GPS telemetry of forest elephants in Central Africa: results of a preliminary study

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Abstract

Few data exist on the ranging behaviour of forest elephants. A feasibility study on the use of GPS telemetry as a tool to study ranging, seasonal movements and distribution was implemented in the Dzanga-Sangha and Nouabalé-Ndoki National Parks Complex of Central African Republic and Congo. The study consisted of two parts – a thorough hand-held testing of an elephant GPS telemetry collar under tropical forest conditions and the deployment of collars on two elephants. During the feasibility study the system performance was satisfactory; GPS fix acquisition success rate, VHF and UHF collar–researcher communications were adequate. Two elephants, a mature bull and an adult female, were immobilized and fitted with GPS collars in October 1998. After deployment, the female's GPS collar performed well initially, but in less than a month the GPS within the collar stopped acquiring fixes. She was subsequently located using VHF tracking. The male was never relocated strongly suggesting complete failure of the collar. Despite these setbacks, the small amount of data retrieved provide an important first insight into forest elephant ranging and daily activity patterns, with significant conservation implications. When technical difficulties of reliability are overcome, GPS telemetry will provide an exceptionally useful tool in forest elephant research and management.

Key words: Africa, conservation, elephants, forest, ranging, telemetry

Résumé

On dispose de peu de données sur le comportement de distribution des éléphants de forêt. On a réalisé une étude de faisabilité de l'utilisation de télémétrie par GPS comme moyen d'étudier la répartition, les déplacements saisonniers et la distribution dans le complexe des Parcs de Dzanga-Sangha et de Nouabalé-Ndoki, en République Centrafricaine et au Congo. L'étude se faisait en deux parties : le test minutieux, à la main, d'un collier pour éléphant avec télémétrie par GPS, dans les conditions de la forêt tropicale, et le placement de colliers sur deux éléphants. Pendant l'étude de faisabilité, les performances du système ont été satisfaisantes, le taux de détermination exacte de la position grce au GPS et les communications entre les colliers VHF et UHF et le chercheur étaient corrects. On a immobilisé deux éléphants, un mle et une femelle adultes, et on les a équipés de colliers GPS en octobre 1998. Ensuite, le collier de la femelle a bien fonctionné au début, mais en moins d'un mois le GPS a cessé de donner sa position. On l'a ensuite localisée par VHF. On n'a jamais relocalisé le mle avec certitude, ce qui laisse supposer une défaillance complète du collier. Malgré ces inconvénients, les quelques données récoltées fournissent un aperçu important sur la dispersion des éléphants de forêt et sur leur schéma d'activité quotidien, avec des implications significatives sur leur conservation, discutées plus bas. Lorsqu'on sera venu à bout des difficultés techniques en matière de fiabilité, la télémétrie par GPS constituera un outil exceptionnellement utile pour la recherche et la gestion des éléphants de forêt.

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Introduction

Radio and satellite telemetry have been an integral part of many research and management projects of African elephants (*Loxodonta africana*) for several decades (Douglas-Hamilton, 1971; Viljoen, 1989; Lindeque & Lindeque, 1991; Whyte, 1993; Thouless, 1995, 1996). Data have proved invaluable in determining ranging patterns, home ranges, habitat preferences, seasonal distribution, long-distance movements and migration. Savanna elephants vary considerably in their ranging patterns, from sedentary populations with small home ranges of tens of square kilometres (Douglas-Hamilton, 1971), vast home ranges of over 10,000 km^2 (Lindeque & Lindeque, 1991), to those with seasonal migration patterns (Tchamba *et al.*, 1994; Thouless, 1995; Verlinden & Gavor, 1998). Telemetry data have been used in land use management planning (Lindeque & Lindeque, 1991), conflict resolution between elephants and people (Tchamba *et al.*, 1995), and understanding the impact of intensive management (e.g. culling) on herd movements (Whyte, 1993).

In the mid-1990s GPS technology became widely available to wildlife biologists. Douglas-Hamilton (1998) conducted a pilot study using GPS elephant collars in the Amboseli National Park, Kenya. Two bulls were collared and their movements recorded over several months. Both collars recorded over 2500 fixes, and showed that the elephants spent the majority of their time outside the park. The pilot study showed that GPS elephant telemetry could provide high quality ranging data important in management planning.

In Central Africa, the ranging and migration patterns of forest elephants (*Loxodonta africana cyclotis*) are poorly understood (Turkalo & Fay, 1995; Vanleeuwe & Gautier-Hion, 1998). An understanding of ranging behaviour and seasonal movement patterns is important for effective conservation and management of elephants in protected areas. Two national parks of high elephant conservation value, Dzanga-Ndoki (DNNP) and Nouabalé-Ndoki (NNNP), form a contiguous forest block of 5150 km^2, straddling the international border between the Republics of Congo and Central Africa. Turkalo & Fay (1995) suggested that seasonal movements might take elephants outside these parks for extended periods. Given the success of the GPS collars used in the Amboseli pilot study (Douglas-Hamilton, 1998), a sister GPS telemetry research project was initiated in the Nouabalé-Ndoki and Dzanga-Ndoki National Parks. The aims of the study were to assess the feasibility of GPS elephant telemetry under forest conditions, and to determine elephant ranging patterns to assist management planning for the parks. The study, which is ongoing, consists of four stages:

1 a feasibility study of the GPS telemetry system under forest conditions;
2 fitting collars to two forest elephants in the DNNP, followed by a period of data collection to ensure successful operation on the elephants;
3 fitting collars to four more elephants in the NNNP;
4 GPS data collection over a period of 2 years, followed by a re-evaluation of the project.

This paper describes stages 1 and 2 in two parts. The aims of the paper are (i) to show that GPS telemetry is a feasible tool in forest elephant research, and (ii) to present data on the movements of elephants in the forests of Central Africa. Conservation implications of the data collected to date are discussed.

Materials and methods

The Nouabalé-Ndoki and Dzanga-Ndoki National Parks (hereafter referred to as Nouabalé-Ndoki-Dzanga Complex, NNDC) form a single contiguous forest block of 5150 km^2 (Fig. 1). Vegetation consists primarily of Sterculiaceae-Ulmaceae semi-deciduous forest, areas of monodominant *Gilbertiodendron dewevrei* forest, and swamp forests following watercourses. Local human population density is low ($< 1\ km^{-2}$), particularly in Congo, although a large logging village (Bayanga), with a population of about 2000, is only 12 km from the park border in CAR. The large mammal fauna is largely intact, and is characterized by high densities of forest elephants, gorillas (*Gorilla gorilla gorilla*) and chimpanzees (*Pan troglodytes troglodytes*) (Fay & Agnagna, 1991, 1992; Fay, 1997). The forest is among the last major forest blocks in Central Africa with few permanent human habitations, and where elephant movements are still largely unrestricted.

The GPS telemetry system

The GPS telemetry system has been described in detail by the manufacturer (LOTEK Engineering Inc., 1997) and by Douglas-Hamilton (1998). In summary, the system consists of an 8-channel GPS receiver, which has a built-in RAM capable of storing over 3500 fixes. The collar can be programmed to search for fixes at time intervals decided by the researcher, up to a maximum of once every 5 min. Vertical and horizontal motion sensors record an index of animal activity before every fix attempt. A traditional VHF receiver allows the collar to be located, and a UHF modem link allows communication between the collar and a remote laptop computer, usually from an aeroplane. This link allows data to be downloaded, RAM

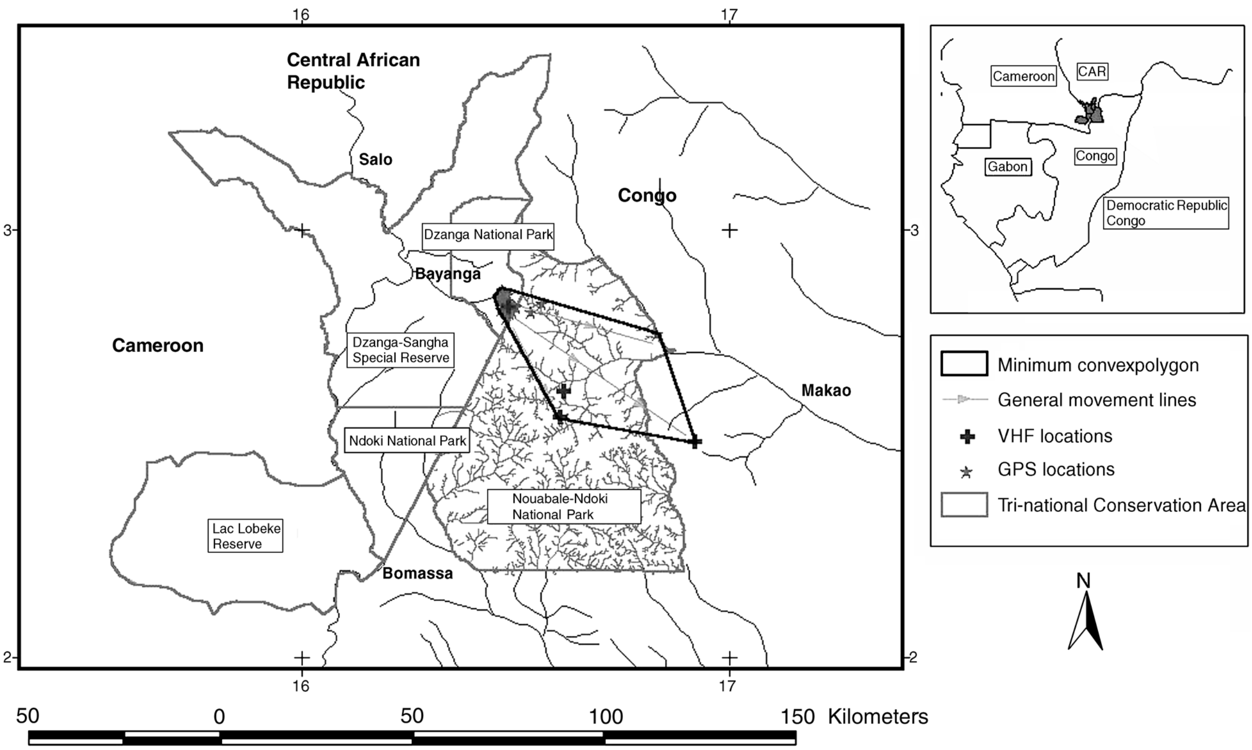

Fig 1 GPS and VHF locations of collared female forest elephant showing minimum convex polygon home range estimate

memory to be cleared, and the collar to be reprogrammed. With a regime of eight fixes per day and minimal communications sessions, battery life, according to the manufacturers, is ≈2 years.

Feasibility study

The aim of the feasibility study was to test all components of the GPS animal location system under operational conditions, although not on an elephant, in the forests of northern Congo. Specifically, the following questions had to be answered before the research team could make an informed decision on whether to proceed with fitting collars onto elephants:

1 What is the success rate of GPS fix acquisition attempts under the forest canopy conditions in the study area?

2 What are the characteristics of the VHF beacon, including the maximum detection distance from an aircraft and from the ground, and can the system be relied on to locate collars in dense forest from the air, and also from the ground?

3 What are the capabilities of the UHF communications modem under forest conditions, and can it be relied on to successfully communicate with collars?

Fix acquisition

A collar, programmed to take fixes every hour, was taken to the forest strapped to the backpack of a researcher, or attached to a tree or camera tripod stand. Elephant trails were followed, and feeding areas were visited to simulate actual elephant movements. At night, the collar was put on a tree with the antenna at a height of ≈170 cm and clear of large tree trunks. For all fix acquisition attempts details of weather conditions, vegetation type, canopy type, suitability of antenna position, and whether the collar was stationary or moving were recorded. All commonly encountered vegetation types found in the region were visited. Previous work with GPS units in the forest (Blake, unpublished) demonstrated that precision of fixes is as expected with selective availability errors (i.e. 95% of fixes taken at a point location are within a radius of 100 m of the mean value), and forest type appears to have no further influence. It was assumed that the performance of the collar GPS would be similar to those of hand-held units.

VHF beacon tracking and UHF modem communications

Ground test. This test determined the maximum communication distance between VHF receiver and collar. The ability to track a collared elephant on the ground would be crucial to the collaring programme, because an animal must be relocated from the ground for collar maintenance (battery change) and removal. The collar was hung in a tree with the GPS antenna ≈170 cm above ground, and with the belt containing the VHF antenna held out in a circular fashion to simulate the round neck of an elephant. The VHF receiver (Suretrack STR_1000 Telemetry Receiver, LOTEK Engineering Inc., Toronto, Canada) was assembled, and whilst walking in a straight line on a compass bearing, signal strength and gain setting were recorded with distance from the collar. This was repeated in several different habitat types, and also on sloping ground. The user continued walking until the signal was completely lost.

Aircraft test. Aerial surveys are the primary means of locating the collared elephants. The collar was placed over a branch in an area of closed canopy *Gilbertiodendron dewevrei* forest in a gully following a watercourse at ≈1 m off the ground. The GPS and UHF modem antennas were at ≈170 cm. Two VHF antennas were tested, a standard LOTEK Engineering H antenna and a four-element yagi antenna. These, together with the UHF antenna, were fitted in turn to the wing strut of a Cessna 182 aircraft. On test flights, altitudes of between 900 m and 2350 m above ground level (agl) were maintained until the VHF beacon was heard, and an attempt was made to keep at right angles to the collar for maximum range performance. On establishing VHF contact, UHF modem communications were attempted. Both VHF and modem communications were continued at varying altitudes and distances from the collar until failure. Gain was varied throughout for optimum VHF reception.

Collar deployment and preliminary data collection

A site in the DNNP was selected for the immobilizations. Site selection was based on several criteria: very high elephant densities, a forest clearing complex (called *Bais* by local Bambenjele pygmies), which offered excellent darting possibilities with elephants in the open, and a site at one end of a hypothesized migration route through the NNDC.

Two elephants, a mature bull and a mature female (accompanied by a juvenile of ≈4 years), were immobilized and fitted with GPS collars. Several elephants were darted but not fitted with collars due to either failure of immobilization or other extenuating circumstances. All animals were darted with carfentanil hydrochloride administered with 3 mL plastic Telinject darts with 2 × 60 mm non-collared needles. No mortalities occurred during or following immobilization. Two males and one female darted with 3 mg of carfentanil in the forest did not become immobilized, for unknown reasons. One female darted with 3 mg of carfentanil was found immobilized in the forest being protected by a male of approximately 6 years of age. When the young male was immobilized with 1 mg of carfentanil, the adult female simultaneously recovered from anaesthesia and stood by the immobilized young male. The male was reversed with 100 mg of naltrexone administered using the darting technique described above.

The adult female (estimated weight 2000 kg) was immobilized with 3 mg of carfentanil. On darting, she moved approximately 200 m into the forest before lying down. During the collaring procedure she was given a supplemental dose of 1 mg carfentanil IM to maintain relaxation. On completion of collar fitting she was revived with 350 mg of naltrexone hydrochloride IM (52 min after initial darting). Throughout the collaring procedure her assumed offspring remained standing ≈100 m away until her recovery. The immobilized bull elephant (estimated weight 4000 kg) was thought to be 40 years old. His tusks were 34 cm in diameter at the base and averaged 101 cm and 111 cm along the inside and outside curves, respectively. This male was darted in a clearing with 4 mg of carfentanil and was found standing in the forest approximately 100 m from the darting site and was minimally responsive to auditory stimulation. After being darted with 1 mg of carfentanil the animal became recumbent and another 1 mg was administered in an ear vein to provide good muscle relaxation. Twenty minutes later, the bull began to be aroused and was given another 1 mg IV to provide another 15 min of anaesthesia. Within 5 min of 1000 mg of IV naltrexone administration (72 min following the first darting), he stood up and walked away.

Results

Feasibility study

Fix acquisition. Fix acquisition rate for all habitat types was 52.4% of total attempts. Of these, 38.1% were 2D fixes and 15.2% were 3D. Vegetation types with open or sparse upper canopy cover provided the best conditions for fix acquisition (Table 1 and Fig. 2), with clearings, light gaps, plantations and villages having the highest success rates. Intermediate fix acquisition success was found in forest vegetation with an open upper canopy, including mixed open forest, vine forest and Marantaceae forest. Mixed closed forest gave the lowest fix acquisition rate at 9.8% of total attempts.

VHF beacon tracking and UHF modem

Ground test. The ground test involved six trials in varied habitats, all with a dense or heavy under-storey of herbs and woody lianas. The mean maximum VHF communication distance was 1000 m, with an overall mean maximum of 1189 m and overall mean minimum of 924 m.

Aerial trials. Using the standard H antenna, the maximum VHF reception distance between aeroplane and collar was 10.9 km at an altitude of 1820 m agl, at a gain setting of 80. On descending to 914 m agl the signal was lost until aeroplane to collar distance was reduced. At less than 2 km from the collar the signal was frequently lost due to it falling into the null zone of the antenna depending on aeroplane and antenna/collar attitude. When a four-element yagi antenna was used, maximum reception distance went up considerably, to over 25 km. The maximum UHF modem communication distance tested was 4.0 km at 914 m agl. It failed at 5.8 km and 914 m agl. However during subsequent tests at 2366 m, communications could be established at distances of over 20 km though with some failures. At less than 4.0 km at 914 m agl, UHF communications were successful for all attempts.

Table 1 Summary data for fix acquisition success under different canopy conditions

Upper canopy type	2D fix	3D fix	No fix	Total fix acquisition attempts
Closed	99	34	130	263
Open	116	52	133	301
Total	215	86	263	564

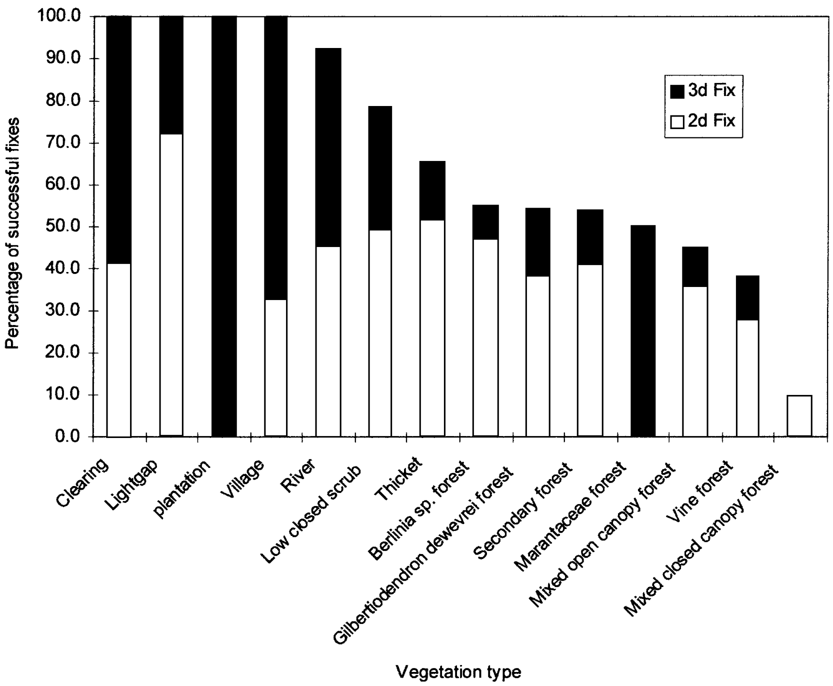

Fig 2 Percentage of successful GPS fixes obtained by vegetation type ($N = 564$)

Based on these results a decision was made to proceed with immobilization and collar deployment.

Preliminary GPS data

Nine months after collar deployment, only one of the elephants, the female, had been successfully located. The bull was not found and it is thought that both the VHF beacon and the UHF modem failed. He was seen in a large forest clearing close to the collaring site ≈4 months after immobilization, by gorilla researchers working in the area. The collar appeared to be intact, and was positioned correctly on the elephant. However no attempt could be made to communicate with the collar or test the VHF beacon because of logistical problems. To date no data have been collected from the male's collar.

The female has been successfully relocated from the air four times since collar deployment. Figure 3 shows fix acquisition success for her collar. Initially the fix success rate was high, but it quickly decreased, and only 1 week after deployment success rate was down to one or two successful fixes in eight attempts. After this it became more intermittent and the last fix was on 2 November 1998, only 45 days after deployment.

Elephant movements

The known locations of the female are shown in Fig. 1. On initial deployment of the collar she stayed within a 10 km radius of the collaring site for at least the first 2 weeks. Subsequently, she travelled extensively on at least three occasions, with a maximum straight line displacement of ≈60 km from the collaring site. She undertook three return journeys of more than 35 km from the site. The first (1) took her 40 km east, after which she returned to the collaring site. Very soon after this the GPS stopped working. The remaining locations are from VHF tracking only. The second movement took her 60 km south-east of the collaring site (2), and involved a complete traverse of the NNNP. She was located ≈10 km outside the national park boundary. She was relocated 3 weeks after this in the same forest clearing where the immobilization took place. The third displacement took her 37 km from the collaring site again to the south-east (3), where she was found ≈ 5 km from the main centre of elephant concentration within the NNNP, the 'Mingingi Bai'. At the last location in September 1999, she was again found at the immobilization site. The area of a minimum convex polygon constructed from all known locations is 880 km^2.

In the course of these movements, she has consistently crossed the international border between Congo and CAR, traversed the NNNP on two occasions, has left the DNNP on at least four occasions, and has been relocated in the same forest clearing on three occasions.

Daily activity patterns

The female showed a marked diurnal activity pattern. A high activity period appears to be between 12.00 and 21.00 hours, with a peak at 15.00 hours. Low activity was between 00.00 and 09.00 hours, with the lowest period at 06.00 hours. There was a highly significant difference in activity level between sampling periods

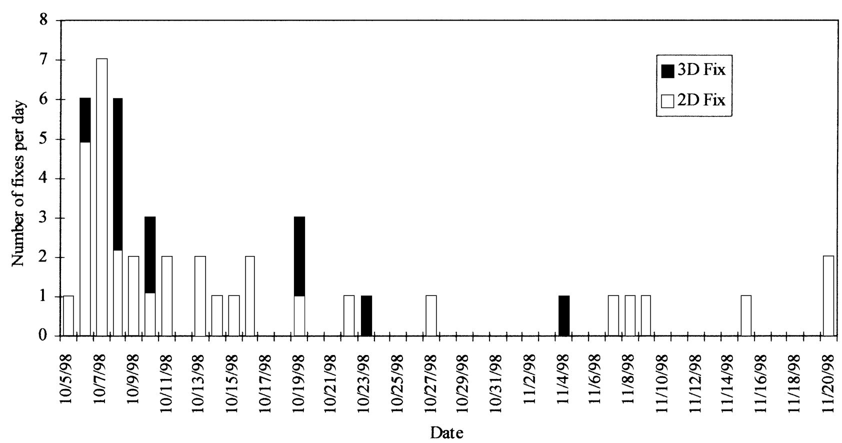

Fig 3 Fix acquisition success rate for female's collar from date of deployment until permanent failure

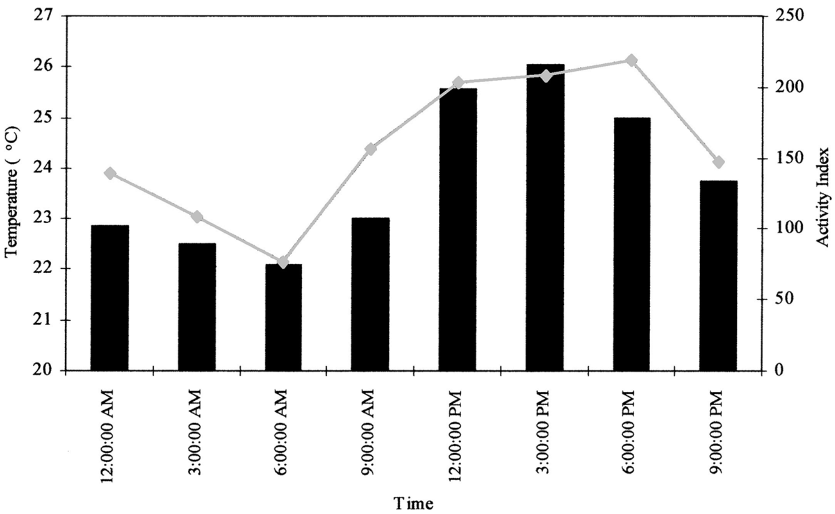

Fig 4 Mean activity index and mean temperature recorded by collar with time of day (GMT)

(one-way ANOVA, two-tailed, $F = 136$, $df = 871$, $P < 0.00001$). There was a strong correlation ($r_s = 0.92$, $N = 8$, $P > 0.01$) between activity level and temperature (Fig. 4).

Discussion

Equipment performance

It is probable that the male's collar has failed, although there are other possible reasons for the inability to relocate it. First, the bull may have ranged deep into Cameroon and outside the search pattern of over-flights. This is unlikely for several reasons. Firstly, even though elephants do cross the Sangha River, observations and many interviews with fishermen and local residents over the last 10 years suggest it is an infrequent occurrence. Even if he had travelled into Cameroon or elsewhere outside the search pattern, the fact that he was seen at the original darting site only days after an over-flight makes this unlikely. It is also possible that the bull has been in particularly thick vegetation or deep in water when over-flights have been conducted, and transmission has been poor. Again this is unlikely, and the possibility decreases with each flight. Over-flights will be continued until the theoretical end of battery life, based on the possibility that the collar is still working.

The failure of the GPS unit in the female's collar appears to be irreversible. This collar did at least give 1 month of GPS data before failure. All other systems, VHF, UHF modem, activity sensors and thermometer appear to be working well. Douglas-Hamilton (personal communication) has found similar apparently inexplicable failures of the GPS unit within the collars, and several of his collars are being examined to determine the cause of failures.

Forest elephant movements

Despite the disappointing performance of the equipment, several important points come out of the dataset. These are the first reliable ranging data for the forest elephant and have provided an initial reference point. Based on such a limited dataset, the minimum convex polygon is only useful as a minimum estimate of the home range of this female elephant. The movements observed do not appear to constitute a seasonal migration, but short-term displacements within a range. Home range studies of savanna elephants have been estimated from under 200 km^2 in Kenya (Douglas-Hamilton, 1971) to over 10,700 km^2 in the arid environment of Namibia (Lindeque & Lindeque, 1991). The two bull elephants fitted with GPS collars by Douglas-Hamilton (1998) in Amboseli had home ranges of 210 and 140 km^2. These estimates were based on more than 2000 fixes over several months. The minimum 'home range' estimate for the female forest elephant is comparable with the lower end of these estimates, but is higher than many others. This suggests two possible explanations. First it is possible that the Nouabalé-Ndoki elephants are less restricted in their movements than many savanna populations, or second, given that the availability of resources is thought to determine ranging behaviour in elephants, important resources are as sparse in the forest environment as they are in many savannah habitats. White (1994) suggested that elephants may travel 50 km in order to exploit seasonal favoured fruits and the data presented here show that this is entirely feasible.

Activity level

The relative activity pattern demonstrated by the collared female is rather different to that observed in savanna elephants. The lull in activity at 06.00 hours is comparable to data from Douglas-Hamilton (1998) for savanna elephants in Amboseli, however both of his elephants in that study showed a marked increase in activity after 06.00 hours to a peak between 09.00 and 10.00 hours. Thereafter both showed a reduction in activity from ≈ 11.00–14.30 hours, after which there was a further increase until 18.00 hours. This is probably a behavioural response to high temperatures and the risk of overheating in open savanna habitats. In the continuous shade of the forest, it is likely that this response is unnecessary and elephants may forage and remain active even through the hottest part of the day. This would imply that forest elephants are under less pressure to maintain high activity levels through the night to make up for the foraging time lost through the day, as is the case in savanna elephants. This could account for the night-time lull in activity in the forest elephant suggested by these data.

Importance of these data

While the data obtained from the forest elephant telemetry project are extremely disappointing, they are nevertheless an important first step in developing our understanding of forest elephant movement patterns. The information is also critical in the context of conservation, which was the primary motivation for initiating the study. It is clear from the data that elephant conservation must be planned on a larger scale than the two national parks alone. They show that a female elephant darted in the heart of a park created largely with elephant conservation in mind, can leave that park on a regular basis, cross an international border, completely traverse a second national park, and move a straight line distance of 60 km. Given the failure of the collar, the data presented here are likely to be just a small fraction of her total range. This study has shown that if technical problems of reliability can be overcome, GPS telemetry can provide high quality ranging data for forest elephant of considerable conservation and scientific importance.

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