Leopards in African Rainforests: Survey and Monitoring Techniques

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Executive Summary

Forest leopards have never been systematically surveyed in African forests, in spite of their potentially vital ecological role as the sole large mammalian predators in these systems. Because leopards are rarely seen in this habitat, and are difficult to survey using the most common techniques for assessing relative abundances of forest mammals, baseline knowledge of leopard ecology and responses to human disturbance in African forests remain largely unknown. This technical handbook sums up the experience gained during a two-year study of leopards by Philipp Henschel in the Lopé Reserve in Gabon, Central Africa, in 2001/2002, supplemented by additional experience from carnivore studies conducted by Justina Ray in southwestern Central African Republic and eastern Congo (Zaire) . The main focus of this effort has been to develop a protocol that can be used by fieldworkers across west and central Africa to estimate leopard densities in various forest types. In developing this manual, Henschel tested several indirect methods to assess leopard numbers in both logged and unlogged forests, with the main effort devoted to testing remote photography survey methods developed for tigers by Karanth (e.g., Karanth 1995, Karanth & Nichols 1998; 2000; 2002), and modifying them for the specific conditions characterizing African forest environments.

This handbook summarizes the results of the field testing, and provides recommendations for techniques to assess leopard presence/absence, relative abundance, and densities in African forest sites. We briefly review the suitability of various methods for different study objectives and go into particular detail on remote photography survey methodology, adapting previously developed methods and sampling considerations specifically to the African forest environment. Finally, we briefly discuss how camera trapping may be used as a tool to survey other forest mammals. Developing a survey protocol for African leopards is a necessary first step towards a regional assessment and priority setting exercise targeted at forest leopards, similar to those carried out on large carnivores in Asian and South American forests.

I. Why the Concern About African Forest Leopards?

The status of the leopard (*Panthera pardus*) in Africa has been a matter of debate since 1973 when the species was first listed under CITES Appendix I. Several attempts have since been made to determine the leopard's status in Sub-Saharan Africa, most of which have relied heavily on interviews and questionnaires. Martin & de Meulenaer (1988) carried out interviews on a continental scale, but also developed a leopard population model that used linear regression techniques to link leopard densities with annual rainfall and predict numbers of leopards throughout their range in Africa. To date, their study is the only quantitative attempt to estimate leopard numbers across the continent, including forested areas in Central and West Africa where leopard surveys had never been undertaken.

This model predicted very high densities in tropical rain forest (up to 40 leopards, including young and transients, per 100 km^2) and produced population estimates for Central African countries that were widely considered to be too high (e.g., Jackson 1989, Norton 1990). Bailey (1993), Jenny (1996), and others argued that because terrestrial mammalian prey biomass is lower in rainforest than in savanna environments, leopard densities will be correspondingly lower. Perhaps more importantly, Martin and de Meulenaer's model failed to include wild prey as a factor affecting leopard densities. As a result, their model may seriously overestimate leopard numbers in areas such as tropical Africa where forest wildlife has declined in abundance under ever ever-increasing local and commercial demands for bushmeat (Angelici et al. 1999, Wilkie et al. 2000).

The leopard's broad geographic distribution over Africa and much of Asia offers little reason for concern for the survival of the species. In contrast to other endangered large carnivores in Africa such as cheetahs (*Acinonyx jubatus*) and wild dogs (*Lycaon pictus*), leopards exhibit marked adaptability to different habitat and prey conditions, and have been recorded to alter their behavior when in close proximity to humans (Bailey 1993). In eastern and southern Africa, leopards are not infrequently sighted near or within urban or highly-cultivated areas (Hamilton 1986; see references in Nowell & Jackson 1996), thereby giving further ammunition to their reputation as a resilient species. On the other hand, ecological knowledge and information on the conservation status of leopards is poor in many parts of their range. This is especially true in African forest environments, where knowledge lags far behind that from savanna habitats. The little empirical data that have been gathered on leopards in forested areas suggest that this top predator is already disappearing from parts of its former range. Bailey (1993) notes that most leopards were extirpated from the west African coastal forest belt by 1945. Leopards once ranged throughout Nigeria (Nowell & Jackson 1996), however, surveys in the southeastern part of the country revealed leopard sign in only 2 of 47 forest patches (Angelici et al. 1998). Researchers report that the situation is becoming similar in the rainforests of southern Cameroon; in Banyang-Mbo Wildlife Sanctuary, for example, forest leopards may already be extirpated (Bennett 2001); in the neighboring Bamenda Highlands leopards were wiped out from the montane forests of Kilum-Ijim about 20 years ago (Maisels et al. 2001).

Forest leopard populations are likely to be negatively affected by a variety of factors, including prey depletion, direct hunting, and habitat conversion. It is difficult, however, to determine particular causes of leopard decline in any given area. Recent studies have shown that prey depletion can be more important than poaching or habitat loss in reducing populations of large cats (e.g., Karanth & Stith 1999, Sunquist & Sunquist 1989). The tremendous volume of wild meat currently being taken from some central African forests is well documented (e.g., Wilkie et al. 2000). Given that these high hunting levels are likely not sustainable, and the high dietary overlap between African forest felids and human hunters (Ray 2001), further declines in leopard populations can be expected where bushmeat hunting is prevalent. Hunting of leopards also occurs in the African forest belt. In northern Congo for example, 15 leopard skins were seized last year in a two-week period (P. Elkan in Ray & Quigley 2001). In Gabon, leopard claws and canines are easy to find in all larger markets in the capital (Henschel pers. obs.).

Anthropogenic influences, therefore, pose an increasing threat to leopard populations in West and Central Africa (Nowell & Jackson 1996). However, our poor knowledge about ecology and conservation status of this largest terrestrial predator in African forest ecosystems hampers our ability to properly assess management needs or to set regional priorities for conservation research and action. Aside from the few studies mentioned above, leopard status is unknown throughout the African forest belt.

2. The Goals of this Manual

To remedy this lack of information on leopard populations, the IUCN Cat Specialist Group Action Plan recently called for a project to study leopard ecology and densities in African rainforests in order to produce accurate population estimates (Nowell & Jackson 1996 [Project 34]). With leopard ecology already well studied in the savanna ecosystems of eastern and southern Africa, there are density estimates available for several different habitat types from these regions (Bailey 1993, Norton & Henley 1987, Bothma & Le Riche 1984, Hamilton 1981, Smith 1977). Unfortunately, because of the low visibility in forested environments, study methods developed in open habitats (such as direct counts of individuals and darting from vehicles) are not practical. While a number of methods have been developed for evaluating and monitoring forest carnivore abundances elsewhere using non-invasive techniques (e.g., Karanth & Nichols 2002, Zielinksi & Kucera 1995), they have been largely untested for African forest leopards.

The main goal of this manual is to provide recommendations for survey techniques to assess leopard presence, relative abundance, and densities in African forest sites. The methods described in this manual are primarily targeted for shorter-term survey efforts (i.e., those of several months' duration), with the recognition that long-term carnivore studies undertaken in one area often permit detailed knowledge of individual animals. In addition, the emphasis here is on non-invasive techniques, necessarily sidestepping descriptions of live-trapping and telemetry, which will continue to be vitally important tools for addressing questions related to the ecology and conservation of elusive tropical carnivores.

In addition to providing recommendations on survey methodology, we briefly review the suitability of various methods as they relate to possible study objectives. We then go into particular detail regarding remote photography survey methodology, using the statistical framework developed for Asian large carnivores and adapting methods and sampling considerations specifically to the African forest environment. We also discuss briefly how camera trapping may be used as a tool to survey other forest mammals. This handbook draws on the experience of Henschel during a two-year study of leopards in Lopé Reserve, Gabon and additional experience of Ray in southwestern Central African Republic and eastern Congo (Zaire). Its development has been supported by the Global Carnivore Program of the Wildlife Conservation Society as a first step towards a regional assessment of forest leopard conservation status.

This effort builds on the excellent work of Ullas Karanth and others (e.g., Karanth 1995, Karanth & Nichols 1998; 2000; 2002, Franklin et al. 1999, O'Brien et al. 2003), who developed many of the techniques described here and the theoretical basis for population censusing of large predators. It does not provide details on the conceptual framework or the principles of survey design behind estimating animal abundances, which can be found in White et al. (1982), Lancia et al. (1994), Thompson et al. (1998), Nichols & Conroy (1996), Karanth & Nichols (2002) and others. We strongly recommend that investigators peruse these works to get better acquainted with these concepts. Using these works as a foundation, this manual provides a survey protocol that is tailored to the particularities and peculiarities of leopards in the African rainforest environment. At the same time, we hope that this work may prove useful for surveying large carnivores in other tropical rainforest localities.

3. Defining the Objectives of the Survey

The particular objectives of a leopard survey must be matched with the logistical realities (human and financial resources, time availability) when deciding what type of survey to undertake and what degree of precision is required. Ascertaining whether or not leopards are present in a given area, for example, is a much simpler task than attempting to estimate abundances. Fewer resources and less effort are required to determine presence/absence; a more complex survey would be needed to estimate abundance using the capture-recapture approach (Table 1).

Table 1. Possible objectives of forest leopard surveys and compatible survey levels.

	Survey Level			
STUDY OBJECTIVE	**Presence-Absence (ad hoc)**	**Presence-Absence (systematic)**	**Relative Abundance**	**Absolute Density Estimates**
Evaluate presence or absence of leopards in a specifically defined area	Y	Y	Y	Y
Map the distribution of leopards at a regional (e.g., country) scale		Y	Y	Y
Generate habitat relations or spatially-explicit population viability models		Y	Y	Y
Evaluate what proportion of an area is occupied by leopards		Y	Y	Y
Compare the abundance of leopards between areas			Y	Y
Monitor leopard population density or relative abundance in a given area over time			Y	Y
Monitor change in spatial distribution of leopards at a regional (e.g., country) scale		Y	Y	Y
Estimate the absolute density of leopards in a given study area				Y
Evaluate the impacts of prey or habitat change on leopard presence, relative abundance, or density		Y	Y	Y

The next step is then to define the minimum intensity of survey necessary for the objectives and degree of precision, which must be balanced with available resources, as discussed by Karanth & Nichols (2002). Variables to consider are personnel (number and skill level), size and access into the area to be surveyed, material resources and/or money, timing, and other logistical constraints (such as vehicle availability). For example, a single researcher working without any expensive equipment can conduct an ad hoc presence/absence survey (see Section 5.1), but this will provide the minimum level of information of any method discussed here. More detailed data collection requires greater resources and effort. It is pointless to embark on *any* survey without having clear objectives and the available resources to achieve them.

4. A Brief Introduction to Sampling Considerations

We define the spatial distribution of individuals in a population as the occurrence and spatial arrangement of leopards within a defined area at a particular time. At the least, we are interested in knowing whether or where leopards occur in an area. Often, however, in the interest of assessing a population's status, we would like to find out approximately how many individuals are present (relative abundance or density). Achieving valid measurements of spatial distribution, relative abundance, or density of leopards requires a survey (a partial count of individuals in a defined area) or a census (a complete count within a particular area and time period), the latter being virtually impossible to carry out when elusive large carnivores in closed forest habitats are the target.

A survey is obviously tied to a defined area and requires careful delimiting as part of the objectives. The eventual size of the area surveyed (the effective sampled area) will be determined by the survey method that is employed. Virtually all inferences about animal populations are based on count statistics. For many animals, it is possible to come up with such statistics by counting the animals (or photo-records) themselves. In other situations, count statistics will be based on indirect sign (such as scats or tracks).
As Karanth & Nichols (2002:24) discuss: "Two basic problems confront biologists and managers who would like to use such count statistics to estimate and draw inferences about animal population size: observability and spatial sampling…..Observability refers to the usual inability to detect and enumerate all animals….," or "….more generally to an inequality between the count statistic and the true number of animals. Spatial sampling, on the other hand, refers to the fact that we are frequently interested in areas so large that we are unable to obtain count statistics over the entire area. Instead, we must select smaller areas thought to be representative of the entire area, with the idea that we will try to use counts on these sampled areas to draw inferences about the number of animals in the entire area."

When dealing with the problems of observability and spatial sampling in determining leopard presence/absence, relative abundance, or absolute abundance, it is helpful to keep in mind a conceptual framework provided by the following equation:

$$\hat{N} = C' / \hat{p}\,\alpha$$

Where $\hat{N}$ is the estimated abundance, C' is the count statistic in sampled areas, $\hat{p}$ is the estimated probability of detection of leopards, and α the proportion of the total area from which the count statistic is taken. A variety of methods presented in this model fall within this general framework, which should not be taken as a specific estimation equation for leopard abundance. Rather than assuming that $\hat{p} = 1$ and $\alpha = 1$, both parameters can be estimated regardless of the goal of the survey using statistics.

5. Types of Surveys

5.1 Presence/absence – ad hoc surveys

Depending on the severity of bushmeat offtake, extent of direct hunting, or habitat alteration in a given area, leopard distribution and abundance may be negatively impacted, with the extreme condition being local extirpation. If the study is restricted to a discrete area, such as a protected area or forest fragment, and the goal is only to identify presence or absence, ad hoc surveys will suffice. The easiest and least expensive way to go about this is to walk along game trails or roads throughout the area, and search for leopard sign, such as tracks or feces (Box 5A). Normally, scats and scrapes in particular should be in evidence on a regular basis if leopards occur, as they are usually left in prominent spots as territorial markers for conspecifics. Inside many protected areas in Gabon, CAR and Congo (Zaire) where hunting is prohibited, leopard sign is usually encountered on a daily basis. But in areas where leopards are directly persecuted, it can become difficult to discover any sign of their presence, as they often avoid using roads and trails which are frequented by human hunters. As a consequence any researcher surveying only trails will have difficulties in finding any sings of their presence in that area. It is important to note that although these are known as presence/absence surveys, they are actually surveys of detection vs. non-detection, as absence may actually indicate failure to detect even when leopards are present. Therefore, while absence can never be verified for certain, the presence of leopards in a given area becomes relatively unlikely if no evidence is encountered during several weeks of fieldwork (Box 5B).

Box 5A. Recognizing leopard sign

Unlike the tropical forests of Asia and South America, leopards are usually the sole large mammalian carnivore in African forest environments. Adult resident leopards will often travel along roads or paths and deposit their feces in visible places for marking purposes, and their signs are therefore the most frequently encountered, leaving little chance for confusion with other species. The tracks and scats of young leopards can, however, overlap in size with those of adult small cats, such as golden cat (*Profelis aurata*), caracal (*Caracal caracal*) or serval (*Leptailurus serval*), the latter two species frequenting forest-savanna edges. Moreover, in some rainforest areas, such as Nouabalé-Ndoki in Congo, or Ivindo in Gabon, spotted hyena (*Crocuta crocuta*) are starting to infiltrate forests via logging roads, increasing the likelihood of making mistakes in identification for those who are not trained in recognizing sign. We strongly urge that ambiguous sign not be utilized as evidence for leopard, and that only obvious traces left by adult leopards be used.

Fig. 1a. Diagram of front and hind tracks of leopard (Stuart & Stuart 1994); 1b. Photo of leopard tracks (J. Ray)

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Tracks

Felid tracks have an overall circular shape, with length and width about equal (Fig. 1a, b). A full-grown leopard will have a track that measures 7.5-11 cm in width and length, with the main pad at 4-7.5 cm. The dimensions of adult spotted hyena tracks are comparable but the overall shape is ovoid (Fig. 2a,b). Hyena tracks always show blunt claw impressions and lack three lobes on the posterior edge of the main pad, which is a distinctive feature of leopard tracks. Details on how to measure tracks and gaits can be found in Rabinowitz (1997) and Parnell (2000).

Fig. 2a. Diagram of front and hind tracks of spotted hyena (Stuart & Stuart 1994); 2b. Photo of hyena tracks (www.safaricamlive.com)

Scats

Leopard scats are elongated with one end often tapering, generally in several pieces each measuring over 6 – 13 cm in length and 2.5- 4cm in diameter (Fig. 3). While leopard scats can certainly be smaller than 2.5 cm in diameter, they should never be identified as such unless they are found in close association with adult leopard tracks. Interestingly, African civet (*Civettictis civetta*) scats are known to similar diameters to those of leopards, but can generally be distinguished by the contents (arthropod exoskeletons, fruit and seeds), odor (sweet), and placement (latrines, near puddles). Hyena scats are generally less elongated than leopard scats and typically have a higher bone content which rapidly turns them chalky white (Fig. 4). Felid scats with high calcium content also turn white, particularly when bleached by the sun, but typically a dirty white less like the 'plaster of Paris' appearance of hyena scats. Further aiding identification, hyenas typically deposit their scats in prominent latrines which leopards do not, although no evidence for this behavior on the part of hyenas has been found in forest habitats. For dietary analysis methods, see Ray (2000).

Fig. 3. Leopard scat (P. Henschel)

Fig. 4. Hyena scat (G. Balme)

Box 5B. An example of an ad hoc presence/absence survey

Philipp Henschel conducted surveys in several areas in southern Gabon between 2001-2003, to investigate the presence/absence of lions and leopards. During each survey he spent 4-6 weeks in the field, and deployed up to 12 camera traps. In one heavily hunted area, no evidence of large felid presence could be found, nor were any images of large cats captured by the camera traps. Interviews with local hunters strengthened the impression that large cats were absent from this area. During a four-week survey in an adjacent area with lower hunting pressure, leopard scats and tracks were encountered four and three times respectively, and the camera traps produced two images of male leopards. Leopards were believed to be present at low numbers in this area, and interviews with local hunters corroborated this impression.

If an area where a survey is planned is frequented by local human populations, people can often be an invaluable source of information prior to the survey, and to validate results after the fieldwork. One convenient aspect about large carnivores is that encounters with such animals (or their sign) happen at low enough frequencies and are considered memorable enough that people tend to readily recall when and where they have seen them. Hunters are often the most knowledgeable informants, and cover substantial ground during their hunting forays. It should be remembered that there is an important difference between information derived from casual conversations and questioning of local people, and formal interview surveys. Special care should be taken to remain neutral during questioning, so as not to bias the answer (see details in Rabinowitz 1997, White & Edwards 2000).

Detection devices, such as camera traps, can also be used for the simple objective of detecting leopard presence. If their placement occurs in an ad hoc fashion (as opposed to systematically [see Section 5.2]), their use should be limited to confirming presence, and not establishing absence. They should be used to supplement leopard sign and interview surveys, rather than to replace either one of those methods.

5.2 Presence/absence – systematic surveys

More ambitious study objectives, such as evaluating spatial distribution, or estimating the proportion of a given area occupied by leopards ("patch occupancy;" MacKenzie et al. 2002; 2003), can be accomplished using presence/absence surveys, provided they are executed in a systematic, rather than ad hoc fashion. Knowledge about spatial distribution of leopards or patch occupancy is as important as estimating how many individuals are present to assess leopard status (Thompson et al, 1998). Careful attention to the sampling design is critical to ensure that the survey is systematic. First, the area of interest should be divided into a grid using a manageable grid cell size. There is no rule regarding the size of the grid cells, only that it should not exceed the minimum home range area of the target animal. Cell size will, however, influence the coarseness of the resulting data, and is a balance between required resolution of the survey and degree of effort. There is also no rule regarding the shape: square or hexagonal grids are examples of spatial sampling units that have the smoothest fit against one another, leaving no gaps in between.

Using the grid cells as the sampling units, the survey objective would be to identify presence or absence of leopards within each unit, either by searching for leopard sign, or using detection devices. With a sufficient and representative sampling effort, leopard spatial distribution in a larger area can be mapped. Typically, it will be impossible to sample all grids in the study area. Therefore, special attention must be paid to the sampling design. For example, distances between sampled cells must be minimized, otherwise one might be left with large enough gaps across which it cannot be sure whether leopards are present or not. There are numerous sampling designs available (systematic sampling, and simple and stratified random sampling, for example), but the method widely considered most suited to the typical distribution of large carnivore individuals within a population is adaptive cluster sampling (Karanth & Nichols 2002). This builds on a simple or stratified random sampling design by sampling all the cells bordering those where leopard presence was recorded in the initial survey, and continuing to do so until the cluster is surrounded by cells that fail to detect leopard presence.

While detection of leopard presence is assumed to be determined without error, the same cannot be said for non-detection, which can indicate either absence of leopards or "presence with non-detection" (Karanth & Nichols 2002). Assuming that failure to detect leopards indicates absence, therefore, would lead to biased estimates of site occupancy (MacKenzie et al. 2003). The next step would then be to estimate detection probability, or probability that animals that are present have escaped detection (Karanth & Nichols 2002). The detection probability can be assessed either by having multiple observers independently visit the same cell where no sign has been detected, or having the same observer visit that cell on different occasions. This statistic can be used to adjust the estimate for the number of cells where leopards were detected, which can yield information as to the proportion of area occupied (see Karanth & Nichols 2002). MacKenzie et al. (2002; 2003) have developed this further using models to estimate site occupancy rates when the probability of detection < 1. They have written a program PRESENCE, whereby these types of data discussed in this section can be entered and analyzed automatically to come up with estimates of patch occupancy rates and related parameters. This program is available for download along with other population analysis software from the U.S. Geological Survey Patuxent Wildlife Research Center, at http://www.pwrc.usgs.gov/monitoring2/.

5.3 Relative abundance

i. Using indices to derive relative abundance estimates

Relative abundance estimates can be derived from quantitative indices of abundance that have a direct relationship to absolute densities. Examples of such indices may include number of leopard sign encountered per unit distance or number of leopard photos per unit effort. If it is impossible to obtain absolute density estimates, monitoring programs based on relative abundance data — if collected consistently and with a sufficiently high sampling effort per survey — can indicate whether a leopard population is increasing, decreasing, or relatively stable (see Section 5.3ii). Estimating the relative abundance of leopards throughout a given area can provide a robust index for the relative abundance of potential prey species (medium-sized mammals [5 – 70 kg; Hart et al. 1996, Henschel 2001, Ray & Sunquist 2001]), as they are likely a main determinant for leopard abundance. However, if leopards are hunted by humans in the study area, variation in leopard abundance may instead reflect differences in hunting pressure and not differences in prey availability (as long as domestic prey [goats, sheep, dogs, etc.] are not prevalent).

The most efficient way to estimate relative abundance for leopards is to go one step beyond presence/absence surveys by quantifying all tracks or scats encountered along game trails or artificial roads, while keeping track of distance surveyed using a GPS or hip chain unit. A study on large carnivores in Namibia revealed a strong correlation between track counts along trails and roads and absolute population density (Stander 1998). Relative abundance can then be expressed as an encounter rate (e.g., the number of tracks/scats per 100 kilometers walked). This allows for comparisons of different areas within a larger site, or for comparisons between sample years or seasons. As mentioned above, variations in leopard abundance may be related to natural variation in prey availability due to seasonal, habitat, or inter-annual productivity. Leopard abundance may also be related to direct or indirect human hunting pressure, either on the leopards themselves or on their prey base. Care should be taken during analysis of such survey results to control for such variables, to identify if there is an existing or potential threat to the leopard population under study.

Depending on the prevalent substrate, tracks might be more difficult to find than scats, with the latter often proving to be a better indicator of leopard activity in African forest environments. We do advise, however, that surveys be conducted simultaneously for both tracks and scat to generate a combined index. If a survey route is to be re-surveyed, an adequate interval should be left in between walking the same routes, so as to be sure that old sign perishes and only new sign is counted in each subsequent survey. The length of this interval will depend on the season (with scat decay occurring faster during the wettest periods), but our recommendation is one month. It should be noted, that the number of sign collected represents "standing crop" only (Wemmer et al. 1996), and not the amount of sign accumulated over the entire one month period (i.e., the disappearance of some sign is inevitable). Removing all sign after each survey is also an option if surveys are planned at shorter intervals, but then one must be certain that the intervals are of more-or-less equal duration, and that all sign is also removed for a similar interval prior to the first survey. The data should then be expressed as N/L (number of sign per unit length walked), where L is the total of the cumulative number of kilometers walked.

One tool that can be used to augment scat sample size is to place artificial track beds in strategic locations known or likely to be used by leopards. The use of scent stations or track beds with prepared tracking substrates, that were mixed to match pre-existing trail surfaces but recorded tracks better, served to increase the number of collectible tracks in a study on jaguars (Miller 2001). Maintenance of these areas, however, can be quite problematic depending on the existing substrate in the study area. The characteristics of clay substrate often found in African rainforest sites (including both authors' study areas), has a tendency to harden quickly after a few hours of sun. Without regular importation of different substrate (such as sand) and/or a moistening agent, the quality of tracks obtained on these surfaces will degrade quickly after they have been laid out. This type of system requires considerable upkeep, and although it might be useful if track beds can be maintained properly, we do not recommend this technique when study sites are remote, or the field team is small. The use of attractants to lure cats to these track station has been applied with some success for Neotropical cats (Miller 2001, Harrison 1997), but has never been attempted for leopards to our knowledge.

Relative abundance can also be assessed with remote cameras (Carbone et al. 2001, O'Brien et al. 2003) using an index of leopard photos obtained per 100 trap nights of effort. Such a method does, however, make assumptions that capture probabilities are constant across time and locations, which may be easily violated (Jenelle et al. 2002). Furthermore, there is the consideration that because the cost of camera traps, personnel, etc. required to derive rate-based indices would not differ markedly from that needed to obtain estimates of capture probabilities, abundance, and densities of leopards (see Section 5.4), there is little reason *not* to utilize a population estimate framework, given that the theoretical foundation for use of mark-recapture methods have been adequately demonstrated. While obtaining mark-recapture-based estimates is certainly the preferred survey method, particularly when individual leopards can be identified, there are circumstances where rate-based abundance indices would be useful. Examples include: 1) in new study areas where investigators might have little idea where to place cameras where it might be difficult to set up an appropriate mark-recapture survey design, 2) where camera trapping programs are already in place in which leopards are not the target species, and/or 3) where the number of cameras are insufficient to obtain accurate individual identifications.

ii. Monitoring

Leopard status can be monitored over space and time using either presence/absence or relative abundance statistics. Monitoring distinguishes itself from simple surveys as being repeated assessment of status within a defined area over a specified time period rather than one time only (Thompson et al.1998). Investigating the variation in relative abundance of leopards in a study area over time is a means to evaluate their response to certain threats. By the same token, the ability to detect declines in the spatial occurrence of leopards can be helpful in understanding the effects of land use changes that occur differentially over a broad area (Zielinski & Stauffer 1996). Evaluating the null hypothesis, i.e., that there has been no change in relative abundance between time *a* and time *b* begs the important question: if a significant population decline has occurred, what is the probability that the survey has enough power to be able to detect it (Kendall et al. 1992, Zielinski & Stauffer 1996)? Correctly rejecting the null hypothesis (and accepting the alternative) is known as statistical power, which must be considered *a priori* when designing and planning a monitoring scheme.

Sample size and variance are the most important factors that will determine the ability to detect a change in leopard status. If the number of sampling units is too small, and/or the variance too large, a monitoring program is in danger of joining the many that have been determined to be "insufficient to detect even catastrophic declines in populations over short periods" (Zielinski & Kucera 1995:8). In developing a sampling scheme to monitor changes in population status, it will be critical to determine *a priori* the probability of detecting significant changes for varying sample sizes. This will allow an investigator to choose an adequate sample size to ensure that a change in occurrence or abundance will be detectable with an acceptably high probability.

5.4 Population density

It is always preferable to design surveys that will estimate absolute abundance (number of leopards in the study area), or population density (number of leopards per unit area), and provide an estimate of the variance associated with the estimates. Encounter rates of scat and tracks often vary with habitat and/or substrate, so apparent differences in relative abundance between sites with differing habitats may be due in fact to detectability differences. Density estimates factor in habitat variation and are thus preferable.

Population density is defined as the number of individuals (N) per unit area within a predefined study area. Collecting robust capture-recapture statistics depends on the ability to differentiate between individual leopards. Because of their elusive nature, it is highly unlikely that one can identify (photo-capture) all individual leopards using a certain area. However, capture probabilities and population sizes can be estimated mathematically if some of the animals can be individually identified and periodically recaptured (White et al. 1982).

During each sampling period, all individuals captured must be identified. The data from all the sampling periods are used to calculate the total number of individuals in the population within the study area as a function of the sample population (those individuals that were identified, as well as the mean number of unknown individuals that appear on occasion, known as transients; for details, see Section 7.1i). Once the total number of individuals has been calculated, this is divided by the size of the study area to obtain an estimate of leopard population density. This result represents an absolute value that can be compared with density estimates derived from any other study regardless of size and/or habitat type. In addition, estimated variance can be used as a measure of the reliability or the precision of a given density estimate. Leopard densities ascertained within protected areas is the first step towards determining whether a given population exists at levels viable for long-term persistence. This will depend, in some measure, on the degree of protection leopards can count on outside protected areas. Comparisons of leopard population densities between areas within a larger region that vary in protection level and/or degree of threat gives conservation managers baselines against which to gauge the impacts of forest modification and human pressures on forest leopard populations.

6. Survey Techniques that Allow for the Individual Identification of Leopards

The ability to identify individual leopards is a vital pre-condition for obtaining robust population density estimates. Although traditional mark-recapture models were developed with the premise that individuals were physically caught and marked, noninvasive identification of individuals by their fur patterns or other markings serve exactly the same purpose (Karanth & Nichols 2002).

6.1 Tracks

Several authors have demonstrated that it is possible to identify individual large cats in a population using careful measurements of their tracks (Smallwood & Fitzhugh 1993, Grigione et al. 1999, Lewison et al. 2001, Miller 2001). With a series of measurements developed especially for hind foot tracks, individuals theoretically can be identified using Discriminant Function Analysis (Smallwood & Fitzhugh 1993). The disadvantage with this method is that a high number of track sets (ideally consisting of up to 20 prints of the same paw) must be obtained from each of several individuals to determine discriminating variables for any given population. To obtain tracks that will yield accurate measurements, they must be lifted from a hard substrate covered by dust or sand; those lifted from loose or muddy soil will distort track shapes (see Karanth et al. 2003). Soil conditions are highly variable across rainforest sites and, especially during the wet seasons, trails and roads are often too muddy to acquire good sets of tracks. If the soil is deep, toes are often splayed and the measurements become distorted. Aside from the track quality problem, finding tracks may be difficult. During 10 months of fieldwork in this study, Henschel only encountered two good sets of rear leopard tracks. Although it is certainly possible to accumulate large numbers of track samples of resident individuals over time, it is not feasible in many situations to do so in shorter term survey efforts. Karanth et al. (2003) recently cast considerable doubt on the validity of the "pugmark census" method used in India to derive density estimates for tigers in India, raising the point that even though individual tracks can be discriminated against statistically, the essential next step to derive population estimates in a general sampling framework has not been done.

We recommend that any high-quality leopard tracks that are encountered should be recorded. At the very least, such data will be of use as a supplement to other survey methods discussed in this manual. The longer the residency in a study area, the more useful this technique will be over time for identifying individual leopards. Moreover, collection of track measurements will be of use in the event that new means are developed to handle these data. Ideally, one should collect tracks by tracing or photographing tracks in the field, and record information on associated parameters to generate a useful database (Box 6A).

In summary, although tracks are very important sources of information, we do not recommend them as the sole means of deriving population density estimates because of the improbability of being able to identify individuals in surveys of relatively short duration. The exception would be in sites with favorable soil conditions, where a large enough sample of tracks that would reflect the existing variability across all individuals frequenting the area, can be obtained easily. In some central African sites, for example, logging roads may consist of adequate substrate over long stretches, which in the dry season may yield similar conditions as in studies on mountain lions, where this method has delivered good results (Smallwood & Fitzhugh 1993). Regardless of the frequency of encounter of tracks, we advocate careful recording of track data and associated parameters in any leopard survey.

Box 6A. Recording and measuring leopard tracks

Because large cats generally step into the tracks of the front feet, rear feet tracks are generally of the best quality. Hence, most track measurements are of rear feet, which can be distinguished from front feet tracks by their smaller size and the edge of the heel pad which is curved inward rather than straight (1). The lead toe, or the second toe extending farthest from the pad (2), provides the clue in distinguishing left from right feet. In left feet it is positioned on the right, while the converse is true for right feet.

front left foot **hind left foot**

The two options for collecting and recording tracks are tracing or photographing tracks in the field. Tracks can be traced with water soluble marking pen onto a rectangular plexiglass suspended just above the track, and transferred onto acetate sheets. Tracks can also be photographed with digital or 35-mm cameras, preferably with a macro or close focus setting (Miller 2001).

There are as many as 52 measurements one can make of tracks, including length and width measures of the track, the pad, toes, ratios of features, angle measurements, and others (see Smallwood & Fitzhugh 1993, Riordan 1998, Grigione et al. 1999, Miller 2001). Carolyn Miller (2001; 2003) has developed a software-assisted track measurement program for jaguars that might be useful for leopard. Other information associated with the track that should be recorded in the field include location, substrate, front or hind foot, left or right, and relative age of track.

6.2 Genotyping scats and hair

Genotyping of fecal DNA is a recent technique, used to identify individuals of a given species. Individuals of mountain lions (Ernest et al. 2000) and coyote (Kohn et al. 1999) were identified using microsatellite markers in DNA extracted from scats collected in the field. It must be noted, however, that these studies (and many more) were carried out in temperate zones. Assembling a large collection of carnivore scats can be an enormous challenge in tropical forest areas. In these forests, scat tends to decay much faster, due to the higher humidity and temperatures, and to the activities of termites, dung beetles, and other invertebrate fauna. Sometimes vertebrates are attracted by any undigested (particularly meaty) matter, and quickly consume any material apart from hair and bone. During 10 months of fieldwork in this study, for example, only seven out of 61 scats obtained were not invaded by insects or covered in fungus. Sometimes scats exposed to direct sunlight (e.g., on a logging road) are an exception: if the whole scat dries rapidly and thoroughly, it loses its attractiveness for most organisms apart from termites, and can remain intact for several days depending on the rain.

Sample size of scats is also influenced by weather conditions and by scat collection effort. In areas with a pronounced dry season it is common to encounter two or three times more scats during the dry season than the rest of the year (Henschel, pers. obs.; Ray & Sunquist 2001). With minimal assistance during his study, Henschel accumulated 61 scats during 10 months. When there are more people available to search for scats, as was the case during leopard diet studies conducted in CAR (Ray & Sunquist 2001) and Congo (Zaire) (Hart et al. 1996), large scat collections may be built up. During both studies, modest monetary or other bonuses rewarding scat collectors were offered as extra incentive for search effort.

If fresh leopard scats can be encountered on a regular basis, genotyping them may offer an excellent option for identifying individuals. This technique and its potential as a census method, however, have not yet been explored for large carnivores in tropical forest environments. With digestion of DNA by bacteria occurring at the fastest rates in warm, humid environments, genotyping of tropical scats may never enjoy as much success as those from temperate environments. It is only likely to be successful for scats that are quite fresh or were quickly dried (e.g., on a road surface; G. Mowat, in litt.). In addition, there is the common problem of identifying a wildlife genetic lab that will perform the analyses, which may also be an additional (substantial) expense. Furthermore, because DNA identification can have associated errors (Creel et al. 2003), one cannot be 100% certain of positive individual identification, which can lead to spurious capture-recapture estimates. At any rate, assuming such problems can be solved as they have in temperate environments, scat genotyping as a census technique has at least some promise for the future. In the meantime, it is probably well worth the effort to collect DNA samples from collected scats for future opportunities (Box 6B).

Box 6B. Collecting DNA samples from scat

To obtain a sample for DNA extraction from a scat, about 1 cm^3 of soft matter should be removed from the surface of the scat, using rubber gloves and a sterile stick. Carnivore faecal samples can be used for both species identification and individual identification There are a number of liquid and dry preservation methods that can be used, including 90% ethanol, various buffers, silica dried, and oven-dried, the latter two either stored at room temperature or frozen. Murphy et al. (2001) found that both preservation method and storage time affected PCR amplification success rates, with ethanol-preserved samples having the highest success rates. Their recommendation was to collect faecal DNA samples in 90% ethanol at =4:1 ratio by volume (12 ml ethanol:2-3 ml faeces). Alcohol stops degradation immediately, which is a particularly significant problem in hot, humid environments.

Collecting hair in a snagging device and genotyping this for individual identification is an additional technique that is being widely used for cats in temperate and boreal habitats (McDaniel et al. 2000), but to our knowledge, this method has not been attempted for carnivores in the tropics. Bait sites surrounded by barbed wire or rub pads baited with a lure (such as catnip) are two methods that merit testing; an essential first step will be to test leopard response to scent. Some of the same problems faced by fecal DNA will impact hair sampling efforts in the tropics, although to a lesser extent. Avoiding collection during rainy seasons would likely assure that hair would contain enough DNA for genotyping for several days to a week (G. Mowat, in litt.).

6.3 Remote photography (camera trapping)

Individual leopards can be identified relatively easily as each has a unique spot pattern. Because direct sightings of leopards are exceedingly rare in the tropical forest, identification of individuals is only possible using remote photography. Photographic capture-recapture estimates of the abundance of a large cat were first obtained for tigers in India (Karanth 1995). A great deal of work followed, further developing this technique for estimating densities of forest cats, which has led most researchers to conclude that this method holds the most promise for estimating absolute abundance of large elusive carnivores. Like tigers, forest leopards regularly use game trails and roads for their movements, and placing camera traps in strategic positions along these travel routes will deliver photographic captures of individual leopards using the study area.

During two separate field exercises in 2001 and 2002, Philipp Henschel deployed camera traps to collect mark-recapture statistics for density estimates. He adapted aspects of sampling design and camera trapping methodology developed in Asia to African forest environments. During the first field season, Henschel conducted the first assessment of African forest leopard densities in one 18 km^2 area in Lopé National Park, Gabon. During the second phase, he estimated densities in four 100 km^2 study areas characterized by different habitat types. This experience forms much of the basis for the detailed look at camera trapping methodology that follows. For this method to yield the most robust estimates, it is crucial to have a high enough capture rate of leopards to be able to apply capture-recapture statistics. The following sections will provide guidelines in achieving high capture rates, which relate to delineation of the study area, equipment, the setup, and trap placement, among other factors.

7. A Detailed Look at Camera Trapping as a Method to Estimate Leopard Abundance

7.1 Sampling design considerations

i. Study area boundaries

There is often little choice in defining a study area, as it may be dictated by jurisdictional boundaries, habitat divisions or by logistics. In general, the larger the study area, the better. The accuracy of the density estimate increases with population size, as the larger the area, the smaller the 'edge effect' (the chance of overestimating density because some animals counted along the edge of the survey area are only "partial residents", i.e., they do not reside in the study area 100% of the time: White et al. 1982). The proportion of partial residents declines with study area size. However, striving for a larger study area must be balanced against the need to maximize recapture probabilities of individuals as well as to meet certain assumptions in mark-recapture models. Failure to meet the assumption of population closure (sampling period is short enough such that no births, deaths, or emigration/immigration incidents occur) during mark-recapture studies, for example, can also lead to overestimates in population size. Maximizing probability of recapture can be addressed through trap placement and number of traps (see Section 7.1iii).

Therefore, the safest bet will be to maximize the study area relative to the available effort within the time frame necessary to meet the closed population assumption. Logistical considerations such as number of camera trap units, the daily distance that can be covered, and number of personnel, will dictate the available effort. It should be noted that there is no golden rule for determining the maximum allowable time for meeting the closed population assumption. While this would ideally be determined through relatively detailed knowledge of the demographic parameters of the leopard population in question, this is generally impossible. Karanth & Nichols (2002) recommend a maximum sampling period of 8-12 weeks in their study on tigers, but parameters can change considerably in between species and even study areas, and the sampling period should always be kept as short as possible. The program CAPTURE (see section 7.6) however, allows to test one's data for population closure, and open models, although less preferable, are also available if necessary (Karanth & Nichols 2002).

Like all large carnivores, leopards maintain home ranges that must be large enough to provide them with sufficient prey year round. While information on African leopard home range size in savanna habitats is plentiful, only three individuals have ever been radio-collared in the forest biome. Jenny (1996) placed radio collars on one male and two female leopards in the Taï NP, Ivory Coast, and found that the home range was 86 km^2 for the male, and for the females 29 km^2 and 22 km^2, respectively. In between sexes there can be a complete overlap of home ranges (Jenny 1996), and even for home ranges of individuals of the same sex, there can be some degree of overlap (Rabinowitz 1989, Grassman 1999). The study area should ideally be large enough to contain at least parts of the home ranges of several individuals. For their studies on tigers in India, Karanth & Nichols (1998) placed their camera traps over areas ranging in size from 49 – 142 km^2, and identified a minimum of five individuals in each area.

ii. Number and placement of units

For most camera trap studies, the number of units available is usually the limiting factor. It is, however, crucial to the sample design that the whole study area is evenly covered with traps, and that none of the individuals present has a zero chance of being captured (Karanth & Nichols 2000; 2002). The individuals with the smallest home ranges in a population of leopards are adult females. In prey-rich habitat, adult female home range can be as small as 9 km^2 (Grassman 1999). It should therefore be assured that at least 2-3 traps are placed in an area of this size, if prey numbers are expected to be high in the study area (Karanth & Nichols 2002). This will result in a distance of about 2 kilometers in between traps, and as a consequence about 25 traps would be needed to cover an area of 100 km^2 evenly. It is important to note that the effectively sampled area will be considerably larger, once the buffer is added (see Section 7.6iv).

If fewer camera units are available, the solution is to subdivide the area into smaller sub-sections and sample them one by one (Karanth & Nichols 2002). If, for example, the plan is to sample an area 100 km^2 with only 10 available camera traps, the study area can be subdivided into four blocks of the same size, with each block sampled one by one. This, however, increases the total length of time required to execute the survey. If the area is divided into three smaller pieces, the sampling of the whole area will logically take at least three times longer than it would if one had enough units to cover the whole area at once. However, complete coverage of sampling in all the sub-sections would have to be accomplished within the time frame dictated by population closure (2-3 months). This will determine decisions regarding the length of time units are left out in the field, as well as how many desired or planned occasions of capture and recapture. During data analysis, all the sub-sections are treated as one large area (see Section 7.1iii).

Because one of the most important aspects of camera trapping theory is to obtain as many photo recaptures of each individual, and to photocapture as many different individuals as possible (Karanth & Nichols 2000; 2002), it is critical to optimize trap placement so as to maximize the chances of capturing a leopard. As we have mentioned before, leopards, like other large cats, are known to travel along roads and trails, so we strongly recommend the placement of traps along well-used elephant trails and logging roads. Ideally, one should do several weeks of reconnaissance walking throughout a study area to evaluate relative use of leopards based on sign, and place the camera traps accordingly, along routes where leopard sign has been spotted. Local hunters may be of additional help in defining such areas. Spots where trails/roads intersect, river or stream beds, or where prey species naturally congregate may be good candidate sites, even when there are no overt indications that leopards have been there.

The major factor affecting leopard capture probability seems to be the availability of travel routes in the different study sites (Box 7A). If there are many trails of comparable widths, leopards have more choices of where to go and it becomes correspondingly difficult to foresee where a leopard will travel, and hence where to place a detection device. In areas with a relatively low road density (i.e., logging concessions), leopards have fewer choices for their travel, and capture probability, and hence capture rates, will increase along these roads. The capture-recapture approach should deal with this difference in capture rates, because it actually estimates the prevailing capture probabilities for individuals in the respective area, and produces a population estimate with confidence limits. But there might be sites where the capture probability is so low that one cannot get enough captures (let alone re-captures) to yield a robust density estimate and the confidence limits are very wide. Even if no leopards are re-captured, however, as long as there have been single captures of several individuals, it will be possible to use certain recapture models to derive a density estimate. Otherwise, the only real option available is to increase effort (see Section 7.1iv). There is also the possibility, however, that the low rate of captures is actually indicative of a leopard density that is too low to achieve a reliable estimate of density, regardless of the amount of camera trapping effort (Karanth & Nichols 2000).

iii. Number of occasions for capture and recapture models

In capture-recapture studies the same area should be sampled several times with equal effort. Each event of sampling the area is defined as one 'trapping occasion' (Karanth 1995, Karanth & Nichols 1998). Increasing the number of 'occasions' for capture and recapture will usually also enhance the precision of the results. As always, it is the more the better, but about ten occasions of capture-recapture should yield good results in capture-recapture studies on tigers (Karanth & Nichols 1998). While designing a study, it is useful to try and find a compromise between the number of days that units are set up and the number of desired trapping occasions. In areas where there is easy access it might be possible to change the location of each trap after each sampling occasion, but for more remote areas it is advisable to leave all units set up for a certain number of days, and later define each day as a separate trapping occasion. So if the decision is to leave all units set up in one area for ten days, all animals that are being photographed on the first day are captured during occasion one, all animals filmed on the second days are grouped as being captured during occasion two, and so on. In cases where a larger area is subdivided, all captures occurring on the first day of trapping in each of the subsections are summed up, and represent the number of captures on capture occasion one. The number of captures/recaptures obtained on capture occasion 2 will then be retrieved by summing up the number of capture/recaptures for the second day of trapping in each block, and so on.

Box 7A. How road or trail type might impact leopard capture probability: Results from the Gabon study (Henschel)

During a pilot study on leopards in the Lopé Reserve in 2001, I distributed camera traps evenly over a small study area of 50 km^2, which consisted of a mosaic of forest and savanna in the north, and Marantaceae forest in the south. I chose a total of 30 trap sites and half of them were placed along the many available dirt roads in the forest-savanna mosaic, and the other half on elephant trails in the forest to the south, where no roads were available. During a period of 72 days, where the five units were periodically moved in between all sites, I obtained 16 pictures of leopards, with only three taken on an elephant trail, and the remainder of captures from the traps set up along dirt roads. To detect the reason for this significant difference in capture success, I conducted another study in four different habitat/disturbance settings.

1. Marantaceae forest: A natural secondary forest with a very dense understory and no roads, few large elephant trails, but a dense network of elephant feeding trails. No disturbance apart from researchers and occasionally tourists using parts of the trail network.
2. Primary forest: Open understory forest with no roads, few but very large elephant trails. Subsistence hunting and low levels of market hunting occurred in the area.
3. Abandoned logging concession: Network of abandoned logging roads embedded within open understory logged primary forest. Roads were overgrown to some extent, but still much bigger than elephant trails. No human presence for at least six years.
4. Active logging concession: Network of active logging roads embedded within relatively dense understorey young primary forest. Roads received varying levels of traffic. Few elephants were present in this area due to disturbance from logging, obvious elephant trails were rare.

These habitat/disturbance settings are among the most common ones for tropical forests in Africa. Marantaceae forest might be a local variety, but can be compared in structure to other types of open canopy, secondary forest with very dense understorey, dominated by a different family of herbaceous plants. For this reason these sites were chosen for this comparative study on estimating leopard densities in various African forest types. In each of the four sites, traps were set up on the available trail type that was thought to be most frequently used by leopards, as judged by frequency of leopard sign. These were: 1) For Marantaceae forest and primary forest, the largest available elephant trails, which were often those trails that followed rivers or ridgelines; 2) for sites with past logging, the largest available logging roads; 3) for sites with active logging, all logging roads except ones with heavy logging truck traffic, as during this study neither tracks, nor scats were ever encountered on these heavily used roads. In all sites except primary forest, no hunting occurred, and prey availability (likely to be the main factor influencing numbers of large carnivores), was comparable between all sites. This was also reflected by the results for capture rates for all mammals combined (Table 2).

Table 2. Photo capture rates for all mammals.

site	trap days	captures	capture rate[1]	disturbance
Marantaceae forest	389	463	119.02	none
primary forest	223	46	20.63	hunting
abandoned concession	344	251	72.97	none
active concession	399	139	34.84	logging

[1] captures/trap day x 100 to standardize

continued next page ➤

continued from previous page

An important question of this study was to explore the relationship between density of leopard paths and leopard photo-capture probability. For each study site, I estimated the total length of the optimal potential leopard trail by collecting 'tracklogs' along each trail with a Garmin 12 XL GPS unit. I then expressed trail density as the km of trail/road /km^2 for each study site.

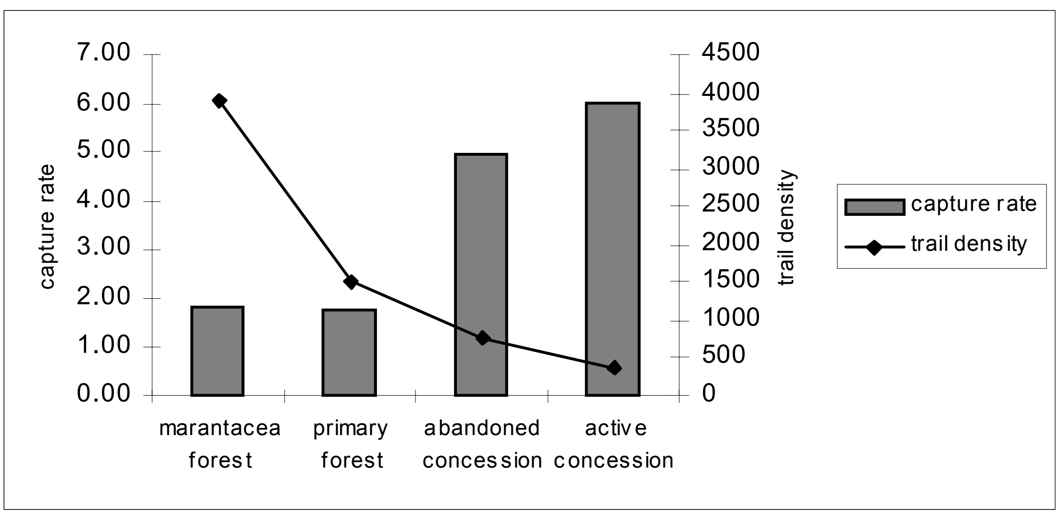
Capture rates were highest in Marantaceae forest, and lowest in primary forest where hunting occurred. The majority of the animals captured in all sites consisted of potential prey species for leopards, especially duikers and pigs. Assuming that differences in capture rates reflected actual differences in animal densities, it could be concluded that the available biomass was by far the highest in Marantaceae forest. Logically, the availability of potential prey should then also allow the highest densities of leopards in this habitat, but this was not reflected through capture rates for leopards (Table 3; Fig 5). Capture rates for leopards were low in Marantaceae forest, where the highest capture rates for potential prey species were recorded. But these low capture rates are not believed to reflect low leopard numbers in this habitat, corroborated by the relatively high number of individuals identified (Table 3; Fig. 5). Four different leopards could be identified on seven photographic captures, whereas in the active concession, where some hunting occurred and leopard numbers were probably lower, only five individuals could be identified from a total of 24 photographic captures. High capture rates do not therefore necessarily reflect high numbers of leopards, but rather an elevated ability to capture leopards along a certain trail or road type.

Table 3. Leopard photo capture rate comparison between sites.

site	trap days	captures	capture rate[1]	no. of individuals	trail density[2]
marantaceae forest	389	7	1.8	4	3898
primary forest	223	4	1.79	1	1498
abandoned concession	344	17	4.94	7	764
active concession	399	24	6.02	5	357

[1] leopard captures/trap day x 100 to standardize
[2] km of available trail/km^2

Fig. 5. Leopard photo capture rate comparison between sites.



iv. Adapting the sampling scheme to experience in actual capture rates for leopards

Depending on the capture rates achieved for leopards during the first weeks of the study (which might be considered a pilot study), one should be ready to modify the time units remain set up, or the number of days defined as one sampling occasion when appropriate. If the total number of captures is very low, the ability to investigate sources of variation in capture probability, and thus to select the most appropriate model for estimating abundance (see Section 7.6iii), are expected to be limited (Karanth & Nichols 1998). To acquire enough data for a more precise estimate of population size, one might then consider boosting effort by increasing the amount of time units remain in one site, and to group several days together as one occasion. To give an example, if just three images of the same leopard were obtained during a study period of ten days, where all camera traps were set up in one area, this could mean that there is just this individual using this area. Another option however, is that no other individual was photographed because capture probabilities for individual leopards were extremely low in this area. This can sometimes be due to a dense system of elephant trails in the area, which makes it difficult to predict which paths leopards will choose (see Box 7A). One way to overcome this problem is to increase the number of trap days (the total sum of days each unit remains activated) in the area. For the next attempt of sampling the area, a period of three days in a row could be defined as on sampling occasion, and all camera traps remain set up in the area for a total period of 30 days (check after 15 days to change film and batteries if required). These 30 days worth of data can later be subdivided into ten separate trapping occasions, each consisting of three consecutive days, and each of them comprising an independent data set. Logically this longer study period should yield three times more captures, and there will be a higher probability that other individuals will be photographed if they occur in the area.

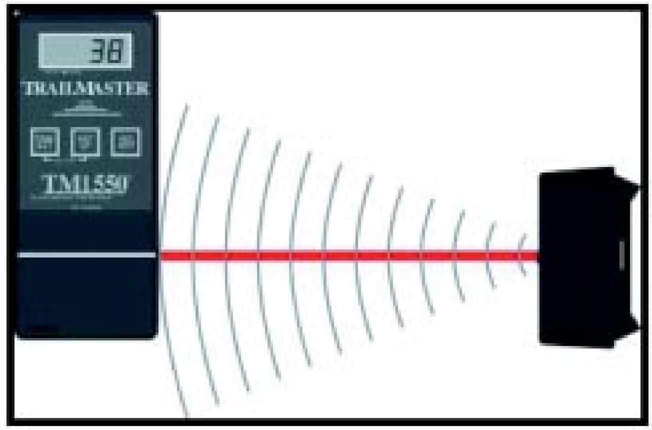
7. 2 Choice of camera trap: the TrailMaster or the Camtrakker?

While there are increasingly more choices on the market, the TrailMaster and Camtrakker brands are currently the two dominant brands for mark-recapture surveys of forest carnivores.

i. The active TrailMaster (TM) trail monitor

The TM 1550 is a two-piece monitor which sets up an invisible beam across the trail between the transmitter and the receiver (Fig. 6). This unit can be used with various accessories; most important is the TM35-1 Camera Kit, which allows one to obtain photos of target species. By setting the beam at the chest height of the animal that is being monitored, and controlling the length of time the beam must be blocked before it registers as an event, certain species can be effectively targeted, although certainly other species roughly the same size will trigger the camera as well. Each time an animal passes through the infrared beam, the event is recorded by date and time to the minute, storing up to 1000 events. The unit can be programmed to trigger the camera at certain times of the day. For example, if the study species are only nocturnal animals, the TM can be activated only during the hours of darkness, which saves both film and batteries. If there is diurnal vehicle traffic along a road that would trigger the units during the day, the units can be programmed to be active only at night, in order to save film. A delay can also be programmed where the camera remains inactive after it has been triggered. This avoids multiple photos of a group of animals passing in front of the unit, or animals foraging in the vicinity of the trap for extended periods of time. The delay option ranges from 6 seconds to 98 minutes, and can be programmed in steps of 2 seconds in the beginning, and in steps of two minutes from 40 onwards. Recommendations for programming the TrailMaster tailored to leopards are presented later in this document (Section 7.3). These camera units can be ordered by accessing www.trailmaster.com.

Fig. 6. TM camera set-up



ii. The passive CamTrakker (CT) trail monitor

The CT unit combines a 35mm camera with a passive infrared motion detector that senses heat-in-motion within a conical area (Fig.7). The unit is attached to a tree on one side of the trail to be monitored. It should be secured at chest height of the target species, thereby maximizing capture probabilities, although a wide range of species is usually picked up by this passive trail monitor. If an animal walks along the trail the sensor should be triggered and the camera will take the picture. Like the TM, the unit can be programmed to 24-hour operation, day-only or night-only, and a delay can also be programmed where the camera remains inactive after it has been triggered. But there are only six delay options, ranging from 20 seconds to 45 minutes, which can de disadvantageous compared to the wider range and the possibility of finer tuning with TM units. These units can be ordered at www.camtrakker.com.

Fig. 7. Camtrakker unit

iii. TrailMaster versus CamTrakker

The TM unit offers more data collection opportunities than the CT unit. In addition to the 35mm camera that will imprint either date or time of the photograph, the receiver will separately record date and time, for all incidents. Hence, if a unit remains set up for several weeks, and the camera is programmed to record the time, the receiver will record date and time, and by comparing times in between camera and receiver the date every picture has been taken can be worked out. It is necessary to go through the developed rolls of film frame by frame, browse the receiver's recorded incidents simultaneously, skip incidents where the camera was delayed (see below) and note the date for each frame. Apart from the photographic captures obtained, these images provide data on diurnal activity patterns of the target species. The sensitivity of the unit can also be modified in TM units. The factory settings proved to be well suited for leopards, but if smaller species are targeted, the sensitivity can be enhanced to increase capture rates. The wider range in the programmable camera delay and the possibility for a finer tuning of this delay, have already been mentioned above.

The CT unit is much simpler to set up, lighter in weight, less cumbersome to carry, and about US 120.00 less expensive than the TM unit. If a tighter budget is called for, and/or the work is being undertaken in a relatively remote area, where there is no vehicle access and units must be carried in a backpack over long distances, we recommend the CT. CT units are also easier to set up, and require little training relative to TMs. Setting up a TM 1550 is much more complicated and involves several more steps, in contrast to CT units, which can just be strapped to a tree pointing to a trail and simply turned on. In areas where theft of units might be an issue, it is also convenient that CT units are delivered with a locking flange and can be securely locked to a tree or post, making the whole units tamper-proof. With CT units we experienced a high rate of "out of the box" damage. Of 24 units ordered from CamTrakker, six units, or a total of 25%, never worked. These units were ultimately replaced by CamTrakker, although not without discussion, and the transport between the US and Africa was challenging, to say the least. Our recommendation would be to order the units early enough so as to avoid the inevitable delays in the launching of fieldwork. TM units can fill up with water during heavy rains, and sometimes cameras are triggered for unknown reasons, without any events having been recorded. CT units also produce fewer empty frames (Box 7B), and TM units sometimes triggered the camera because the beam is broken by insects walking along the unit housing, or leaves simply fell on the trail. For a direct comparison of pros and cons for both brands of camera traps see Table 4.

iv. Other options

An option would be to retain the advantages of a TM unit, which is that it records every incident with date and time and has a wider range for camera-delay, and to remove the disadvantage of the infrared beam, which is that it produced 50 % of empty frames during this study. The TM 550 trail monitor is a passive infrared motion detector that records all movements of warm-blooded animals in front of the sensor. Combined with the TM 35-1 Camera Kit it will produce photographs of animals walking along the trail in front of the sensor, but cannot be triggered by insects, rain or falling leaves. The TM 550 has the same capabilities for data storage and delay options as the TM 1550. This unit however, has not been tested in this study, and its performance in the field has yet to be tested for a rainforest environment. This unit is also available at www.trailmaster.com.

CamTrakker also offers a unit that is fitted with a digital camera, the price of which is US 650.00. The advantage is that even in the field images can be downloaded to a portable computer, with the additional (and not always predictable) costs of film processing therefore avoided. The disadvantage is the initial higher price, which may be problematic in cases where units are destroyed or vandalized. In this study, for example, Henschel lost five units to elephants, and would be reluctant to pay a higher price and then maybe lose more money in the end. In areas where elephant (or human) damage is unlikely, the use of the Digital CamTrakker may be a good option. As with any other digital camera, one can change the resolution of photographs obtained, and the lowest resolution setting (1024 x 768) will allow 65 images.

Table 4. Comparison of Trailmaster and Camtrakker camera traps.

Unit	TrailMaster	Camtrakker
current price	US 550.00	US 429.59
approximate weight including batteries	1700 gr.	900 gr.
is sensitivity adjustable	yes	no
camera delay options	fine tuning, 6 sec - 98 min	six steps, 20 sec -46 min
set up process	requires some training	very easy
weather proofness	can fill up with water	water proof
can unit be locked?	no	yes
out of box damage during this study	0%	25%
failure rate in the field	29%	11%
rate of empty frames	52%	12%

Box 7B. Testing the CamTrakker against TrailMaster in the field (Henschel).

To test the performance of both brands in the field, I set up CamTrakker and TrailMaster units in identical spots in four different study areas and on different types of trails. There were no significant differences between TM or CT for their capture rates of leopards and of other mammals (Table 5).

Table 5. Comparison of capture rates between camera trap brands.

unit	species	trap days	captures	capture rate[1]
Camtrakker	all mammals	1110	742	66.85
Camtrakker	leopard	1110	44	3.96
Camtrakker	golden cat	1110	12	1.08
Trailmaster TM 1500	all mammals	245	157	64.08
Trailmaster TM 1500	leopard	245	8	3.27
Trailmaster TM 1500	golden cat	245	1	0.41

[1] captures/trap day x 100 to standardize

Although I experienced a relatively high out-of-the-box failure rate with CTs, once working, CT units proved to be more reliable than TM (Table 6).

Table 6. Comparison of failure rates between camera trap brands.

unit	trap days	days unit failed	failure rate (%)	frames taken	empty frames	empty frames (%)
Camtrakker	1110	139	11.13	844	102	12.09
Trailmaster TM 1500	245	98	28.57	327	170	51.99

In addition to the CT and TM units that are the subjects of this manual, there is an ever-growing number of additional camera trap options out on the market, many of which have not been tested by wildlife biologists (Appendix 1). Researchers working in less remote North American fieldsites are beginning to evaluate other systems; WCS' Global Carnivore Program is currently testing two alternative systems and will summarize the results for distribution once an adequate assessment is made .

7. 3 Setting up and programming the units

i. Camera activation

Deciding whether cameras should be active during the entire 24 hour period or just during night hours really depends on the activity cycles of the target species. In this study it was found that leopard activity cycles seemed to vary with the amount of human disturbance in the study area (Box 7C). This observation goes against the common perception that leopards are mainly nocturnal or crepuscular, and we therefore advise that units should be active both day and night.

Box 7C. Relationship between leopard activity and human disturbance (Henschel)

During the Lopé study, camera traps were placed in four different areas that were characterized by varying degrees of human disturbance. All traps were activated day and night, but the trend was that leopard movements on trails appeared to be affected by the relative degree of human disturbance (Table 7).

Table 7. Time of day for leopard captures.

site	no. of leopard captures	percentage of captures in daylight	disturbance at site
Marantaceae forest	7	28.6%	none
primary forest	4	0%	hunting
abandoned concession	17	64.7%	none
active concession	24	8.3%	logging & hunting

In areas with hunting pressure, leopards only used trails at night, and in an active logging concession where hunting also occurred, their movements were nearly restricted to the hours of darkness (6 pm – 6 am). But in the abandoned concession, where there had been no appreciable human disturbance over the last six years prior to the study, more than 60 % of the leopards' movements on trails occurred during daylight hours.

ii. Programmed delay for sequential photographs

It is always advisable to use the fastest available camera settings (shortest delay options), if the circumstances in the study area allow one to do so (O'Brien et al. 2003). Otherwise, the longer the delay between sequential photographs (maximum is 45 minutes for the CT, and 98 minutes for the TM unit), the greater the chance that for a hole to develop in the trapping grid while the camera is blocked from taking pictures and any leopard moving through the trap during the delay would have a zero capture probability, thus violating the model underlying capture/recapture studies (see Section 7.1ii). In some areas, however, using the fastest settings is not feasible due to the densities and behavioral traits of animals using the study area. In our experience, it is not uncommon for a whole roll of film to be exposed in a matter of hours by groups of elephants or pigs if cameras are programmed with short delays. O'Brien et al. (2003) left cameras in place for about 30 days, and in 84 % of all cases there was still unexposed film left. During the pilot study in Lopé, on the other hand, cameras were set up using the fastest settings, and were checked every two days, but even after this relatively short period no unexposed film was left in 10 % of all cases, a rate similar to what O'Brien et al. (2003) experienced after 30 days. If the rate of film exposure experienced in Lopé is used to calculate the percentage of cases where unexposed film would be left using the fastest settings, in only 21 % of all cases would unexposed film be left after 30 days. This would leave about 80% of all traps no longer functional towards the end of the sampling period, thus leaving very large holes in the trapping grid and creating big areas with a zero capture probability – again, a violation of the model underlying capture/recapture studies. It is therefore advisable to use longer camera delays if units cannot be checked frequently, and if high numbers of elephants and pigs in the study area are likely to use up film quickly. Rain, and insect walking along the housing of the unit and cutting the infrared beam repeatedly, can cause further problems for TM units, and can easily result in the entire 36 exposures being used up in a short time. The decision about how long the delay should be is therefore a trade-off between the risk of losing a leopard who walks by after the unit has been triggered by one of the more numerous forest inhabitants, and that of losing several days of data if the delay is programmed for too short a time and the film is used up. Based on our experience we would recommend the longest delay in remote areas with abundant wildlife, as especially curious elephants or large groups of feeding animals (especially terrestrial monkeys and pigs) sometimes loiter around the unit for up to several hours. Places where we advise the shortest possible time delay are some logging concession areas, or other regions that are characterized by lower elephant densities. One should, however, settle on a uniform delay setting for all cameras operating within the same survey site.

iii. The number of cameras at a station

For complete identification of a leopard (see Section 7.5), it is generally necessary to acquire photographs of both sides of its body. The spot pattern is different on each side, so photos of the left side of an individual tell us nothing about the right side. The scenario that is strongly recommended therefore is to set up two cameras on each side of the trail at each station. However, if one is experiencing important constraints due to high costs, personpower and/or the remoteness of the area that might limit the total number of cameras available, one might explore other options. While we are not advocating cutting corners unnecessarily, we are mindful of the reality of certain field conditions. We stress only that in making due with a less than optimal study design, a researcher be keenly aware of the risks inherent in following certain approaches, particularly as they pertain to violating mark-recapture assumptions.

One solution might be to collect two different sets of identifications, left sides and right sides. The side represented by the most photographs would form the basis of analyses (O'Brien et al. 2003). Another method that can be used to acquire complete identifications of individual leopards frequenting the study area is to set up a pair of cameras on both sides of the trail at a subset of stations (O'Brien et al. 2003). While it would be certainly ideal to do so at every site, the disadvantage is naturally the higher cost per setup and the longer setup process. And if the supply of cameras is limited, they will be used up rapidly. For resident leopards, there could be a high probability of getting a full identification in a trap with two cameras at one single point, and then this individual can subsequently be identified from stations with one camera, no matter which side is shown on the photograph. We must be careful to stress that such a system relies a good deal more on luck than a two-camera set-up, and is therefore considered unadvisable by some experts.

The amount of effort required to set up cameras on both sides of the trail, varies considerably in between the two camera trap brands used in this study. If using TM equipment, one can purchase two TM 35-1 Camera Kits per unit and the TM Multi-Camera Trigger II, which allows one to operate TM units with up to three cameras (Karanth & Nichols 2002). One disadvantage is the camera cable for the opposite camera, which must be protected from animals, particularly elephants. One camera is usually set up close to receiver, and the camera cable can be secured to the same tree or post where receiver and camera area attached. For the other camera on the opposite side of the trail, it is a bit more complicated. The cable cannot be left lying across the trail because animals might trip, or remove the cable intentionally. The safest solution is to dig a trench across the trail, insert the cable into a hosepipe and bury the hosepipe in the trench. If the intention is to remove the cable after the site is surveyed, a cord can be tied to one end of the cable, pulled through and recovered. If the site is reactivated the cable can be pulled in through the same way. But digging the trench can be a considerable effort in remote areas, as well as carrying hosepipe or some other form of protection for the cable. Setting two CT units on opposite sides of the trail will incur about the same cost as the TM set-up described above, but will be much easier.

iv. The appropriate heights and distance from trail

The infrared beam for the active trail monitors should be at a height of about 40 cm from the ground. At this level one can be sure that at a normal gait leopards will cut the beam with their body, rather than just with their legs. The beam will then be cut for a long enough interval, so that the camera is triggered by the receiver. The heat-in-motion sensor for passive trail monitors should be attached at a similar height. For these sensors it is also crucial to aim at the center of the body, where body temperature here is higher than in the extremities of the animal. For these sensors however, one must be careful not to point them towards objects that could heat up in the sunlight (like rocks or exposed tree trunks), or else the unit might no longer detect the warm-blooded animal if the background is even warmer than the animal. Open areas are also a potential problem during daylight hours.

Regardless of whether active or passive trail monitors are used, the camera itself should be mounted about two meters away from the center of the trail. If it is moved closer to the trail, difficulties arise of obtaining full photographs of the leopard, and if further away than about three meters, images obtained by night are often not well lit, because the in-built flash for the camera is relatively weak.

v. Factors that determine checking interval

Battery life is usually not the restricting factor in tropical environments. CT units can operate 1-2 months on one set of batteries, after which point the control light starts getting faint and batteries should be changed. TM units can operate with one set of batteries for up to six months; if battery power diminishes, this is indicated on the LED of the receiver.

The factor that generally determines the time interval in between which cameras should be checked, is the amount of time it takes until all film is exposed. As a general rule the cameras should be checked as often as the logistical situation in the study allows one to do so. If logistics are easy, the camera delay can be programmed to the fastest settings (see above), and the unit should be checked on a daily basis. This will deliver the best results, because the unit is always active and chances are low that the film will be exposed in just one day. A leopard walking past that trap site will therefore never have a zero capture probability, and the model for capture/recapture is not violated (see above).

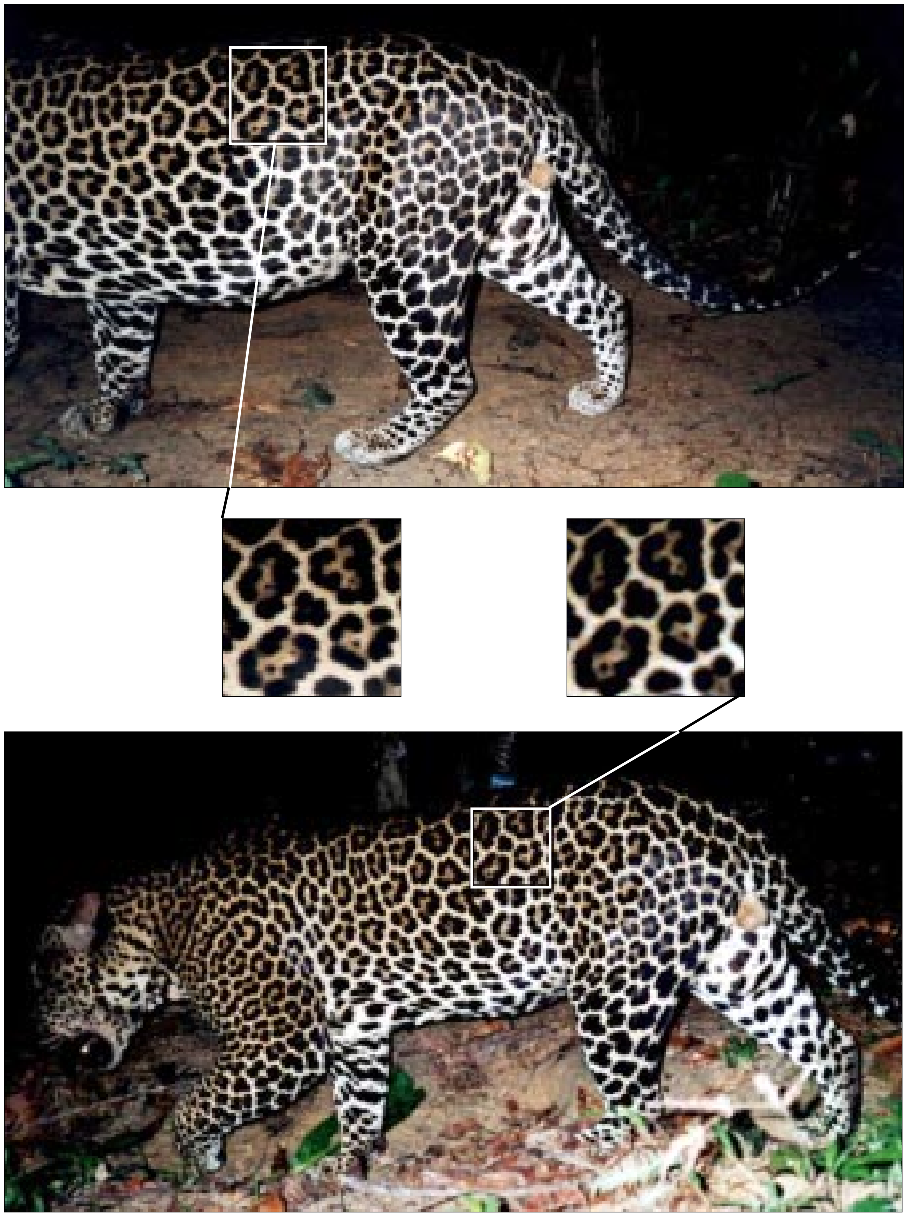
In most areas complicated logistics will dictate a much longer period in between the checking of each trap. As discussed above, programming the longest available delay will save film, thereby avoiding a situation where holes are created in the trapping grid. Henschel generally had success checking units every 10 days. Even on heavily used game trails one whole roll of film was never totally exposed during this period, as long as the longest possible camera delay was programmed. In heavily hunted or otherwise unproductive areas on the other hand, as few as 5 frames were exposed in two weeks. If, in any given study area, it is apparent that trail use by animals is generally low, one might be able to decrease the programmed camera delay, and even increase the interval between visits to check the cameras, if there is still no risk of having no unexposed film left in the units.

vi. Deploying baits or lures

Baits or lures are often deployed by researchers at camera trap sites as attractants to encourage visitation by carnivores in temperate environments (e.g., Zielinski & Kucera 1995). The rationale behind this is to provide extra incentive to widely dispersed individuals that may not otherwise happen to pass by a passive camera set. In effect, it has the potential to increase effort with the same number of camera traps. Another reason for going this route is in cases where cameras are set up away from trails. Although we do not recommend this, it may be perceived as necessary in some cases if regular game trails and travel routes have high volumes of human traffic.

As long as the effort and baiting pattern/protocol is standardized, the use of such attractants probably does not have any major sampling implications and poses no statistical problem for capture-recapture estimates. For cats, the most common ingredient in lures is catnip, which can be purchased in dry form from North American pet supply stores (G. Mowat, in litt.). Kitchener (1991) has reported that leopards respond to catnip. Given that cats generally have a weak sense of smell, the lure is unlikely to draw one in

Fig. 8. Example of the unambiguous identification of the same male leopard, using camera-trap photographs of the characteristic spot pattern on the flanks.



from any great distance. On the other hand, if the cat is stimulated by lure, there is always the small risk that a ritualized rubbing response will be elicited which may cause the individual to remain at the spot and even return (G. Mowat, in litt.). Lures have not been tested for forest leopards in humid forest environments, and their lasting power is unknown. Acquiring bait sources is highly problematic in African tropical forests, due to the low availability of livestock and difficulties of transport. The accelerated decomposition rate in such environments adds further complications that in most cases will not be worth the effort.

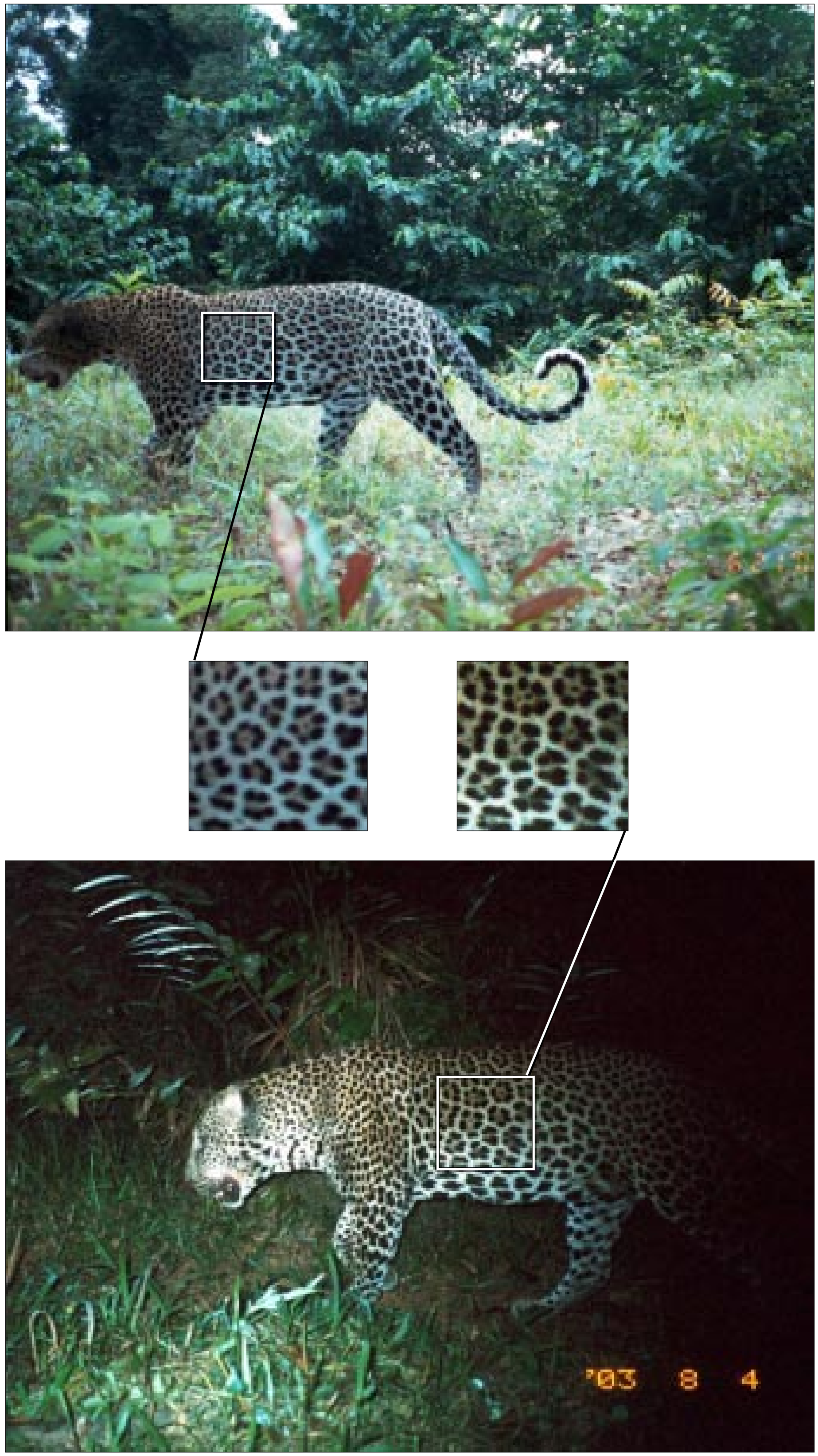
7.4 Recording data

The most important aspect is that field researchers must take care to provide unique identification numbers to each camera and each roll of film before it is loaded, which should be retained all the way through the processing stage. Trap-stations must also have identifications as well as corresponding map locations, and care must be taken to match rolls of films, dates, and camera units with those locations. Leopard photos by themselves will be of little use without taking meticulous records. With such a system in place, it should be possible for different people to check the status of cameras. Karanth & Nichols (2002) contains further recommendations for field protocols.

7.5 Identifying individual leopards from photographs

The photographs obtained are generally of high enough quality to enable individual identification of leopards, even in cases when only parts of the body are evident. The next or confirming step in individual leopard identification is by use of coat pattern. In the beginning, the process can be overwhelming if one is trying to separate individuals from a series of images. Individual identification using spot patterns should not be attempted by looking at the whole animal. The easiest way that we recommend to proceed is to scan each image, and to create digital ID cards for every individual. Using a computer program such as Adobe Photoshop, one can zoom in to certain parts of the flanks, and search for areas with distinct features, like clusters of rosettes with unusual shapes. One large male shown in Fig. 8 was captured several times during Henschel's study. Even at the first glance, a cluster of spots on the hind part of his upper left flank seemed to deliver a good means of identification; a series of small spots enclosed in larger rosettes in different positions, a feature easy to retain and useful for comparisons with other individuals. For new photographic captures of males it is then just necessary to enlarge the same part of the flank, and it can either be confirmed that the new capture shows the same individual, or the cluster of rosettes will have a different appearance. For an example of unambiguous identification of two different individuals see Fig. 9. One can also use a regular scanner to scan portions of the negative, slide or print, and analyze the images using black and white printouts (A. Noss, in litt.).

Fig. 9. Example of the unambiguous identification of two different leopards.



For any new photograph, simply judging from size and proportions of the animal shown, it is usually possible to figure out which of the already known individuals this animal could be. After having scanned the new image, one should zoom in to parts of the flank where the known individuals show distinct features (see above), and usually one can discern quickly whether this animal is known, or if it is a new identification. In addition, it is often possible to determine from the proportions of photographed leopards whether they are juveniles or adults, and in the case of adults, their sex (Fig. 10).

Fig. 10. Differences in size and proportions between adult female (above), and adult male (below)

We recognize that not all field workers will have access to a computer or appropriate software that enables one to handle scanned images. Identification of individuals will certainly not be impossible under such circumstances, and the same principles as described above can still be followed using actual photos with the aid of a magnifying glass and bright light.

7.6 Data analysis

i. The computer program CAPTURE

The computer program CAPTURE (White et al. 1982, updated version by Rexstad & Burnham 1991) has been developed to implement closed-population capture-recapture models. For just two cycles of capture and recapture, the calculation of the resulting population size is still simple, but for more than two cycles it is advisable to use this program. As mentioned previously, to meet the assumption of a closed population, the study period should be kept no longer than 8-12 weeks (Karanth & Nichols 1998). If the study period must be extended to have enough time to cover the complete study area, and it is not known whether the assumption of a closed population was met, CAPTURE provides an opportunity to test the closure assumption statistically. The program and useful literature can be downloaded at www.cnr.colostate.edu/~gwhite/software.html.

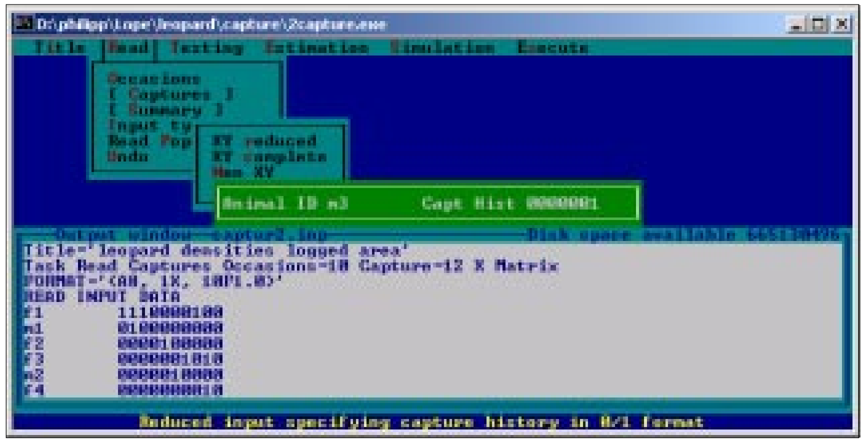
ii. Developing a capture history of each individual leopard

After all data collection is terminated, 'capture histories' must be developed for each individual identified during the study. These capture histories can be entered for all individuals directly into the program CAPTURE in form of a matrix. This matrix is called 'X matrix', and every row in it represents one individual leopard, and every column one sampling occasion. This matrix can be filled out row by row (meaning individual by individual), by typing either "1", or "0", depending on if the individual was captured during the occasion or not (Fig. 11). The number of occasions and the total number of captures can also be entered in the matrix. Then one can precede to the select a model for the calculation of population size.

iii. Model choice

The program CAPTURE offers seven different estimators of population size. The simplest model, the null model (M_0), assumes no differences in capture probability in between different individuals and sampling occasions. M_h tests for differences in capture probability in between different individuals, and M_b allows differences in capture probabilities between newly caught individuals, and animals that were already captured. Thus, the program can actually model whether the fact of having been photographed once affects the probability that an animal will be photographed a second or subsequent time(s): in other words, whether it avoids the camera-trap site. M_t assumes difference in capture probabilities in between different occasions, and CAPTURE also allows one to combine all the above models, resulting in three more estimators, M_{bh}, M_{th} and M_{tb}. It is also possible to choose all estimators of population size, and CAPTURE will choose the most probable model among these. Karanth & Nichols (2002) recommend M_h as the model of choice, as it incorporates heterogeneous captures probabilities. This makes sense given the biological fact that large cats are territorial animals, with home range size and trap access variable depending on social position and spatial location of the animal on the landscape (U. Karanth, in litt.). The advantages of this program are that it can cope with violation of many of the original assumptions in earlier capture-recapture programs (e.g., that individual might avoid traps, there are sex differences in capture probabilities, or that seasonal differences are in play).

Fig 11. Data entry into the programm CAPTURE. At the current state capture histories are entered for all individuals identified.



iv. Calculation of population density

To acquire a solid estimate for leopard population density using the resulting population size from CAPTURE, it is crucial to estimate the size of the study area as precisely as possible. In trapping-grid studies it is recognized that the area from which animals are captured, is not equal to the area enclosed by the outer traps (Otis et al. 1978). It is therefore typical to add a boundary strip to the area defined by the outer traps, because animals are being captured from this area as well (Otis et al. 1978). In their study on tigers, Karanth and Nichols (1998) computed the boundary strip width using the "mean maximum distance moved" for all tigers that are captured on more than one occasion. The boundary strip width was then defined as being half the mean maximum distance moved (Karanth & Nichols 1998), resulting in the equation:

$$W = (\Sigma d / m) / 2,$$

where W was the resulting boundary strip width, d the maximum distance moved, and m the number of maximum distances compared. Then the boundary strip of width W must be added around the perimeter of the area covered by camera traps, to obtain the sampled area. One can then estimate leopard population density as

$$D = N / A(W),$$

where D is the resulting leopard density, N the population size computed by CAPTURE, and $A(W)$ the resulting area sampled, including the boundary strip.

A slight modification of this approach was recently utilized by Silver et al. (in press) in estimating jaguar densities. Rather than using a boundary strip, the effective sampling area included a circular buffer around the outer camera trap sites, the radius of which was calculated as half the mean maximum distance among multiple captures of individual jaguars during the sampling period.

7. 7 Using camera traps to survey other species

i. Smaller carnivores

Altogether seven species of carnivores were photographed during Henschel's camera trapping efforts. Even though the units were set up for the much larger leopard, the passive CT trail monitors in particular were able to pick up a wide array of smaller carnivores. The species captured were golden cat (*Profelis aurata*), servaline genet (*Genetta servalina*), African civet, palm civet (*Nandinia binotata*), marsh mongoose (*Atilax paludinosus*) and black-footed mongoose (*Bdeogale nigripes*) (Fig. 12). All the above species were captured on a regular basis, apart from palm civets which are more arboreal and probably do not move along trails so often. For understandable reasons more aquatic species like the spot-necked otter *Lutra maculicollis* were never captured. Slender mongoose *Herpestes sanguinea* is probably too small to be picked up. Two other carnivores present in all study areas were honey badger *Mellivora capensis* and blotched genet *Genetta maculata*, but they were never captured.

Fig. 12. Photos of other carnivores opportunistically recorded during leopard camera survey in central Gabon: a) servaline genet (*Genetta servalina*); b) spotted hyena (*Crocuta crocuta*); c) African palm civet (*Nandinia binotata*); d) African golden cat (*Profelis aurata*); and e) Black-footed mongoose (*Bdeogale nigripes*).

It should be noted that several of these species (golden cat, genet, and black-footed mongoose) were never captured in live traps during two years of effort in southwestern CAR (Ray & Sunquist 2001), and very little is known about any of them beyond the notes of the old museum collectors. Several species — particularly genets and civets — have distinct coat markings, such that identification of individuals should be possible with high quality photographs. Because the principal aim of this study was to obtain full images of the larger leopard, traps were set up about two meters away from the center of the trail, and other carnivores appear relatively small on the images. However, if the survey objective is the smaller carnivores and the units are moved closer to the trail, a study targeting these smaller carnivores using photographic captures and capture-recapture theory should be feasible without constraints, and should be tested in the near future. Indeed, researchers in Bolivia have used mark-recapture techniques for estimating densities of small carnivores that they are able to identify individually, such as ocelots (A. Noss, in litt.). Even if individuals cannot be identified, it may be possible to use cameras to come up with relative abundance estimates (see below). Our recommendation for smaller carnivores would be to delineate a much smaller study area (1-5 km^2), to significantly decrease spacing between units, and to set cameras along smaller game trails in addition to logging roads and larger elephant trails.

ii. Other species

There are not many ungulate species in the African rainforest that have distinctive markings on the coat, so distinguishing individuals will be impossible for most. One exception is bushbuck (*Tragelaphus scriptus*): In the forest-savanna interface in the northern Lopé Reserve, they were frequently photographed, and can be easily identified by their stripe pattern. Indeed, densities were calculated using the photographic captures obtained (Lopé, unpublished data). Sitatungas (*Tragelaphus spekei*) occur throughout the whole region, but no single photograph was obtained for this species during this effort, a result that is probably best explained by their preference for marshy areas. The distinctive coat patterns and large size of bongo (*Tragelaphus euryceros*) and okapi (*Okapia johnstoni*) make them an easy target for a study using camera traps. Bongo has already been studied with success using this methodology (Elkan 2003).

During Henschel's study, 17 good quality images were obtained for gorilla, and 14 for chimpanzee. It might be relatively difficult to build up a catalog with identifications just from these images, as for some pictures it might just be possible to see parts of the face (the most distinctive feature for apes), and a complete ID card with a description of the whole face cannot be obtained. But in areas with ongoing studies on gorillas or chimpanzees, where several individuals are already identified, distributing camera traps throughout the area might deliver supplementary information about the movements of known individuals.

Besides duikers and pigs, elephant was the species most frequently captured on film during Henschel's study. Most images however, just showed feet and parts of their belly. For the identification of elephants, vein structures and holes and rips in the ears and size and shape of tusks are very important characteristics. If the camera is attached about 1 ½ meters above the ground good pictures of that part of the body may be obtainable. As for gorillas and chimpanzees, full identifications just from pictures can be difficult, depending on the position of the ears in different pictures. In addition, if there is an ongoing elephant project at a site, additional information can be acquired about the movements of known individuals.

iii. Presence/absence and relative abundance

Even if animals cannot be individually identified, camera trapping will still be very useful for evaluating presence/absence and/or relative abundance. For the wider-ranging mammals (i.e., those that cover > 1 km/day), photographic rate indices can serve as a measure of relative abundance. This statistic can be calculated for each species from the number of camera days (24 hour period) per photograph summed against all cameras in the study (Carbone et al. 2001). Photographic rates must however, be calibrated against independent estimates of animal density in representative sites (O'Brien et al. 2003).

8. The Next Steps

Leopards cannot be effectively surveyed using the standard census techniques that target primates and ungulates — the two species groups most commonly studied for their research and conservation interest within the African forest biome. As a result, there is little known of either the natural history or the conservation status of forest leopards, the largest mammalian predator and sole large carnivore in this rapidly diminishing ecosystem. The little information that is available points to: a) a high degree of overlap between the principal prey species of leopards and human hunters (forest ungulates and pigs), b) a skin trade that is still active on a regional level, and c) evidence that in spite of the well-known adaptability of leopards, they have disappeared from many of West African forests, and have begun to exhibit signs of vulnerability on the fringes of the Congo Basin (Angelici et al. 1998, Bennett 2001).

This document is the result of an effort supported by the Global Carnivore Program of the Wildlife Conservation Society aimed at developing an effective survey protocol for African forest leopards. We view this as the necessary first step towards a regional assessment and priority setting exercise targeted at forest leopards, similar to those carried out on tigers (Wikramanayake et al. 1998) and jaguars (Sanderson et al. 2002). While some might argue that forest leopards are not under the same immediate threat that characterizes the situation facing the other two cats, it is our view that there are many advantages for proactive regional coordination right from the start.

For a region-wide assessment of leopard status, it will be important to conduct density estimates in areas with a range of vegetation cover and degrees of human disturbance (hunting and habitat clearing), preferably in a controlled "natural experimental" situation, to quantify the impact of such variables on leopard numbers. When representative leopard densities are known for the major forest types, the effects of habitat alterations like logging can be better evaluated. By comparing leopard numbers between sites with different human disturbances, for example, threats to leopards can be identified and quantified. Baseline surveys will form the essential first step towards developing conservation and research priorities for, and monitoring of, forest leopards in the Congo Basin and highly fragmented forests of West Africa (Abernethy et al. 2001). Depending on the results of such exercises, it may be useful in the future to hold a meeting where field scientists working in central and west Africa can collectively assess the available information, train field scientists in carnivore survey techniques, and establish a forest carnivore information clearinghouse.

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Appendix 1. Web Sites for Free Analytical Software

(updated from Appendix 6.0 in Karanth & Nichols 2002)

The programs CAPTURE and PRESENCE are downloadable from the web at the sites of the USGS Patuxent Wildlife Research Center, Laurel, Maryland.
http://www.mbr-pwrc.usgs.gov/software.html

The software CAPTURE, MARK, JOLLY, JOLLYAGE, etc. and the out of print Wildlife Monograph of Otis *et al*. (1978) are available from the Web Site of Gary White at Colorado State University, Fort Collins, Colorado. The site is maintained by Gary White who also maintains the MARK list server discussion group at the Colorado site that deals with capture-recapture issues.
http://www.cnr.colostate.edu/~gwhite/mark/mark.htm

The program DISTANCE 3.5 and DISTANCE 4.0 BETA 3 and the out of print book Buckland *et al.* (1993) are downloadable from the website of Centre for Research into Ecological and Environmental Modelling (CREEM). This site is maintained by Len Thomas at the Research Unit for Wildlife Population Assessment, University of St. Andrews, Scotland, U.K.
http://www.ruwpa.st-and.ac.uk/distance/

Appendix 2. Web Sites for Camera Trap Equipment Suppliers

(updated from Appendix 6.0 in Karanth & Nichols 2002)

CamTrakker - The big Buck Surveillance system
- target customers: deer hunters
- cameras use a passive infrared motion detector that senses heat-in-motion
- both 35 mm and digital cameras available

http://www.camtrakker.com/

Critter-Getter Game Cameras
- target customers: hunters and sportsmen
- camera uses an infra red heat/motion detector

http://www.critter-getter.com

Crow Systems
- target customers: "professional wildlife biologists and field researchers"
- designs and manufactures custom field research electronics "effective for virtually any research application"
- Web Site products page provides helpful insights towards the pros and cons of using Film-based camera systems, Digital Still, and Video - Analog/Digital.
- Crow Systems also provide field researchers assistance in acquiring a broad range of research tools

http://www.crowsystems.com/cameras.htm

Game Country Hawk-eye and Hawk-eye Jr. Game Cameras
- target customers: mainly deer hunters

http://www. game-country.com/

Game-Vu - Digital trail camera system
- target customers: game hunters
- product is a digital camera that uses 16 non-visible infrared lights

http://www.gamevu.com/

Highlander Photoscout
- target customers: game hunters
- offers both digital and 35 mm cameras

http://www.highlandersports.com

Kalimar Photo Tracker
- company appears to provide a wide range of photographic products

http://www.tiffen.com/

Moultrie Got-cha
- target customers: game hunters

http://www.moultriefeeders.com/

Non Typical DeerCam Game Cameras
- target customers: hunters

http://www.nontypicalinc.com/

Snapshot Sniper Digital Scouting System
- target customers: game hunters
- digital camera

http://www.snapshotsniper.com/

Stealth Cam Game Cameras
- target customers: game hunters

http://www.stealthcam.net/

TrailMAC
- target customers: game hunters
- both digital and 35 mm camera models available

http://www.trailsenseengineering.com/

Trailmaster - Trail monitoring systems
- target customers: field researchers, photographers, hunters
- has both active and passive infrared monitors, and a remote trigger video trail monitor

http://www.trailmaster.com/

Trail Timer - Game Monitors
- target customers: game hunters
- infrared 35 mm camera system
- also has a system that lets you use your own camera

http://www.trailtimer.com/

Vigil - Trail Infrared Monitor
- target customers: game hunters
- 35 mm camera

http://www.roc_import.com/gb/monitor/vigil_gb.php

WoodsWatcher
- target customers: game hunters
- 35 mm camera

http://www.woodswatcher.com/

Make your own Camera Traps

The Home Brew Game Trail Camera Project
- web site providing instructions on how to build your own camera trap

http://www.jesseshuntingpage.com/homebrew-cams.html

Field Pix Game Camera Systems
- Field Pix offers entire systems, partial systems, or just circuit boards for those who wish to build the camera themselves

http://www.fieldpix.com/

Jesse's Hunting Page
- web site detailing how to make one's own camera traps.

http://jesseshuntingpage.com/homebrew-cams.html
- also contains a feature comparison of brands.

http://jesseshuntingpage.com/cams.html

PixController
- provides electronic circuit boards for 35 mm Cameras, Electronic shutter control of Digital Cameras, and Video Camcorders.
- boards use an integrated Passive Infrared (PIR) Motion Control circuit to shutter the camera device, thus cameras are triggered when body heat **and** motion are detected

http://www.pixcontroller.com/

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