bined use of three separate antigens maximizes the effectiveness of serodiagnosis. Similarly, Julian *et al*.[5] found that sensitivity is improved when antibodies are detected together in a test based on different antigens (proteins and glycolipids) and suggested the use of a cocktail of specific antigens from *M. tuberculosis* to develop a serodiagnostic test. In our earlier studies[17], a cocktail of ES-31 and ES-41 was explored by ELISA and was found to be useful for screening of broad spectrum of TB sera in PTB and extrapulmonary TB compared to ES-31 or ES-41 alone. However, the present study showed that a combination of ES-31, ES-41 and ES-43 is still better and more sensitive in ELISA compared to blotting. Thus ELISA using a cocktail antigen is simple, sensitive and easy to perform and more sensitive compared to blotting and can be useful in analysis of a large number of samples for serodiagnosis of TB.

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Using satellite telemetry to mitigate elephant–human conflict: An experiment in northern West Bengal, India

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Satellite tracking of animals has advantages in the study of species that migrate across international borders, have large home ranges and occupy remote and inaccessible areas. The efficacy of this technology in dense tropical forests may, however, be limited. At the same time, its use in mitigating wildlife–human conflict has not been examined so far. Here we report the movement patterns and habitat utilization of an adult male Asian elephant, and a preliminary assessment of the potential use of satellite technology as an ‘early warning system’ for conflict mitigation. Data on the location of the animal were obtained from a Platform Transmitter

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Terminal mounted on an elephant in Jaldapara, West Bengal, the first if its kind used on this species in India. We found that the animal preferred forest and forest plantations during the day, making visits to cultivated lands at night. There was some predictability in the movement of this animal, suggesting that similar technologies such as the more advanced Global Positioning System can be used for near 'real-time tracking' of problem elephants.

SATELLITE tracking of animals has advantages in field ecological research, where conventional radio-telemetry is difficult or not feasible. Studies on migratory species crossing international borders such as the common crane[1] travelling from India to its breeding grounds in Siberia, bar-headed goose that winters in India and travels to Tibet[2], Kemp's Ridley sea turtle[3] and other migratory sea-birds[4] and raptors[5] have used satellite telemetry to varying extents. Satellite tracking has also been used to study migrations in large mammals, particularly where home-range sizes are large or terrain and landscape make ground-tracking difficult. Elephant home-ranges in parts of semi-arid and arid Africa tend to be large and satellite tracking has been used to determine seasonal movement and home-range size[6]. In Malaysia, where the dense rainforest habitat precludes ground tracking, satellite tracking of two elephants, relocated from isolated forest patches into a national park, provided valuable information on the movement of these animals[7].

Locations of animals fitted with Platform Transmitter Terminals (PTTs) are determined by a system of polar orbiting satellites monitored by the National Oceanic and Atmospheric Administration (NOAA), USA. These locations are calculated from Doppler shifts in signals received by the satellites and transmitted to ground stations in USA and France maintained by Service Argos (Tolouse, France). Potential users of this facility have to subscribe to this service by paying an annual fee. Data are regularly sent by email to the subscriber or can be viewed on secure websites. Location data are updated every 24 h and users can track the movement of tagged animals on Geographical Information System (GIS) maps of the study area (Figure 1). Location data received are classified into several data classes. Usable classes are LC1 (data are most accurate in a 1000 m radius), LC2 (most accurate in 350 m radius) and LC3 (most accurate in 150 m radius). More details on the Argos system can be found in Javed *et al.*[8].

In many parts of Africa and Asia, the close proximity of elephants and humans results in serious elephant–human conflict, manifested by manslaughter, crop raiding and the destruction of property by elephants, and retaliatory killing of elephants by people through shooting, electrocution or poisoning[9–11]. Several methods for mitigation of elephant–human conflict have been instituted and results vary substantially. This conflict can often be attributed to a specific set of problem animals that can be recognized[9,11]. In countries such as India, where the killing of problem animals may be culturally unacceptable and legally regulated, their tracking on a regular basis may help pre-empt conflict. Information about the precise location of a problem animal or animal group, its movement in the recent past, and possible future movement into areas of human settlement or cultivated land can potentially help wildlife managers as well as local communities maintain increased vigil or take steps to chase the animals before they cause damage. Satellite-based telemetry can be potentially used for setting up an 'early warning system' towards this purpose.

Here we evaluate the relevance of satellite telemetry technology for elephant–human conflict mitigation through an experiment carried out in West Bengal through the first PTT fitted on an Asian elephant in India. We also analyse patterns of habitat utilization of this bull elephant during the dry season in the Jaldapara Wildlife Sanctuary. With the help of local forest officials, we identified a known problem elephant, a tuskless male (or *makhna*) aged about 40–50 years, in Jaldapara for this experiment.

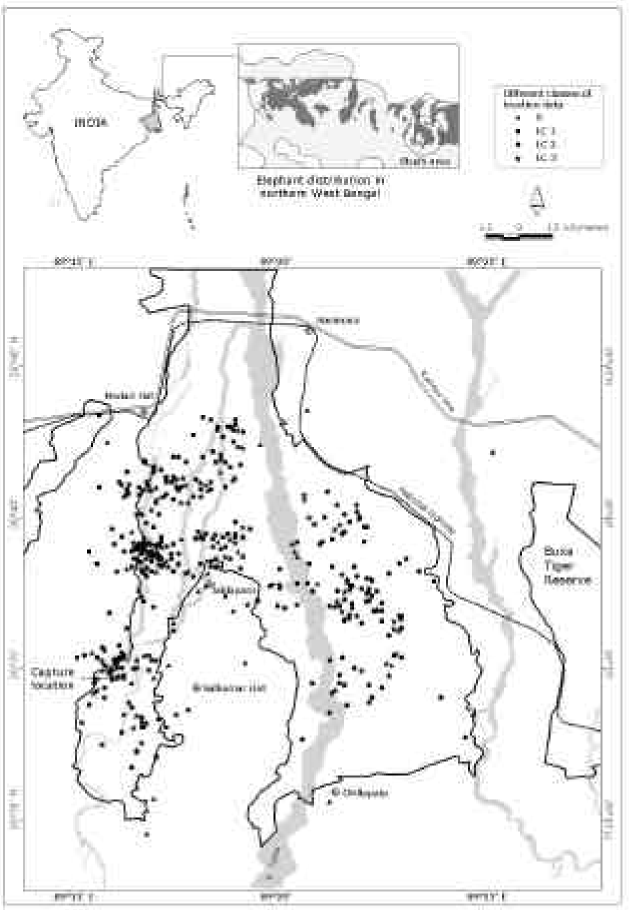

Figure 1. Map of the southern part of Jaldapara Wildlife Sanctuary, West Bengal showing all locations of the collared bull elephant received from the satellite. Quality of the location data (see text for details) is indicated by different symbols. Exact location of capture of the animal is also shown.

Jaldapara Wildlife Sanctuary comprises grasslands and open canopy forests. Satellite signal strength is likely to be severely attenuated in dense canopy forests, resulting in the loss of a high percentage of locations[7] and interruptions in monitoring. As the 'early warning system' requires that problem animals are located continually, we believed that satellite signal strength would be consistently high in Jaldapara, allowing for near continual monitoring of the animal.

The animal was immobilized with a mixture of 9 mg Etorphine and 40 mg Acepromazine (i.e. 4.5 ml of commercially available Immobilon L.A.) on 23 January 2003 and fitted with a PTT mounted on a collar[12]. The PTT has activity (activity within 1 min and 24 h before each location is recorded) and ambient temperature monitors. Conventional radio-telemetry was also possible with an additional VHF (Very High Frequency) transmitter fitted on the same collar. The PTT cycle is: 8 h on – 4 h off – 8 h on. Approximately 10–15 locations were received every 24 h. The animal was monitored until 24 April 2003. The activity monitor stopped after this date; subsequently we retrieved the collar from the VHF signals. An examination indicated that the collar had sheared and fallen-off, though the transmitter continued working. The animal was later seen in good condition.

After capture, the animal was located by satellite 486 times. A total of six satellites provided these locations. Of these, 384 locations were LC1 (31.0%), LC2 (40.9%) and LC3 (28.1%) and therefore considered usable. The dry season home-range size of the animal from these locations using the minimum convex polygon method was 179 km^2 over the three month study period. GIS maps of the locations of the animal were sent electronically on a daily basis to the park manager and other forest officials in the region, so that they could participate in monitoring its movement. Table 1 shows the numbers and percentages of locations obtained in each habitat type of the locations for that habitat type and for total locations in all habitat types. Of the total locations, the highest percentage of locations were in sal (*Shorea robusta*) plantations and dry deciduous forests. The lowest percentages were in evergreen forests and cultivated lands outside the park boundary. Of the total usable locations, 182 (47.4%) were recorded at night (1800–0600 h) and 202 (52.6%) during the day. Locations were thus equally distributed over nights and days. The animal thus spent considerable proportion of its time in sal plantations and in deciduous forests during both night and day, making occasional visits to cultivated lands outside the park boundary.

To determine any habitat preferences within the home range, the proportion of time spent within a particular habitat type has to be compared with the proportion of the home-range area constituted by this habitat type. We thus compared observed and expected values of habitat use in a chi-square goodness of fitness test, where expected values were obtained by distributing the total number of usable locations (384) across habitat types in proportion to their areas (Table 2). Cultivated land and locations within these are omitted from the analysis. The distribution of observed values varied significantly from that expected ($c^2 = 149.8$, d.f. = 6, $P < 0.05$). This was largely due to fewer than expected locations of the animal in floodplains and greater than expected locations in teak plantations and mixed vegetation forests. Similar patterns were seen when data for night time ($c^2 = 86.8$, d.f. = 6, $P < 0.05$) and day time ($c^2 = 78.4$, d.f. = 6, $P < 0.05$) locations were analysed separately (Table 2).

Locations in cultivated lands during the day were, however, higher than those at night. Based on our knowledge of elephant behaviour and of this particular individual, this is rather anomalous (elephants generally raid crop fields at night; see Sukumar[11]). One possibility is that the animal was erroneously located in cultivated lands during the day through the error associated with location data. Thus, if the animal is actually at the edge of a forest patch during the day, within 1000 m of cultivated lands, and the data

Table 1. All locations and usable locations (see text for details) in different habitat types during daytime and night time for the bull elephant fitted with a satellite collar in Jaldapara Wildlife Sanctuary

Habitat type	Total number of locations obtained	Number of LC1, LC2 and LC3 locations obtained (% total locations in brackets)	Percentage of LC1, LC2 and LC3 locations in each habitat type of total home range	Total number of locations at night (% total night locations in brackets)	Total number of locations during the day (% total day locations in brackets)
Mixed vegetation	62	50 (80.6)	12.7	24 (13.1)	26 (12.9)
Sal plantation	107	95 (88.8)	24.1	45 (24.7)	50 (24.7)
Teak plantation	56	45 (80.4)	11.4	25 (13.7)	20 (9.9)
Floodplains	15	10 (66.7)	25.4	5 (2.8)	5 (2.5)
Grasslands	44	37 (84.1)	9.4	15 (8.2)	22 (10.9)
Deciduous forest	119	95 (79.8)	24.1	45 (24.7)	50 (24.8)
Evergreen forest	34	27 (79.4)	6.8	13 (7.1)	14 (6.9)
Cultivated land outside the park boundary	49	25 (51.0)	8.6	10 (5.5)	15 (7.4)
Total	486	384 (78.9)	100	182	202

Table 2. Contingency table to assess habitat preferences of the elephant in entire home ranges, at night, and during day. Expected values were calculated by distributing total locations across habitat types in proportion to their areas

Entire home range

Habitat type	Area (km^2)	Proportion of total area	Expected number of locations	Observed number of locations	c^2
Deciduous forest	103.03	0.36	136.7	95	12.74
Floodplains	58.44	0.20	77.6	10	58.86
Mixed vegetation	21.56	0.08	28.6	50	15.97
Sal plantation	64.72	0.22	85.9	95	0.97
Teak plantation	12.91	0.04	17.1	45	45.29
Evergreen forest	12.93	0.04	17.2	27	3.58
Grasslands	15.73	0.05	20.9	37	12.44
Total	289.34		384	384	149.85

At night

Habitat type	Expected number of locations	Observed number of locations	c^2
Deciduous forest	61.3	45	4.31
Floodplains	34.7	5	25.46
Mixed vegetation	12.8	24	9.75
Sal plantation	38.5	45	1.11
Teak plantation	7.7	25	39.09
Evergreen forest	7.7	13	3.67
Grasslands	9.4	15	3.41
Total	172	172	86.8

During day

Habitat type	Expected number of locations	Observed number of locations	c^2
Deciduous forest	66.6	50	4.13
Floodplains	37.8	5	28.44
Mixed vegetation	13.9	26	10.44
Sal plantation	41.8	50	1.60
Teak plantation	8.5	20	16.27
Evergreen forest	8.4	14	3.81
Grasslands	10.2	22	13.77
Total	187	187	78.45

class is LC1 (most accurate in 1000 m), there is a likelihood of the animal erroneously being located in cultivated lands. From direct observations of the behaviour of this animal, we know that it spent a considerable part of the day literally in hiding within a small forest patch close (less than 500 m) to the boundary with cultivation. We examined the 15 instances where the animal was located outside the park during the day and how far the animal was from the park boundary. Among these 15 locations, in six cases the error bars associated with the location were greater than the distance of this forest patch from the park, indicating that the animal could have well been in the park. Among the other nine locations, five were in the evening (after 1600 h), two were in the late afternoon (1500–1600 h) and two in the early afternoon. Location data for night time were more reliable. Among the ten night locations, only two were found to be possibly erroneous.

The animal was located 25 times outside the park. The mean distance of these locations from the park boundary was 1.5 km (± 1.6 SD; range 0.45–6.0 km). Because the animal moved to its maximum distance from the park in pursuit of a captive female elephant in oestrus, a possible anomaly in its 'normal' movement, we removed locations associated with this known movement and obtained a mean of 0.94 ± 0.5 km. To determine how far an animal moved from a position within the park to cultivated lands (thereby evaluating the use of the system in predicting visits to nearby fields), we carried out the following analysis. Among the 25 locations outside the park, only 16 were usable (LC1–LC3 classes). For these 16 locations we calculated the distances between two successive locations in two situations: (A) when the preceding location was within the park, and (B) when the preceding location was either within the park or in cultivated land. The mean distance between locations for situation A was 1.94 ± 1.15 km (range 0.80–4.58) and for B was 1.79 ± 1.17 km (range 0.15–4.58). The mean time taken to move between successive locations for situation A was 1 h 29 min ±

55 min (range 1 min – 3 h 7 min) and for situation B was 1 h 27 min ± 51 min (1 min – 3 h 7 min). These represent maximum time intervals as the animal could have been standing at a location for a while, prior to a location being recorded.

We conclude that satellite telemetry using PTTs on Asian elephants provides relatively high quality data in tropical moist habitats such as Jaldapara that are a mosaic of grassland and forest. Despite greater attenuation of satellite signals reported in forests with dense canopy, nearly 80% of the locations of the animal was recorded in this habitat, including a significant proportion of these within tropical moist forest and plantations of usable data classes. This indicates that the quality of signals using this technology in tropical moist forests is satisfactory. The animal actually displayed a marked preference for forested habitats, sheltering in them during both night and day, and making forays into cultivated lands at night and sometimes in the evening. In this region, elephants are known to visit fields in the evening, particularly during winter when darkness descends by 1600 h. For the early and late afternoon locations, there is a possibility that the animal was sheltering in small patches of forest or plantation not determined by our image analysis.

Due to truncation of the study after three months, a comprehensive assessment of the use of satellite-based technology for elephant–human conflict mitigation cannot be obviously made from this experiment alone. However, the experiment indicates that daily tracking of an individual animal (or the group it represents) is certainly possible. The errors associated with the location data (ranging from about 100 to over 1000 m) using this earlier technology, also limit the use of the data in an early warning system. However, the newer GPS technology that provides location data to within 50 m would overcome this problem.

A possible drawback of the PTT technology is that the website with the data on animal locations is updated every 24 h. Wildlife managers may need more frequent relay of data in order to act effectively. Presently, several other technologies that are becoming available allow for the continuous transmission of location data and their remote viewing. GPS data can be transmitted through GSM (global systems for mobile communication) phone network computers anywhere and can be viewed at intervals defined by the user. Application of this technology to the early warning system may be more relevant. However, GSM coverage though increasing rapidly, is still limited in forest areas.

Satellite telemetry of elephants does have its advantages, particularly in border regions such as our study area. From northern Bengal, elephants frequently move into Bhutan making conventional VHF radio-telemetry difficult or nearly impossible in the dense forests and mountainous terrain there. Even if GPS signals and data transmission through a satellite are partly hindered, PTT technology could be expected to provide far more data than would VHF telemetry in such habitats. This could shed more light on trans-border movement and habitat utilization by elephants, thus facilitating greater international cooperation in the conservation of this species.

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