Hystrix, (n.s.) 11 (2) (2000): 27-37

THE USE OF GPS RADIO-COLLARS TO TRACK ELEPHANTS (*LOXODONTA AFRICANA*) IN THE TARANGIRE NATIONAL PARK (TANZANIA)

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ABSTRACT - The GPS (Global Positioning System) telemetry was used in Tarangire National Park (Tanzania) to study migration routes and the use of space by elephants (*Loxodonta africana*). Five female elephants were captured in November 1997 in five different areas of Tarangire National Park and fitted with GPS collars. The collar consists of a 6 channel Global Positioning System (GPS) receiver, a radio-modem for data communication, a non volatile memory, and an independent VHF transmitter. The operator can «communicate» with the collar through a command unit connected to a PC. The GPS collar receives signals from different satellites which permits automatic calculation of its position, with an accuracy of 25 m. The data collected in the period November 1997 – April 1998 show that three female elephants mainly used the northern sector of the park, moving sometimes outside the protected area about 10 to 20 km NE of the park boundary. Also the two female elephants captured in the southern sector of the park moved outside, travelling about 80 km SE of the park boundary Home range size varied between 159 and 660 km^2 for the northern elephants (n= 3), and between 2104 and 3314 km^2 for the southern elephants (n= 2). The elephants whose ranges extended outside the park exhibited their highest movement rate from 4 p.m. to 12 p.m., while those animals within the park had the highest movement rates during daylight hours (from 8 a.m. to 4 p.m.). We discuss the advantages and shortcomings of GPS-telemetry as a means of gathering useful information on space use and movements of elephants for the development of long-term conservation strategies for large herbivores in the whole Tarangire area.

Key words: Elephant *(Loxodonta africana)*, GPS collars, Tarangire National Park, migration routes.

INTRODUCTION

The increasing rate of fragmentation of natural habitats in large parts of Africa, has been recognized as a major threat to the survival of natural populations and the functioning of ecosystems (Diamond, 1981; Mwalyosi, 1991; Newmark, 1996). In particular for large mammals, the reduction of large, more or less continuous habitats to smaller and isolated remnants can drastically affect their abundance and cut-off migration corridors (Borner, 1985; Mwalyosi, 1991; Newmark, 1996). These problems occur in northern Tanzania, where the national parks host some of the most important large, migratory herbivore populations of eastern Africa (Borner, 1985; Davison, 1991; Newmark, 1996).

The Tarangire area, containing Tarangire National Park, hosts the largest population of elephants *(Loxodonta africana)* in northern Tanzania (TWCM, 1998a,b). Moreover, in the dry season (June-November) thousands of herbivores converge on the protected area because of the constant water supply of the Tarangire River, with zebra, wildebeest, buffalo and elephants being key species both in numbers and biomass (Lamprey, 1964; TWCM, 1995, 1998a). During the rainy season, most of these herbivores leave Tarangire NP and spread over a wide area of the Maasai Steppe. For more than six months they depend on the resources available in this area where communities of farmers live (Borner, 1985; Newmark *et al.*, 1993, 1994). In fact, outside the park, the continuing conversion of savanna to agricultural land and the fast-growing human population has two major consequences: an increased impact of human activity on natural habitats; an increased number of conflicts between wildlife and humans (e.g. damage to crops) (Newmark *et al.*, 1993, 1994). Many of these conflicts occur along the traditional migration routes: some of these have already been completely blocked by extensive agriculture and human settlement, to others the access has been restricted (Lamprey, 1964; Borner, 1985). The remaining corridors are essential for the long-term survival of migrating large herbivores which, during the wet season, need to have access to the areas outside the park where they can find richer grassland and have access to specific mineral nutrients (TCP, 1998; McNaughton, 1985, 1990), or find habitats which satisfy other specific needs. Therefore, in the framework of the Tarangire Conservation Project (TCP), one of the most challenging objectives in the sustainable management of large herbivores in Tarangire NP and in the whole of northern Tanzania, is to ensure the long-term conservation of the natural areas by reducing conflicts between people and wildlife in the areas surrounding the park. Specific objectives include the mapping of the remaining migration routes that are still used by the different large herbivore species, and to increase the knowledge of the areas, outside the park, of major importance during the wet season in order to define efficient conservation strategies for the whole Tarangire area.

To achieve these objectives, detailed studies have to be carried out to describe the space use of large herbivores in the dry and the wet season, and to monitor their movements in order to determine the main migration corridors. In this paper we present the first data on space use and migratory movements of elephants, collected using GPS radio-tracking.

STUDY AREA

The study area is situated in the eastern limb of the East African Rift Valley, and includes Tarangire NP and the surrounding areas used by migratory wildlife, extending over 35,000 km^2. Tarangire NP (2642 km^2) is located in Arusha Region, between 3'40' and 4'35' latitude and 35'50' and 36'20' longitude, at an average altitude of 1200 m.

The entire study area has been classified as ecological zone IV and V (Pratt *et al.*, 1966) with a semi-arid climate. The average annual rainfall is 600-650 mm. There are two rainy seasons, the short rains from November to January, and the long rains from February to May.

The topography is predominantly that of a gently undulating plateau; the main soil type is the dark red sandy clay loam of the semi-arid plains. There is black clay known as Black Cotton soil (Kahurananga, 1979) in the depression where drainage is impeded.

The most prevalent types of woody vegetation in Tarangire NP are *Acacia* woodlands along the drainage lines and *Commiphora-Combretum* deciduous woodlands on the uplands (Vesey-Fitzgerald, 1973).

Recent studies have revealed that during the dry season, the maximum number of elephants in the Tarangire NP varies between 1997 (total count in 1998) and 2334 (total count in 1995) (TWCM, 1998a,b). Slightly lower numbers of elephants are present during the wet season, ranging from 1386 (1996) to 1631 (1998). In the past, several migratory routes of elephants and other large herbivores have been described. The most important ones are to the east and northeast towards the Simanjiro and Lolkisale Game Controlled Areas (GCA), to the northwest along the Rift Valley to an area south of Lake Manyara, and towards the southeast and south into the Mukungunero GCA (Lamprey, 1964; Borner, 1985). GCA's represent 8% of the total network of protected areas. In GCA wildlife utilization is allowed, through tourism and resident hunting. In the Tarangire area, important concentrations of domestic animals (36% of regional stock) and cultivated land (18%) occur inside these GCAs.

In late 1989, the international trade on ivory was banned. This was achieved under CITES, the convention responsible for regulating the international trade of endangered species, and the African elephant was moved to Appendix I, the category offering the highest protection. Tanzania has been part of CITES since February 1980. Except for safari hunting, the elephant is protected. No individual or organization can engage in commerce in ivory. This applies to both raw and worked ivory (Government of Tanzania, 1989). Export of elephant tusks as hunting trophies is permitted from Tanzania. A quota of 100 tusks was allowed both in 1998 and 1999.

Material and Methods

Telemetry used to track wildlife has definitely improved over the past two decades, revolutionizing the way in which wildlife tracking research is conducted. Two systems currently used to locate radiotagged animals using satellite signals are ARGOS and GPS (Global Positioning System, Tomkiewicz, 1996). We used GPS-telemetry, based on the GPS system, a satellite-based navigation system providing accurate position data in real time using satellites that continuously broadcast two L-band spread spectrum radio-signals modulated by a low (50 bps) data stream. The data carried by the signal include clock corrections, high precision orbital details of individual satellite position, and an almanac of approximate orbital information for the entire satellite constellation (Tornkiewicz, 1996; TCP, 1998).

We made the choice to capture and radio-collar five female elephants in different areas of the park to obtain data on elephant-group movements, which possibly belonged to different populations. Elephant capture operations were conducted in Tarangire NP, November 17-19, 1997. Two animals captured in the northern section of the park (Bella and Fraha) were approached and darted from a car. The others, one captured in the middle section of the park (Kikoti), the last two (Maajabu and Kibonge) captured respectively in the southeastern and southwestern section, were darted by helicopter. Gun-propelled syringes containing 12 mg of Etorphine were used. While anesthetized, vital signs, heart rate, respiration rate, body temperature and blood pressure, were monitored continuously. A physical examination was carried out and biological samples (blood, feces, hair, ectoparasites) were collected. Biometric measurements (back length, tail length, length and circumference of hind foot, length and circumference of both tusks, trunk length, and neck girth) were also taken. After collaring, the animals were given between 30 and 72 mg of Diprenorphine as a reversal drug. Based on tooth wear, age of the captured elephants was determined between 15 and 30 years-old; hence all radiotagged animals were adults even if not all of them were fully grown.

The five elephants were equipped with a GPS collar-1000 (Lotek Engineering Inc., Canada). The GPS system consisted of five animal collars and a command unit, organized in a local network. The elements of the system are: collar, modem and command unit.

Collar

Each collar contains a 6-channel GPS receiver, which can acquire and lock onto 6 satellite signals simultaneously, a radio modem for data communication, an independent VHF tracking beacon, sensors and a computer/memory module. Collection and storage schedules for GPS position fixes and sensor measurements are user specified via a UHF data communication link with the command unit. To save energy consumption, the GPS receiver is turned on every time a **fix** is required and turned off immediately after. The VHF beacon signal has an individual frequency for each radiocollar and can be used to locate animals using conventional direction finding telemetry techniques. A fix is an univocal position of the animal, identified by latitude and longitude coordinates, acquired by the GPS receiver.

Modem

A link may be established to download stored data, to modify the current GPS fix schedule, to provide information on remaining operational battery life and to upload satellite almanac data for use by the animal unit's GPS receiver.

Command unit

The command unit is a battery-powered instrument which provides a command, control and interrogation of the animal borne collar. A portable host computer, running Lotek's GPS Host software under MSDOS, manages transport and session services for the network and also provides a windowed, menu-driven interface for user control of system parameters, formatting and storage of received data and system diagnostics. The system is designed to give data retention the highest priority. The data is stored in a specific bank of non-volatile random access (RAM) and memory capacity can storage up to 3640 records.

The data available from the animal unit consists of geographical coordinates (accuracy of 25 meters), date, time, air temperature, and animal activity in terms of head movements. The GPS collar was scheduled to record coordinates every 4 hours.

The GPS collars put on Tarangire elephants have been active since 17-19 November 1997. In this paper, only the data collected in the field before 18 April 1998 have been used in the analyses. Radiotracking monitoring, used to locate the VHF transmitters, was carried out by both aerial (Frankfurt Zoological Society FZS and Tanzania National Parks, TANAPA, Cessna 206) and ground surveys. After the location of a radiotagged elephant, data were downloaded using the command unit.

All data on home range size, home range overlap and distance moved were calculated using the RANGES V program (Kenward and Hodder, 1995), Excel and ArcView (ESRI, 1996). For each elephant the following data were calculated: 1) total home range size using 100% of the pointfixes (Figure 1), and total home range size taking only two fixes per day (at 8 a.m. and 8 p.m.), using the Minimum Convex Polygon (MCP); 2) home range overlap, expressed as a percentage overlap of an elephant's home range with the home range of each of the other elephants; 3) linear distance (m) between successive radio-locations (Kenward and Hodder, 1995). Total monthly distance covered was calculated by summing all the linear distances between successive fixes gathered within that month. Minimum speed was estimated by dividing linear distance between subsequent locations by the time in which they were bridged (m/h). The cal-

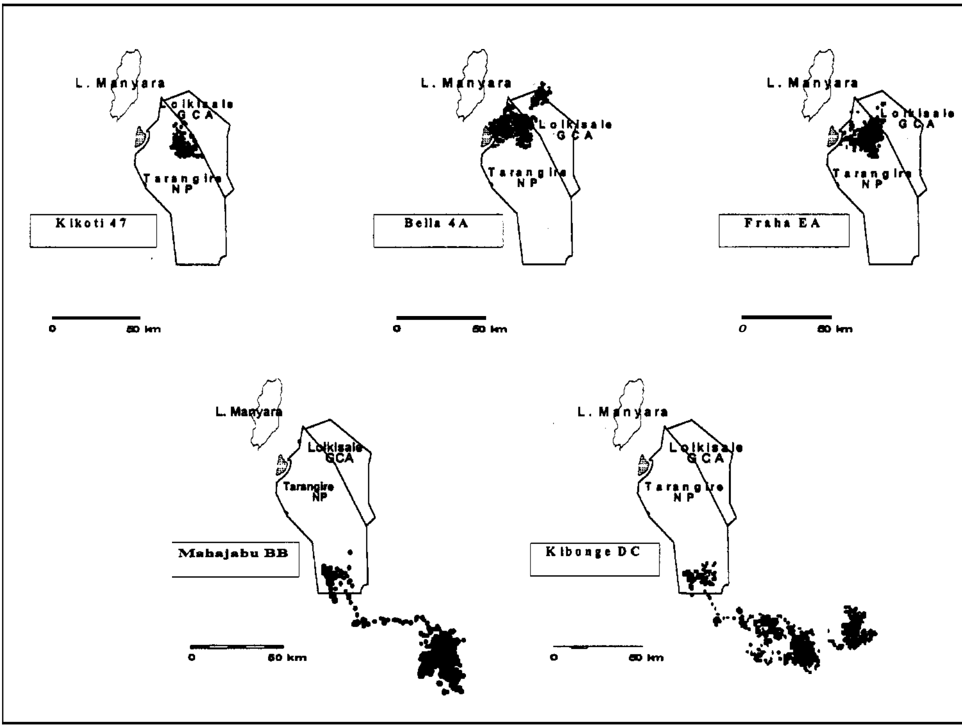

Figure 1 – Distribution of 5 GPS collared elephants in Tarangire National Park (November 1997 - April 1998). Dates refer to the last downloaded radio locations.

culated speed was categorized in one of six hour-intervals (median hour of intervals 4, 8, 12 16, 20 and 24, Figure 2) and a one-way analysis of variance was used to compare mean speed at different hours of the day for each elephant separately. Differences between means were compared a posteriori with a Tukey test (Sokal and Rohlf, 1981).

Results

Number of locations recorded for each elephant, length of monitoring period and space use estimates are shown in Table 1, whereas elephant distribution relative to the park boundaries is shown in Figure 1.

Movements

Elephant Bella mainly used the northern part of the park, the north-eastern shore of Lake Burungi and the northern tip of Lolkisale GCA, moving a maximum of about 20 km outside the park boundaries (Figure 1). Elephant Fraha remained inside the park, mainly in the area around Tarangire River. She migrated only once outside the park, in Lolkisale GCA, where she spent only one day (Figure 1).
The collar of elephant Kikoti developed a technical failure very soon. In December the data was downloaded for the last time. The available data show that this female remained inside the park, using an area located more to the south of the distribution of the previous two animals (Figure 1).

Table 1 - Home ranges of 5 elephants estimated by GPS-telemetry in Tarangire National **Park** and surroundings (November 1997 - April 1998).

Elephant name	N° days	N° fixes used in ArcView	ArcView MCP HR (km^2)	N° fixes used in Ranges	Ranges MCP HR (km^2)
Bella	106	690	766	202	660
Fraha	144	1000	548	286	403
Kikoti	30	328	246	56	159
Maajabu	151	936	2884	275	2104
Kibonge	151	936	3595	280	3314

Table 2 - Percentage of home range overlap of each radiotagged elephant with all other radiotagged elephants (n= 5).

	Home range overlap (%) with other elephants				
	Bella	Fraha	Kikoti	Kibonge	Majaabu
Bella	100	48.8	8.0	0	0
Fraha	79.5	100	26.7	0	0
Kikoti	33.2	67.4	100	0	0
Kibonge	0	0	0	100	56.6
Maajabu	0	0	0	89.2	100

However, in February the animal started to migrate and was found in the center of Lolkisale GCA, and in April it was located again being found this time in the vicinity of the Oldonyo Sambu Hill, in Lolkisale **GCA.**

Elephants Kibonge and Maajabu moved outside the park 12 days after their capture, travelling in a southeasterly direction about 80 km from the park boundary, to Kiteto Region. They both crossed the park boundary in a straight line, during the night, moving almost 15 km in 10 hours. From December to April they always used the same area (Figure 1).

Home ranges

Home range size was largest for the two female elephants using the southern section of the park, which, during the entire study period, roamed over an area of more than 2000 km^2 (Table 1). Home range overlap was large for Bella and Fraha, while Kikoti showed a smaller percentage of overlap than both these females (Table 2). The home range of Maajabu overlapped nearly 90% of Kibonge, but both of these elephants did not show any home range overlap with the other three radiotagged females (Table 2, Figure 1).

The MCP method was also used to estimate the monthly home range size. Only home range size estimates obtained with fixes available for the whole month have been compared. Maajabu, one of the two elephants that migrated southwards, had the biggest monthly home range of 902 km^2 in December, while Fraha, which remained inside the park, had the smallest monthly home range of 53 km^2 in March. Differences between mean monthly home range sizes (December, n= 5, mean±SD=

5302350 km², January, n= 4, 4372227 km², February, n= 4, 337±198 km², March, n= 3, 168±116 km²) were not statistically significant (Kruskal-Wallis analysis of variance H= 3.918, df= 3, P= 0.27). However, when the home range used in December or January (excluding Kikoti which could only be monitored in a single month) was compared to home range size in March, elephants used significantly larger ranges in December (or January) than in March (Mann-Whitney U-test, U= 1, P= 0,039, one-tailed).

Speed

The total monthly distance moved by each single elephant was higher in December than in February-March (Bella 346 against 235 km, Fraha 304 against 145 km, Kibonge 296 against 217 km, and Maajabu 298 against 180 km; Wilcoxon-test P= 0.068, two-tailed).

The average speed of the elephants that remained in the northern section of the park differed significantly according to hour of the day (Bella F= 12.32, P<0.0001, Kikoti F= 12.72, P<0.0001, and Fraha F= 13.92, P<0.0001). Speed was significantly lower at 4 a.m. in the morning than at midnight (Bella 171m/h at 4.00 h, 365 m/h at 24.00 h; Kikoti 102 m/h at 4.00 h, 293 m/h at 24.00 h; Fraha 133 m/h at 4.00 h, 220 m/h at 24.00 h), and the speed at which the elephants traveled was lower at both 4.00 and 24.00 h than during the other daylight hours (Figure 2). The elephants Kibonge and Maajabu, that migrated southwards outside the park, also traveled at a different speed at different hours of the day (Kibonge F= 4.61, P<0.0005, Maajabu F= 6.25, P<0.0001). At 4 a.m. their speed was significantly lower than at 8 p.m. (the highest speed of the day), but was not significantly lower in the other daylight hours (Figure 3).

Discussion

Most studies on space use and movements of African elephants have used VHF transmitters, locating animals with a portable receiver by airplane or by car. Because of the high costs per single fix, the number of animals radiotagged have generally been very low (reviewed in Thouless, 1996). Satellite telemetry techniques, using the ARGOS system, have been used on two female elephants in Cameroon (Tchamba *et al.*, 1995) and on seven animals in Namibia (Lindeque and Lindeque, 1991). In both cases, together with our study at Tarangire NP, the low number of radiotagged animals was a consequence of the high cost of the individual radio-collar and satellite receiver system. Only one study, carried out on the largest elephant popula-

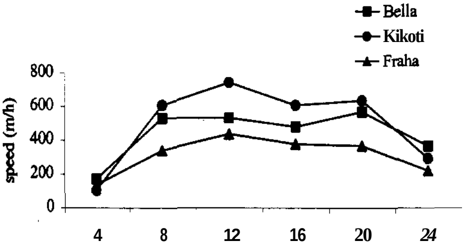

Figure 2 – Speed (m/h) of northern elephants of Tarangire National Park.

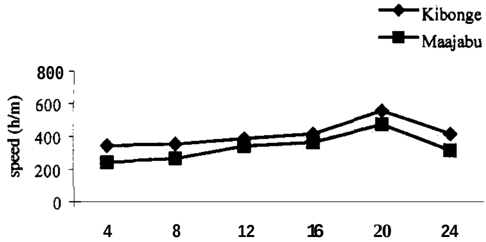

Figure 3 – Speed (m/h) of southern elephants of Tarangire National Park.

tion of Kenya that occurs primarily outside protected areas (the Laikipia-Samburu population, about 3000 animals), monitored a considerable number of animals (20 female elephants marked with VHF radio-transmitters), and obtained a sufficient amount of fixes to allow realistic estimates of home range sizes over both wet and dry seasons (Thouless, 1995, 1996). The latter population inhabits a 15,000 km^2 area comparable with the Tarangire area. There is one stream with a permanent water supply, many seasonal water sources, evergreen and savanna vegetation, a considerable amount of cultivated and ranchland for cattle farming and a large area which is included in game reserves (Thouless, 1996). The radiotagged elephants in Kenya were all females that belonged to different family groups (Douglas-Hamilton, 1972). The whole population was subdivided into several subpopulations that had little range overlap (which increased during dry season) and generally used different portions of the area. Elephant home range sizes ranged from a minimum of 102 to a maximum of 5527 km^2 and individual range size was negatively correlated with annual rainfall in the area used by the different subpopulations. Average home range size in different subpopulations was smaller when group size was small and when evergreen vegetation was available. However, it strongly increased with increasing group size and in areas where considerable movements needed to be made between foraging grounds used during the dry and during the wet season (Thouless, 1996). Our first results on range sizes during the dry season of the 5 female elephants that occupied different sectors of Tarangire NP agreed with the situation described for Kenya: animals from the northern sector, near permanent water sources had smaller home ranges (159-606 km^2) than those living in the southern sector, which showed more consistent migratory movements (>2000 km^2). Continuous monitoring of elephant locations over a whole year, thus covering the entire wet and dry season, will be carried out in future research to confirm these trends. More research also needs to be carried out to test the hypothesis that the distribution, and the degree of disturbance (interference from cattle and human activity, including poaching) around permanent water sources has a strong impact on migratory movements of elephants. In fact these seem to have changed in recent times in non-protected areas (Thouless, 1995).

Our results on the average speed per hour of the 5 radiotagged elephants showed that the elephants outside the park exhibited their highest movements during the late afternoon/evening hours of 4p.m. to 12p.m., while those that remained in the park had movement peaks during the day. The elephants outside the park appeared to change their daily movement patterns to avoid contacts with humans. They presumably tried to hide in thicker vegetation during daylight hours, and fed more intensively, in more open habitats, at night. In contrast, the elephants in the park were not restricted in their movements or activity by human disturbance and could feed extensively during the day. Undisturbed elephant family groups usually slept between 1-5 a.m. (Douglas-Hamilton, 1972), which was confirmed by the significantly lower speed at 4 a.m. of all our radiotagged elephants.

In the case of elephants, the high costs of satellite-based GPS-telemetry means that radio-collars must be distributed with care. In particular the number of animals that needs to be monitored, sex and age of target animals and knowledge on the social group to which they belong, are important elements in the development of a working plan for elephant management purposes (TCP, 1998). By using adult females, monitoring the locations of the radio-collar can be considered as representing the actual movements made by the family group to which the target elephant belongs (Douglas-Hamilton, 1972; Thouless, 1996). However, such data need to be confirmed by regular traditional radio-tracking of the target elephant, and by combining GPS-telemetry with low-cost monitoring techniques, such as elephant track surveys and transects (TCP, 1998). When standardized properly, the latter are still very useful identifying (or confirming) migration routes and monitor their importance over long periods of time. Combined with more intensive dung-count surveys on sample-areas, quantitative estimates of the number of elephants using certain migration routes can be obtained.

Finally, the Systematic Reconnaissance Flight (SRF) surveys, during which animals are counted over a strip of defined width, provide a density index for the species counted. This is very useful to map wildlife abundance and distribution during the wet and the dry season. As far as elephants are concerned, the SRF of 1998 (TWCM, 1998a, b), showed that Tarangire NP, Lake Manyara NP and Lolkisale GCA are the most important areas during the dry season. Our radio-tracking data confirmed the extreme importance of Tarangire NP itself, and in particular that of the northern, central and southeastern sectors of the park, during the dry season. During the wet season, a considerable number of elephants remain in Tarangire NP, while other large groups are found in Lolkisale GCA and in the northern sector of the park. Our radio-tracking data gathered during the wet season confirmed that Lolkisale GCA is an important foraging habitat for elephants, as is northern Tarangire.

The GPS-telemetry data we gathered during these first six months confirmed current knowledge (Borner, 1985) of one of the two most important migration routes starting from the northern sector of Tarangire NP. The NE corridor towards Lolkisale GCA is still of extreme importance. In fact, both elephant track surveys and aerial surveys showed that large numbers of elephants intensively use this GCA, in both the dry and wet season. However, the number of radio-tagged elephants was apparently too limited to reveal the importance of the second N-NW migratory route. Aerial surveys demonstrated the importance of Lake Manyara NP, during the dry season, and groups were found in the area north of Tarangire NP during the wet season. These data confirm the extreme ecological importance of the so-called Kwakuchinja Wildlife Corridor, already noted by Lamprey (1964) and Borner (1985). This corridor has remained partly intact because it is principally occupied by nomadic Maasai and their cattle, and by Wambugwe tribes conducting small-scale farming. However, during the last decades, human immigration (increase in density of human population 1967-1988: 6.5 to 37.9 individuals/km^2), accompanied by an increased land use for agriculture purposes (36 km^2 cultivated land in 1958, 185 km^2 in 1988), and the development of intensive bovine-farming, have strongly increased conflicts between local populations and migrating herbivores (Mwalyosi, 1991). A combination of creating buffer zones for the most intensively used sectors of the corridor, together with the development of a strategy of sustainable and beneficial use of wildlife resources by the local population (Wildlife Management Areas, WMAs), seems to be the only way to ensure long-term conservation of these areas (Mwalyosi, 1991; TCP, 1998).

The application of GPS-telemetry also revealed new information. The two elephants that during the wet season migrated about 80 km south of Tarangire NP into the Kiteto District were found to form part of a large group of approximately 300 individuals that used a S-SE migration route towards foraging habitats in the SE of the Tarangire area (Makame and Ndedo area). This area was beyond the boundaries of any aerial survey ever undertaken before (TCP, 1998).

The data gathered on elephants during the first six months of GPS-telemetry allowed us to draw the following conclusions. The main advantages of GPS-telemetry are: 1) large amounts of very accurate location data (fix-error of only 25 m) are automatically recorded; 2) the costs of a single fix is lower than when traditional car or airplane radio-tracking is used; 3) the system permits the programming of the frequency of data acquisition which can be varied to suite specific research needs; 4) the possibility to track animals night and day, and in every environmental condition; 5) the unlimited range over which radiotagged animals can be monitored. The major disadvantages are: 1) the high starting expenses (cost of a single collar: 6800 USD; cost of command unit: 6500 USD); 2) the problems related to any technical failure of the system (see elephant Kikoti), thus the need of higher equipment reliability over long-term periods for animals with ecological and ethological characteristics such as elephants. Because of the high costs and the need for well-trained technical personnel, GPS-telemetry is not sustainable as a yearly routine monitoring method. Therefore, it needs to be combined with low-cost standardized ground counts (elephant tracks transects) to monitor population distribution and estimate population size on a regular basis (TCP, 1998). We plan to continue the radio-tracking of the 5 elephants, in order to obtain detailed data on elephant distribution, and their space use and habitat use during several wet and dry seasons. More precise information on their migration routes will be gathered in order to design a Wildlife Management Plan compatible with the needs of local human communities.

ACKNOWLEDGEMENTS

Tarangire Conservation Project (TCP) is a joint project between University of Insubria (Varese Branch), Istituto Oikos NGO and Tanzania National Parks (TANAPA), carried out in 1995-1998, and funded by the European Community. Elephant capture operations were organized by TCP and conducted in co-operation with TANAPA, Wildlife Division (WD), Kenya Wildlife Ser-, vice (KWS) and Tarangire Elephant Project (TEP). We would particularly like to *thank* Luc Wauters for his comments and advice,

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