Effectiveness and cost efficiency of monitoring mountain nyala in the Bale Mountains National Park, Ethiopia

Running head: Monitoring mountain nyala

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ABSTRACT: Due to the financial limitations faced by many protected areas today, identifying cost-efficient monitoring protocols has become important in ensuring the long term sustainability of conservation. The selection of monitoring protocols is usually driven by a range of factors, such as widespread practice or accuracy with the cost efficiency of protocols rarely considered. The mountain nyala, an endangered species, is endemic to the Ethiopian highlands. This species has a high economic potential for local communities through tourism and trophy hunting, but the expansion of human settlement is causing habitat degradation and fragmentation. A significant proportion of the global mountain nyala population occur in the Bale Mountains National Park (BMNP), thus the development of a long term monitoring protocol was identified as a priority. Like many protected areas, the BMNP is operating well below its financial needs, hence developing a robust, cost effective method that can detect changes in population size is important. This study compared the effectiveness and cost efficiency of distance sampling and total counts. Results showed that while the population estimates were relatively similar, total counts underestimated population size but were more precise, had a greater power to detect changes in population size and required only 12% of the resources needed compared to distance sampling. We suggest that investing in initial comparisons of the effectiveness and costs of different methods can result in significant cost savings, without jeopardizing the effectiveness of a survey.

KEY WORDS: ecological monitoring, census techniques, DISTANCE, protected areas, total counts

INTRODUCTION

Long term ecological monitoring is essential for conservation because it provides crucial information on the state of the system and the effectiveness of management interventions (Sinclair et al. 2000, Yoccoz et al. 2001, Singh & Milner-Gulland 2011). Ecological long term monitoring reduces uncertainty and thus forms the basis for managers' and stakeholders' decision-making (Bunnefeld et al. 2011) and lays the foundation for adaptive management (Kendall 2001, Nichols & Williams 2006). As many protected areas already operate with limited funds (Balmford et al. 2004), resources for ecological monitoring are often limited. This makes prioritization and cost efficiency of monitoring activities particularly important (Caughlan & Oakley 2001).

Despite financial limitations, monitoring protocols in most protected areas are typically selected for accuracy and precision (effectiveness) with little attention given to cost effectiveness (efficiency) (Gaidet-Drapier et al. 2006; for an exception see Hockley et al. 2005). Thus, selecting monitoring methods that maximize ecological effectiveness and economic efficiency is a key question for applied ecology, management and conservation (Elphic 2008). Few case studies have assessed the effectiveness of different monitoring protocols based on site specific pilot studies. For example, in the tall flood plains of India, total counts were more accurate for barasingha, *Cervus duvauceli*, whereas distance sampling (using programme DISTANCE) provided better estimates for species such as wild boar, *Sus scrofa*, in the same habitat type (Wegge & Storaas 2009). Hassel-Finnigan et al. (2008) showed that animal-to-observer distance was more accurate than using the DISTANCE approach for white-handed gibbons *Hylobates lar carpenteri* and Phayre's leaf monkeys *Trachypithecus phayrei crepusculus* in Thailand. Marshall et al. (2008) review different line-transect methods, including DISTANCE and strip (truncated distance) transects, to estimate primate density and suggest a decision tree based on feasibility of correct estimates of distances and modelling expertise. However, even fewer studies have compared the cost efficiency of different sampling methods.

The mountain nyala *Tragelaphus buxtoni* is a large ungulate endemic to southern Ethiopia, principally the Bale Mountains and is listed as Endangered in the IUCN Red List (IUCN 2011). Between 95% (Evangelista 2006) and 30% (Atickem et al. 2011) of the population, depending on the source of the data, occurs in the Bale Mountains National Park (BMNP). Much of the mountain nyala's habitat has become highly fragmented by human settlement and agriculture. This species is a major tourist attraction for the park, providing alternative livelihood opportunities for park-associated communities. It is also a trophy hunting species. Hunting permit fees for this species are amongst the highest in the country fetching up to $15,000 per trophy with 24 permits being sold in 2009/2010 (pers. comm. Ethiopian Wildlife and Conservation Authority). Thus this species has the potential to provide significant economic benefits to local communities. For these reasons, developing a standard long term monitoring protocol for mountain nyala was identified as a major priority by stakeholders for the BMNP's ecological monitoring program (Kinahan 2010).

Historically total counts were used to assess mountain nyala populations in the BMNP. Total counts assume all individuals are observed, but this assumption is difficult to test for mountain nyala because of dense vegetation in the area and total counts do not provide confidence limits making the precision of estimates difficult to assess. Furthermore, distance sampling has become an increasingly popular method for population surveys (Plumptre 2000; Focardi et al. 2002; Karanth et al. 2004; Wegge & Storaas 2009). Given BMNP's limited resources, a robust, cost efficient method is required if long term sustainability is to be ensured.

Hence, in this paper we compare the effectiveness and cost efficiency of total counts and line transect distance sampling (Buckland et al. 2001) as long term monitoring methods for assessing mountain nyala population trends in the BMNP.

MATERIALS AND METHODS

Study Area

The Bale Mountains National Park (2,200 km^2) is located in the south-eastern highlands of Ethiopia 39°28' to 39°57' E and 6°29' to 7°10' N. The park has a large altitudinal range (1500 to 4377 m asl), including the largest expanse of afro-alpine habitat in Africa and the second largest moist tropical forest in Ethiopia. The Gaysay valley (34.4 km^2) covering 1.6% of the parks area, is located in the northern part of the park at 3200-3500 m above sea level (Figure 1). This area is dominated by open and swampy grassland on chromic luvisol and eutric cambisol soil and surrounded by *Juniper spp*., *Hagenia spp.* and *Erica spp.* Woodland (Oromia Agriculture and Rural Development Bureau 2007). Climate in this area can be divided into the dry season (November- February), the early rains (March-June) and the rainy season (July-October). Average annual rainfall is between 900-1300 mm, with average minimum and maximum temperatures of 10^{o}C and 12.5^{o}C (Oromia Agriculture and Rural Development Bureau OARDB 2007). Seventy-seven percent of the park's mountain nyala population occur in the Gaysay valley with the remaining 22% at the nearby park Headquarters (see figure 1) and <1% in other areas of the park (BMNP Ecological Monitoring Programme 2010 Annual Report).

Sampling techniques

Total Counts

We placed a total of six zig-zag transects across 10 clearly defined vegetation blocks in the Gaysay valley (Figures 2a and b). Zig-zags are preferred to parallel lines in cases where resources are limited or counting is expensive (e.g. shipboard and aerial transects; Waltert et al. 2009, Strindberg & Buckland 2004). Zig-zag transects allowed for shorter distances in between transects while covering the desired area to count all individuals, compared to parallel straight line transects increasing travel distances between transects. The vegetation blocks were chosen by considering the natural changes in vegetation type, for example from shrubland to woodland and where natural features such as rivers occurred. Transects were between 21 km and 43 km in length, with a total transect length of 198 km traversing the entire Gaysay area. Where transects were longer than 30 km (4 of 6), we divided the transect in half and two different teams walked half the transect each. We located zig-zag points 500 m apart in open grasslands and shrubland habitat transects (due to the fact that mountain nyala, with a shoulder height of 120-135 cm, are taller than grasses and shrubs), whereas we sampled forested habitats more intensively with zig-zag points placed 250 m apart, since we assumed detection to be more difficult and at shorter distances than for more open habitats. A key assumption of total counts is that all individuals in the covered area are detected. We will compare our results with this assumption in the discussion.

Teams comprising two individuals, a core nyala monitoring team member and a local community member walked each transect or half transect. The core nyala monitoring team had been trained in GPS use and data recording and participated in annual censuses (n=4). Community members (n=16) acted as spotters and more importantly to promote and encourage community participation in park conservation activities. Members of different Gaysay valley communities were selected each year in order to try and share benefits more equitably. In order to avoid double counting, teams were instructed to record individuals only within the designated strata or stratum where their transect lay. All teams commenced each transect at the same time (10.00 in the morning) and all transects were completed in one day. Thus, the entire area was covered at the same time. The number of people involved is presented in Table 1.

We repeated the same sampling procedure three times in order to examine the precision of the total counts. We carried out the counts on three consecutive days in 2007, to minimize variation due to immigration and emigration of individuals and seasonal movements in and out of the Gaysay valley. Due to limited financial and personnel resources, total counts were replicated only once in 2008 and 2010, and were not conducted in 2009.

Distance Sampling

We placed 25 transects in the Gaysay valley across the same geographic area as total counts, following a systematic parallel grid with transects at a 10° bearing north and south of the road that traverses the area (Figure 3). We followed the approach of a systematic design using parallel lines with a random first start instead of zig-zag lines as outlined by Buckland et al. (2001). Transects were at least 500 m apart and avoided river crossings. Due to a steep ridge on the northern edge of the Erica habitat zone, which prevents transects from the woodland zone extending into this zone, we placed Erica habitat transects in an east-west (90° bearing) direction. The 25 transects ranged from 0.65 to 3.5 km in length and totalled 44.1 km.

Two teams of trained mountain nyala monitors walked two different transects per day resulting in a six day period required to cover all transects. Transects for each team occurred on different sides of the roads and each team walked a different transect at least 1 km apart in the morning and afternoon. Otherwise, the order of transects walked were randomly selected during protocol development, but this order remained the same in each year of sampling.

Data were collected using standard line transect distance sampling methods (Buckland et al. 2001) where the distance (meters) and angle of each sighting of nyala or group of nyalas (and the total number of individuals) to the transect line were recorded using a manual range finder and a compass. Each sampling procedure was repeated three times in 2007 and 2010, but only once in 2008 and 2009 as a result of limited resources. Thus, each of the transects were walked once over a six day period (day 1-6; replicate 1), then repeated again in the same order over the next consecutive six days (day 7-12, replicate 2) and then repeated a third time (day 13-18, replicate 3).

We used conventional distance sampling (CDS) with the DISTANCE Software VERSION 6 for clustered animals to analyse our data (Thomas et al. 2010). To estimate the probability of detection the uniform, half-normal and hazard rate functions with polynomial or cosine series expansion were fitted. The model with the lowest Akaike Information Criterion (AIC) was selected as best model. Density and encounter rate were estimated from the best model. Detection functions were modelled using exact distances and to reduce observer bias the same observers were used throughout the entire protocol in each year. For repeated sampling, the sampling effort was multiplied by the number of times the transects were replicated in each season. In the discussion, we compare our results against the main assumption of DISTANCE sampling that detection is perfect on the line. We carried out both DISTANCE and total counts in September, late wet season, when nyala are most likely to spend their days in the open areas rather than woodlands, hence maximizing visibility and to avoid any seasonal population or detectability differences between the two methods.

Measuring Effectiveness

Surveys were considered effective if they could meet the long term mountain nyala monitoring objective, defined as "to obtain repeatable mountain nyala population counts in order to detect long term trends in population size" (Kinahan and Randall 2010).

Two indicators were identified as measures of effectiveness:

i) *Precision* – i.e. Repeatability of the survey, where the same or similar population estimates are obtained with repeat sampling under similar conditions. The coefficient of variation in percent (%CV) between repeated surveys within the same season was used to assess precision. A lower %CV implied less variation between the estimates and thus a greater confidence in the repeatability of the survey design. The %CV between survey estimates was calculated by the following equation

$$\%CV = \frac{s}{x} \times 100 \qquad \text{Eqn 1}$$

Where s is the standard deviation of the population estimates and x the mean value across the estimates

ii) Power to detect change- the likelihood to detect a given percentage change in population size. This was measured using the resolution of a density estimate (R) which is defined as the percentage change that will be detected between two independent surveys (Plumptre 2000). Thus, given a resolution of a density estimate of 0.2 (using the CV of the surveys estimate), the population would have to increase or decrease by 20% between two independent surveys for the changes to be detectable. Typically, 80% power to detect change is used (Plumptre 2000). To determine 80% power to detect change the resolution (R) is calculated by

$$R = 3.96SE\left(\frac{D_1}{D_2}\right) = 3.96\left(\frac{CV}{100}\right) \qquad \text{Eqn 2}$$

where CV is the coefficient of variation between the samples, SE is the standard error and D_1 and D_2 are the density estimates at time t and t_{+1} (Plumptre 2000).

The population estimates and the number of sightings obtained through DISTANCE and total counts were compared with a Mann-Whitney U because the data were not normally distributed and the sample size differed for the two methods.

Measuring cost efficiency

The total costs (US$) required for both methods considering manpower and consumable costs are provided (Table 1). Given the number of individual sightings required for DISTANCE, which is around one hundred as a general guideline (Buckland et al. 2001), it required each of the transects to be walked three times (Table 2); we used this as our basis for resource calculation for distance sampling. Standard field equipment costs such a GPS, range finders and compass were not considered here as they were required for other monitoring protocols and so were regarded as standard park equipment.

RESULTS

Effectiveness

Table 2 shows the results of both survey methods in each of the years sampled. Although total counts continuously provided lower population estimates compared to DISTANCE, all total counts fell within the confidence intervals provided by the pooled DISTANCE analysis and no significant difference in the population estimates were observed (Mann-Whitney $U=3$, $P>0.1$). Total counts showed an average annual population increase of 20% compared to 17% from DISTANCE.

Generally, DISTANCE provided significantly lower number of sightings per survey compared to total counts (Mann-Whitney $U=4.5$, $P<0.03$). On average, 39 (range: 31-56) mountain nyala groups were sighted using one replicate of the distance sampling transects. This is well below the recommended minimum number of sightings (100) required for clustered animals to be able to obtain reliable density estimates in DISTANCE analysis (Buckland et al. 2001). Further analysis showed that walking each of the transects three times per survey period resulted in near to or more than the recommended 100 sightings, N=99 in 2007 and N= 155 in 2010 and thus a more acceptable %CV ($\leq$ 20%) of population estimates (Table 2).

Figure 4 shows the detection functions from DISTANCE in each year, generally the models show the detection probability of seeing an animal on the line is 1, with a decline in detection probability the further the animal is from the transect. The figure shows that on average the probability of detecting an animal at $\leq$ 50 m is 100%, at $\leq$ 100 m, 50% and at distances greater than 200 m there is less than 10% detection probability.

The Gaysay valley comprises both open and closed habitat types. Due to the small number of sightings possible for each type we were unable to obtain density estimates by stratifying habitats. However, the detection functions for both open and closed habitat types shows that the detection probability is less than 1 on or close to the line in closed habitats and, compared to open habitats, has lower probability of detecting species at a given distance from the line (Figure 5). Thus, while our assumptions for total counts were true in that the detection probability will be lower in closed compared to open habitats, the detection functions suggest that our 250 m and 500 m distance between zig-zags overestimated the distance we could actually locate mountain nyala reliably. In closed habitats the average distance between the two zig-zag transects was 125 m (distance ranges between 0 m and 250 m, figure 2) , which gives an average sighting distance of 62.5 m at any given point on an individual transect (i.e. half the area between two transects). Similarly for open habitats the average sighting distance expected is 125 m. It can be seen from the detection functions that at these distances, after 50 m, there is approximately a 20% probability of detecting animals. This implies therefore that the total count survey is missing some individuals at distances over 50 m from the transect line and therefore is likely to provide an underestimate of true population size.

Total counts had a higher repeatability with 2% CV between the three replicates in 2007, whereas DISTANCE sampling showed a wide variation between the three replicates, 56% and 18% in 2007 and 2010 respectively. Total counts (2% CV) result in R=0.07 or an 80% probability of being able to detect a 7% change in population size between two independent samples. DISTANCE generated a 56% CV (R=2.2) in 2007 and 18% CV (R=0.71) in 2010 and hence requires a large change in population between surveys before it can be detected (22% and 71%).

Efficiency

Table 2 shows that for effort, distance sampling is the most efficient survey method, with greater encounter rates per km transect walked (0.90 ± 0.23 km^{-1}) compared to total counts (0.36 ± 0.13 km^{-1}). However, the costs for walking a km of transect is almost 16 times cheaper for total counts than distance sampling (Table 1). The main cost increase was due to the fact that sampling effort needed to be increased from one day for the total counts to six days repeated three times (18 days) for distance sampling. The untrained field assistants required for total counts were not needed for the distance method because all field workers needed to be trained. However, this resulted only in small savings for distance sampling compared to total counts (Table 1). The higher number of days out in the field for distance sampling increased the costs of the salary and the field allowance for para-ecologists, the food allowance, batteries, and fuel and added costs for kerosene and a camp attendant for the period of the field work. Thus, although distance sampling may be more than twice as efficient in terms of encounter rate, the cost is 16 times more than for total counts.

DISCUSSION

We show that considering effectiveness as well as cost efficiency, a factor not often explicitly incorporated into monitoring protocol choice, can result in significant cost saving in the long term. Although distance sampling is typically considered a preferable survey method (Buckland et al. 2001, Karanth et al. 2004), in some circumstances, such as in the case of monitoring the mountain nyala population in Gaysay, it may not be the most effective or cost efficient method to meet monitoring objectives.

Population Size

Results show the number of mountain nyala occurring in Gaysay valley increased between 2007 and 2010 from 774 to 1280 individuals using total counts and 950 to 1463 individuals using DISTANCE. However, 95% confidence intervals overlap for the results estimated by the DISTANCE method (Table 2) indicating that given the variation the increase in the population size is not strongly supported due to large variation in the data. Atickem et al. (2011) used faecal samples to estimate the population size of the mountain nyala to be 776 individuals (95% CI: 528-1290) in the Gaysay valley, which are only two individuals more than our results obtained from total counts. The three replicates from our total counts in 2007 yielded a small variation (2% CV) between counts. DISTANCE detection functions suggest our total counts are not detecting all individuals on the line as previously assumed, and that despite our efforts to mitigate the variability in sighting distances (by reducing the distance between zig-zags in more dense vegetation) our total counts likely still underestimated the population size. This is in line with a review by Gaillard et al. (2003) showing that total counts generally underestimate population size by 22-62% and in habitats where visibility is very limited, e.g. dense forests (Houssin et al., 1994; Cano et al., 2009). However, total counts provided values that fell within the confidence limits of the pooled DISTANCE analysis and both methods yielded similar cluster size values.

Precision and Power to Detect Change

For conservation managers, population trends, rather than absolute levels, are an important determinant for management evaluation and intervention. In this study, total counts of mountain nyala were both more precise and exhibited greater power to detect change than distance sampling. DISTANCE estimates had overlapping confidence limits over the years, lower precision between independent surveys (CV 56% and 17%) compared to total counts (CV 2%) and lower power to detect changes in population size than total counts. This suggests that total counts provide better information on population trends and thus are more reliable for decisions on management interventions. Similar to Wegge & Storaas (2009), we found the DISTANCE confidence limits are linked to the number of sightings, with low sighting numbers resulting in wide confidence intervals, and confidence intervals becoming narrower as the number of sightings increased (Table 2). Thus, in DISTANCE it is harder to detect declining trends in small populations, since confidence intervals increase as population size decreases, and so confidence intervals are more likely to overlap.

Cost efficiency

This study showed that cost efficiency was much higher for total counts with 20 times lower cost per survey compared to distance sampling. Although we sustained a high initial investment to compare these monitoring methods, $1,169 per annum, or $11,696 over the next ten years can now be saved by using the more cost-efficient method. This is a significant saving representing 5% of the current annual funds available to the park for their ecological monitoring program (Kinahan 2011).

Total Counts versus DISTANCE

Many technical monitoring schemes such as distance sampling require considerable funds and scientific expertise and produce results which are generally not as quick and easy to interpret or act upon as simpler methods such as total counts (Danielsen et al. 2010). In this study, we have not included the scientific expertise and the number of hours that were used by experienced quantitative scientists to analyse DISTANCE sampling data because it is hard to estimate the cost of having a quantitative scientist available for a single study. This means that we have calculated only the minimum costs in this study; the real cost of distance sampling might be considerably higher. For the mountain nyala in BMNP, total counts are transparent to the local people, provide a greater economic benefit to the communities through temporary employment and involve more community members in park activities than DISTANCE sampling. As a result, local communities can relate directly to field observations and results are immediately transparent, whereas DISTANCE involves significant time for data entry and expertise in its analysis and interpretation. Total counts are therefore more likely to be accepted in the local community, generate community support and improve protected area-community relations (Danielsen et al. 2005). There is increasing evidence that stakeholder involvement and acceptance is crucial for conservation success (Waylen et al. 2010, Bunnefeld et al. 2011) which can be further promoted by including local people in monitoring such as total counts.

Our results show that total counts were more effective (in meeting monitoring objectives) and cost-efficient than distance sampling in the Gaysay valley of the BMNP. However, it should be noted that the best monitoring method depends among other factors on the scale, the habitat, the species biology and the budget of the case study (Singh & Milner-Gulland 2011). Previous studies have shown that while total counts may be useful for rare or elusive species (Wegge & Storaas 2009), or species not easily detected on the line (Rodda & Campbell 2002; Smolensky & Fitgerald 2010), distance sampling may be more preferred for species that are large and easily detected (Focardi et al. 2005; Durrant et al. 2011), where individuals are numerous (Wegge &

Storaas 2009), where there is dense vegetation (Herrero et al. 2011) or where large areas not easily covered by total counts occur. The suitability of total counts is perhaps not surprising in the Gaysay valley, given its small area (34 km^2), low coverage of dense forest, and the small number of mountain nyala. However, a large disadvantage is the lack of confidence limits surrounding the total count estimates and the uncertainty as to how detection levels change with changes in population size and habitat types. Hence, given the cost savings of total counts, where possible total counts should be repeated more often than once a year and resources permitting, distance sampling carried out every 3-5 years in order to attain confidence limits around the estimates and to allow for differences in detectibility due to changing population size and habitat.

Conclusion

Total counts are more effective and cost-efficient in achieving the monitoring objective of repeatable population counts in order to detect long term trends in population size for mountain nyala in Gaysay in the BMNP. We show that the power to detect a change in population size was high with an 80% probability of being able to detect a 7% change in the population. Our study demonstrated that the initial high financial investment in comparing both the effectiveness and cost efficiency of two common population survey methods revealed important insights for the future monitoring scheme of mountain nyala, and will result in dramatic cost savings over the long term. Furthermore, total counts allow for increased local people involvement and higher transparency of the data-to-results process among stakeholders and managers. Local community and stakeholder involvement is of key importance for conservation success and is more likely to be achieved through total counts than distance sampling. In general, initial investment into a pilot study comparing methods is worth the cost in the long term and is a practice that should be adopted for monitoring programs in other protected areas. We highlight the importance of including economic costs when comparing monitoring methods in pilot studies so that appropriate recommendations can be provided for monitoring plans that are economically feasible in the long term.

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Figure Legends

Figure 1. Map showing the Bale Mountains National Park (BMNP) location within Ethiopia and the Gaysay valley area and Headquaters (HQs) within the BMNP.

Figure 2 a & b. Maps showing the ten vegetation blocks identified for the Gaysay valley (a) (A. Atikem pers comm.) and the six transects that traversed the area across these vegetation blocks (b) that were used to carry out total counts. Each transect was walked once on the same day for total counts, with this protocol being repeated three times in the same season for some years.

Figure 3. Map showing the location of the 25 transects across the Gaysay valley for distance sampling. Each of the 25 transects was walked once over a six day period, with this protocol being repeated three times in the same season in 2007 and 2010.

Figure 4: Detection functions for 2007 (a), 2008 (b), 2009 (c) and 2010 (d) all years selected the Hazard rate model as best fit.

Figure 5: Detection functions in closed and open habitats for mountain nyala in the Gaysay valley

Table 1: A breakdown of the total field resources required to implement both methods effectively and their costs in US dollars.

		Total Counts (L=198)			Distance (L=132.3)		
Resource	**Unit cost ($)**	**No. of units**	**No. of days**	**Total cost ($)**	**No. of units**	**No. of days**	**Total cost ($)**
Para ecologists salary	2.70	4	1	10.80	4	18	194.40
Para ecologists field allowance	2.50	4	1	10.00	4	18	180.00
Field assistants	3.75	16	1	60.00	0	18	0.00
Camp attendant	3.50	0	1	0.00	1	18	63.00
Food allowance	1.50	20	1	30.00	5	18	135.00
Batteries (pack of 4)	4.00	10	1	40.00	8	18	576.00
Kerosene (per litre)	1.00	0	1	0.00	18	18	324.00
Fuel (one way (7km))	4.00	2	1	8.00	4	18	288.00
Total costs ($)				**158.80**			**1760.4**
Cost per km				**0.80**			**13.32**

Table 2: A comparison of the number of individuals seen in total counts (Tot(N)), the total number of individuals seen in distance sampling (Ds(N)) and the population estimates obtained from DISTANCE analysis (Ds(estimated n)). %CV is the coefficient of variation in percent and cluster size is the average number of individuals occurring in one group or per sighting. The number of groups sighted is given for total (Tot) and distance (Ds).

		Population size				No. of group sightings		Encounter rate (per km)		Cluster size	
Year	Replicate	Tot (N)	Ds (N)	Ds (estimated n, 95% confidence interval)	Ds %CV	Tot	Ds	Tot	Ds	Tot	Ds
2007	1	774	614	760 (399-1447)	33	78	33	0.39	0.75	7.5	7.2
	2	740	309	2560 (1172-5591)	25	60	31	0.30	0.70	7.3	8.2
	3	759	510	1838 (1006-3360)	29	54	35	0.27	0.79	7.8	8.1
	Pooled		1433	950 (640-1409)	20		99		0.75	7.5	
2008	1	848	1011	1131 (642-1994)	29	40	33	0.20	0.75	6.1	6
2009	1		500	1052 (564-1961)	32		31		0.70	7.0	
2010	1	1280	421	1208 (737-1664)	20	120	56	0.61	1.27	5.3	5.6
	2		333	1645 (953-2839)	28		42		0.95	6.8	
	3		320	1697 (1043-2760)	25		54		1.22	5.9	
	Pooled		1074	1463 (1087-1968)	15		152		1.15	5.9	

Figure 1:

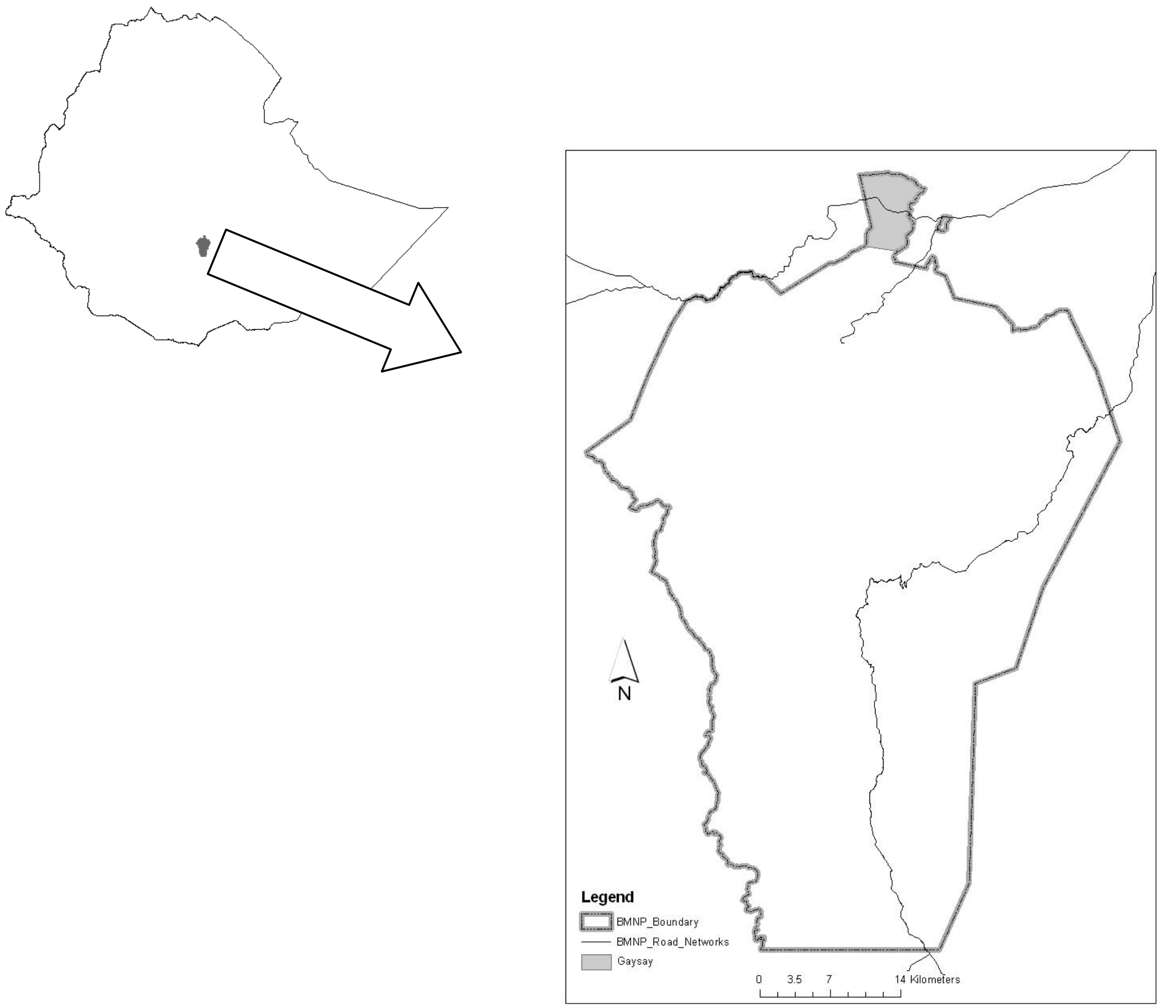

N
Legend
BMNP_Boundary
BMNP_Road_Networks
Gaysay
0
3.5
7
14 Kilometers

Figure 2a & b.

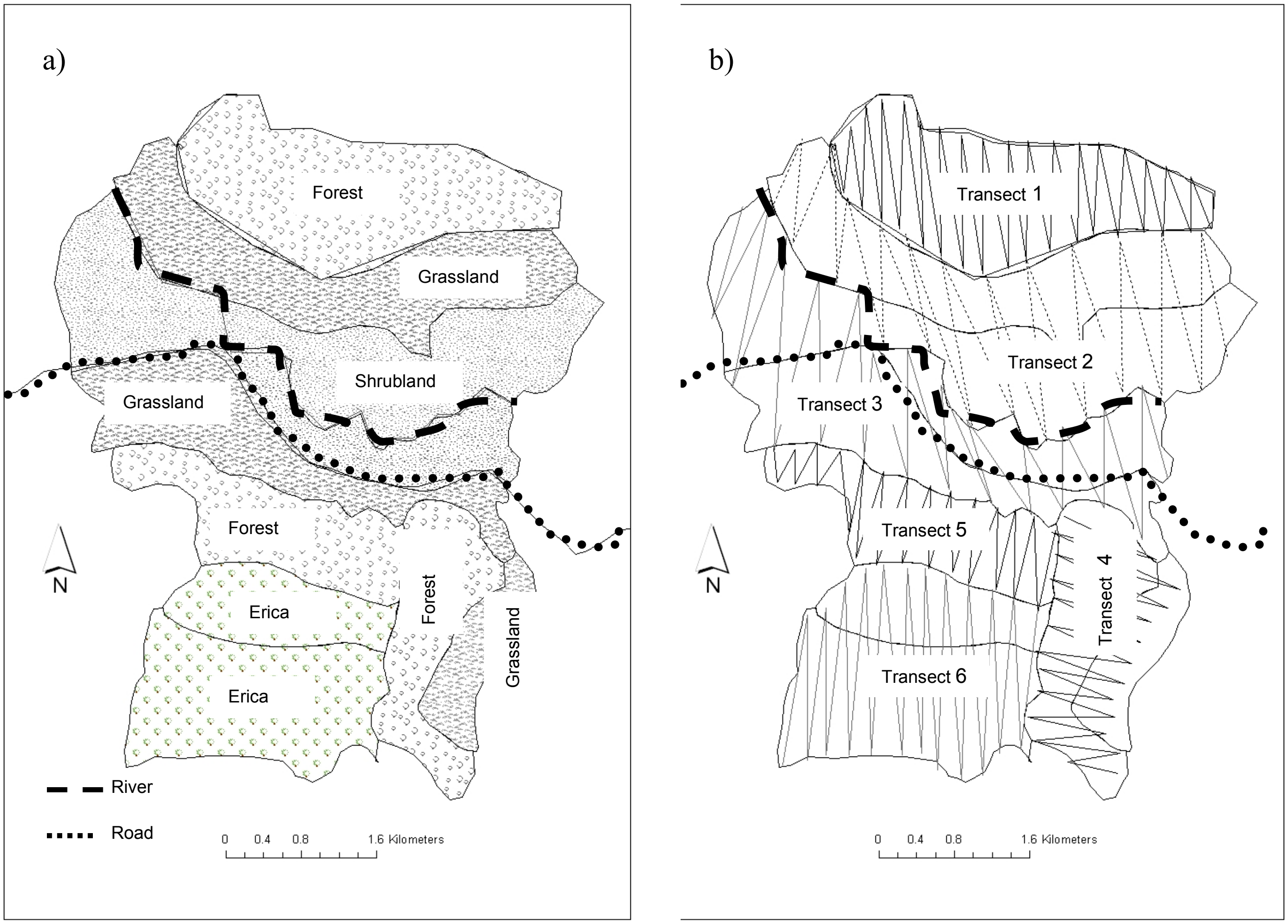
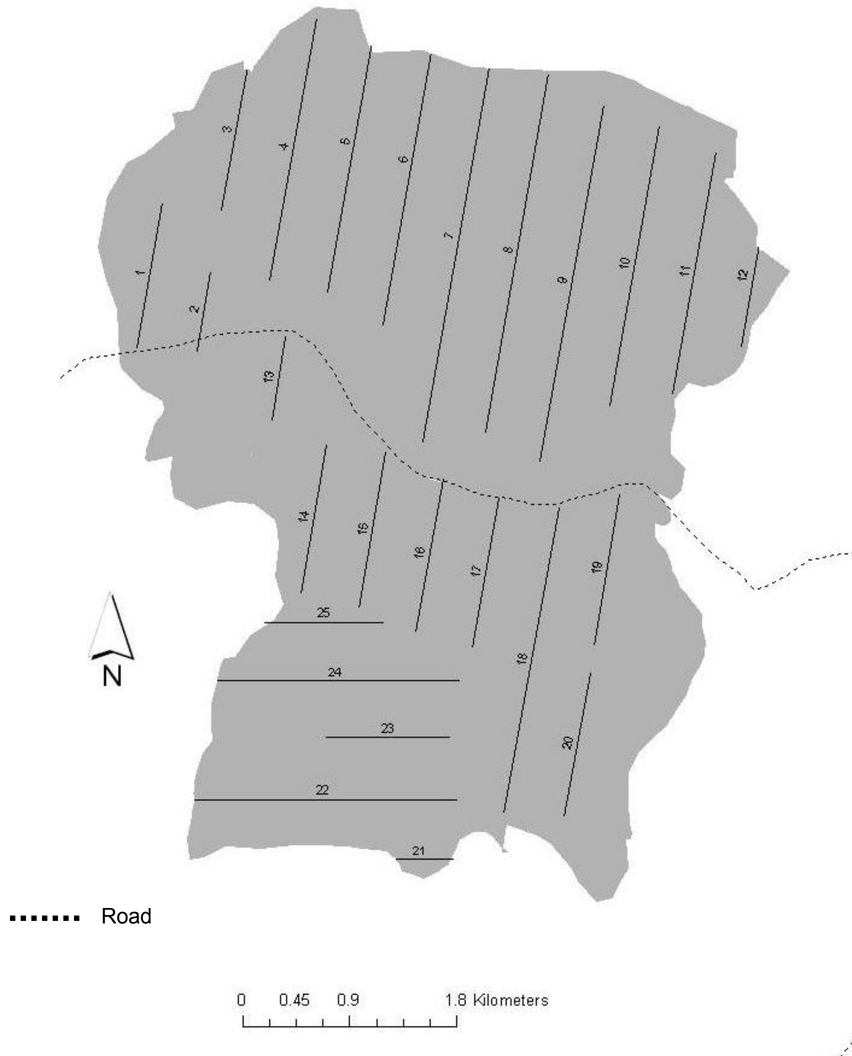
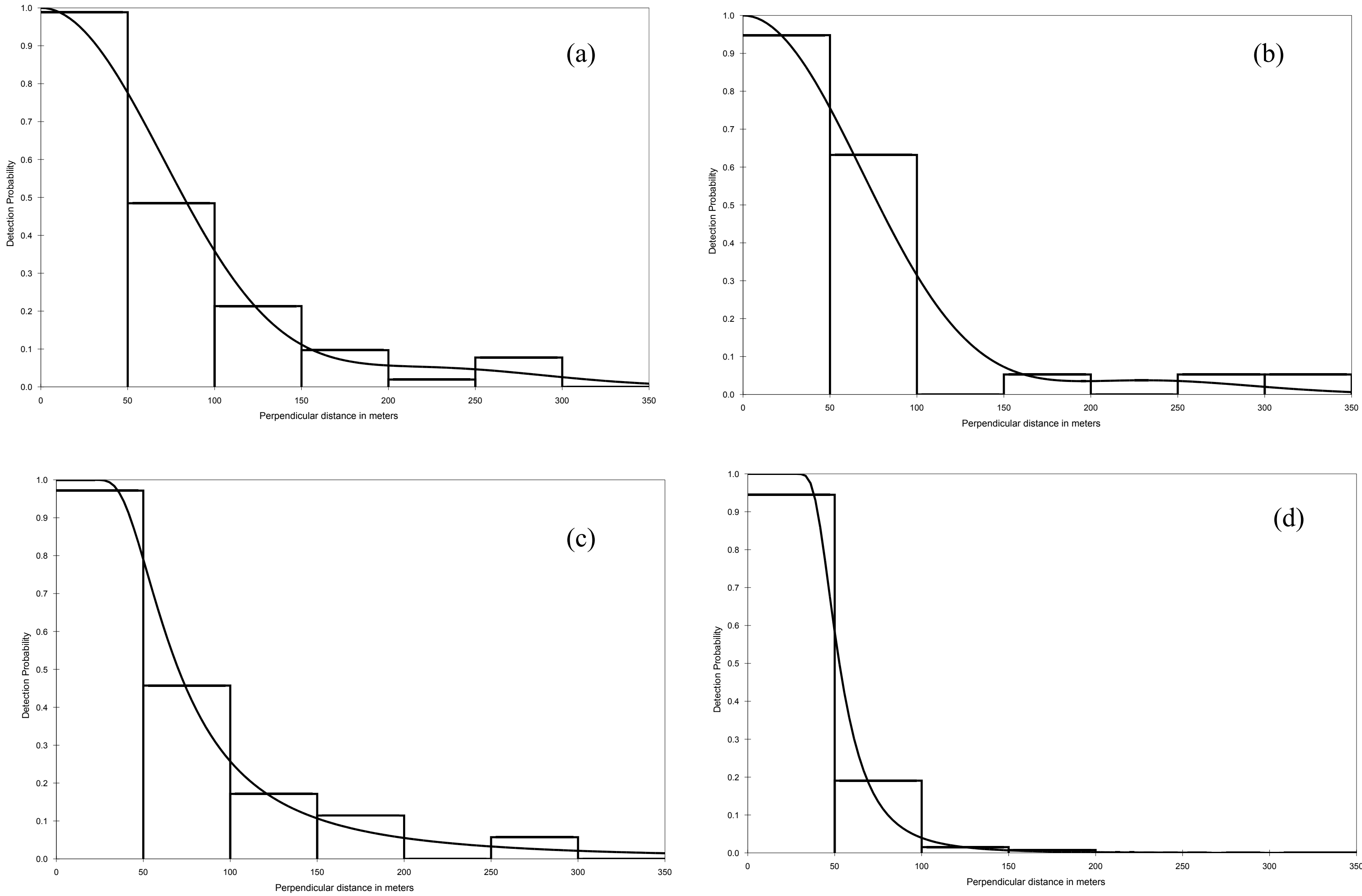

a)
Forest
Grassland
Shrubland
Grassland
Forest
Erica
Forest
Grassland
Erica
N
River
Road
0 0.4 0.8 1.6 Kilometers
b)
Transect 1
Transect 2
Transect 3
Transect 5
Transect 4
Transect 6
N
0 0.4 0.8 1.6 Kilometers

Figure 3.



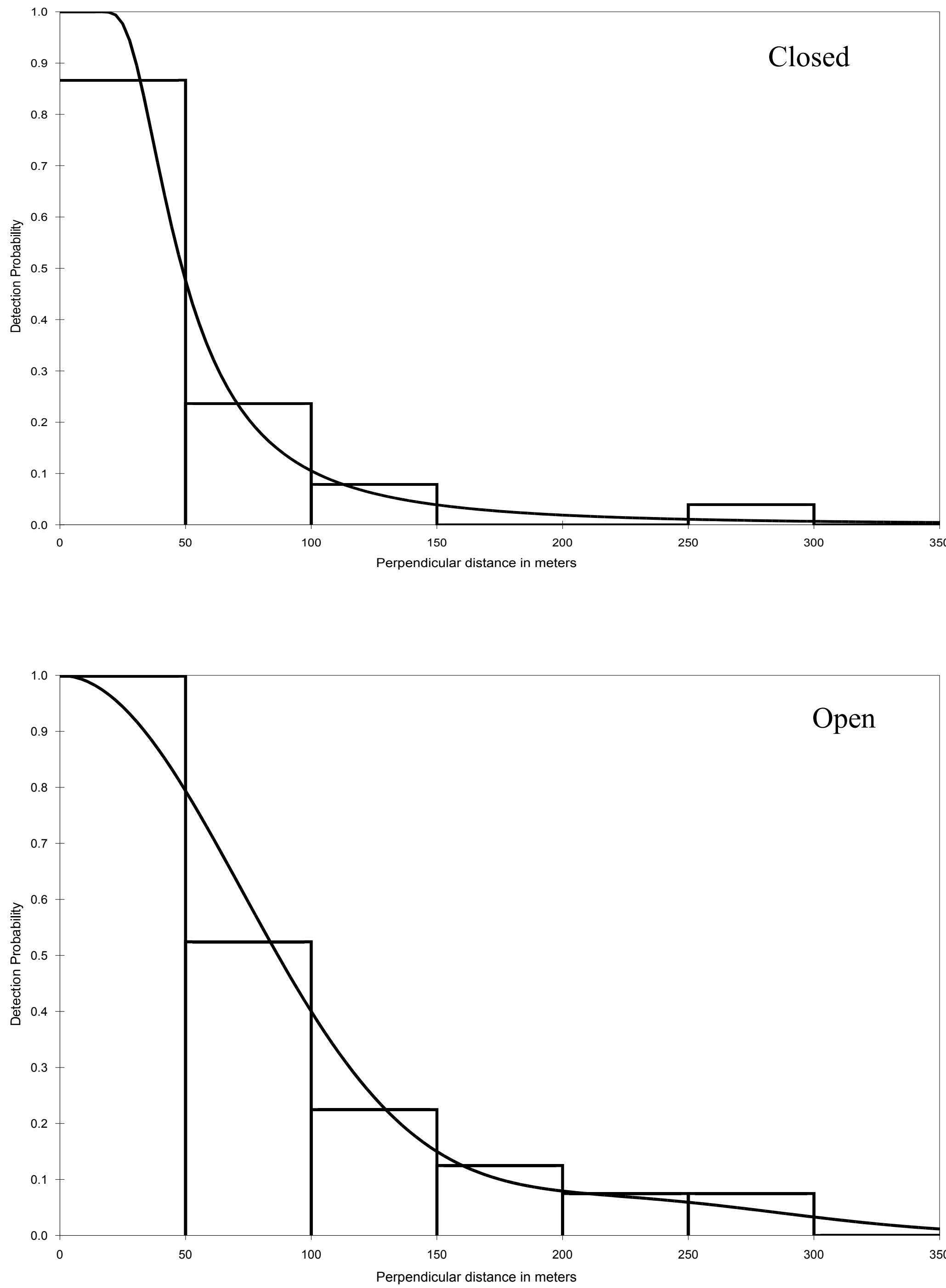
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
N
Road
0 0.45 0.9 1.8 Kilometers

Figure 4



(a)
(b)
(c)
(d)
Detection Probability
Perpendicular distance in meters
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
50
100
150
200
250
300
350

Figure 5:


Closed
Detection Probability
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
50
100
150
200
250
300
350
Perpendicular distance in meters
Open
Detection Probability
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
50
100
150
200
250
300
350
Perpendicular distance in meters