), after examining stripe pattern on flanks, limbs, forequarters
- Following tiger identification, capture histories (X matrix) were developed and analyzed using the program MARK, CAPTURE and CARE.
- CAPTURE gives various probabilities models of the underlying capture-recapture process, that are likely to have generated the observed capture histories
- Analysis of capture history involves comparison between competing models using a series of hypothesis tests and results of an overall discriminant function test, in order to select the most appropriate abundance estimation model
- Assumption: sampled population was demographically and geographically closed during the sampling period

- Since the entire tiger reserve is camera trapped the total population within the reserve is estimated. Also the same area is camera trapped in consecutive years therefore the population is directly comparable and there is no need to compute density of tigers which adds variability and loss of precision to detect trends.

Annexure-VI

Capture-recapture Sampling using Camera Trapping [Mark Software Format]

Tiger ID	Trap Occasion (day)						
	1	2	3	4	5	6	n
1							
2							
3							
4							
5							
6							
7							
N							

Data to be entered as 01 format.

Annexure-VII

Data Sheet for Tiger, Other Animals & Human Sign Encounter Rate

Observer Name: ______________________ Date: __________________ Start Time: ______________________ End Time:__________________
Begin GPS: Lat: ______________________N, Long: __________________E End GPS: Lat: ___________________N, Long : ____________________E
Forest Circle_________________________ Forest Block & Range: _______________________________ Beat __________________________________
Approx. Kms. travelled: _______________________Km. Time Spent in any other activity________________Min.

SL No	Time	GPS Location (only for tiger sign)						*Animal Species	^Sign Type	Mangrove Type			Creek Bank Type			Sign		Width of mud flat (water to Mangrove edge)
		Lat.			Long.					Tall >10’	Medium 4-10’	Small <4’	Steep	Moderate	Gentle	Fresh	Old	
		D	M	S	D	M	S											
1.																		
2.																		
3.																		
4.																		
5.																		
6.																		
7.																		
8.																		
9.																		
10.																		
11.																		
12.																		
13.																		
14.																		
15.																		

* Animal species to be recorded: tiger, fishing cat, jackal, monitor lizard, crocodile, chital, wild pig, rhesus macaque, humans and others.
^ Sign types to be recorded are pugmark/hoof mark/foot print, scat/pellet (with condition), vocalization and direct sighting.

Data sheet 1 ctd…

1) Has any tigress with cubs been reported during the past 12 months?
Yes____No_____Approximate date/month____________
a) Seen by staff, b) Pug Marks,
c) Reported by local persons, d) Seen by officials (√ the appropriate)
How many cubs ___________, approximate age of cubs _________________.

2) In case tigers are known to be present in the beat, but no sign was obtained during the sampling period then mention on what evidence was this conclusion made (pugmark, direct sighting, scat, other sign) ____________.
Approximate date/month________Tiger presence was last recorded in the beat.

3) How many livestock predation events have been recorded in the past 3 months, ________by tigers, which carnivores if known______, ______, ______.

4) GPS Coordinates at all creek/channel junctions in serial order of survey

Sl.No.	Time	Lat			Long		
		Degree	Minutes	Second	Degree	Minutes	Second
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

5) Comments & Remarks:

____

____

Annexure-VIII

Encounter Rate on Line Transects

Observer Name: ______________________ Date: __________________ Start Time: ______________________ End Time:___________________

Begin GPS: Lat: _______________________N, Long: ___________________E End GPS: Lat: ___________________N, Long : ____________________E

Forest Circle_________________________ Forest Block & Range: ________________________________ Beat ___________________________________

Approx. Kms. Travelled: __________________Km.

S. No	Time	Species*	Total Number (Adults & Young)	Young	Mangrove Type			Bank Type			Perpendicular Distance of animal from water's edge	Activity of the animal(s) Basking, foraging, moving, etc.
					Tall >10'	Medium 4-10'	Small <4'	Steep	Medium	Gentle		
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

*Species that need to be recorded on the transect: chital, rhesus, macaque, wild pig, monitor lizard and estuarine crocodile and other mammalian species seen.

Annexure-IX

VEGETATION

(To be recorded at every 15 minute travel interval)

Name of Observer: …………………. Date: ………………… Forest Circle: …………….. Forest Division…………
Range: ………………………………. Beat: ………………… ID No. of Line Transect: …………………………………

Sl No	GPS Reading at every plot from beginning of creek transect						Location of Plot- Left side/ Right side	Tree Species (Descending Order of Abundance, (Give Names)					Grass/Herbs/Sedges Species (Descending Order of Abundance including reg. mangroves, all vegetation < 4 ft.)					Density of Vegetation 0 to 4 0- Open 4- very dense	Remarks
	Lat			Long															
	Deg	Min	Sec	Deg	Min	Sec		1	2	3	4	5	1	2	3	4	5		

Annexure-X

Human Disturbance

Name of Observer: …………………. Date: ………………… Forest Circle: …………….. Forest Division………..
Range: ………………………………. Beat: ………………… ID No. of Line Transect: …………………………………

Sl No	GPS locations of the beginning of creek transect and at every 15 min. travel interval thereafter						Human Disturbances 0-4 Rating, 0-None, 4-Very high			
	Lat			Long			Wood Cutting 0-4	Lopping 0-4	Fishing evidence seen from the vegetation plot Y/N	People Seen from the plot Y/N
1	Deg	Min	Sec	Deg	Min	Sec				
2										
3										
4										
5										
6										
7										
8										
9										
10										

Are there any permanent human settlements in the beat? *(Yes/No)*. If Yes, how many? _________. Approximate human population____________,

Is there NTFP collection in the beat______*(Yes/No)*. If yes, what NTFP is collected_______________, ___________, ____________, ____________,

Rate NTFP collection on a scale of 0-4, 0-No to 4-Very high _________________, _________________, _________________, ________________.

Intensity of fishing ....and tiger prawn seed collection .... in the beat at 0-4 scale (*0 is nil, 4 is very high)*