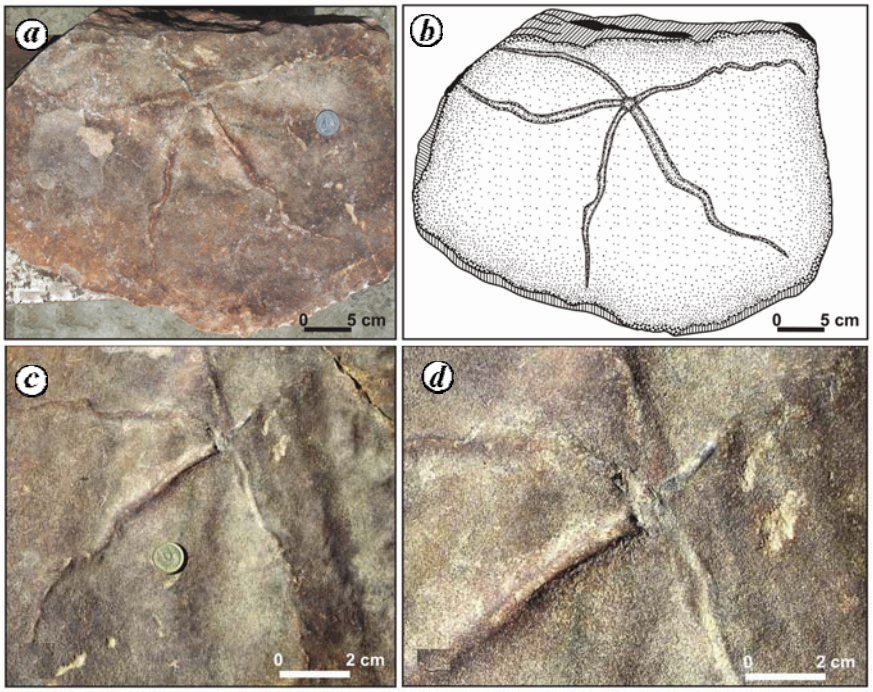

Figure 3. Five-armed body fossil on the bedding surface of the Jodhpur Sandstone. ***a***, ***c***, Five-armed body fossil. ***b***, Line diagram of the fossil seen in (***a***). ***d***, Enlarged view of (***c***) showing a disc-like structure at the centre of the body fossil.

ralization stage in the evolution of echinoiderms during the Ediacaran period.

1. Chauhan, D. S., Ram, B. and Ram, N., *J. Geol. Soc. India*, 2004, **64**, 265–276.
2. Pareek, H. S., *Mem. Geol. Surv. India*, 1984, **115**, 1–95.
3. Sarkar, S., Bose, P. K., Samanta, P., Sengupta, P. and Eriksson, G., *Precambrian Res*., 2008, **162**, 248–263.
4. Raghav, K. S., De, C. and Jain, R. L., *Indian Miner*., 2005, **59**(1&2), 23–30.
5. Kumar, S. and Pandey, S. K., *J. Palaeontol. Soc. India*, 2008, **53**(1), 83–97.
6. Kumar, S., Misra, P. K. and Pandey, S. K., *Curr. Sci*., 2009, **97**(5), 701–705.
7. Kumar, S. and Pandey, S. K., *Curr. Sci*., 2009, **54**(2), 171–178.
8. Prasad, B., Asher, R. and Borgohai, B., *J. Geol. Soc. India*, 2010, **75**, 415–431.
9. Kumar, S. and Pandey, S. K., *Curr. Sci*., 2008, **94**, 1081–1085.
10. Kumar, S. and Pandey, S. K., *J. Asian Earth Sci*., 2010, **38**(3), 77–86.
11. Pandit, M. K., Sial, A. N., Jamrani, S. S. and Ferreira, V. P., *Gondwana Res*., 2001, **4**, 387–394.
12. Rathore, S. S., Venkatesan, T. R. and Srivastava, R. K., *Gondwana Res*., 1999, **2**(2), 271–281.
13. Häntzschel, W., *Treatise on Invertebrate Palaeontology Part W 'Trace Fossils and Problematica'*, The Geological Society of America, 1975, p. 191.
14. Hofmann, H. J., O'Brien, S. J. and King, A. F., *J. Paleontol*., 2008, **82**(1), 1–36.
15. Paul, C. R. C. and Smith, A. B., *Biol. Rev*., 2008, **59**(4), 443–481.

ACKNOWLEDGEMENTS. We thank Dr N. L. Chhabra, Head, Centre of Advanced Study in Geology, University of Lucknow, Lucknow for extending laboratory facilities and Prof. A. K. Jauhari for reviewing the manuscript. Financial assistance through a DST project to S.K. is acknowledged.

Received 1 August 2011; accepted 21 November 2011

S. KUMAR*
D. K. SRIVASTAVA
S. AHMAD

Centre of Advanced Study in Geology,
University of Lucknow,
Lucknow 226 007, India
**For correspondence.*
e-mail: surendra100@hotmail.com

A simple technique to estimate linear body measurements of elephants

An objective assessment of body growth among elephants is important in optimizing their management. Elephants of both sexes never stop growing; the older they get, the taller and heavier they become[1]. Initially both sexes grow at the same rate, but once puberty is reached, male elephants begin to accelerate their growth (so called 'post-pubertal growth spurt'). As a result, adult males tend to be taller than adult females and may become twice as heavy. The importance of body measurements cannot be overstated for as Hanks[1] points out, it is possible that in habitats that are over-utilized, body growth rates may slow down before food becomes scarce, and this in turn could reduce the birth rate in the population. Any study of the dynamics of a population depends on an ability to assess the age of individual elephants[2]. To date, the most accurate method of ageing elephants is that of Laws[3], who utilized the elephant's molar replacement in the lower jaw to describe 30 age groups. The culling of hundreds of elephants in East Africa in order to protect their habitat enabled Laws[3] to refine the techniques of age determination. But in Asia where such culling is not an option practised in the management of elephants, there is a need to use non-invasive methods to estimate the age of elephants. Shoulder height and body length have been found to be reliable parameters to describe linear growth in elephants[3–5]. Estimates of shoulder height can be used as indices of the age of elephants in the wild.

There are several methods available for estimating shoulder height of elephants, and some are of limited reliability and too cumbersome for general field use. According to Tennent[6], one of the methods used by natives of Sri Lanka to measure Asian elephants (*Elephas maximus*) was by throwing a rope over them, the ends brought to the ground on each side, and taking half the length as the true height. Such a contour method is often misleading and exaggerates the height of elephants. A rod held perpendicular to the measuring pole and parallel to the ground, will rarely give more than

10 feet, the majority being under 9 feet[6]. But such methods are useless when it comes to estimating the height of wild elephants. For the purpose of quick, on-the-hoof assessment of shoulder height of a wild elephant, the simplest way is to multiply the forefoot circumference by two – a fact that was known to the local mahouts and colonial hunters in Sri Lanka. However, as Sikes[7] points out, shoulder height estimates based on circumference of the forefoot will always exceed the recumbent or raised-foot measurement, due to its expansion as the sole receives the full weight of the standing or walking elephant.

In a study of the age structure of the elephant population in the Mudumalai Wildlife Sanctuary in South India, Arivazahgan and Sukumar[8] compared the results from the visual method where elephants were assigned age groups based on diagrams of shoulder heights obtained from captive elephants with those obtained from (i) the pole method and (ii) the distance measurement method, both of which involved photography. In the pole method[8–11], at first the lateral view of an elephant is photographed, after which a second photograph is taken of a calibrated pole held by an assistant on the very spot where the elephant once stood before it had moved on. Although this method had been widely used in the past in Africa, it has been described as time consuming, cumbersome and prone to error[11].

The distance method was far more complicated and involves the measurement of the distance to the object (elephant), magnification and the focal length of the camera used. Two factors, namely the ratio of the focal length of the lens and the distance between the camera and the object must be known[12]. In the pole method, one can never be certain exactly where an elephant stood, especially if the habitat is grassland, where no footprint and other tell-tale marks can be observed. It may also take a lot of time: for sometimes an elephant herd may decide to spend a few hours grazing in an area and so the researcher too needs to wait until the coast is clear to move in to hold the pole exactly where the animal concerned stood. It can be a long wait. At times, it can be dangerous too.

The method we suggest as an alternative is not something original but one, to the best of our knowledge, that has never been used in Asia to measure morphological traits of elephants. Our method uses a Canon Digital Rebel X*Ti* digital camera and two parallel laser beams and is based on the principle that parallel laser beams are equidistant regardless of the distance from the origin[13]. The camera is mounted on a metal frame that holds two laser pointers 20 cm apart on either side (Figure 1). The laser beams will illuminate the object (e.g. an elephant) exactly 20 cm apart, thereby giving a scale useful in calculating the height at withers or commonly known as shoulder height of the elephant from the photograph (Figure 2). At first we used red laser beams, but later we replaced them with green lasers as the latter could be seen clearly at a distance of over 80 m even during mid-day in bright sunshine. This simple and accurate technique could benefit many ecological studies that require linear measurements, such as shoulder height, body length, etc.[13,14]. It has also been used in the identification of marine mammals such as killer whales[15], and even fish[12]. Using this method we were able to obtain highly accurate and repeatable measurements of elephants in the wild and in captivity.

The laser system was tested for accuracy using a 100×100 cm^2 board marked with a 10 cm grid. The board was fixed to a stand which could be rotated to different angles. The board was photographed at 10 m intervals up to 100 m using different zooms (50, 100, 200 and 300 mm), while maintaining an angle of 90° between the camera lens axis and the vertical plane of the board. Two types of test were performed: first to calculate the actual height and length of the board from the photographs; second to determine the effect of the angle of the object's plane to the axis of the camera lens. In order to complete the test photographs of the board were obtained by changing the angle of the board from 0° to 45° at 5° increment at a fixed distance of 20 m with 200 mm zoom power. The results revealed that when the plane of the grid was rotated up to 15° with respect to the vertical axis, the error of the calculated length of the board increased only by

Figure 1. The Canon Rebel X*Ti* digital camera mounted on a horizontal metal frame, flanked by tubes housing the laser pointers 20 cm apart.

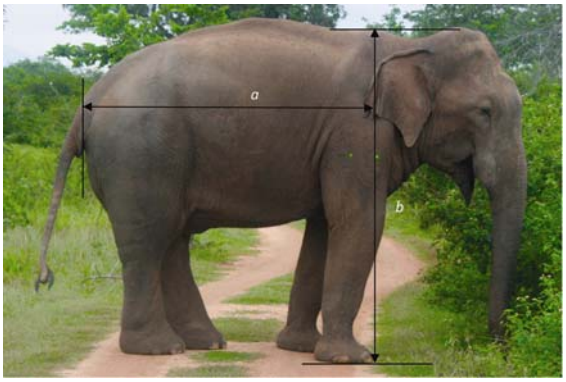

Figure 2. Photograph of a wild bull elephant taken from Uda Walawe National Park, Sri Lanka, showing the two green laser points which are 20 cm apart, thereby making it possible to calculate accurately body length (*a*) and the shoulder height (*b*). (Photograph: S. Wijeyamohan.)

3.3%. When the angle was increased to 20°, the observed error was 5%. But within this limit of rotation, the measured height of the board remained the same. ACDSee Pro 3 software was used to measure the height and length of the board in the photographs.

Error can be minimized by making sure that the laser beams remain absolutely parallel and the photograph showing the two spots is sharp, for there could be an error if the photograph is blur. Hence, measurements taken from the known object of 100×100 cm^2 at 100 m distance with 50 mm zoom, gave an error of 6%. However, when the clarity of the photograph was improved by reducing the distance and increasing the zoom level, the error reduced to as low as 0.7% on an average. The error is likely to increase with poor photography using low quality equipment. The device was tested against a known sized object at different distances (up to 100 m) at different zoom levels, where the accuracy of the instrument was found to be 99.3%.

Given that the length is a fundamental metric in the study of wildlife[12], its accurate measurement is vital to an understanding of an animal's life history and behaviour. Although the technique of using parallel laser beams to measure physical traits of wildlife is not new[16–18], to the best of our knowledge, it has not been previously used in the study of elephants in Asia, either in the wild or in captivity. In Africa, Shrader *et al.*[19] had followed a different digital photogrammetric technique successfully using a range finder to obtain accurate measurements of the shoulder height of African elephants (*Loxodonta africana*). The method we describe here provides an accurate, non-intrusive, user-friendly, remote and relatively inexpensive method to obtain shoulder height measurements of elephants under virtually any condition. There are, however, some limitations to the method. First, the two laser beams must remain absolutely parallel to one another. We ensured this by getting a reflection of the two laser beams back to the source from a completely flat mirror held perpendicular to the beams. It was further confirmed by measuring the distance between the two laser spots on the board within the tested distance of 10–100 m. Second, the laser projections must be on a flat surface, for if the target surface is curved or bumpy, the distance between the lasers may be altered with no reliable correction factor[13]. Hence while taking photographs of elephants, the laser beams were directed to the upper part of the leg (humerus), just below the scapula (Figure 2). According to Sikes[7], the dorsal edge of the scapula corresponds with the top of the highest neural spine of the thoracic vertebra. Third, even though there is no risk of injury to the human eyes from short exposure to laser beams classified as class IIIA, care must be taken to avoid focusing them on the eyes of the elephant. Finally, the photographs must be of the best quality with sharp images, devoid of fussiness.

Shoulder height was found to be highly correlated with the age of Sumatran elephants (*Elephas maximus sumatranus*) in captivity, using the van Bertalanffy growth function[20]. Our study provides a means to obtain accurate estimates of the shoulder height and length of elephants even in the wild without disturbing them in any way. The photogrammetry described here is an invaluable tool in classifying and standardizing elephants as calves, juveniles, subadults and adults based on their shoulder height and therefore age. It remains one of the most valuable tools for taking measurements of elephants and wildlife from a distance.

1. Hanks, J., *A Struggle for Survival. The Elephant Problem*, Country Life Books, London, 1979, p. 176.
2. Caughley, G., *Analysis of Vertebrate Populations*, John Wiley, Chichester, 1977, p. 234.
3. Laws, R. M., *East Afr. Wildl. J.*, 1966, **4**, 1–37.
4. Laws, R. M., Parker, I. S. C. and Johnstone, R. C. B., *Elephants and their Habitats*, Clarendon Press, Oxford, 1975, p. 376.
5. Sukumar, R., Joshi, N. V. and Krishnamurthy, V., *Proc. Indian Acad. Sci., Anim. Sci.*, 1988, **97**, 561–571.
6. Tennent, J. E., *The Wild Elephant and the Method of Capturing and Taming it in Ceylon*, Longmans, Green & Co, London, 1867, p. 198.
7. Sikes, S., *The Natural History of the African Elephant*, American Elsevier Publishing Co Inc, New York, 1971, p. 397.
8. Arivazhagan, C. and Sukumar, R., *Gajah*, 2008, **29**, 11–16.
9. Foster, J. B., *East Afr. Wildl. J.*, 1966, **4**, 139.
10. Douglas-Hamilton, I., Ph D thesis, University of Oxford, Oxford, 1972.
11. Jachman, H., *Neth. J. Zool.*, 1980, **30**, 622–634.
12. Rohner, C. A., Richardson, A. J., Marshall, A. D., Weeks, S. J. and Pierce, S. J., *J. Fish Biol.*, 2011, **78**, 378–385.
13. Bergeron, P., *J. Wildl. Manage.*, 2007, **71**(1), 289–292.
14. Rothman, J. M., Chapman, C. A., Twinomugisha, D., Wasserman, M. D., Lambert, J. E. and Goldberg, T., *Am. J. Primatol.*, 2008, **70**, 1191–1195.
15. Durban, D. W. and Parsons, K. M., *Mar. Mamm. Sci.*, 2006, **22**(3), 735–743.
16. Breuer, T., Robbins, M. M. and Boesch, C., *Am. J. Phys. Anthropol.*, 2007, **134**, 369–382.
17. Domb, L. G. and Pagel, M., *Nature*, 2001, **410**, 204–206.
18. Caillaud, D., Levrero, F., Gatti, S., Menard, N. and Raymond, M., *Am. J. Phys. Anthropol.*, 2008, **135**, 379–388.
19. Shrader, A. M., Ferreira, S. M. and van Aarde, R. J., *S. Afr. J. Wildl. Res.*, 2006, **36**(1), 1–7.
20. Reilly, J., *J. Zool.*, 2002, **258**, 205–213.

ACKNOWLEDGEMENTS. We thank Mr Kenneth Feld, CEO, The Feld Entertainments Inc., USA for funding the project as part of his efforts to enhance the management and conservation of the Asian elephant in Sri Lanka. We also thank A. J. A. Abeyrathne (University of Peradeniya) for help in testing the accuracy of the method in the laboratory; Thiripura Sivapalan and Rameetha Jayapalan (University of Peradeniya) for help in the analysis of the data, and Dilip Alagoda and Weerasinge for help in constructing the prototype.

Received 28 June 2011; revised accepted 14 December 2011

S. WIJEYAMOHAN[1]
V. SIVAKUMAR[2]
BRUCE READ[3]
DENNIS SCHMITT[4,5]
S. KRISHNAKUMAR[6]
CHARLES SANTIAPILLAI[7,*]

[1]*Postgraduate Institute of Science,*
[2]*Department of Physics, and*
[7]*Department of Zoology,*
University of Peradeniya,
Sri Lanka
[3]*Feld Entertainment Inc,*
8607 Westwood Center Drive,
Virginia, VA 22182, USA
[4]*Ringling Bros,*
Center for Elephant Conservation,
Florida, USA
[5]*Darr School of Agriculture,*
Missouri State University,
Missouri, USA
[6]*Department of Computer Science,*
Vavuniya Campus of the University of Jaffna,
Sri Lanka
**For correspondence.*
e-mail: charlessantiapillai@gmail.com