TRACKING AFRICAN ELEPHANTS WITH A GLOBAL POSITIONING SYSTEM (GPS) RADIO COLLAR

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ABSTRACT

Conventional radio-tracking defines a wide range of elephant home ranges in Africa, but only one record can be made per elephant per tracking session and cost factors limit the frequency of locations. Satellite tracking using the ARGOS system allows more frequent data acquisition but gives a proportion of inaccurate fixes and is also expensive. Global Positioning System (GPS) technology, however, promises improved radio tracking with frequent and accurate fixes. A prototype GPS collar weighing 12kg was tested in July 1995 and worked for ten days giving two fixes per 24 hours. An improved collar, designed by Lotek Engineering was tested from December 1996 to May 1997, in and around Amboseli National Park, on two bulls.

The GPS instrument and VHF modem package were attached to the top of the collar, counter weighted by a battery pack at the bottom. The whole unit weighed 4.5kg. Data were stored cumulatively in a dedicated bank of non-volatile random access memory (RAM). Sensors in the collar also recorded motion and temperature. The frequency of acquiring fixes, the times at which the collar was open for communication, a back-up radio beacon, the sensors and functions of power consumption were remotely controlled. Position records and data from the sensors were downloaded remotely though a VHF modem linked to a control unit and a laptop computer. Downloading sessions were conducted from a light aircraft, which first located the elephants using the back-up radio beacon on the collar.

One of the GPS collars was tested in a fixed position and gave a mean position error of 43.6m (95%CL±4.3m, n=281). The collars on the two bulls were monitored for 134 days and 168 days. Readings were made either 24 or eight times per day in different periods. On average each elephant was located 20 times per day and downloadings were made every two weeks. One collar gave a total of 3,136 readings of which 2,966(94.6%) gave successful position records, the other made 2,734 readings of which 2,638 (96.5%) were successful. Failure to log a position peaked just before dawn with a subsidiary mode one hour after midday. It is thought that these failures were caused mainly from elephants tending to lie down at these times of day, which placed the GPS antenna at an unfavourable angle. Tracking was terminated in each case when the collars dropped off. A weak point was discovered where the collars passed under a sharp metal clamp. The collars have since been redesigned to correct this error in a new strengthened version.

The results were converted to spreadsheets (MS Excel) from which maps were created using MapInfo software. The mean daily movements of the two elephants were 10.3km (± 0.8km, 95% CL) and 8.6km (±.6km, 95% CL). Average movements for each hour over the entire period were also calculated. The greatest movements occurred between dawn and midday and from sunset to midnight, with the elephants tending to travel most in the first part of the night. The periods of least movement occurred in the three hours before dawn and from 11:00am to 15:00pm. The motion detector recorded a similar activity pattern.

Both bulls were darted in the national park but spent most of the period outside. One occupied a range of 210km^2 that extended from the park to the West and across the border into the West Kilimanjaro area in Tanzania, and the other a range of 140km^2 mainly in the East in the Kimana area close to human settlement. The western bull spent 92% of his time in the Longido Conservation Area in Tanzania, and the eastern bull 99% of his time in the Kimana Group Ranch area The bulls spent 7% and 1% of their time respectively in the national park, but this was covered on a fraction of the years and may not be representative. The nocturnal crop raiding forays of the eastern bull were plotted and timed precisely.

The trials demonstrate that GPS radio tracking of elephants is feasible and generates large amounts of high quality data 24 hours per day, and under all weather conditions. The chip in the GPS can store up to 3,640 waypoints so even recording at a frequency of 24 times per day would necessitate downloading only once every five months.

The minimal human intervention eliminates most human errors. Although the initial cost of $6,800 per collar is high the cost per location will be low relative to conventional or ARGOS radio tracking as hundreds of records can be collected per animal per flight. Although longevity was not tested the manufacturer claims that the 700gm battery pack provided with the elephant collar may give two years of operation at eight fixes per day.

In conclusion GPS animal tracking systems are set to establish a new standard for studies of daily movement patterns and ranges of large mammals over the next five to ten years.

RESUME

Le système de suivi conventionnel par radio permet de déterminer les grandes aires de distribution des éléphants en Afrique, mais ce suivi ne peut se faire que de manière individuel sur un éléphant. Aussi, son coût relativement élevé limite son utilisation. Le système de suivi par satellite à base du système d'ARGO, permet d'obtenir régulièrement des informations, mais donne également une proportion de repèrcs inexactes et coûte aussi cher. Cependant, le système de positionnement global (GPS) peut améliorer le système de suivi par satellite en fournissant régulièrement des repères exactes. Un prototype de GPS sous forme de collier de 12kg testé en Juillet 1995 et utilisé pendant 10 jours a donné deux positions toutes les 24 heures. Un collier amélioré et mis en place par Lotek Engineering a été testé de Décembre 1996 à Mai 1997 sur deux éléphants mâles dams les environs du Parc National d'Amboseli.

L'instrument GPS et le modem FHF ont été attachés au sommet du collier et alimentés par une batterie au-dcssous, le tout pesant au total 4,5kg. Les informations étaient cumulativement stockées dans une mémoire vive non volatile (RAM). Les détectives dans le collier enregistraient aussi le mouvement et la température. La fréquence des positions, les moments où le collier cst disponible pour la communication, le témoin de fonctionnalité de la radio, les détectives et les fonctions de la batteries sont contrôlés à distance. Les enregistrements de la position et les données des détectives sont transférès à distance à travers le modem VHF relié à une unité de contrôle et à un ordinateur portatif. Les opérations de transféré se font à partir d'un avion ultra léger, qui repère la position des éléphants grâce au témoins de fonctionnalité fixé sur le collier.

Un des colliers GPS testé dans une position repérée, a donné une erreur de 43,6m (95% LC ± 4,3m, n=281). Les colliers sur les deux éléphants mâles ont été suivi pendant 134 à 168 jours. Les lectures étaient faites entre 8 et 24 fois par jour en différentes périodes. En moyenne, chaque éléphant est localisé 20 fois par jour et les enregistrements étaient faites toutes les deux semaines. Un collier a donné un total de 3.136 lectures dont 2.966(94%) ont eu du succès au niveau des enregistrements de la position, l'autre a fourni 2.734 lectures dont 2.638 (96%) réussies. Les faillites sur l'enregistrement dc la position sont beaucoup plus fréquents au lever du jour et dams les environs d'une heure de l'après midi. On pense que les faillites proviennent du fait que les éléphants à ces heures de la journée tendent à se coucher et placent l'antenne du GPS dams un angle qui n'est pas favorable. Dans chaque cas, le suivi est terminé quand les colliers deviennent défectueux. Nous avons découvert sur le collier, des endroits où le métal avait légèrement été frotté. Les colliers ont été refaits pour corriger ces erreurs en vue de les améliorer. Les résultats ont été convertis dans un logiciel (MS Excel) dans lequel des canes ont été insérées en utilisant le sosft Info Map. Les principaux mouvements des deux éléphants étaient de 10,3km(±8km, 95% CL) et 8,6km(±0,6km,95%aCL). En moyenne, les mouvements pour chaque éléphant ont été calculés pendant toute la période. Les plus grands déplacements ont été enregistrés entre le lever du soleil et midi, et également entre le coucher du soleil et minuit, avec une tendance des éléphant à se déplacer beaucoup plus dams la première partie de la nuit. Les périodes de moindre mouvement ont été enregistrées pendant les trois dernières heures avant le lever, et aussi entre 11heures et 15heures. Le détecteur de mouvements a enregistré la même activité.

Les deux éléphants mâles ont été fléchés à l'intérieur du Parc, mais passent la majeur partie de leur temps au dehors. L'un utilise une superficie de 210km^2 qui s'étend à l'Ouest du Parc et traverse jusqu'au niveau de la zone du Kilimanjaro en Tanzanie. L'autre évolue dans une zone de 140km^2 principalement à 1'Est dans la zone de Kimana, fermée par les installations humaines. Le mâle se trouvant à l'Ouest passe 92% de son temps dans la zone de conservation de Longido en Tanzanie, et celui de l'Est 99% de son temps dans la zone du Ranch de Kimana. Les éléphants mâles passent respectivement 7% et 1% de leur temps dans le Parc national, mais cela n'a été étudié que pour quelques années, et n'est peut être pas représentatif. Les dommages nocturnes occasionnés par le mâle de l'Est, ont été recensés avec précision dams le temps.

Les essaies ont démontré que le suivi des éléphants par satellite est faisable et procure des données de qualité 24heures par jour sous toutes les conditions du temps. L'appareil du GPS peut stocker jusqu'à 3640 positions différentes si bien qu'un enregistrement de 24 fois par jour nécessiterait un transfere une fois tous les cinq mois. Une intervention minimale de l'homme peut éliminer les erreurs potentielles de manipulation. Même si le coût initial de 6800 $ par collier est élevé, il est relativement bas par rapport au suivi par ARGOS car des centaines d'enregistrements peuvent être effectués sur chaque animal durant le vol. Bien que la longévité n'ait pas été testée, le constructeur estime que les 700mg de paquet de batterie fourni avec le collier d'éléphant pent être opérationnel pendant 2 ans en raison de 8 repérages par jour.

En conclusion, les systèmes de suivi par GPS ont été établis pour les études standards des mouvements journaliers et de distribution des grands mammifères pendants des périodes allant de 5 à 10 ans.

INTRODUCTION

African elephants have been tracked by conventional radio beacons since the late sixties and the technique has defined home ranges of individuals in many different parts of Africa. The method has been an effective way of monitoring movements when animals disappear into inaccessible terrain. However, its limitation is that only one record can be made per elephant per tracking session (usually from an aeroplane) and each session is costly (Whyte, 1996). Fixes may be acquired as frequently as twice daily (Douglas-Hamilton, 1971), but more usually are recorded weekly, monthly or at longer intervals. In one of the most detailed studies 20 collared elephants in Laikipia were located on average once every two weeks for a period of two years, then at approximately once a month for another five years (Thouless and Dyer, 1992; Thouless, 1996a and 1998). Where the elephants went in between the fixes could not be determined.

Satellite radio tracking using the ARGOS system allows more frequent data acquisition, but gives a proportion of inaccurate fixes that can be as much as 10km out. In this method the collar transmits a signal to a receiving satellite within the ARGOS system that measures the Doppler effect between the transmitter and the receiver and calculates a position. The results are transmitted down to an earth station. Theoretically this can give four to six fixes a day, but in one of the more successful elephant studies in Namibia, position fixes were acquired only once every three to four days (Lindeque and Lindeque, 1991). The method is once again costly and ARGOS readings are less accurate than fixes made with visual sightings from an aeroplane. Erroneous points may cause inaccurate calculations of range. It is suitable for very far ranging elephants where such errors would not make a big proportional difference to calculations of home range. Both methods have been extensively reviewed by Thouless (1996b), but neither measure fine scale movements of animals on an hourly basis.

A Global Positioning System (GPS) has the potential for improving radio tracking with more frequent and more accurate fixes. The GPS is a satellite based navigation system providing accurate position data in real time. Receivers are commercially available that detect and analyse signals from the Global Navstar constellation of 26 satellites installed in high earth orbits (about 20,000km) by the US military. These devices receive coded signals that allow the precise time at which the signal left the satellite to be calculated. By knowing the positions of the satellites and the speed at which the radio waves travel, the distance of the receiver from the satellite can be accurately measured. A minium of four satellites is needed to provide a 3D triangulation, but commonly receivers monitor six or more channels, which improves accuracy. Typically locations can be made within 30 to 40 metres. Measurements would be even more accurate but for a deliberate downgrading of the signal available to civilian users known as selective availability. GPS tracking was first used in Kenya in the Tsavo Elephant Counts from 1991 to 1994. GPS units were fitted to aircraft and were progammed to store co—ordinates every few seconds, in order to plot out exact flight paths (Douglas-Hamilton, 1996). From tracking aircraft it was a small conceptual step to the idea of tracking elephants, and this led to the present study. However, the high power consumption of GPS units had to be overcome if a realistic battery life was to be obtained. In addition, elephants pose a special challenge, as the GPS units would need to withstand several tonnes of pressure every day, exposure to the elements and total immersion in water.

There were three possible ways of collecting GPS information from an animal's movements. The first and simplest is to create a data logger that would accumulate fixes, but which had no capacity for remote downloading. The units would have to be recovered from animals before data could be read. Such units could be lightweight, but the disadvantage was that there was no way of knowing if the system was working *in situ*. The second possibility is to download data via a satellite, or to fixed ground receivers. However, the technology had not yet been developed. A third method is to download a GPS unit by means of a VHF modem communicating with a receiver and control unit mounted in an aeroplane. This last method was adopted in the present study. A prototype GPS elephant collar weighing 8kg, made by OHB Systems (a German aerospace company), was tested in July 1995 in Amboseli. The collar worked continuously for ten days giving four fixes per 24 hours. It then failed, probably due to premature passivation of the NiCad batteries, and could not be resuscitated. The results however seemed promising. An improved design was then tested in this study, modified from a moose collar that had already been extensively deployed in North America (Moen et al., 1995; Rodgers *et al.*, 1996). Lotek Engineering manufactured the collar. This paper reports the testing of two prototypes, the sort of data produced, and how it may lead to new analyses.

THE GPS TRACKING SYSTEM

In the Lotek GPS tracking system the GPS and modem aerials are enclosed in a tough plastic housing attached to the top of the collar, and counterweighted by the electronics housing and battery pack at the bottom. The two components are connected by power and antennae cables that weave between double layers of belting separated by spacers and fastened by rivets, stitching and glue. The battery can be replaced by undoing six screws. Data are stored cumulatively in a dedicated bank of nonvolatile random access memory (RAM). Sensors in the collar also record motion and temperature. The frequency of acquiring fixes, the times at which the collar is open for communication, a back-up radio beacon, the sensors, and functions of power consumption are remotely controlled. Position records and data from the sensors are downloaded remotely through a VHF modem liked to a control unit and a laptop computer. Downloading sessions in this study were conducted from

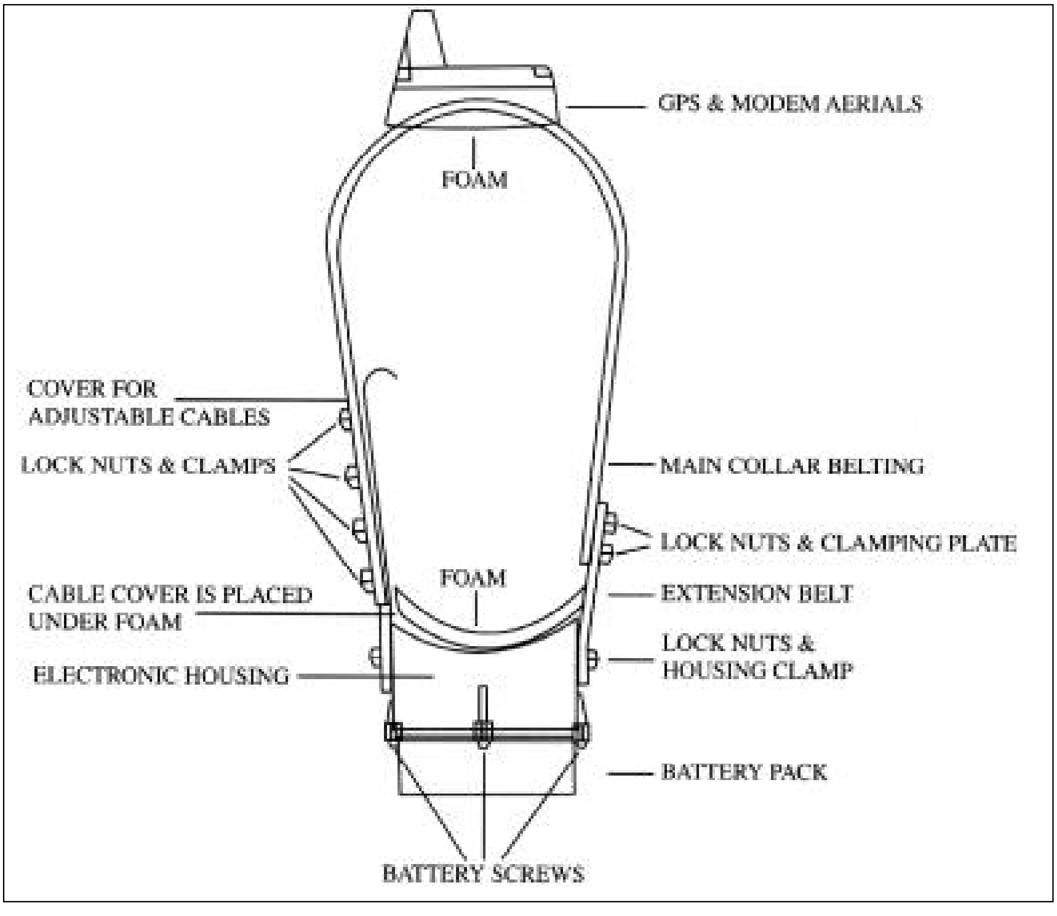

Figure 1. Lotek GPS Elephant collar. Belting is adjustable on both sides.

a light aircraft, which first located the elephants using the back-up radio beacon on the collar. The results were converted to spreadsheets (MS Excel) from which maps were created using Maplnfo software. Each record contained the coordinates and the status of the fix, whether it was 2D, 3D or a failure. The chip in the GPS can store up to 3,640 waypoints, so even recording at a frequency of 24 times per day necessitates downloading only once every five months. A further refinement in the system is the ability to alter the schedule of fixes, to turn the radio beacon and modem on and off and to set the period over which the motion detector is activated. These parameters can be adjusted to prolong battery life.

Field trials of the prototype Lotek GPS elephant collars began on two bulls in Amboseli in Kenya in early December 1996. Each of the collars eventually broke at a point where the collar was attached to the electronics housing by a sharp metal clamp. The double belting was rolled on both collars, but the rivets had kept the two edges together and the cables intact. The plastic housings and the battery box were scored, but the electronic components were fully functional. Some strong force must have caused the break, perhaps a log wedged between the neck and the belting, or a tussle with another bull with a tusk giving a huge tug. Since then the collar design has been improved (see Figure 1). The metal clamp is now rounded and the belting made of a heavier, industrial material. The two layers are separated by a spacer with a hollow in the middle, down which the antenna and power cables run coiled in such a way as to be extensible allowing 96cm of adjustment. Where the cables emerge from the two layers they are protected by an adjustable cover. Each collar weighs 4.2kg.

RESU LTS

Static testing

One of the prototype collars was tested off an elephant by setting it in a fixed position with an open view of the sky. 281 readings were taken at one-hour intervals. An average centre point was calculated from all the readings and taken to be the true position. From this point the deviation of each data point was calculated. The mean deviation was 43.6m, the maximum 196m, and 95% of the points lay between 27 and 48 metres of the centre point. This level of accuracy is greater than other radio-tracking systems. However, Lotek collars may also be ordered in a configuration that permits differential correction of the GPS results, which will increase accuracy down to the level of five to ten metres (Moen et al., 1995).

Field trials on elephants

The trials were conducted in and around the Amboseli national park in collaboration with the Kenya Wildlife Service and the Amboseli Elephant Research Project Two bulls were selected with the help of the Amboseli Elephant Research Project and both were known to disappear for prolonged periods from the park, the extent of their range being unknown. M86 was a bull of about 38 years, believed to cross the border into Tanzania to the West, and M169 a bull, of about 33 years, thought to be a crop raider in the Kimana area to the East. KWS veterinarians carried out immobilisation of these elephants on 5 and 6 December 1996. A GPS collar was fastened around the neck of each elephant, bolts tightened up, and antidote administered. In the course of the next few months downloading was made from a Cessna 185. First the elephant was tracked by its radio beacon using directional H antennae mounted on the wing struts. Once a strong beacon signal was obtained, a “Whose There” signal was sent out by the software through the control unit, which would initiate a link, followed by downloading of the data through the VHF modem.

The electronics of both collars worked satisfactorily. M86 was tracked for 134 days and M169 for 168 days before the collars dropped off. Readings were made either 24 or eight times per day in different periods. On average each elephant was located 20 times per day and date were downloaded every two weeks. The collars were successful in obtaining fixes in 94.6% and 96.5% out of 3,136 and 2,734 attempts as in the table below. The relatively low number of failures to acquire a fix were related to time of day and peaked at 05.00 to 06.00hrs with a subsidiary mode at 13.00 to 14.00hrs (Figure 2). These are times when elephants have a higher probability of lying down or standing under the shade of trees. Either of these activities would tend to interfere with GPS reception.

Table 1. Number of GPS fixes acquired by two GPS elephant collars.

	M86 Fixes	%	M169 Fixes	%
Total Days	168		134	
3D readings	1,124	36%	1,630	60%
2D readings	1,842	59%	1,008	37%
Failures	170	5.4%	96	3.5%
Successes	2,966	94.6%	2,638	96.5%
Total	3,136		2,734	

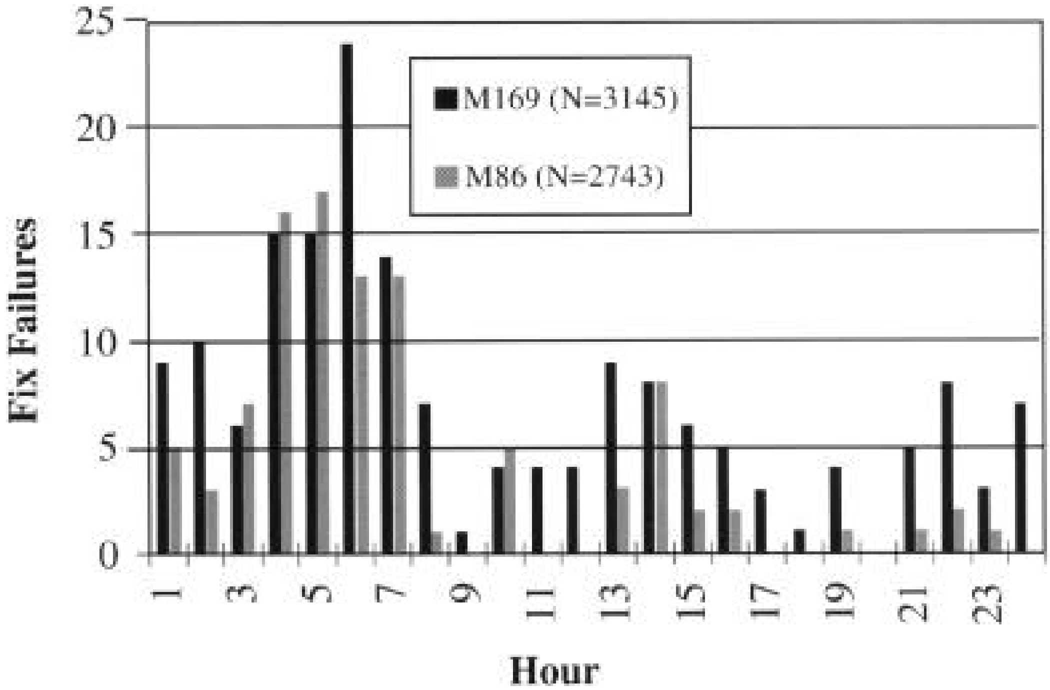

Figure 2. Fix failures at times when elephants were lying down or in the shade.

Daily movements

Daily movements were totaled for each elephant by cumulating the distances between fixes over a 24-hour period from midnight to midnight Figure 3 presents daily movements, as five-day running averages, over the 168-day study period. The frequency distribution of daily distances traveled is shown in Figure 4 and Table 2.

M86 over the whole period averaged 10.3km per day. When first darted he was in musth and covered between 15 and 29 kilometres a day. Much of this was spent in patrolling areas of the national park, apparently searching for females in oestrous. Later he crossed the international border into Tanzania and made an up and down movement, covering ten to 15 kilometres in 24 hours on a straight line, then returning in the opposite direction on the same axis in the next 24 hours, probably still patrolling. Later his movements became more rambling and it appeared that he had come out of musth and was now engaged in feeding in a well wooded area within the Longido Game Controlled Area in Tanzania.

M169, the smaller of the two bulls, was not in musth and did not travel such great distances, except when he moved from one distinct locality to another. He was darted in the east end of the Amboseli National Park. After lingering for one day he made a fast night time march to the Kimana swamps in the east covering 20km in 12 hours of darkness. Thereafter his usual days' travel averaged 8.6km, as he moved from the safety of the forest, and on frequent nights he raided the crops of the Kimana villagers.

Table 2. Daily Movement Statistics.

Movements in kilometres	M86	M169
Mean	10.3	8.6
Standard Error	0.4	0.3
Confidence Level(95.0%)	0.8	0.6
Median	9.5	8.0
Minimum	2.7	2.6
Maximum	29.4	27.3

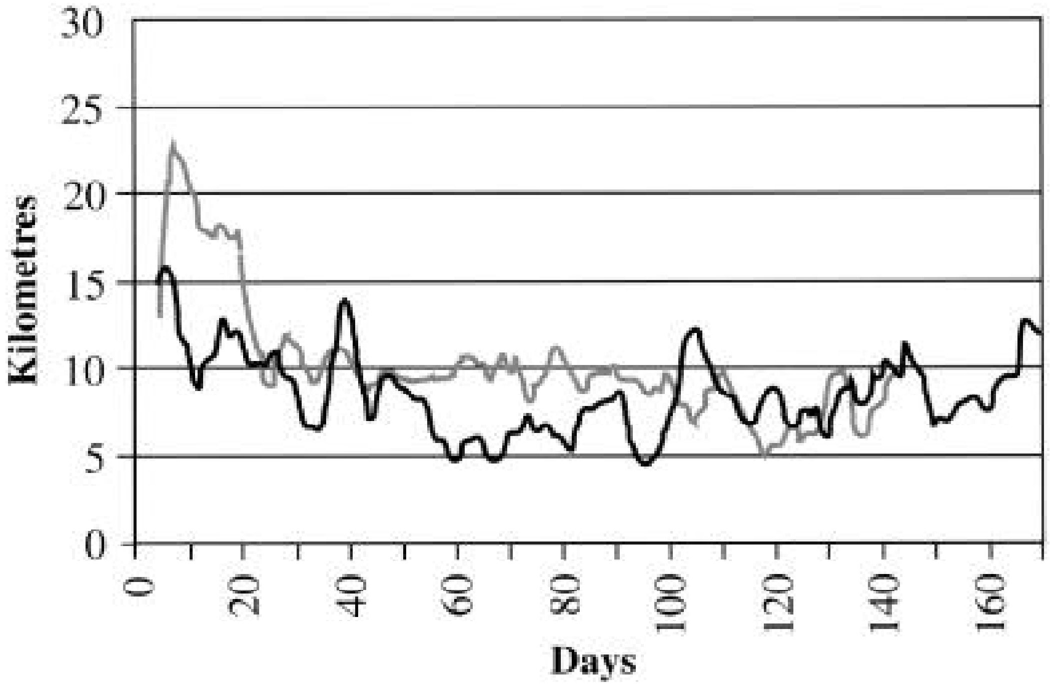

Figure 3. Dally distances (five day running averages) traveled by two bulls, M86 and M169, over the 168 day study period.

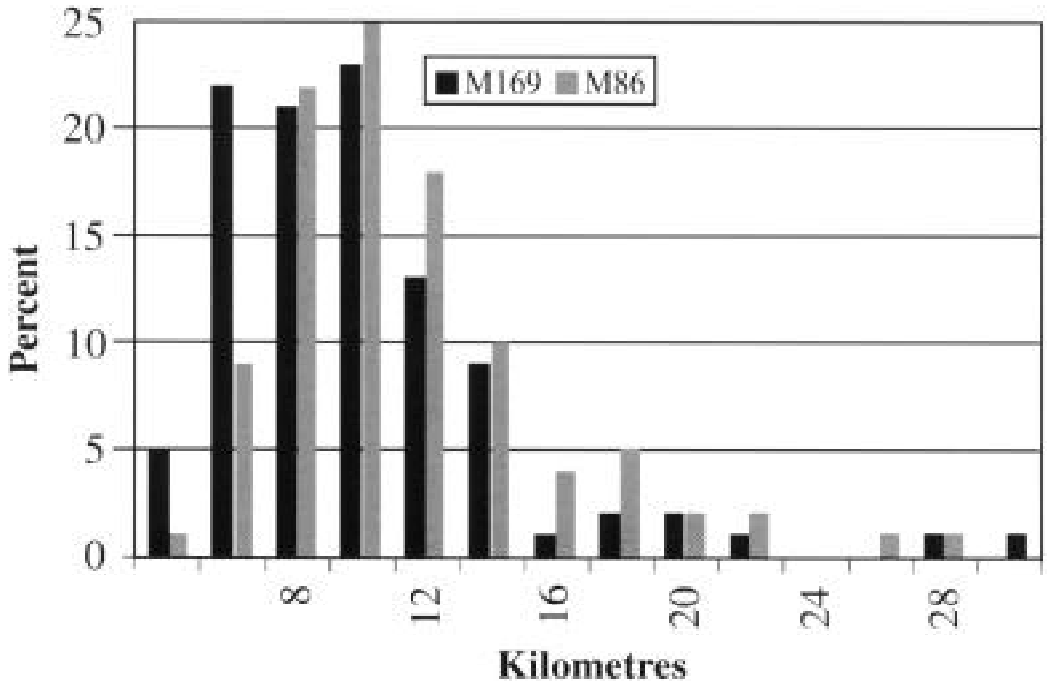

Figure 4. Frequency distribution of dally distances traveled by two bulls M86 and M169.

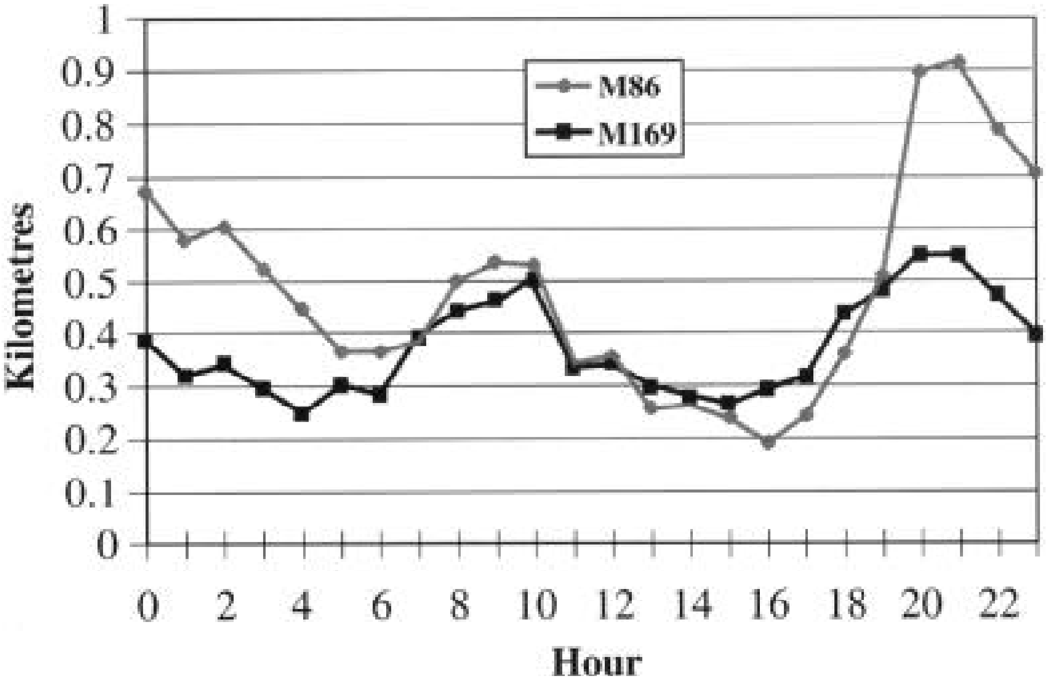

Figure 5. Average distances traveled per hour by the two bulls, M86 and M169. Movements peak mid morning and in the first half of night.

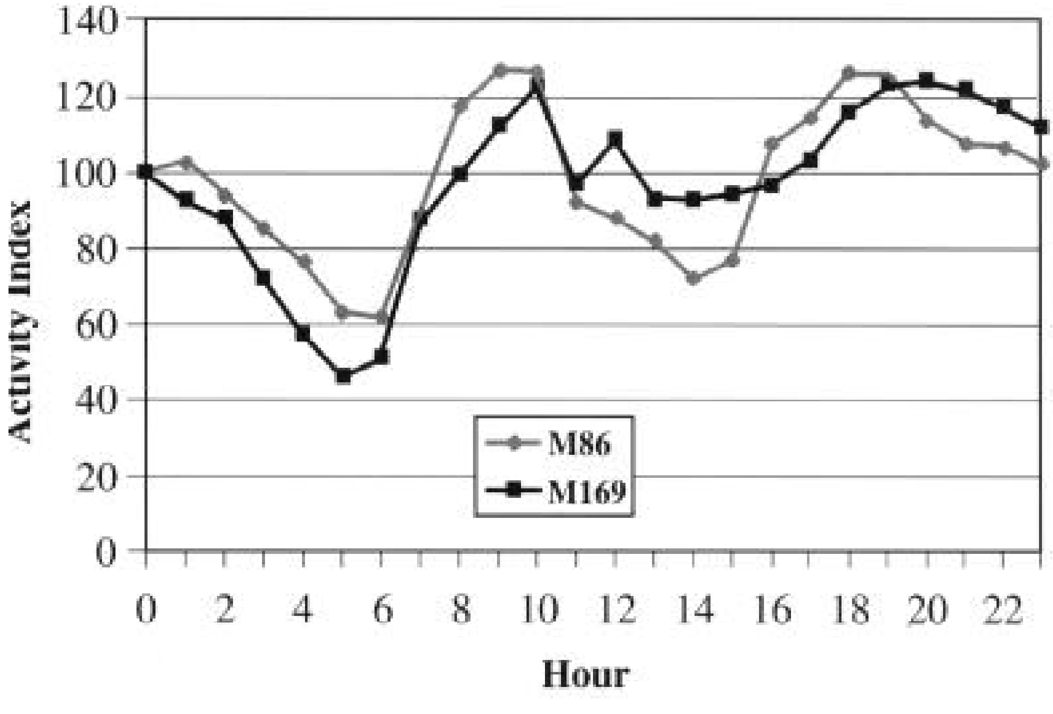

Figure 6. Average activity per hour recorded by motion detectors, for the two bulls M86 and M169, showing a similar pattern to distance traveled.

Hourly movements and activity

Hourly movements were calculated as the distances between hourly fixes. The motion detector also gave hourly readings, which could be caused by any movement. Averages were then calculated both for hourly movement and for hourly activity (Figure 5 and 6), and both bulls showed similar patterns. Movement and activity on average shared the same peaks and troughs. Movement of both elephants was lowest in the pre-dawn hours and then rapidly increased in the early morning to reach a maximum at 09:00 and 10:00, which then dropped off rapidly as the day warmed to reach another minimum from l5:00 to 16:00. In the late afternoon and early night movements increased rapidly. M86 tended to walk throughout the night until about 04:00, covering more distance than he did by day, while M169's night time movements were similar to his morning schedule.

Activity (i.e. unspecified motion) was very similar to movements except that the pre-dawn trough was more marked. At this time motion records tended to sink to zero and both elephants were presumed to be asleep. The possibility that they were lying down is reinforced by the distribution of GPS fix failures, which peak simultaneously at these hours (Figure 2). This could be because when the body is recumbent it obscures the GPS antenna on the top of the collar from part of the sky.

Home ranges

Although both the bulls were immobilised within the Amboseli National Park they spent little time there. M86 spent 92% of his time in the Longido Game Controlled Area in Tanzania, and M 169 spent 99% time in the Kimana Group Ranch area to the East of the park (Table 3). The time they spend outside of the park shows how important these external areas are to the elephants.

Table 3. Proportion of fixes in different localities.

Location	Time Spent in National Park			
	M169		M86	
	Fixes	Percent	Fixes	Percent
In Amboseli NP	180	7%	17	1%
In Kenya outside Park	29	1%	3,119	99%
In Tanzania	2,525	92%	0	0%
Total	2,734		3,136	

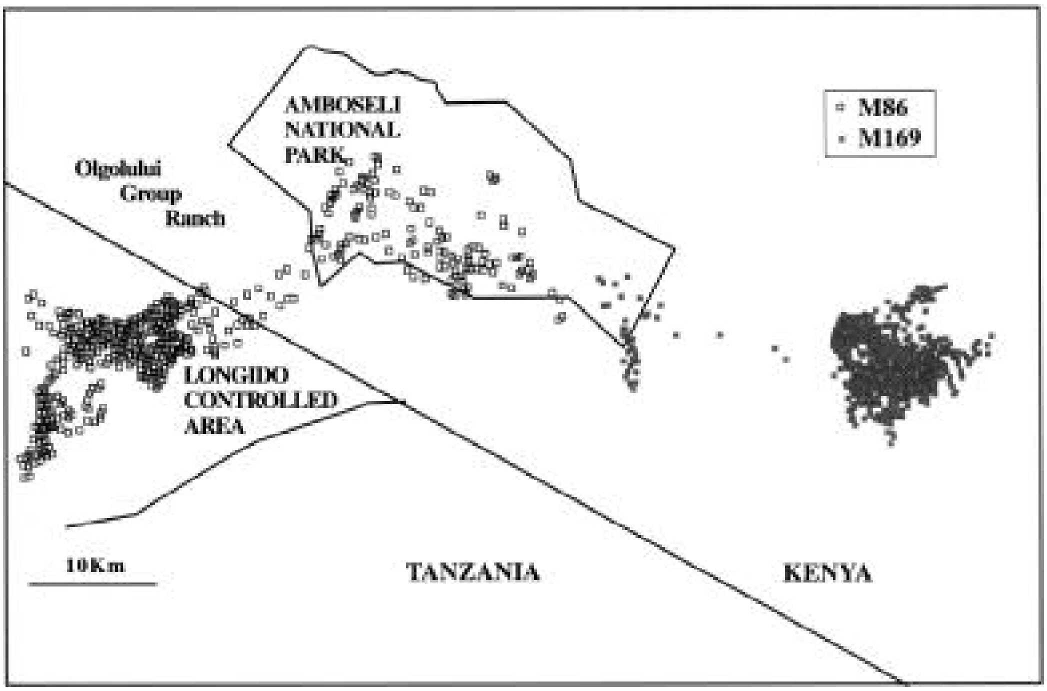

Figure 7. Fixes plotted for the two bulls M86 and M169 in the Amboseli National Park, Olgolului and Kimana group ranches, in Kenya and in the Longido Game Controlled Area in Tanzania.

For the time the collars lasted home ranges could be defined as the actual area occupied by the fixes plotted on a map. M86 occupied a range of $210km^2$ that extended from the south central portion of Amboseli National Park to the West into Tanzania as far as the Seven Sisters Hills in the Longido Game Controlled Area (Figure 7). In December1996 when this elephant was in musth he spent most of his time in the Park in company with female groups, but in January he moved to Tanzania and stayed there for four months. It is likely that he came out of musth at the same time that his movements slowed down. He was observed mainly associating with bulls and never came into the Park. His collar dropped off on 22 April, after which he was observed back in the park in May, in full musth once again and in company with females. The problem of large bulls leaving Amboseli National Park and entering the Longido Game Controlled Area in Tanzania is highlighted by this data on one bull. It supports the decision of the Tanzanian Government to close elephant hunting in this area as an activity incompatible with the objectives of the neighbouring Amboseli National Park.

M169 occupied a range of $140km^2$. He spen tthe first few days after immobilisation in the eastern portion of Amboseli National Park. Then he walked to Kimana area, which contains an *Acacia xanthophloea* woodland of mixed age stands with some dense regeneration. This woodland is heavily browsed by elephants on the edge of a swamp filled with nutritious swamp grasses. Villagers have expanded cultivation over the last 30 years into the heart of the elephant range. Elephants are therefore surrounded by people at Kimana and spend much of the day hidden in the dense vegetation. The GPS tacking allowed the precise logging of movements into areas of cultivation. M l96's excursions into the Kimana shambas were done

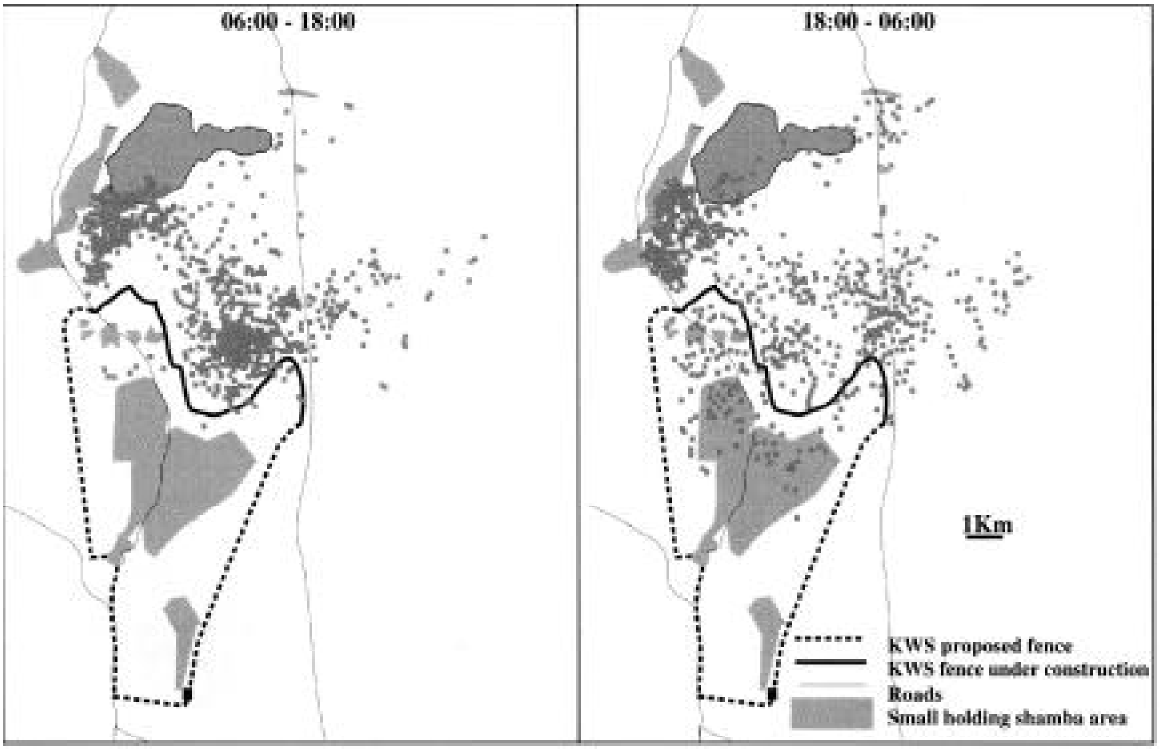

Figure 8. Day and night fixes for Kimana Area in relation to shambas and the elephant fence under construction by KWS.

exclusively at night. In relation to the KWS fence under construction the data show that the fence will exclude this elephant from its nightly crop raiding, but the daytime range will remain almost unaffected (Figure 8).

The fence line will protect people and still allow the elephants access to the Kimana Wildlife Sanctuary which provides a corridor to the Amboseli elephants for their dispersal to the East and into the Chyulu Hills.

CONCLUSIONS

These trials demonstrate that GPS radio tracking of elephants is feasible and generates large amounts of high quality data 24 hours per day, and under all weather conditions. The technique minimises human error in recording positions and allows detailed mapping of elephant movements. Software is being developed to display these movements in animated form on maps which will help to explain how elephants move in relation to food and water availability, relative protection and each other. Although longevity was not tested the manufacturer claims that the 700gm-battery pack provided with the elephant collar should give a life of 575 days at six locations per day; assuming that the tracking window is open in "power save" mode for eight hours per day and five days per week.

Although the initial cost of US$6,800 per collar is high the cost per location is low relative to conventional or ARGOS radio tracking as hundreds of records can be collected per animal per flight. However I should point out that to embark on GPS elephant tracking involves a great commitment in money and energy. Although software problems were not experienced in the trials here, there have been some bugs subsequently and these can prove costly to the researcher. However, the software is continuously evolving and improving.

A number of plans exist to use these GPS collars more widely in Africa. Promising tests have been made of the performance of GPS elephant collars under rain forest canopy in Congo Republic and it is planned to deploy them on elephants in the near future (Blake, pers.comm.). Lotek GPS elephant collars are currently deployed in Samburu National Reserve, Laikipia District, Meru National Park and in the Shimba Hills area in Kenya by Save the Elephants and in Tarangire National Park in Tanzania (Rossi and Foley, pers. comm.). In the Kruger National Park they will soon be deployed in connection with elephant birth control research (Whyte, pers.comm.) and in the Timbavati Private Nature Reserve in South Africa in connection with "Green Hunting" (Douglas-Hamilton, 1997).

In future simultaneous point sampling of behaviour, including feeding behaviour, social behaviour, and reactions to human factors would enhance the value of recording detailed movements with this technique. The presence or absence of other elephants, the availability and condition of browse, grazing and water and some quantitative measure of danger from human predators would help interpret movements. It will be a potent tool for understanding elephant social behaviour, especially if deployed with known animals and accompanied by studies of spatial and social interactions at different levels of elephant society.

The technique will show how elephants raid crops. Such knowledge can be used to reduce conflict between people and elephants by the designation of elephant corridors or by designing fences tailored to protect human interests while disrupting elephant needs as little as possible. The technique will map fine scale movements in relation to detailed vegetation and habitat, or in relation to land-use; protected areas, fence-lines, crops or topographical features. This is important in view of large-scale changes in habitats induced by human beings and the threat this now poses for elephant populations. It will also provide unparalleled insights into how elephants use their environment and into what they need in order to survive.

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