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SHORT COMMUNICATION

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Field testing a global positioning system (GPS) collar on a Japanese monkey: reliability of automatic GPS positioning in a Japanese forest

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Abstract A global positioning system (GPS) collar recorded the locations of an adult female Japanese macaque over a 9-day period in a habitat with mixed suburban and rural land-uses in Chiba Prefecture, Japan. The GPS device acquired positions even in forested areas. The GPS data located the female mostly in forested areas, although the female had ranged through a habitat with inter-mingled fields, orchards, quarries, and residential areas. However, the GPS position acquisition rate was low compared to studies carried out on North American mammals. The GPS fixed a position in 20% of positioning attempts. When the collared female was tracked by radio-telemetry, almost all failures of the GPS to fix a position occurred in forest.

Keywords Global positioning system · Japanese macaque · *Macaca fuscata* · Forest canopy · Rural land-use

Introduction

The global positioning system (GPS) holds out the promise of improving the efficiency and accuracy of wildlife telemetry (Phillips et al. 1998; Hulbert and French 2001). GPS collars have shown great success in recording the positions of free-ranging North American mammals [elk (*Cervus elaphus*), Rumble and Lindzey 1997; Gamo et al. 2000; Biggs et al. 2001; Rumble et al. 2001; deer (*Odocoileus virginianus*), Merrill et al. 1998; Bowman et al. 2000; moose (*Alces alces*), Moen et al. 1996, 1997; Dussault et al. 2001; wolf (*Canis lupus*), Merrill et al. 1998]. However, the utility of GPS collars varies according to an animal's habitat and behavior. Most importantly for many primatologists, forest canopy interferes with the satellite signals that GPS devices receive to calculate a position (Rumble and Lindzey 1997; Sigrist et al. 1999; Gamo et al. 2000). Blake et al. (2001) tested GPS collars at fixed locations in a rain forest in Central Africa, and found that the position acquisition rate under closed canopy varied from about 80% in "low closed scrub" to 9.8% in "mixed closed canopy forest."

Primatologists working in Japan have applied radio-telemetry to field research on the Japanese macaque (*Macaca fuscata*; e.g. Koganezawa and Imaki 1999; Muroyama et al. 2000), and have started to consider using GPS collars. However, primatologists face the possibility that GPS collars could fail to acquire positions under the dense, closed canopy of the forests characteristic of the habitat of the Japanese macaque. GPS devices vary in the ability to maintain contact with satellites within a forest. In particular, GPS collars small enough to be worn by a monkey may sacrifice function to achieve low weight.

We tested the utility of a light-weight GPS collar in recording the locations of a female Japanese macaque ranging in a mixed suburban and rural habitat. We tracked the collared animal with conventional radio-telemetry to monitor the operation of the GPS device, identify locations where the GPS may fail to fix a position, and confirm whether a GPS collar would record positions in the broad-leaved and coniferous forests of a Japanese study site.

Methods

The GPS collar was a Televilt Porsec 120 manufactured by TVP Positioning (Lindesberg, Sweden) weighing 189 g. This model was the lightest GPS collar commercially available at the time of the study. The GPS device was programmed for this study to record a

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position every hour on the hour, 24 h per day, broadcast a radio beacon from 8:00 a.m. to 5:00 p.m., and drop-off automatically when the battery was depleted. The collar was returned to the manufacturer for data download and refurbishing.

The collar was fit on a 7.2-kg female Japanese macaque ranging with the Ichibuse troop between Kyonan and Tomiyama Townships in the Boso Peninsula of Chiba Prefecture along Tokyo Bay, Japan. The female was captured by a baited cage trap and sedated for about 1 h with 0.125 cc/kg ketamine while we fit the collar.

K.H. attempted to locate the collared female by conventional radio telemetry during daylight hours, every hour on the hour at about the same time the GPS device attempted to record a position. The GPS device's radio beacon stopped while the GPS operated. Whenever possible, K.H. recorded the time the beacon stopped and started as a measure of the time the GPS took to fix a position.

The GPS device recorded: date and time in GMT, satellite reception mode as 2-D, 3-D or 3-D+ mode, latitude–longitude position in decimal degrees in the WGS84 datum. For analysis, we converted the date and time to Japan Standard Time (GMT +9 h), and the positions to meters in the universal transverse mercator grid of the Tokyo datum, used by Japanese topographic maps, with the geographic analysis package Arc/Info (Environmental Systems Research Institute).

The position acquisition rate was measured in two ways by comparing the number of GPS positions acquired to the numbers of: (1) hourly GPS positioning attempts from the first position to the last attempt as detected from the radio beacon; and (2) radio-telemetry positions obtained at the same time as the hourly GPS positioning attempts.

The GPS device indicated the difficulty in tracking satellite signals by the time taken by the GPS to measure a position, and the satellite reception mode. The GPS device searched for satellite signals to measure a position first for 1 min, then for 2 min, and shutdown without recording a position if it failed to detect at least three satellites. When the GPS fixed a position, reception mode was 2-D when tracking the minimum required three satellites, 3-D mode with four satellites, and 3-D+ mode with five or more satellites. Accuracy is poorest under 2-D mode and best under 3-D+ mode.

Land-use at the GPS and radio-telemetry positions was identified from the topographic map issued by the Geographical Survey Institute of Japan, and an aerial image taken by helicopter (Sky Map) on 13 March 2002. In addition, we carried out a ground survey to observe land-use at the 3-D and 3-D+ positions, which we assumed were accurate enough to allow us to go to the correct location.

Results

The GPS collar operated for 9 days from 3 to 11 March 2001 (Fig. 1). The GPS measured the first position at 3:13 p.m. on 3 March while being initialized as it was held by hand. The GPS measured the second position after being fit to the female Japanese macaque while the female was still in the cage. After release, the female ran immediately into the nearby forest, climbed up a hill, and disappeared from sight. The GPS's last positioning attempt occurred at about 12 noon on 11 March, as indicated by the pause in the radio beacon. Soon after 1:00 p.m. on the same afternoon the radio beacon indicated that the collar had dropped off, and K.H. retrieved the collar.

The GPS device recorded 38 positions, including the two initial positions described above (Fig. 1). A minimum convex polygon drawn around the GPS positions was 1.54 km^2 in area. The female had traveled at least 7.4 km, as measured by the sum of the straight line distances between the 2nd position and the collar pickup point. One advantage of the GPS collar is that it measures position at night. The straight line distance of 157 m connecting positions no. 9–11 suggests the possibility that monkeys may move moderate distances during the night.

The GPS device had encountered difficulty in tracking satellite signals. The overall position acquisition rate was 20% compared to the 190 hourly positioning attempts by the GPS device from the initial position to the last positioning attempt detected from the radio beacon. Of the 38 GPS positions, 63% had been recorded in 2-D mode, 26% in 3-D mode, and 11% in 3-D+ mode (Table 1, Fig. 1). In the 27 cases when the radio beacon cessation time was recorded, the GPS device acquired a position in the initial 1 min in 15% of attempts, used 2 min to acquire a position in 19%, and recorded no position in 66% of attempts.

The study troop ranged in an area with low, forested hills adjacent to paddy and dry fields, orchards, quarries, housing, roads, and a railway. The collared monkey's presence in forested areas did not preclude GPS positioning. The forests, confined mostly to the hilly parts in the study area (highest peak 256 m), consisted of a mixture of evergreen broad-leaved tree species (e.g. Fagaceae, Lauraceae), and plantation conifers (e.g. *Cryptomeria japonica*) with essentially 100% canopy cover. Forest accounted for 74% of the GPS positions (Table 1). The GPS also recorded positions in orchards (13%), and one position (3%) each in a field, a quarry, and on the railway track.

In the 40 hourly locations obtained by conventional radio-telemetry, the GPS had fixed a position in 13 cases, for a position acquisition rate of 33% (Table 1). All but one of the GPS failures occurred in forest area; the position acquisition rate in forest was 30%. Radio-telemetry detected one failure of the GPS in an open land-use in wasteland, and did not detect any failure in a field or orchard. There were 25, mostly nighttime or early morning GPS positions for which no radio-telemetry position was obtained.

The possibility remains that measurement error may have caused the GPS device to incorrectly record positions in forest area when the collared monkey had actually been in an open land-use. Eleven of the GPS positions in forest were judged to be far enough away from an open land-use (e.g. orchard or field) that they were highly likely to have been within forest (Fig. 1). The judgment is based on the assumption that 3-D or 3-D+ fixes were accurate to within 50 m, and 2-D fixes to within 100 m. The non-forest 3-D or 3-D+ fixes were the initial hand-held fix, and fixes in a field and orchards.

Discussion

This study demonstrated that a lightweight GPS collar can monitor the ranging of a Japanese monkey. A GPS collar is especially useful for tracking monkeys in rural habitats because one critical issue for research in this

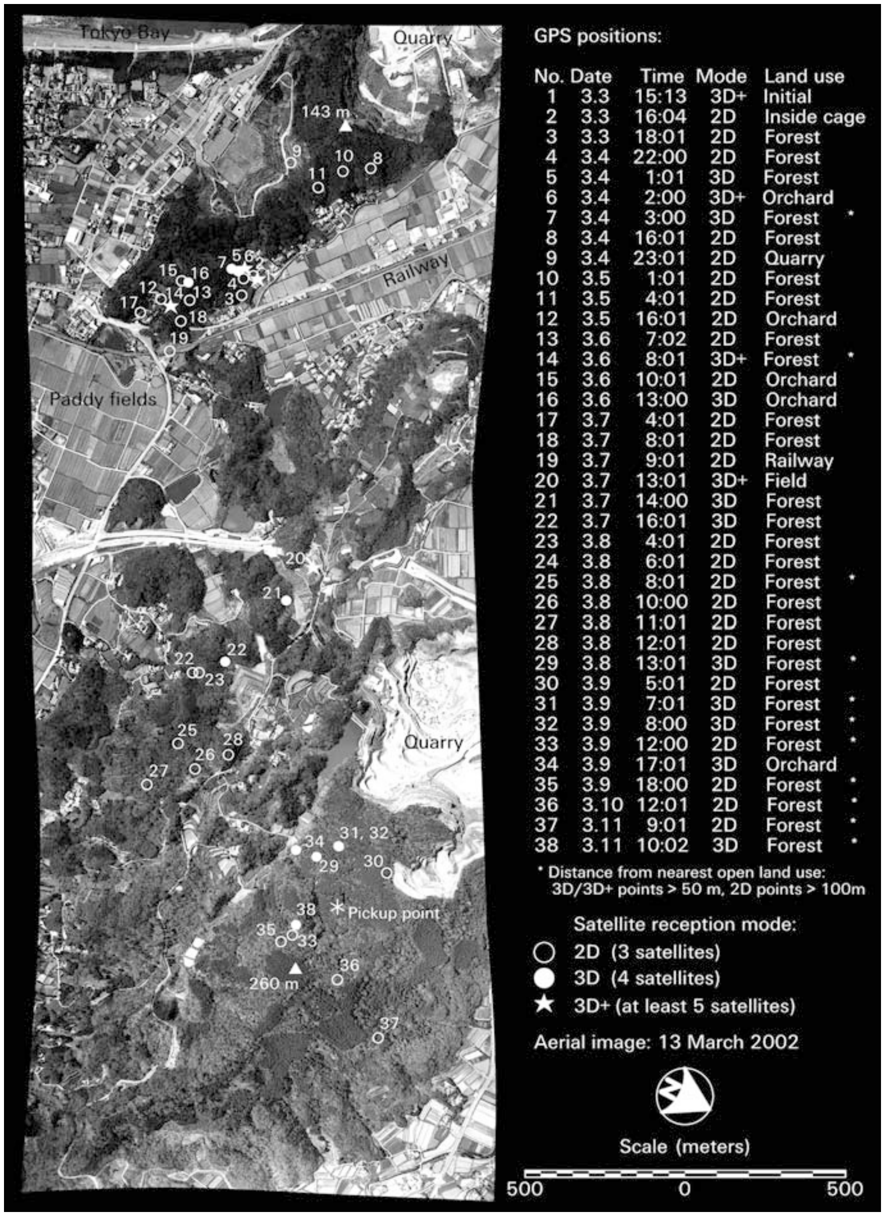

Fig. 1 GPS positions and the pickup point for a GPS collar worn by an adult female Japanese macaque on 3–11 March 2001 in the Boso Peninsula, Chiba Prefecture, Japan

environment is how often a monkey comes out into the open where GPS signal reception should have been far better than in forest. The GPS data showed that the collared female had stayed mostly in forested areas, although it ranged through a habitat intermingled with fields, orchards, quarries, and residential areas.

Sufficient opportunities existed even in forests for the GPS device to receive satellite signals to calculate the position of the collared monkey. Three contexts may explain how the GPS device was able to fix the positions in forested areas. First, the GPS may be able to occasionally receive satellite signals even under a forest canopy. Second, the collared monkey may have been in a clearing or under a deciduous tree without leaves. Third, the collared monkey may have climbed up into the forest canopy. The last context is implied by the 3-D and 3-D+ positions in forest areas. A GPS usually

Table 1 Land-use and satellite mode at global positioning system (*GPS*) positions, and GPS success or failure at the radio telemetry positions obtained at the same time as GPS positioning attempts

Land use	GPS satellite mode				GPS performance at radio telemetry positions		
	2D	3D	3D+	Total	Success	Failure	Total
Initial position			1	1			
Inside cage	1			1			
Forest	19	8	1	28	11	26	37
Field			1	1	1		1
Orchard	2	2	1	5			
Quarry	1			1			
Railway	1			1	1		1
Wasteland						1	1
Total	24	10	4	38	13	27	40

requires a clear view of the sky to receive signals from a sufficient number of satellites to fix positions in 3-D or 3-D+ mode. We checked land-use in the ground-survey at these positions to be sure they were not open land-uses, and several of these positions were far enough away (>50 m) from open land-uses that measurement error was unlikely to account for their locations in a forest.

However, the position acquisition rate was low in this study compared to those in studies on North American mammals. For example, Rumble et al. (2001) reported an 80% success rate with 70% 3-D locations for four GPS collars worn by elk. In the present study, the GPS worn by a female Japanese macaque acquired a fix in only 20% of attempts, starting from the initial position to the last attempt detected by radio beacon, with only 37% in 3-D mode. Among the radio-telemetry positions, the overall position acquisition rate was 30%, and only 28% in forest areas.

The density of Japanese forests is probably a major reason for this relatively low rate. GPS devices cannot calculate a position if the satellite signals are blocked by the canopy, or multi-path effects confuse the GPS receiver with multiple signals bouncing off of tree trunks or moving canopy in windy conditions (Sigrist et al. 1999; Gamo et al. 2000). Other contributing factors may be the satellite search time that is limited to conserve battery power in GPS collars, the topography if hills block the sky, and the lack or poor configuration of GPS satellites in the sky at the moment when the GPS collar attempts to fix a position. Under a clear sky, this GPS collar should be able to acquire more positions (maximum of up to about 500 positions), more quickly, with more positions in 3-D mode.

In summary, to plan a research project using a GPS collar, primatologists need to balance the trade-off between the weight and functions of the collar. To lighten a GPS collar, engineers must reduce functions requiring electricity and a large battery. Smaller GPS collars may limit the satellite search time, record fewer positions, and need to be recovered for data download after detaching automatically. However, GPS technology is improving quickly. Better batteries, antennas, and electrical efficiency will improve position acquisition rates and increase the number of positions recorded. Data download and detachment on radio command may become available for smaller GPS collars as they are on models designed for larger animals.

Primatologists can test GPS collars to determine the utility of GPS for their species and study sites. The commercially available GPS collars should operate reliably for primates living in grassland or sparse woodland. Researchers working in forested habitats may wish to first test the performance of a GPS collar at a fixed site under forest canopy. Even in forested habitats, a GPS can be an effective tool for monitoring the general ranging of primates, and one worn by a primate climbing often to the canopy may find more success than one worn by obligate ground-dwelling animals.

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