Monitoring of key species in the Seima Protected Forest

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Summary

Statistically rigorous surveys of primate and ungulate populations have been conducted in the Seima Protection Forest on an annual or biennial basis since 2005, and are required under Activity 1.2.2 of the SFB Year 2 Work plan. These species are important conservation targets in their own right and also act as indicators of broader ecosystem health, since they face similar threats to many other, harder to survey species.

Sampling effort was greatly increased in 2008 and spatial coverage was expanded in 2010 to enclose the entire core area of SPF. These adjustments resulted in the first statistically robust estimates of ungulate densities for the site and also improved estimator precision and accuracy in measurement of primate numbers. The high conservation value of the site for black-shanked douc, yellow-cheeked crested gibbon, Germain's silvered langur, and green peafowl has been reinforced by these results. The current population estimates suggest that the Seima Protection Forest is one of the most important remaining strongholds in Indochina for these species and underscores the necessity of increased protection if these valuable populations are to be retained. Densities of all ungulate species are depressed compared to natural densities in habitat of this kind, and wild cattle species (banteng and gaur) appear to be in a critical state within SPF. There is considerable potential for recovery for all ungulate species.

Estimates from 2005-2008 are available for Red muntjac, Yellow-cheeked crested gibbon, and Black-shanked douc only. Estimates for wild cattle indicate that these species are undergoing a decline. Wild pigs have appeared to decline in recent years, followed by stabilisation between 2011 and 2013. Wild pig is a species for which population fluctuations are a natural occurrence, and it is unknown to what extent anthropogenic or environmental factors may have contributed to this apparent decline. For wild cattle there is evidence from other sources of continuing heavy hunting of these species, and any evidence which points to a population decline must give serious cause for concern, given their already low numbers. Numbers of red muntjac fluctuate between years, but on the whole appear to be stable, which implies this species is relatively tolerant of ongoing hunting pressure.

Black-shanked doucs and Yellow-cheeked crested gibbons appear to have stable individual and group densitites, which it to be expected as the levels of hunting pressure on those species is considered low. The results from 2013 have allowed estimates for the remaining primate species to be refined, and have confirmed significant populations of both Northern pig-tailed macaque and Germain's silvered langur, with the latter potentially being of global significance. Estimates from 2013 have revealed potentially catastrophic declines within SPF in long-tailed and stump-tailed macaques, which is particularly worrying for the latter as it is listed as Vulnerable with globally decreasing populations.

Additional temporal data are required before population trends can be reliably inferred for all target species in Seima, but if effort and data quality can be maintained at the levels now attained it is clear that each successive survey will add greatly to our understanding of this key indicator of project success. These results emphasise the importance of undertaking biological monitoring at biologically meaningful temporal and spatial scales, and also highlight the need for a substantial investment of both time and resources over several years in the development of a functional monitoring regime.

Introduction

Biological monitoring is a vital component of any conservation project if the effects of management are to be assessed (Green et al. 2005). There is increasing recognition that conservationists need to provide empirical evidence to back up claims of conservation success (Sutherland et al. 2004; Ferraro & Pattanayak 2006) but in many projects in developing countries even rudimentary baseline information is not available for species of conservation concern (Milner-Gulland & Bennett 2003; Sodhi et al. 2009). This makes it difficult to evaluate the biological impacts of conservation efforts (Robinson 2006; Steinmetz et al. 2010).

Data collection is often impeded by demanding field conditions, severe resource constraints and limited local capacity (Danielsen et al. 2003). Nevertheless, it is still possible to employ rigorous methods to assess the status of target populations, even those which have been subject to dramatic declines and persist at extremely low densities (Nichols & Williams 2006).

This has been demonstrated in the case of the Seima Protection Forest (SPF) where biological monitoring activities have been underway since 2002. Since 2005 these activities have focused primarily on the estimation of primate and ungulate densities within the core area of the site. In 2010 green peafowl was also added as a target species. The SPF populations of a number of these species, such as black-shanked douc, yellow-cheeked crested gibbon, silver-langur, banteng and green peafowl, are of particular conservation significance in their own right (see Table 1). In addition, ungulate, primate and peafowl species can be used as indicators of general ecosystem health. All are vulnerable to hunting, habitat loss and other anthropogenic pressures and all of these species are ostensibly suitable for monitoring using rigorous population estimation methods. These target species are part of a wider suite of species selected to represent the site in its ecological entirety and it is anticipated that by developing strategies to conserve these few species, all the biodiversity values of the site will be conserved (WCS/FA 2010).

Density estimation is achieved through the use of distance sampling methods (Buckland et al. 2001), implemented in SPF in the form of line transect surveys. The Distance software package was used for the design of the survey and the analysis of the data (Thomas et al. 2010). Line transect distance sampling has been used widely in tropical forests in South Asia and Africa to estimate absolute densities of ungulates and primates (Karanth & Nichols 2002; Buckland et al. 2010a). A number of alternative survey techniques have also been utilised in SPF including camera-trap surveys (all species) and listening-post surveys (for yellow-cheeked crested gibbon and green peafowl). However, it was not possible in this context to generate absolute estimates using either of these methods and so listening-post surveys were discontinued after 2008 and camera-trapping was continued only in a low-intensity ad-hoc manner, rather than for the purposes of population estimation. Thus, the main focus of monitoring activities, and consequently of this report, rests upon line transects surveys. Species covered by the line transects and the significance of their populations in SPF are listed in Table 1.

A distance sampling approach facilitates the generation of absolute density and abundance estimates and, if implemented appropriately, can produce precise and accurate results. However, in order for this potentially powerful approach to be valid, a number of key theoretical assumptions must be met. In contexts where multiple biological and logistical constraints apply it can often be challenging to satisfy these theoretical requirements. As a consequence line transect surveys in SPF have necessitated a significant investment of time and resources, but ultimately this effort has been vindicated by the success of the surveys and the quality of the results yielded.

Table 1 Species surveyed on the line transects

English Name	Scientific Name	Status*	SPF importance
Primary target species			
Black-Shanked Douc	*Pygathrix nigripes*	EN	Global
Yellow-cheeked Crested Gibbon	*Nomascus gabriellae*	EN	Global
Banteng	*Bos javanicus*	EN	Global
Gaur	*Bos gaurus*	VU	Regional
Sambar	*Rusa unicolor*	VU	Possibly regional
Eld's Deer	*Rucervus eldii*	EN	Regional
Green Peafowl	*Pavo muticus*	EN	Global
Other species surveyed			
Northern Pig-Tailed Macaque	*Macaca leonina*	VU	National
Stump-Tailed Macaque	*Macaca arctoides*	VU	Possibly regional
Long-Tailed Macaque	*Macaca fascicularis*	lc	National
Germain's Silvered Langur	*Trachypithecus germaini*	EN	Possibly global
Red Muntjac	*Muntiacus muntiacus*	lc	-
Wild Pig	*Sus scrofa*	lc	-

* = Status from the 2013 IUCN Red List of Globally Threatened Species
En = Endangered VU = Vulnerable lc = Least Concern (i.e. not Globally Threatened)

Methodology

Distance Sampling

Distance sampling comprises a family of methods which are characterised by the measurement of distances between a fixed point or line and the location where an object is detected. This information is used to estimate the density and/or abundance of objects. Objects in this case are individual or groups of animals and detections are visual observations of these animals (animal sounds or signs are not recorded). Line transect sampling is the most widely used form of distance sampling for large-bodied mammals and involves the placement of a fixed set of survey routes, or line transects, across the survey area. The line transects are walked by observers who record all target species detected and take measurements to calculate the perpendicular distance of animals from the line. Distance sampling uses these measured perpendicular distances from the line to estimate the detection function; that is the proportion of animals present within each distance category that are detected. The detection function can effectively be used to estimate the area covered by the survey, which is combined with the encounter rate of animals on the transects to estimate the density of animals. For clustered animals (a group of animals) the density of individuals is a function of the cluster encounter rate, the detection function for clusters and the mean cluster size. Ideally, 60 to 80 observations of each target species or group of target species are required to accurately estimate the shape of the detection function. However, it is sometime possible to pool data over several years or to "borrow" detection functions from appropriate sources (e.g. similar species which occupy similar habitat) to use in analysis.

Survey Protocols

Using coordinates from the prescribed survey design, the start, end and middle points (corner points in 2010, 2011 & 2013) of each transect are marked and a line connecting each point along a given bearing is marked with paint. Marking with paint allows observers to focus on detecting and recording wildlife rather than on navigation. Vegetation along the transects is cut but only to such an extent that observers can walk quietly along them. If the transects are cut too wide they may become used as trails either by wildlife or people which in turn can affect survey results. Transects are cleared and re-marked each year, at least one month before the start of surveys.

A standard protocol for surveys is developed to ensure that all teams collect comparable information and that the method is implemented correctly. There are three key assumptions underlying distance sampling which must be incorporated into the protocol (Buckland et al. 2001). These assumptions are;

1. Animals on the line are detected with certainty, i.e. no animals on the line are missed by observers.
2. Animals are detected and their location recorded before they move, i.e. observers must see an animal before it sees them and flees.
3. Measurements are exact. Training and appropriate equipment must be used to ensure accuracy of distance measurements.

Well trained, experienced field teams are an integral part of successful distance sampling. Training takes place annually to maintain observer proficiency and data quality is monitored continually.

Transects are walked twice daily in the hours just after sunrise and those just preceding sunset, when animals are most active and easy to observe. Survey teams consist of two people only. For each animal (or animal group) encountered the following information is recorded: location (UTM co-ordinates), number of animals, distance between the animal or centre of a group of animals and the observers on the line (with a laser rangefinder), compass bearing to the animal or to the centre of a group of animals, and compass bearing of the transect line. The latter three pieces of information are required to calculate the perpendicular distance of the observed animal(s) from the line.

Sampling Design & Effort

Between 2005 and 2008 surveys took place on 14 transects 3-5 km in length located within a 1086 km² survey area (Table 2, Figure 1). This area represents the most important habitat for large-bodied mammals within the site, as identified in the 2002 preliminary surveys (Clements 2002). Transects were placed randomly, with stratification by broad forest type (evergreen forest, semi-evergreen forest, deciduous dipterocarp forest) and location (approximately southern, central and northern SPF). Each transect was walked twice in 2005 and 2006 resulting in approximately 113 km of survey effort. In 2007 each transect was surveyed three times giving 170 km of effort. This level of sampling effort resulted in a sufficient number of observations to produce annual density estimates for black-shanked doucs but for other target species encounter rates were extremely low and variable, precluding consistent population estimation at a species- and year- specific level.

Table 2 Survey effort over time

Year	2005	2006	2007	2008	2010	2011	2013
No. Transects	14	14	14	14	40	40	40
Survey Area	1068	1068	1068	1068	1807	1807	1807
Effort (km)	113	113	170	1359	1600	1476	1264

Despite the low number of detections there were several reasons to continue with annual line transect surveys. Firstly; distance sampling can accommodate the pooling of data across multiple years and, when sufficient observations are obtained cumulatively, an average detection function can be derived. This detection function can subsequently be used to produce estimates from a smaller number of observations. Such an approach is limited, however, in that it assumes that detectability (i.e. the probability than an observer will see a given animal when it is present) does not change over time. In reality, detectability can be subject to multiple sources of temporal variation, for example due to changes in species behaviour, in observers, or in environmental conditions, none of which are necessarily related to underlying patterns of abundance. Thus, where possible, it is always preferable to use a season-specific detection function. Secondly; the success of line transect surveys in this context depends heavily on having skilled observers who can detect cryptic species and adhere to the strict protocols required for distance methods. Repeating surveys annually is beneficial in this regard as it provides a training opportunity and ensures a high level of skill is maintained. Thirdly; the presence of survey teams within these key areas for wildlife fulfils a protective function to some extent. Hunters are deterred by active wildlife monitoring teams and anecdotal information relating to the general conditions within these areas can also be collected during the line transect surveys. Monitoring teams are also able to record illegal activities and report them to the law enforcement personnel, who can then take action.

To obtain a sufficient number of animal observations for population estimates across all target species a substantial increase in sampling effort was required. Sampling effort can be increased by either increasing the number of temporal replicates (i.e. the number of times a given transect is walked) or spatial replicates (i.e. the number of transects), both of which should lead to a higher number of animal encounters. Increasing temporal replication is logistically easier to achieve as existing transects can be re-surveyed on multiple occasions, whereas increasing spatial replication requires extra transects to be cut and surveyed. However, all walks on a given transect within a season are combined during analysis and so a greater number of spatial replicates is more useful than multiple temporal replicates. Temporal replication serves to add precision to the estimation of effective half strip width and cluster size, but a minimum of 10-20 spatial replicates is required for an adequate estimation of variance of the encounter rate (Buckland et al. 2001). Beyond this requirement, the greater the number of lines surveyed, the smaller the variance of the density or abundance estimate will be (Karanth & Nichols 2002).

Such modifications to the survey design entailed a major investment of resources and posed significant logistical challenges. With this in mind it was decided in 2008 to focus on increasing sampling effort through temporal replication only, which allowed initial population estimates to be generated, and to redesign the entire system in 2010, in order to improve and refine subsequent estimates.

In 2008 each of the original 14 line transects was walked between 32 and 34 times resulting in a total effort of 1359 km. This level of effort represented an eight-fold increase from that invested in previous years. In 2010 40 new transects, each 4 km in length, were established across an expanded 1807 km^2 survey area (Figure 2). Transect placement was systematic, with a random starting point, which ensures optimal spatial coverage and appropriate representation of the entire core area. The new transects are closed circuits, square-shaped, which allows greater logistical ease as the start and end points are equivalent and can be situated at any point on the circuit. In 2010 each of the 40 transects was walked a total of ten times, over five consecutive days, which resulted in a total sampling effort of 1600 km. In 2010 survey effort was distributed equally across all forest types, irrespective of underlying gradients of habitat quality or animal density. This balanced approach is pragmatic in that it minimises logistical and analytical complexity but it does result in a considerable amount of effort being expended in extremely low-density areas, where very few observations are obtained and therefore contribute little to the estimation of the detection function. Also in 2010, each transect was surveyed once in the morning and once in the evening, resulting in a total of 8 km of survey effort per day. In difficult terrain this level of effort is high and there was some concern that it was causing fatigue and potentially impacting observer performance.

In an attempt to improve sampling efficiency a slightly modified approach was employed in 2011. Based on the results from previous years the survey area was stratified into a "high density" and a "low density" area. Each transect was also coded as being either "normal" or "difficult" in terms of terrain. Effort was concentrated in the high density stratum, in an effort to maximise observations and allow for the estimation of a reliable detection function for some of the rarer target species. The allocation of effort was not influenced by whether a given transect was "normal" or "difficult" but for the "difficult" transects effort was spread over a longer time period in order to reduce fatigue, with teams surveying just 2 km in the morning and the remaining 2 km in the evening. In 2011 a total of 1476 km of walk effort was completed across the 40 transects. The spatial and temporal scale of these surveys, when combined with their utilisation of a rigorous absolute methodology, renders this monitoring program one of the most extensive and ambitious undertaken for large mammals in Indochina to date.

Figure 1a Transect Layout 2005-2008

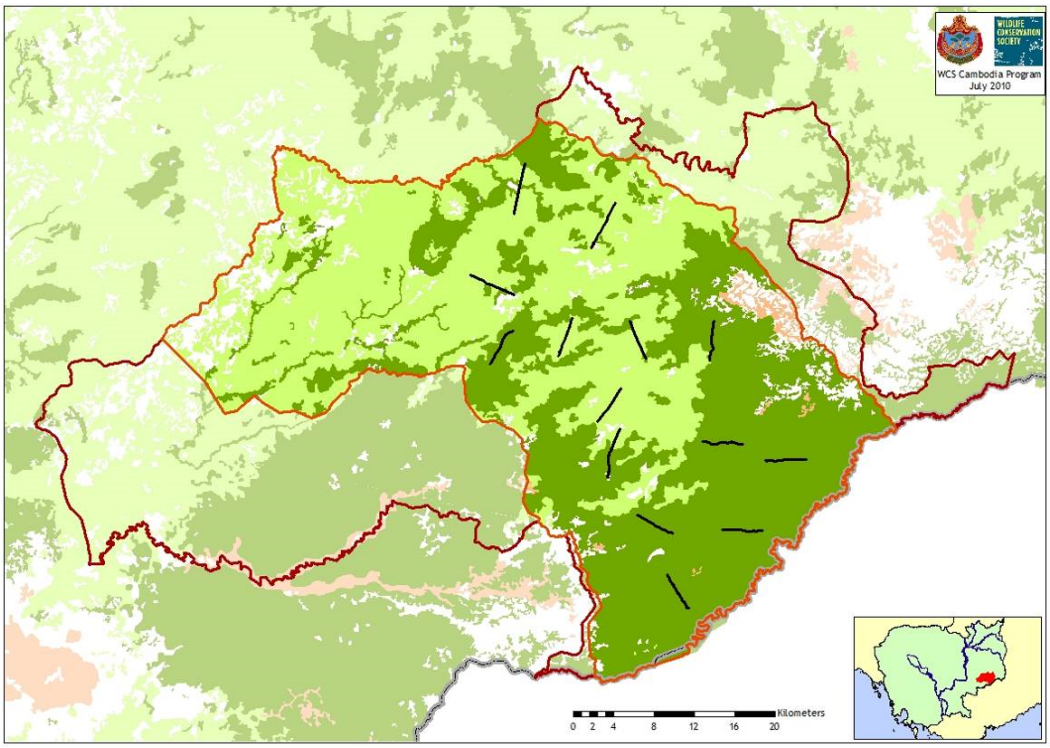

Figure 1b Transect Layout 2010

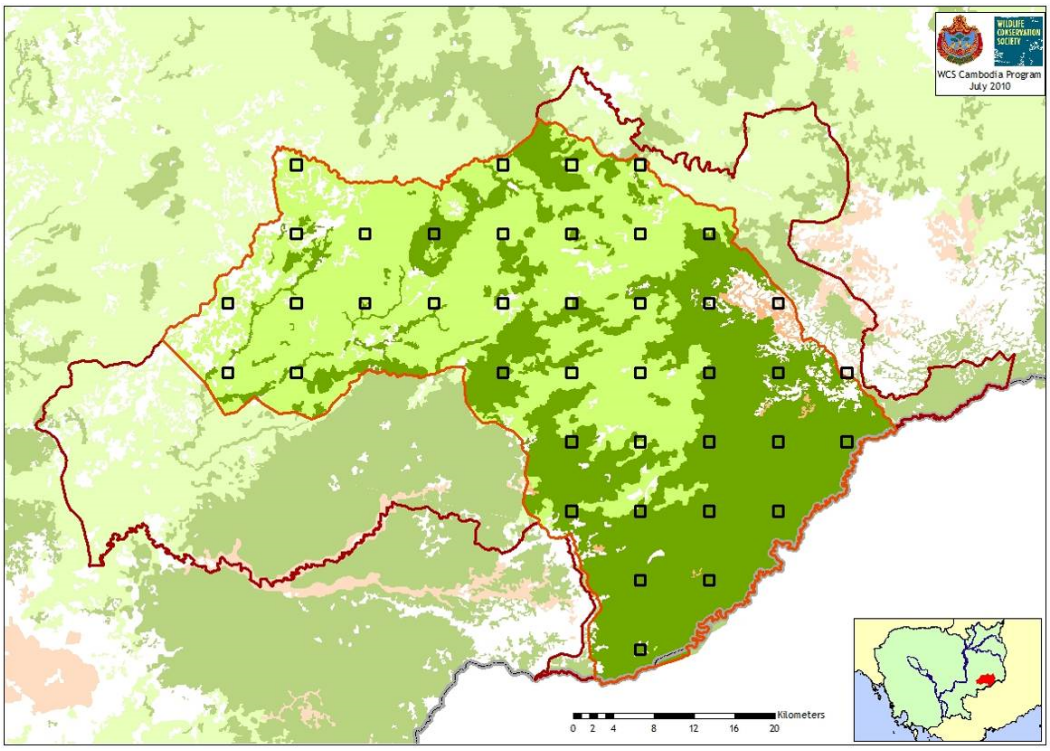

Image 1. Blue paint marking the line transects

Results

During the initial years of the program population estimation was limited to black-shanked douc and yellow-cheeked crested gibbon (using a detection function borrowed from doucs). The intensification of effort from 2008 onwards coupled with the ability to pool data across years has allowed for density and abundance estimates to be generated for all target species (**Tables 3, 4, 5, Figures 2-4**). As data have accumulated over time, it has also been possible to generate estimates retrospectively for earlier years (**Table 5**) for Black-shanked doucs, Yellow-cheeked crested gibbons, and Red muntjac.

Between 2005 and 2008 surveys were carried out in a sub-section of the core area, believed to represent the best quality habitat for target species. Because the survey area changed in 2008, to include the entire core area, a simple comparison between the surveys in 2010 onwards and earlier years is not appropriate. The inclusion of both optimal and sub-optimal areas for wildlife in the 2010, 2011, and 2013 surveys is reflected in the higher abundance but lower density estimates that resulted for most species. The 2010, 2011, and 2013 estimates for the entire core area are the most representative of the site and these results are particularly important for any consideration of the varying environmental and anthropogenic factors which affect the spatial patterns of abundance of target species.

It was necessary to combine gaur and banteng observations during analysis in order to obtain an appropriate number of encounters for 2010 and 2011, an approach that assumes the detection probability for each species is similar. There was not a sufficient number of observations in 2013 to allow an estimate to be produced. There have been no observations of Eld's deer on the transects in any year except 2013 where there was 1 observation, and therefore no estimates are available for this species. A small number of Sambar observations were obtained in the later years (2008-2013) but the data were too few and of too poor quality to reliably generate a detection function and as a consequence population estimates are not presented here for this species.

Table 3 Ungulate status in SPF core area

Species	Year	Detection Prob.	No. Obs.	Effort (km)	Encounter Rate	Detection Function	Mean Cluster Size	Individual Density (km2)	CV %	Group Density (km2)	CV%	No Individuals	95% LCL	95% UCL
Wild Cattle	2010	0.42	19	1600	0.01	global	2.76	0.44	52	0.16	50	701	262	1878
	2011	0.42	12	1476	0.005	global	2.76	0.21	53	0.07	51	384	137	1079
	2013	0.42	2	1264	0.002	-	-	-	-	-	-	-	-	-
Red Muntjac	2010	0.60	169	1600	0.09	independent	1.03	1.56	17	1.5	17	2489	1772	3495
	2011	0.37	175	1476	0.11	independent	1.08	3.18	19	2.9	18	2877	1989	4160
	2013	0.53	170	1264	0.11	independent	1.08	2.18	19	2	19	2759	1904	3997
Wild Pig	2010	0.36	53	1600	0.03	global	2.09	1.33	26	0.64	23	2406	1445	4007
	2011	0.36	28	1476	0.02	global	2.09	1	20	0.48	17	1170	644	2123
	2013	0.36	26	1264	0.02	global	2.09	0.84	30	0.40	28	1523	847	2738

Table 4 Primate & Peafowl status in SPF core area

Species	Year	Detection Prob.	No. Obs.	Effort (km)	Enc. Rate	Detection Function	Cluster Size Used	Mean Cluster Size	Cluster Size Estimated	Individual density (km2)	CV %	Group Density (km2)	CV %	Individuals	95% LCL	95% UCL
Black-shanked Douc	2010	0.54	330	1600	0.37	independent	annual estimate	3.5	3.3	12.2	21	3.70	20	22003	14518	33347
	2011	0.60	461	1476	0.23	independent	annual estimate	3.5	3.3	12.2	21	3.7	21	22076	14408	33823
	2013	0.53	260	1264	0.2	independent	annual estimate	4	3.8	11.9	19.2	3.12	18.5	21465	14634	31484
Yellow-cheeked Crested Gibbon	2010	0.4	17	1600	0.01	global	global mean	2.5	-	0.49	40	0.19	40	884	405	1930
	2011	0.4	47	1476	0.15	global	global mean	2.5	-	1.42	29	0.55	28	1289	734	2266
	2013	0.4	20	1264	0.02	global	global mean	2.5	-	0.77	29	0.30	28	1382	785	2434
Long-tailed Macaque	2010	0.52	36	1600	0.022	global	global mean	5.6	-	1.98	38	0.36	36	3584	1712	7504
	2011	0.52	35	1476	0.015	global	global mean	5.6	-	1.29	30	0.23	27	2332	1282	4240
	2013	0.52	7	1264	0.004	global	global mean	5.6	-	0.35	54	0.06	52	632	230	1739
Pig-tailed Macaque	2010	0.59	26	1600	0.017	global	global estimate	4.4	3.74	1.06	32	0.28	30	1917	1029	3569

	2011	0.59	57	1476	0.042	global	global estimate	4.9	4.13	2.27	34	0.55	32	2053	1054	3999
	2013	0.59	43	1264	0.030	global	global estimate	4.4	3.74	1.91	28	0.51	26	3457	2007	5955
Stump-tailed Macaque	2010	0.33	7	1600	0.004	global	global mean	3.55	-	0.46	65	0.13	63	830	253	2724
	2011	0.33	11	1476	0.009	global	global mean	3.55	-	0.60	33	0.17	29	1019	427	2433
	2013	0.33	1	1264	-	-	-	-	-	-	-	-	-	-	-	-
Silvered Langur	2010	0.45	39	1600	0.023	global	global mean	4.25	-	2.22	52	0.52	52	3548	1315	9575
	2011	0.45	36	1476	0.018	global	global mean	4.25	-	1.61	44	0.38	43	2964	1258	6986
	2013	0.45	27	1264	0.018	global	global mean	4.25	-	1.7	49	0.40	48	2151	851	5433
Green Peafowl	2010	0.44	26	1600	0.015	global	global mean	1.98	-	0.32	38	0.16	34	580	281	1199
	2011	0.44	18	1476	0.013	global	global mean	1.98	-	0.27	52	0.13	50	494	184	1328
	2013	0.44	16	1264	0.012	global	global mean	1.98	-	0.25	38	0.13	34	459	60	1134

Table 5 Ungulate and primate trends in original survey area

Species	Year	No. Obs.	Effort (km)	Encounter Rate	Detection Function	Mean Cluster Size	Individual density (km2)	CV %	Group Density (km2)	CV %	Individuals	95% LCL	95% UCL
Red Muntjac	2005	9	113	0.028	global	1.08	0.5	45	0.46	45	546	227	1312
	2006	15	113	0.062	global	1.08	1.2	32	1.03	32	1211	638	2300
	2007	25	170	0.071	global	1.08	1.27	29	1.17	29	1384	778	2463
	2008	134	1359	0.089	independent	1.10	1.63	23	1.48	23	1769	1091	2869
Black-shanked douc	2005	43	113	0.372	global	3.97	25.53	25	6.97	25	27263	16109	46139
	2006	58	113	0.442	global	3.97	30.39	28	8.3	28	32456	17917	58792
	2007	66	170	0.378	global	3.97	25.93	24	7.08	24	27693	16802	45653
	2008	410	1359	0.291	global	3.97	19.98	20	5.46	20	21341	13857	32868
Yellow-sheeked crested Gibbon	2005	6	113	0.053	global	2.45	2.50	34	1.02	33	2668	1337	5322
	2006	5	113	0.035	global	2.45	1.67	59	0.68	59	1778	554	5713
	2007	11	170	0.053	global	2.45	2.50	37	1.02	37	2667	1246	5708
	2008	44	1359	0.031	global	2.45	1.47	21	0.60	21	1570	1016	2426

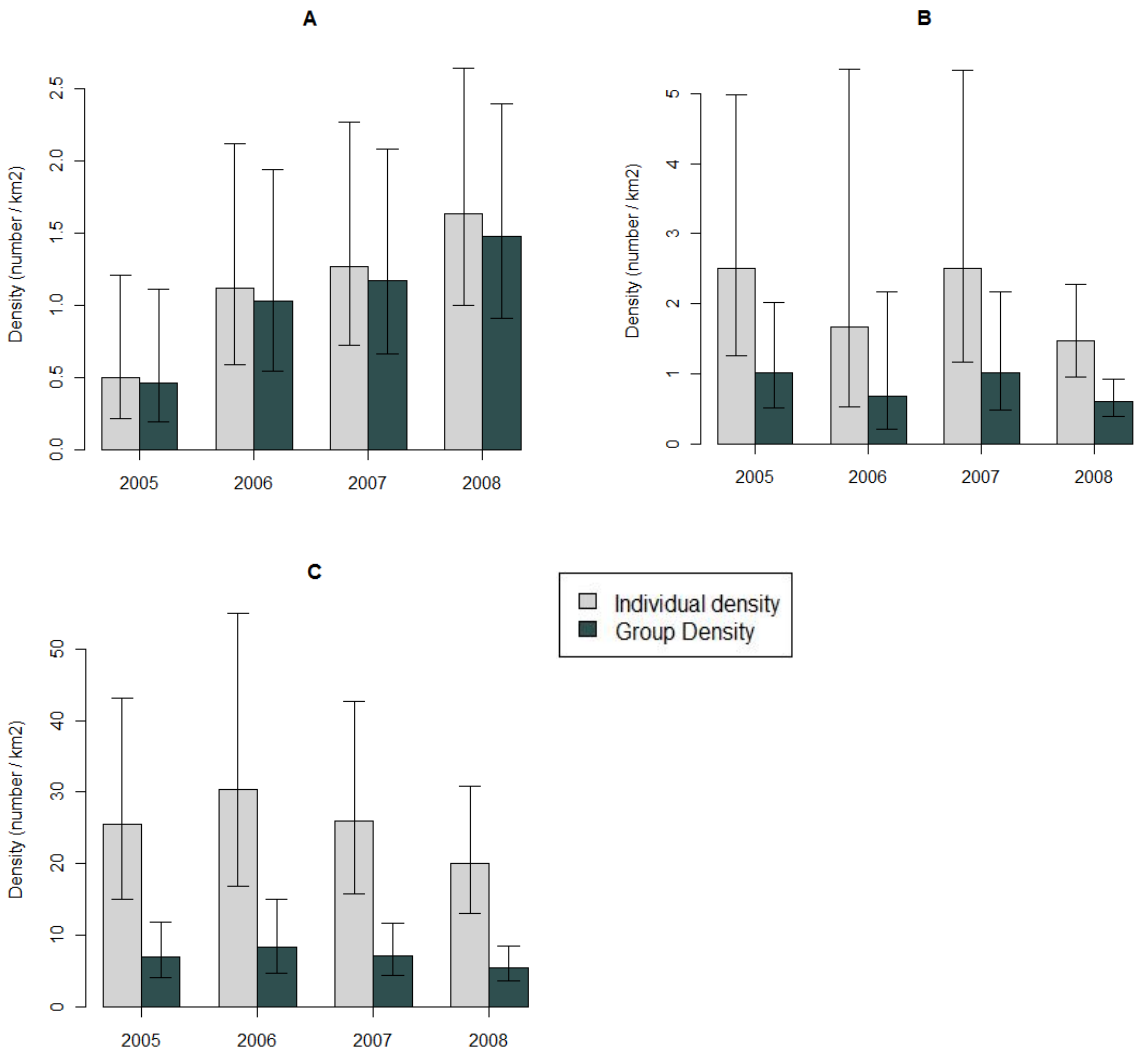

Figure 2. The density of three species in original survey area (1068 km^2). Error bars are 95% confidence intervals. A – Red muntjac; B – Yellow-cheeked crested gibbon; C – Black-shanked douc

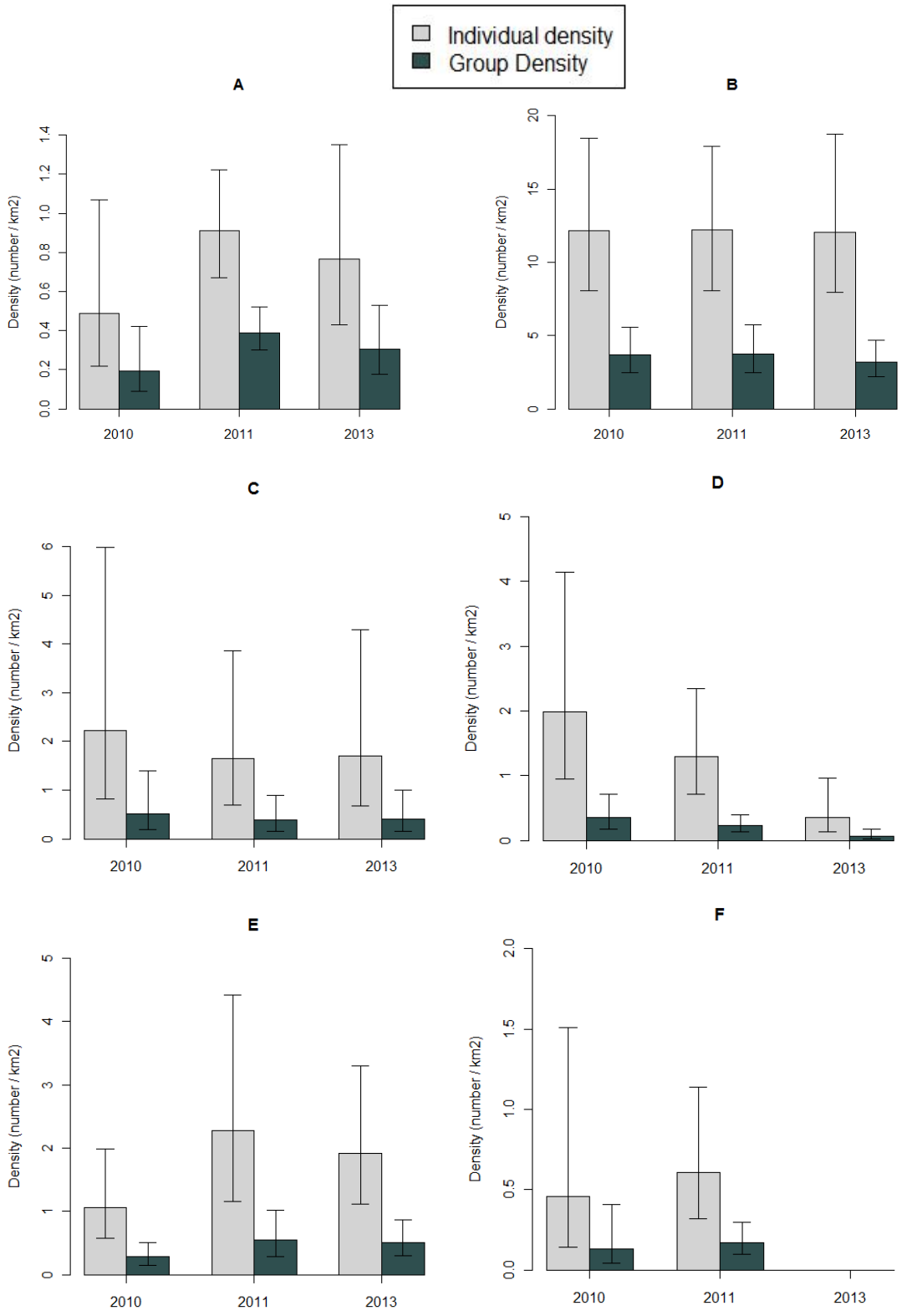

Figure 3. The density of key primate species in the new survey area (1807 km²). Error bars are 95% confidence intervals. A – Yellow-cheeked crested gibbon; B – Black-shanked douc; C – Germain's silvered langur; D – Long-tailed macaque; E – Pig-tailed macaque; F – Stump-tailed macaque.

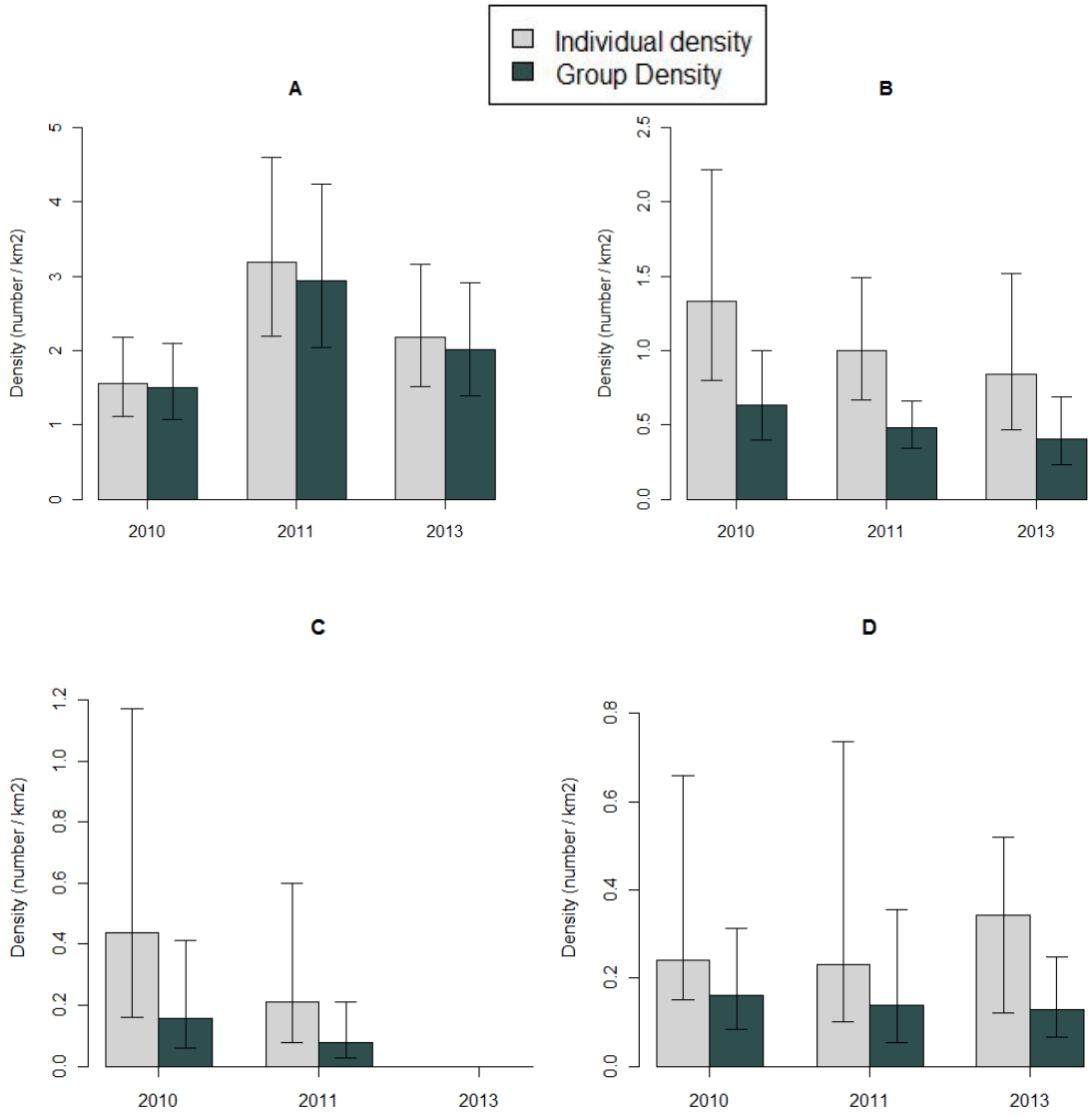

Figure 4. The density of key ungulate and avian species in the new survey area (1807 km^2). Error bars are 95% confidence intervals. A – Red muntjac; B – Wild pig; C – Wild cattle (Banteng and Gaur); D – Green peafowl.

Discussion

Larger ungulates

Sample sizes for all large ungulates have always been small, even when levels of survey effort were high. This is a result of low underlying densities which leads to low encounter rates on transects and high variance associated with the resulting population estimates.

In 2013 there were only two observations of gaur during the line transects surveys, and no observations of banteng. Even when the detection function is estimated using data pooled from previous years, two observations will not allow a reliable estimate to be produced, and therefore an abundance estimate for wild cattle in 2013 was not possible. It is difficult to identify the exact reason for so few observations of wild cattle. Animal behaviour may have changed in response to increased hunting and other anthropogenic pressure, or because of very low underlying densities it is quite possible that field teams were simply unlucky. However, the steady decrease in the number of observations from 2010, 2011, and 2013 (19, 12, 2 respectively) does suggest a decrease in the number of animals available for detection. This is potentially a worrying development because the populations of wild cattle at the site were clearly of high conservation importance, especially for banteng which has an estimated global population of only 5000-8000 (IUCN 2010). If these results do reflect a decrease in wild cattle abundance, it suggests that the population could potentially become locally extirpated within the next year or so. This contention is partially substantiated by additional information from threat monitoring activities. A number of incidents of hunting of wild cattle have been observed or reported during recent years and levels of disturbance have increased as greater numbers of people utilise the core area of SPF due to a sustained upsurge in illegal logging plus gradually increasing human populations of nearby villages (FA/WCS unpublished patrol and biological monitoring data). Domestic stock are also grazed widely in the Core Area in small numbers, and this may increase the risk of disease transmission.

Image 2. Gaur (*Bos gaurus*) caught on a camera trap in SPF

Estimates for wild cattle exist only for the later years (2010-2013) and the relative imprecision of these estimates, as well as the fact that observations are pooled across time and species to produce a detection function, must be taken into account when trying to make inferences about trends over time. As data continue to accumulate in future years, improved time and species specific detection

functions will be obtainable and additional time series data points will allow for hypothesised population trends to be observed with greater certainty.

Density estimation for sambar has proved problematic. The total number of observations combined across all years for this species is less than 40, which is below the recommended minimum required for reliable distance-based population estimation (i.e. 60-80). Although with good quality data (i.e. no measurement error) an adequate detection function may sometimes be estimated with fewer observations, this was not the case with sambar. In SPF this species is highly sensitive to the presence of humans and there is evidence from the data of possible evasive movement prior to detection on the transects. Given this evidence, and also taking into account the timorous nature of the species, together with the extremely low encounter rate, it is suspected that animals are simply evading detection by fleeing before survey teams sight them and/or actively avoiding the transects altogether. Either of these scenarios constitutes a failure of the assumptions of distance sampling and will negatively bias any estimate generated. Given the limitations of the data in terms of both quality and quantity for sambar, the population estimation results are not considered reliable enough to present in detail here. However, the "best" estimates generated do provide a useful approximation, and suggest that minimum sambar numbers in SPF are of the order of a few hundred animals.

All sources of information, including the line transect surveys, observations collected during other types of monitoring activity, and anecdotal reports, concur broadly with respect to distribution patterns for large ungulates within the site. It is further supposed that seasonal movement of populations occurs within the site but the data available to date have precluded any detailed investigation into this phenomenon.

Observations of these three large ungulates have typically tended to be concentrated within the central and southern parts of the site, with an additional hotspot for banteng identified in the north-west of the core area during the 2010 surveys. Gaur and sambar observations tend to be most frequent in evergreen and semi-evergreen habitat while banteng are typically observed in semi-evergreen and deciduous forest. Areas comprised of a mosaic of different habitat types are apparently favoured by all three species over large blocks of uniform habitat type, and there may also be a predilection for areas with multiple water sources and mineral licks. These apparent patterns are consistent with recorded habitat preferences elsewhere in the range of these species (Nguyen 2009; Steinmetz 2004). However, not all areas of suitable vegetation in SPF are occupied, and this is likely to be due to variation in human pressure and levels of active law enforcement.

The prevalence of hunting in SPF is variable across space and time, and is influenced by a range of potentially interacting factors. Ease of access, vegetation density, proximity to roads and settlements, and presence and intensity of law enforcement patrols all appear to be important determinants in the nature and extent of hunting. There are extensive tracts of apparently suitable habitat in which abundances are very low, a situation which we attribute primarily to over-hunting. Thus, large ungulates have generally persisted in areas characterised by good quality habitat together with some level of protection from hunting, either by virtue of their inaccessibility, or a result of anti-poaching efforts, or both.

With adequate protection it is likely that this landscape could support considerably higher numbers of these species as densities appear to be well below habitat carrying capacity. In comparable habitat in Huai Kha Khaeng Wildlife Sanctuary in Western Thailand, combined density of gaur and banteng was estimated to be 1.8/km^2 (compared to 0.21/km^2 in SPF in 2011) while density of sambar in the wet season was 4.2/km^2 and these numbers were also thought to be depressed due to poaching (Srikosamatara 1993). This indicates that there is significant potential for recovery of large ungulates within SPF if adequate protection is in place. If the recent analysis accurately represents the current trend of wild cattle numbers, conservation efforts must be significantly and rapidly increased in order to ensure the continued presence of large ungulates within SPF.

Smaller ungulates

Sample sizes for smaller ungulates were relatively large in comparison to the larger ungulates, particularly for the later years (2008 - 2013).

The red muntjac population was estimated at over 2700 animals in the core area in 2013, a slight decrease since 2011 (2011 = 2877). Of all of the species surveyed, muntjac was exceptional in that density in the "low density" stratum was estimated to be higher than that of the "high density" stratum (3.98 and 2.98 respectively). This calculation was possible for 2011 data due to the survey design stratifying effort based on expected levels of density, and thus the two strata were analysed separately. This survey design was not continued in 2013. This difference in muntajc density may be explained by the species' habitat preferences. Although muntjac occur across the entire core area, they are less commonly observed in dense evergreen forest, a forest type which is almost entirely restricted to the "high density" stratum. Furthermore, in addition to being comprised of a higher proportion of open forest, the "low density" stratum is subject to higher levels of human use, which leads to increased levels of hunting, as well as disturbance and habitat degradation. Muntjac appear to persist in moderate abundance throughout these areas, indicating that they may be more tolerant of anthropogenic pressures than other species in this context. This finding is consistent with other studies (e.g. Steinmetz et al. 2010) that suggest the species is comparatively resilient to some level of hunting off-take.

The wild pig population in the core area was estimated to be approximately 2400 animals in 2010, but the 2011 estimate was less than 1200 animals. The population appears to have stabilised in 2013 however, with an estimate of just over 1500 individuals. There are a number of aspects to be considered when interpreting these results. Firstly, the 2011 and 2013 data sets showed some evidence of evasive movement for this species. Evasive movement before detection will cause a negatively biased result so these estimates must be treated with some circumspection when compared to the 2010 estimate. Nevertheless, encounter rates and group size also decreased in 2011, suggesting numbers had undergone some decline. The encounter rate and mean group size from 2013 are in line with the population estimate in showing a slight increase from 2011, but still remaining below those of 2010. In fact, it is possible the occurrence of evasive movement in the two later years may itself reflect increasing levels of disturbance and possibly hunting, causing wild pig to become more wary of humans. However, this species is also known to be subject to natural population fluctuations, as a result of a range of cyclical environmental factors such as disease and food availability. Thus, it seems likely that the population did decline, but whether this is a result of anthropogenic or environmental pressures or some interaction of the two remains unclear, as does the precise extent of the decline.

Image 3. A family of wild pig (*Sus scrofa*) caught on a camera trap in SPF

Estimates were not possible at the time of the 2005-2007 surveys for any ungulate species but one of the advantages of using distance sampling methods is that as data accrue over time they can be used to retrospectively generate population estimates. For red muntjac a combination of annual

(later years) and global (earlier years) detection functions were used to estimate yearly densities from 2005 to 2008. Differences in the red muntjac population between the earlier years (where the population appears to be increasing) and later years (where the population experiences fluctuations), cannot be assessed together due to different transect systems and a difference in survey area. The reasons for the fluctuations in later years are unknown, but could be due to natural causes such as disease or cyclical fecundity, or anthropogenic causes such as changing patterns of hunting and resource use over time, and the population's natural reactions to them.

Both red muntjac and wild pig are known to experience relatively high hunting pressure at the site but whereas muntjac densities appear to be only slightly lower than those recorded at unhunted sites, wild pig numbers are much lower than would be expected. For example, densities of red muntjac and wild pig in Taman Negara in Malaysia were estimated at 3.2 per km^2 and 4.17 per km^2 respectively (Kawanishi & Sunquist 2004).

Primates

There has been a strong focus on primates within the SPF monitoring program since its inception. In particular, SPF is known to be a global stronghold for black-shanked douc and yellow-cheeked crested gibbon and the extensive data set available from the site from 2005 onwards has yielded the most reliable population estimates to date for either of these species, from anywhere within their range. The 2013 population estimate was over 21,400 individuals for black-shanked douc and over 1,300 individuals for yellow-cheeked crested gibbon.

The program initially focused on just these two species, but as levels of survey effort increased it has become possible to produce estimates for an additional four primate species. These new results from SPF may be particularly important for Germain's silvered langur, for which substantial population estimates of between 2000 and 3000 individuals have been produced (for 2010, 2011, and 2013) and for which very little information is available from anywhere within its range. There are also relatively few studies that have produced robust density estimates for *M.leonina, M.arctoides,* and *M.fascicularis*, with populations in India generally being the most studied (e.g. Choudhury 2002, Choudhury 2003, Fooden 1995, respectively).

The 2011 and 2013 results confirm that a population of northern pig-tailed macaque of between 2000 and 3400 individuals is present within the SPF core area. Of more concern however, are the estimates for both long-tailed and stump-tailed macaques. Long-tailed macaques appear to have undergone a large decline (82.4% decrease in abundance between 2010 and 2013), which is reflected in both the abundance estimates and the number of observations. Although this result is alarming, it must be viewed with caution because although the detection function for long-tailed macaque was estimated using pooled data from previous years, the 2013 density estimate was produced using extremely low numbers of observations (n=7).

A 2013 estimate was not possible for stump-tailed macaque due to extremely low number of observations (n=1). Establishing causation for such a low number of observations is very difficult, especially when the number of observations in previous years have also been low (n=6 and n=11 in 2010 and 2011 respectively). This suggests that the underlying density of stump-tailed macaques has been very low since 2010 at least, making regular observations on the transects challenging.

Nevertheless, it is possible that there have been substantial decreases in population densities for both long-tailed and stump-tailed macaques. The reasons for these apparent decreases are not certain, but persecution by humans is a potential cause. Macaques are notorious crop-raiders (Srivastava, 2006; Linkie *et al.* 2007) and are therefore subject to pre-emptive and retaliatory killings. Anecdotal evidence supports the idea that farmers will set snares around their fields in order to prevent wild animals from crop-raiding. Furthermore, the loss or vulnerability of long-tailed and stump-tailed macaque populations across their ranges have been attributed to live trapping in order to supply the uncontrolled demand for medical and pharmaceutical research (Lee & Priston 2005).

This phenomenon is known to occur in Cambodia, with at least two companies operating a primate export service from Cambodia; the Golden China Group and KF (Cambodia) Ltd. Hsu. A spokesperson for the Golden China Group admitted in 2005 that approximately 3000 long-tailed macaques were captured by local people from the wild, from the Tonle Sap area and Kratie Province, with the final destination being research companies in China, Japan, and the United

States. The increasing scale of the problem is reflected in the US import statistics which report 240 Cambodian primates entered the US in 2005, followed by 2,532 in 2006 (Animal Welfare Institute, 2007). There is no evidence that this industry has contributed to the apparent declines the two macaque species in SPF, but it warrants further investigation.

Several of the primates in SPF make suitable target species for the biological monitoring program because they occur at relatively high abundances and, in contrast to the majority of other large mammals species present, they are generally easy to detect. Nevertheless, it must be stressed that obtaining accurate and precise estimates for arboreal mammals such as primates is notoriously difficult (Buckland et al. 2010b). As ecology and behavioural characteristics differ between species, they present a number of different types of challenge to data collection and analysis. These issues must be taken into account when making inferences from the estimates about underlying population trends.

Doucs occur at high densities and observations are frequent and numerous. However, doucs typically occur in groups of variable size and it is extremely difficult to count every individual within a potentially large and highly mobile group of animals in dense evergreen forest. Accordingly, estimates of group size may not be exact and obtaining an accurate assessment of group spread (and hence estimation of the distance to the group centre) is often highly problematic. These issues are compounded by the fact that distance sampling protocols require observers to distinguish between social groups and geometric clusters, and to record the number of individuals in the latter rather than the former.

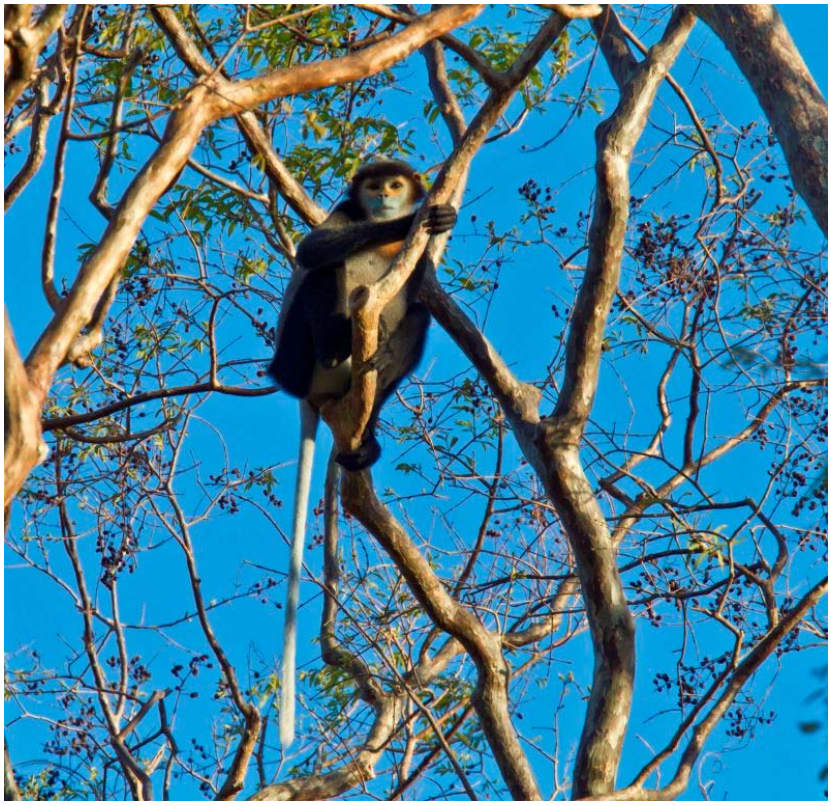

Image 4. Black-shanked douc (*Pigathrix nigripes*). Photo courtesy Elenor Briggs

These difficulties regarding accurate measurement of group size and group centre location also apply to all three macaque species and to silvered langurs, and the fact that far fewer observations are obtained for these species contributes further to the variance within the data, making it all the more problematic to model the detection function. Additional behavioural traits which affect spatial distribution, for example the possible restriction of silvered langur to a limited area of riverine forest, may also be relevant but are beyond the scope of this current analysis.

The reliability of density estimates for Germain's silvered langur is improving as the accumulation of observations increases every year. As has been discussed previously, data collected in previous years can be combined in order to more effectively estimate the detection function, and thus

produce more precise estimates. The number of observations of silvered langurs has been small every year, but when the 2010, 2011, and 2013 observations are combined, there are 95 observations which are enough to estimate an acceptable detection function. The population estimates appear relatively stable across the years, despite slight decrease every year. However, at this stage it would be unwise to attempt to infer any trend due to the relatively rudimentary state of the data set for this species. Further examination will follow in subsequent years.

Recording gibbon observations is easier in that they generally occur in much smaller groups, the size of which is relatively consistent. However, gibbons are amongst the scarcest of the primate species in SPF and encounter rates are low when compared to doucs. In addition, gibbons are an exceptionally cryptic species; they are wary of observers and typically move silently and at high speed through the canopy. Particular vigilance is required to ensure that no gibbons on or close to the transect line are missed by observers, as this would constitute a failure to meet one of the key assumptions of distance sampling. The level of skill and experience of observer teams is always an essential consideration when using this method, but it is a particularly crucial concern for this species. There are an array of factors which can potentially cause observer concentration to wane, including fatigue, loss of motivation, and lack of proper understanding of survey protocols (due to insufficient or inconsistent training), all of which can impact profoundly on data quality.

A number of these points can be exemplified by comparing trends in group and individual density for gibbons and doucs. The 'best' estimates of individual douc density (2010 and 2013) have a coefficient of variation of 21% and 20% but are based on between 250 and 300 observations, whereas a similar level of precision was obtained for the 2008 gibbon estimate (21%) with under 50 observations. This is largely to do with the better 'quality' of the gibbon data, i.e. more accurate distance measurements and greater consistency in group size, and the reduction in variance contributed to the estimation process because of this. On the other hand, there was thought to be a dip in observer performance in 2010, causing some gibbons to go undetected and severely affecting that year's estimate. For doucs, although the 2010 encounter rate was considerably lower, there appeared to be no problems with that year's final estimate, reflecting the robust nature of the now extensive douc dataset

Doucs were the only primate species for which sufficient data were available to estimate species and time specific detection functions. Global detection functions are used for all other primates. Both group and individual density trends are presented for each species.

The individual and group density estimates for black-shanked doucs have remained remarkably stable in 2010, 2011, and 2013 (individual density: 12.18, 12.22, 12.03; group density: 3.70, 3.74, 3.20), which suggest both reliable estimates and a stable population. This is further supported by stable annual cluster sizes; 3.29 in 2010, 3.26 in 2011, and 3.76 in 2013. In the old survey area (2005-2008) the estimates for individual and group densities of black-shanked doucs vary to a greater degree, however the extent of the fluctuations combined with the lack of precision precludes any informative assessment of earlier population trends.

For gibbons there is slightly more of a discrepancy between patterns in group and individual density, most likely due the fewer number of observations and thus higher variance associated with the encounter rate which will affect the precision of the estimates. A similar problem can be seen in the estimates produced for the earlier years, where estimates fluctuate between years. The results from the 2014 line transects will be enlightening in terms of understanding the underlying populations trends for yellow-cheeked crested gibbons.

The 2010 gibbon estimates, which are lowest in terms of individual and group density, must be viewed with caution as few observations were obtained for that year. This may have been partly due to the fact that in 2010 a large proportion of effort was expended in deciduous forest, which is not preferred gibbon habitat. However, there was also some concern that observers may have been missing animals on or close to the line during surveys, thus violating one of the fundamental assumptions of distance sampling and giving rise to negatively biased estimates. Measures were implemented to ensure this do not happen in 2011and 2013 (i.e. further training, a reduction of effort per day for teams).

Although the existence of a market for young gibbons to supply the pet trade means this species is potentially targeted by hunters, hunting pressure is still believed to be low for this species at this site. This belief is supported by law enforcement monitoring (using the MIST and SMART

software) which contains no records of gibbon-related incidences. There is no evidence of any recent increase in hunting for primates. In fact, anecdotal observations from a recently implemented gibbon research project in Andong Kraloeng village in the core zone of SPF have shown that gibbon home ranges (n=3) are within 100 metres of villages, roads, and farms, with one gibbon family often producing their morning song bout within sight of the road. This suggests the gibbons, in that area at least, are not directly threatened by humans. It is possible that environmental or ecological factors are causing real fluctuations in gibbon numbers but it is more likely that the variation in estimates is a result of sampling and/or observer variation.

Green Peafowl

Green peafowl was included as a target species for the first time during 2010 surveys. A relatively low sample size was achieved in all years (2010 n=23, 2011 n=18, 2013 n=15). However, when combined these data are sufficient to generate a detection function but the resulting estimates still lack precision. These estimates nevertheless indicate a population numbering between 400 and 500 birds, which would be considered a large population and implies SPF is a stronghold for the species (Goes, 2009). The estimates remain relatively consistent across the three years which is a further positive sign. In future years it is likely these estimates will be greatly improved upon, and, even as they stand, they represent some of the only robust estimates available from any significant site the region.

Conclusion

Monitoring rare and cryptic large mammals within tropical forest environments is challenging in the extreme. The use of a rigorous, scientifically sound technique such as distance sampling is considered best practice in this context, but it does present methodological difficulties which must be acknowledged. These difficulties notwithstanding, the quality of the results, both in terms of reliability and utility from a management perspective, justify the investment required to produce them. This is in marked contrast to commonly used alternatives, such as index-based methods. Relative methods may appeal in that they are typically less technically complex and less effort intensive, but ultimately they cannot yield reliable results.

Impediments to the successful implementation of this method can arise out of the logistical and technical difficulties involved in conducting the survey, but also due to the inherent traits of the species being surveyed. Failure to meet the assumptions underpinning the method can and does cause bias, but generally any major violation of assumptions is apparent from the data, and at best can be dealt with during the analysis stage, or at worst taken into consideration when examining resulting estimates. This, again, is in contrast to other relative methods, which are subject to numerous sources of potentially severe bias which cannot be tested for or corrected for, and which are therefore commonly, and erroneously, ignored.

For the majority of target species, robust, scientifically defensible estimates have been obtained and some initial indications of underlying population trends are available for consideration. For some species several possible scenarios have been identified that could result in observed status and apparent trends. Triangulation using auxiliary threat monitoring data can help determine which is the most likely scenario and, as data continue to accumulate over time, hypotheses will be continually tested and refined, and a clearer picture will emerge. For two species, sambar and Eld's deer, a lack of adequate data precludes the production of any reliable results from which to draw meaningful inference. In these instances it may be that distance sampling on line transects is not a suitable method for population monitoring at this stage. For Eld's deer this is because they persist in small, highly aggregated groups and for sambar it is probably due to the species' exceptional wariness of human observers in this context. For these two species alternative approaches to population estimation will have to be explored.

Although this approach is effort intensive in many ways, results for multiple species are obtained, and the data are continually re-used as estimates are refined over time. This renders it, in actuality, a cost-effective method of monitoring a range of target species in situations where resources are extremely limited. In most cases, these results represent the first and only robust population estimates from the region for the species. As a consequence, these results have both confirmed

and highlighted the regional and, in some cases global, importance of SPF for wide range of threatened large mammal species.

The results of the 2013 wildlife monitoring programme have yielded some excellent data, which have been used to improve and refine population estimates for ten key species within SPF. Despite the various methodological considerations mentioned above, which must always factor heavily when drawing conclusions, there are four species in particular which have caused concern. Long-tailed macaque (*Macaca fascicularis*), stump-tailed macaque (*Macaca arctoides*), banteng (*Bos javanicus*), and gaur (*Bos gaurus*) all show signs of dramatic declines in their populations. Despite continued law enforcement efforts and multiple, long-term conservation interventions, these species appear to be on the brink of local extirpation. As of yet the causes of these declines are unknown, although the present theories have been discussed earlier. It is therefore imperative that the management authorities in SPF try and establish the true causes of these declines, and take action to prevent further loss.

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