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Individual Identification in Asian Elephants

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Abstract. Individual identification of animals is the first step in studying elephant behaviour, demography, and conservation, but few studies of Asian elephants (*Elephas maximus*) are based on individual identification. We describe in detail, traits that can be used to identify individuals, and examine the variability of different traits. Based on fieldwork in Nagarahole National Park, southern India, we scored trait states for 22 traits in 223 individuals. We found that the top fold of the ear and nicks/tears in the ear were useful for identifying both males and females. Tusk features and the presence of warts/wounds on the body were useful in male identification, and tail characteristics were useful in female identification. The number of marks increased slowly with age, leading to adults having a lower probability of being misidentified than subadults. Analysis of temporal changes in trait states showed that even the fastest changing traits changed only over the course of several years, allowing for reliable identification of animals.

Introduction

Individual identification of animals is invaluable in understanding a species' social organization and behaviour, estimating demographic parameters, and targeting animals for specific conservation and management practices. Identifying individuals using natural physical characteristics, including naturally acquired marks (such as cuts, injuries, etc.) is a well-recognized technique in field studies (Pennycuick 1978; Lehner 1996). While natural physical characteristics are advantageous in being non-invasive, they can change over time and differ in conspicuousness and variability. Knowledge of the diversity and temporal variation in these characteristics in a given population is, therefore, required for reliable individual identification.

Studies of African savannah elephants have largely used patterns of cuts and tears on the edges of the elephants' large ears to identify individuals (for example, Douglas-Hamilton 1972; Croze 1974). Asian elephants have considerably smaller ears and usually fewer tears on them: therefore, a combination with other characters might be more important. Individual identification of a sizeable number of Asian elephants based on natural physical characteristics has been carried out in the context of social organization (Vidya & Sukumar 2005; de Silva *et al*. 2011), mark-recapture population estimation (Goswami *et al*. 2007), movement (Fernando *et al*. 2010), and demography (de Silva *et al*. 2011, 2013). A particular characteristic (feature) of some part of the body that can be scored across animals is referred to here as a trait (tusk characteristics such as length and shape would, for example, be considered two traits) and the alternative forms possible at a trait are referred to as states (for example, *Long* and *Short* while scoring tusk length). Only limited details of the traits and states used previously for individual identification in Asian elephants are available (Goswami *et al*. 2007; de Silva *et al*. 2013). In addition, there is little information on which traits are most suitable for use, in terms of variability across individuals in a population, as well as temporal variability. In a short study, Goswami *et al*. (2012) had examined various traits useful for identification, and had suggested that traits that were fixed across time were the most reliable for an automated process of individual identification, in which individuals could be identified as a string of states from different traits. However, fixed and variable traits were guesses rather than assessments based on data, with fixed traits thought to remain constant over a few years or longer.

Here, we try to address the lack of information and provide a comprehensive list and photos of traits for identifying individual Asian elephants. Since almost all traits that are useful in individual identification are continuous but need to be discretized for consistent identification, we present some objective ways of defining the states of different traits. We assess the applicability of different traits to identifying males and females, and the temporal variability of these traits.

Methods

Study area

The Kabini Elephant Project was set up in March 2009 in Nagarahole National Park and Tiger Reserve (11.85304°-12.26089° N, 76.00075°-76.27996° E), which encompasses 644 km^2 of elephant habitat in the Nilgiris-Eastern Ghats landscape in southern India (Fig. 1), and subsequently expanded to the adjoining Bandipur National Park and Tiger Reserve (11.59234°-11.94884° N, 76.20850°-76.86904° E). Nagarahole and Bandipur are contiguous or nearly so with forests of Madikeri Forest Division, Brahmagiri Wildlife Sanctuary, Wyanad Wildlife Sanctuary, and Mudumalai Wildlife Sanctuary and Tiger Reserve, which together offer a large stretch of forest to the wide-ranging Asian elephant. Nagarhole and Bandipur include a range of forest types, from semi-evergreen and moist deciduous forests in the west to dry deciduous forests in the central areas, to dry thorn forest in the east (Pascal 1986, 1988). Kabini, Nagarahole, Moyar, and Nugu are perennial rivers in the Nagarahole-Bandipur area. Between Nagarahole and Bandipur lies the Kabini reservoir (with an area of ~6 km^2) that has resulted from the construction of the Beechanahalli Dam on the River Kabini. During the dry season (December-June) the areas around the receding backwaters offer an abundant supply of fresh grass close to water, which leads to elephants and other herbivores congregating there. This is an open area where there is excellent visibility for elephant identification. The majority of elephant sampling for the data shown in this paper was conducted in the areas surrounding these backwaters, in Nagarahole National Park and Tiger Reserve. Apart from the

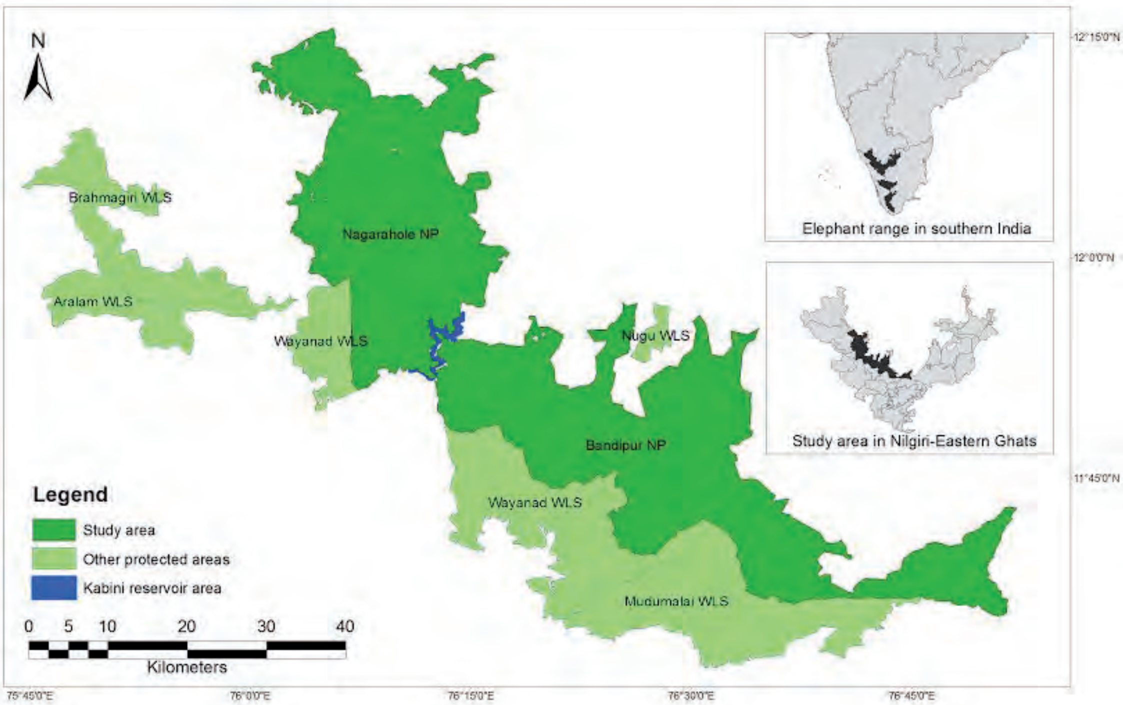

Figure 1. A map of Nagarahole National Park and Bandipur National Park and the adjoining protected areas. Insets: elephant range in southern India and the location of the study area within the Nilgiris-Eastern Ghats landscape.

area around the backwaters, the habitat sampled largely included dry deciduous forest.

Field methods

We carried out fieldwork for the current study from March 2009 – January 2010, end of May 2010 (because of lack of permits during the preceding few months) – July 2010, and October 2010. We drove along pre-selected routes in the forest during the entire day and, upon encountering elephants, age-sex classified them, sketched and photographed them, and noted down the GPS location. Elephants can be sexed easily as they show sexual dimorphism. Individuals were broadly categorized as calves (<1 year), juveniles (1-<5 years), subadults (5-<15 years), or adults (≥15 years) in the absence of data from this population on when animals actually began to reproduce.

Long-term data on identified individuals are required to construct a growth curve for this population. In the meanwhile, since we had seen animals being born and entering the subadult age-class up to the time of writing this paper, calves, juveniles, and younger subadults were aged with a fairly high degree of accuracy. Adults were aged based on skull size, body size, and loose skin folds, using semi-captive elephants of known ages from the same area as reference. Some of the identified adults had also been seen almost ten years before the start of the study, which facilitated their ageing. Adults that were over 20 years old were placed into ten-year age-classes. Individuals were identified based on a combination of natural physical characteristics that included ear, tush/tusk, back, and tail characteristics. Each of these is described in detail below.

Ear characteristics

Ear folds: Photos of the ears taken from the side and front were used to assess folding of the ears. The top fold (the primary fold of de Silva *et al*. 2013) and the side fold (the secondary fold of de Silva *et al*. 2013) were scored separately. The top fold was scored as *Not Folded* (Fig. 2a), *Facing Forward* (Fig. 2 c,h) if the top of the ear was bent forward and formed a right angle with the rest of the ear (equivalent to "L-shaped" of Goswami *et al*. 2007), *Folded Forward* (Fig. 2 b,e,f) if the top of the ear was curled forward on to the rest of the ear (equivalent of "U-shaped" of Goswami *et al*. 2007), and *Backward* (Fig. 2 d,g) if the top of the ear was either facing backward or curled onto itself backward (the two were not discriminated between because it would be difficult to do this in the absence of detailed photos of the ears taken from the back). The *Folded Forward* category could be further classified as *Folded Forward Slightly* (Fig. 2b), *Folded Forward into a Rolling Fold* (Fig. 2e), or *Folded Forward into a Flat Fold* (Fig. 2f). While we used these finer distinctions within the *Folded Forward* category to differentiate between animals, we did not use them in the analysis that assessed the variability of traits. The side fold was scored as *Folded Forward* (Fig. 2h) and *Backward* (Fig. 2 a-g).

Ear angle in relation to the head: The angle that the inner edge of the ear made with the vertical was used to score the ear angle as *Angled Away from the Head* if the angle was 25° or more (Fig. 3 a,b), or *Not Angled Away* if the angle was less than 25° (Fig. 3d). If the inner edge itself was not straight, the longest straight line that the inner edge formed was used to determine the angle. Photos of elephants taken from the side, with the head held in a normal, relaxed position and ear against the head were used to score this trait. The

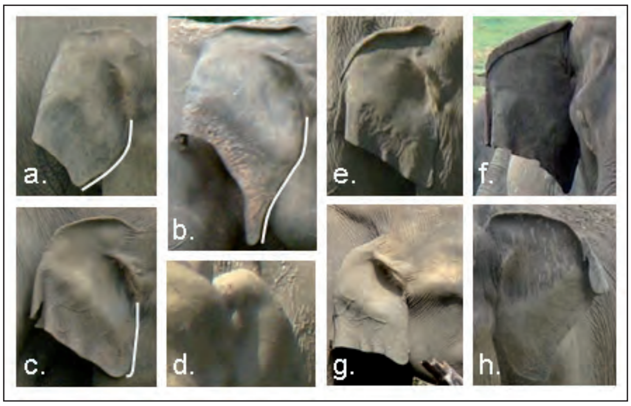

Figure 2. Types of ear folds. Top fold: a) *Not Folded*, b) *Folded Forward Slightly*, c) and h) *Facing Forward*, d) and g) *Backward*, e) *Folded Forward into a Rolling Fold*, f) *Folded Forward into a Flat Fold*. Side fold: h) *Folded Forward*, a-g) *Folded Backward*. The shape of the inner edge of the ear is also shown in white in 2 a-c.

trait was not scored in a few animals, from which it was not possible to obtain suitable photos because they had drooping ears and a tendency to not hold their ears against their head. Photos with the face tilted downward or unusually raised up were excluded as these would give incorrect values.

Ear angle could also be measured from the front and used as an additional trait, but the angles from the front and side appeared to be correlated (although imperfectly; so one should not be used as a substitute for the other), and we did not use angles from the front. The shape of the inner edge of the ear could also be used for identification. We classified this as *Curved Away from the Face* (Fig. 2a), *Curved but in Both Directions* (Fig. 2b), and *Straight Edge* (Fig. 2c). However, the shape of the inner edge of the ear was also correlated with the ear angle (curved ears were usually angled away from the head and straight ears were not), and we did not use this for the analysis of trait variability.

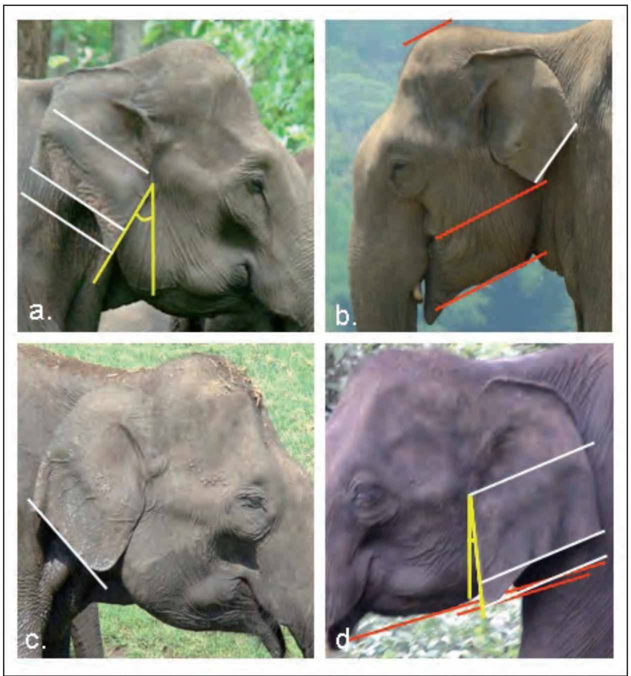

Figure 3. Ear angles, ear lobe lengths, and ear lengths. Ear angle: a) and b) *Angled Away from the Head*, d) *Not Angled Away* (lines to measure ear angle with the head are drawn in yellow). Ear lobe length: a) *Pointed*, c) *Blunt*, b) and d) *Average* (lines to assess ear lobe length are drawn in white). Ear length: b) *Short*, d) *Long*, a) and c) *Medium* (lines to assess ear length are drawn in red, in 3 b,d).

Ear lobe length: Ear lobe length was measured from photos of the ear held against the side of the head. A straight line was drawn through as much of the lower margin of the ear as possible, up to the side fold. A parallel line was drawn at the lowest tip of the ear, and another parallel line through the point where the inner edge of the ear was attached to the head (see white lines in Fig. 3 a,d). The lobe was scored as *Pointed* if the distance between the lowest tip of the ear and the lower margin of the ear was more than one-fourth the distance between the lowest tip of the ear and the upper parallel line (Fig. 3a). The lobe was scored as *Blunt* if the tip of the ear did not extend below the line through the lower margin of the ear (Fig. 3c). The lobe was scored as *Average* if the tip extended below the line through the lower margin of the ear, but the distance between the tip of the ear and the lower margin of the ear was less than one-fourth the distance between the tip of the ear and the upper parallel line (Fig. 3d). This method of measurement dissociated ear lobe length from ear length since long ears could have short ear lobes and *vice versa*, depending on the shape of the ear.

Ear length: Ear length was also measured from photos of the ear held against the side of the head, with the animal relaxed and closing its mouth. A straight line was drawn at the bottom of the lower jaw (Fig. 3 b,d), parallel to an imaginary line connecting the base of the lower lip to the head-neck junction. A parallel line was drawn at the lowest tip of the ear and another at the top of the skull (Fig. 3b). The ear was scored as *Long* if the tip of the ear was below the jaw line (Fig. 3d). The ear was scored as *Short* if the tip of the ear was above the jaw line and the distance between the tip of the ear and the jaw line was more than one-fourth the distance between the jaw line and the top of the skull (Fig. 3b). Ear lengths in between *Long* and *Short* were scored as *Medium* (for example, Fig. 3a).

Ear depigmentation: Depigmentation on the ear was classified as *Prominent* (if about a fourth or more of the ear had depigmentation, Fig. 4c), *Present* (if an eighth to a fourth of the ear had depigmentation, Fig. 4d), *Slight* (if there were small patches of depigmentation covering less than an eighth of the ear), and *None*. The exact location(s) of depigmentation was drawn for better identification. However, unless prominent, depigmentation was often visible only when the ears were wet or in certain light conditions (for example, 4f shows an ear with depigmentation *Present*, but the depigmentation cannot be seen in this photo). Therefore, for purposes of the present analysis, only the categories *Prominent* (Fig. 4c) and *None* were used (with *Present* and *Slight* being pooled together with *None*).

Nicks, tears, and holes in ears: Nicks, tears, and holes, collectively called ear marks, were identified by observing animals from different angles. The difference between nicks and tears (see Fig. 4) as we defined them was that nicks were sufficiently small so that the ear did not bend about a nick while flapping, while the ear moved about a tear. Large parts of the ear that were missing (Fig. 4f) or finger-like projections (Fig. 4d) were classified as tears as the ear would move about them. Rather than a Yes/No categorization of tears and holes as in Goswami *et al*. (2007),

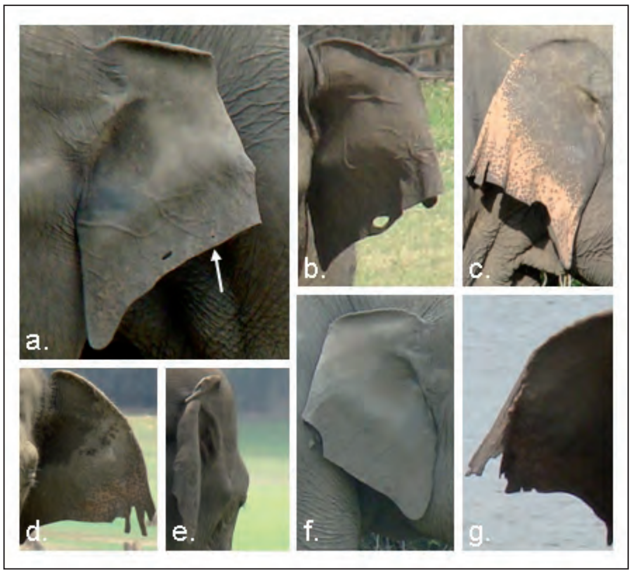

Figure 4. Ear depigmentation and ear marks: a) a *Small* and a *Minute* (with the arrow pointing to it) hole *Before the Side Fold*, b) a *Big* hole *Before the Side Fold*, c) *Prominent* depigmentation and tears (including a semi-circular part missing) *Before the Side Fold*, d) tears (with finger-like projections) *Before the Side Fold*, *At the Side Fold*, and *After the Side Fold*, e) tear *On the Top Fold*, f) tear (large part of the ear missing) *At the Side Fold*, and g) tear *At the Side Fold* and nicks *Before the Side Fold* and *After the Side Fold*.

we also used rough positional information in our analysis of trait variability. Ears were classified as not having a nick/tear/hole (*None*) or having a nick/tear/hole *At the Side Fold*, *Before the Side Fold*, *After the Side Fold*, or *On the Top Fold*. Holes were additionally classified based on size as *Minute* (the smaller hole in Fig. 4a), *Small* (the larger hole in Fig. 4a), or *Big* (Fig. 4b). Holes had to be at least over half the size of the iris of the eye to be classified as *Big* (and were often much larger than that). Those that were between half and one-tenth the size of the iris (typically one-fifth to one-sixth the size of the iris) were classified as *Small*. Holes less than one-tenth the size of the iris (typically much smaller than that) were classified as *Minute*. Minute holes were probably created by small thorns and would be easily missed if not for careful observation. Since many studies may not be able to detect these, they were excluded from the analysis of trait variability.

A single value was entered for the right and left ear combined in the case of ear folds, ear angle with the head, ear lobe length, ear length, and depigmentation because the two ears often shared the same trait state. If they differed in their trait state, the state for the right ear followed by the state for the left ear was entered (for instance, *Pointed/Average* for ear lobe length). However, nicks, tears, and holes were entered separately for each ear as they could be acquired independently. There were several other ear characteristics that were generally used for identification (see Discussion) but not used in the analysis of trait variability.

Tush/tusk characteristics

Tushes in females: Photos of animals taken from the side were used to assess the presence and prominence of tushes in females. Tushes were classified as *Prominent* if they were longer than the diameter of the iris, *Visible* if they were shorter than the diameter of the iris, or *Not Visible* (Fig. 5). As with the ears, tushes of both sides were scored as a combined trait, and were entered as right tush state/left tush state if there were differences between the two sides (for example, *Not Visible/Prominent*). Tushes were scored consistently from the side alone because tushes that looked small from the side could appear prominent from the back or if the mouth was wide open.

Tusk length: Photos of males taken from the side were used to assess tusk length. Unlike Goswami *et al.* (2007), who estimated tusk length in feet, we measured tusk length relative to the animal's height. Tusk length in feet could be difficult to visually estimate correctly when tuskers were alone, with no other animal for comparison. We classified a tusk as *Long* if the length of the tusk was more than half the distance from the tusk's lip line to the ground (Fig. 6i). We classified it as *Medium* (Fig. 6c) if the tusk length was less than half but more than quarter the distance from the tusk's lip line to the ground, and *Short* if it was less than quarter the distance to the ground. The tusk trait in makhnas (tuskless males) was classified as *Tush* if the animal had tushes or *None* if it had no tusks or tushes. As with the ears, since the two tusks were not likely to be independent of each other, tusk traits were entered as a single value for both tusks and entered as right tusk state/left tusk state if there were differences between the tusks (for example, *Long/Medium*). Although tusk thickness was noted down qualitatively, it was not used for analysis of trait variability.

Tusk shape: Photos of animals taken from the front were used to assess tusk shape. Tusks could be *Parallel* (Fig. 6a), *Divergent* (or splayed, Fig. 6b), *Convergent* (Fig. 6f), or *Divergent and Convergent* (if the tusks diverged first, and then bent back inwards, Fig. 6h).

Tusk angle: Photos of animals taken from the side were used to measure tusk angle with respect to the vertical. Animals had to be standing normally without their heads being unusually raised or lowered. Tusks with an angle of up to 30° with the vertical (measured from below upwards to the tusk) were classified as *Vertical*, those above 30° and up to 60° as *Intermediate* (Fig. 6i), and those above 60° were classified as *Horizontal* (Fig. 6c) (similar to the classification in Goswami *et al.* 2007, except for having cut-off angles).

Tusk asymmetry: Photos of animals taken from the front and the side were used to assess tusk asymmetry. Tusks were classified as *Left Crossed over Right* (Fig. 6d) or *Right Crossed over Left* if one tusk actually crossed the other one when viewed from the front. Views from the side could be misleading: for example, Fig. 6e and 6f show photos of the same animal but the tusks in 6e appear to be crossed. If one tusk did not actually cross over the other, but was simply higher than the other, it was classified as *Right Higher* or *Left Higher* (Fig. 6 c,e). Tusks were also classified

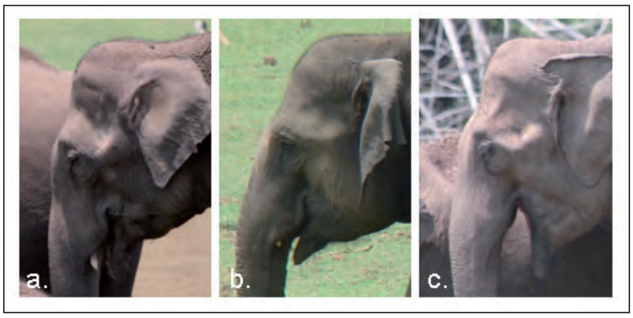

Figure 5. Tushes in females: a) *Prominent* tush, b) *Visible* tush c) no tush (*Not Visible*).

Figure 6. Males with different tusk characteristics. Tusk shapes: a) *Parallel*, b) *Divergent*, f) *Convergent*, h) *Divergent and Convergent*. The animal in g) has a *convergent* right tusk and a *divergent* left tusk. Tusk lengths: c) *Medium*, i) *Long*. Tusk angles: c) *Horizontal*, i) *Intermediate*. Tusk asymmetry: c) and e) *Left Higher*, i) *Right Longer*, d) *Left Crossed over Right*.

as *Left Longer* or *Right Longer* (Fig. 6i) if they were unequal in length. Asymmetry in height and length were usually more evident from the side than from the front. If tusks were symmetric in length and height, tusk asymmetry was classified as *No Asymmetry*.

Tusk shape, tusk angle, and tusk asymmetry were scored as *Not Applicable* when the animal did not have tusks or had tushes.

Back characteristics

Photos of animals taken from the side were used to distinguish between back shapes. The back shape was classified as *Concave*, if the backbone gradually sloped down towards the middle from the pectoral and near the pelvic girdles (Fig. 7a), and *Flat* if the backbone was flat from the pectoral girdle to almost the pelvic girdle (Fig. 7b). If the back was flat with a sudden depression in the middle (rather than sloping down to the middle gradually), it was classified as *Broken* (Fig. 7c). A flat back half the way from the pectoral girdle dropping down to a lower surface and remaining at that level till the pelvic girdle was classified as *Flat and Broken* (Fig. 7d). A back with a single highest raised point in the middle was called *Humped* (Fig. 7 e,f), while a back with two roughly equally high raised points was called *Wavy* (Fig. 7g). If a second raised point was less than three-fourths the size of the first, it was classified as *Humped*, not *Wavy*, because the second raised point in those cases would be visible only from some angles and some parts of the animal's walk. If a back that was *Humped* had a pelvic girdle, whose height was 95% or lower than the height of the pectoral girdle, it was called *Humped and Sloping* (Fig. 7h). This was often seen amongst adult males. The categories *Flat, Broken and Sloping* or *Wavy and Sloping* were also possible (although not *concave*, *flat*, or *broken*, along with *sloping*, as these categories would require the girdles to be at almost the same height).

Tail characteristics

Tail length: Photos of animals taken from the side with the tail held vertically down were used to score tail length. Tail length was categorized as *Very Long* if it extended till or below the ankle (Fig. 8j), *Long* if it reached below the knee but above the ankle (Fig. 8 d,h,l), *Medium* if it reached till the knee, *Short* if it reached above the knee but below the abdomen, *Stumpy* if was above the abdomen. Tail hair was not included in the tail length measurement.

Figure 7. Some back shapes: a) *Concave*, b) *Flat*, c) *Broken*, d) *Flat and Broken*, e and f) *Humped*, f) *Wavy*, h) *Humped and Sloping*.

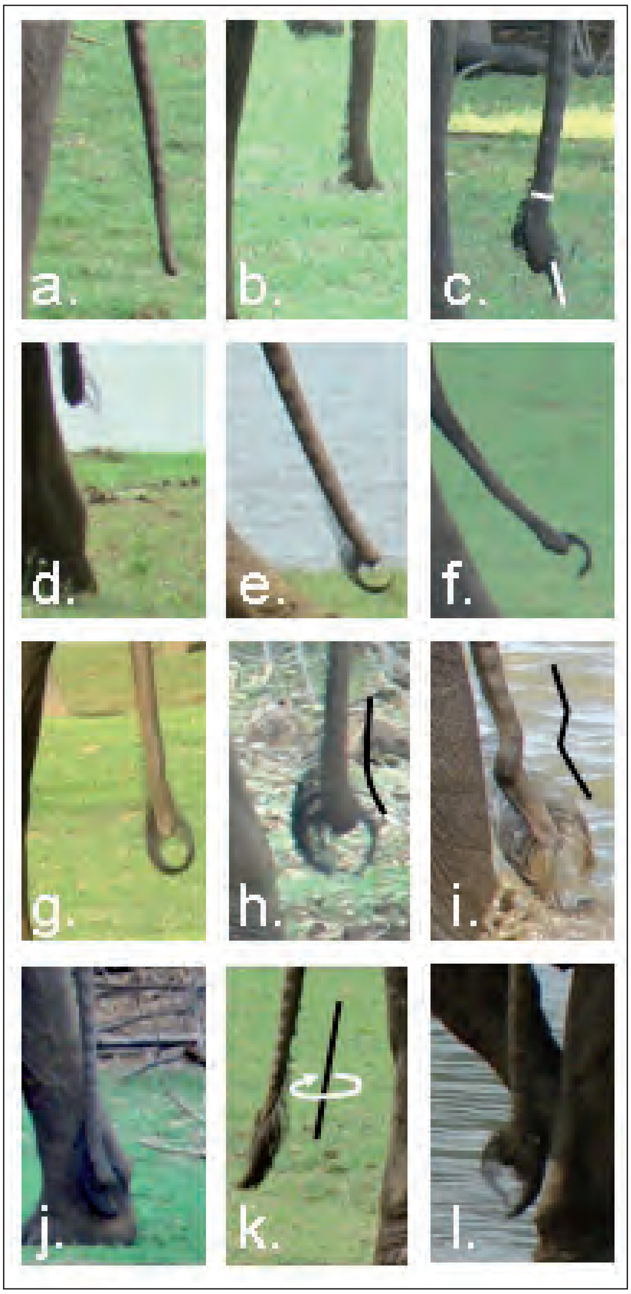

Figure 8. Tail characteristics for individual identification. Tail brush: a) *No Hair*, b) and c) *Short Anterior Short Posterior*, d) *Short Posterior*, e) *Normal Anterior*, f) *Normal Posterior*, g-j) *Normal*. Tail kink: g) and i) *Kinked*, c), h) and j) *Curved*, k) *Curved and Twisted* seen from the side, l) same tail as in k) seen from the back. Black lines show the curve and kink in the tails in 8 h,i. The axis of the tail (in black) and the direction of twist (in white) are shown in 8k. Lines showing the thickness of the tail and twice that thickness are provided in 8c. Tail tips may also be tapered towards the end, remain the same thickness towards the end (for example, 8 b,i,j), or become bulbous at the end (8 f,h). Discoloured hair is seen in 8i.

Tail brush: The tail brush shape was also classified by viewing the animal from the side. The tail brush was classified as *No Hair* (Fig. 8a), *Short Anterior* (short hair towards the anterior side of the tail and no hair on the posterior side), *Short Posterior* (short hair towards the posterior side of the tail and no hair on the anterior side) (Fig. 8d), *Short Anterior Short Posterior* (short hair on both sides, Fig. 8 b,c), *Normal Anterior Short Posterior* (hair on the anterior side of normal length but short hair on the posterior side), *Short Anterior Normal Posterior* (hair on the posterior side of normal length and short hair on the anterior side), *Normal Anterior* (normal hair on the anterior side and no hair on the posterior side, Fig. 8e), *Normal Posterior* (normal hair on the posterior side and no hair on the anterior side, Fig. 8f), or *Normal* (normal hair on both sides of the tail, Fig. 8 g,h,i,j,l). Tail hair was classified as *short* when the length of the hair was less than or equal to twice the thickness of the tail just above the tail brush (see Fig. 8c), and as *normal* if it was longer than that. The tail hair could also be classified as black or discoloured (white/brown), but because of the latter being rare, hair colour was not used in the current analysis.

Tail kink: Animals were examined from the side and from behind to judge whether their tails were straight or crooked. If there was any bend in the tail excluding the tail brush, it was classified as *Kinked* (Fig. 8 g,i), whereas if the tail was bent away at the tail brush, it was classified as *Curved* (Fig. 8 h,j). If the tail was twisted about the vertical, it was classified as *Twisted*. These three states were not mutually exclusive and there could be combinations of these such as *Curved and Twisted* (Fig. 8 k,l) or *Kinked and Twisted*. Whenever the tail was twisted, the tail brush would not be aligned along the anterior-posterior axis and would be seen properly from the back instead of from the side (Fig. 8 k,l). If the tail was straight, the tail kink state was classified as *None* (for example, Fig. 8 a,d,e).

Warts, wounds, lumps

Warts, wounds, and lumps were combined together as it could sometimes be difficult to distinguish between them. For instance, a wound

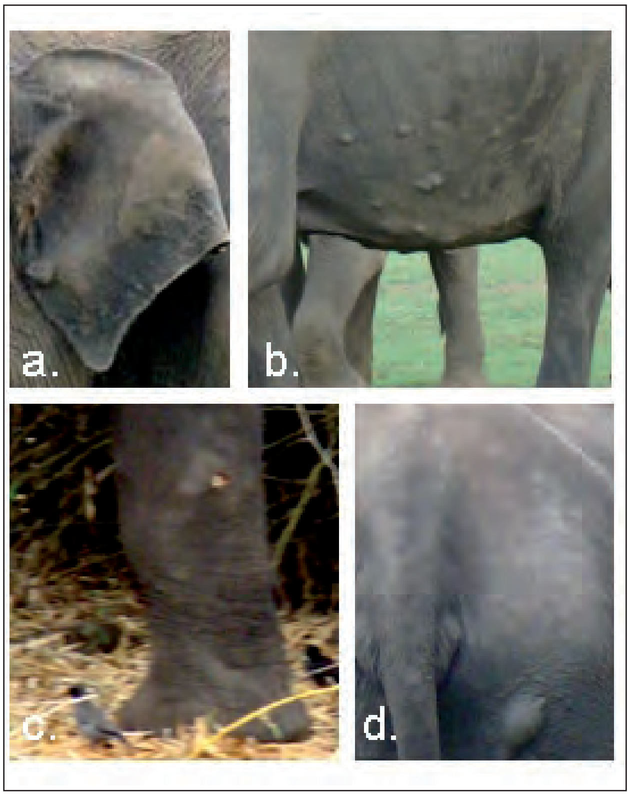

Figure 9. Wounds, warts and lumps: a) wart on the ear (*Left Side of the Head*), b) nodular lumps on the belly (*Left Body*), c) wound on right foreleg (*Right Foreleg)*, d) lump to the right of the tail (*Right of the Tail Base*).

that had partially healed could sometimes look like a lump or a wart. Depending on the presence and position of these features, they were classified as *None* or as being on the *Right Body*, *Left Body*, *Right Foreleg*, *Left Foreleg*, *Right Hind Leg*, *Left Hind Leg*, *Right of the Tail Base*, *Left of the Tail Base*, *Right Side of the Head* (including the ear), *Left Side of the Head* (including the ear), or *Trunk* (see Fig. 9).

Data analysis

The list of all the traits used and their states are shown in Table 1. Data were coded for the different trait states for each animal and the proportions of different trait states (across animals) calculated for each trait. The expected probability of identity (P_{ID}), which is the probability that two different animals might be wrongly identified as the same animal because of low variability in traits across animals, was calculated as the sum of squared proportions of different trait states for each trait. The expected P_{ID}s of all the traits were multiplied to obtain a total expected P_{ID} for the set of animals being considered. Changes in trait states were assessed by examining animals that were repeatedly seen during the present study. We also compared trait states of some of the identified animals that had been seen (by TNCV) during previous field trips to the Kabini area with sightings during the present study. The rate of change of trait states was calculated by dividing the number of changes of a particular trait by the number of elephant years (total number of years between sightings of individuals summed up), following Dufault & Whitehead (1995). We also counted the number of ear marks present on identified elephants of different ages to get a rough idea of differences in ear marks across animals of different ages. Since an age-class (and median age) was assigned to an individual based on the date of first sighting, it was possible for ages to not be whole numbers if a subsequent sighting date was used as the reference date for calculating age (for example, if the age was 20-30 (median 25) years when first sighted on 21. May 2009, it would be 25.61 years on 30. Dec 2009 when some trait was scored). Statistical tests were carried out using Statistica 8 (StatSoft, Inc., Tulsa, USA). Since P_{ID} data were not normal even after transformation, non-parametric tests were used for these data.

Results

Variability in traits across individuals

Trait states were scored for a total of 223 individuals, comprising 168 females and 55 males. Of these, 43 were subadult animals (mostly 10-15 years old) and the remaining were adults. The total expected P_{ID} across all classes of animals was found to be 3.95×10^{-7}, indicating a very small probability of wrongly identifying two different animals as the same animal. The total expected P_{ID} was smaller for males (7.98×10^{-9}) than for females (3.91×10^{-6}) because of tusks providing additional traits for identification in males (Table 2). Fourteen traits were required amongst females to achieve a total P_{ID} of $\sim 9 \times 10^{-6}$, while nine traits were required to achieve a similar P_{ID} amongst males (Fig. 10). Amongst the most useful traits for identification (lowest P_{ID}s)

Table 1. List of traits used and their states. R/L in the 'Combin' column indicates that, in addition to the states mentioned, there could be combinations of two states if they were different on the right and left side. They would then be written as the state on the right/state on the left. Asterisks indicate that, in addition to the states mentioned, there could be various combinations of the states for those traits. For traits 7-12 and 21-22, all combinations of states, with the exception of '*None*', for the respective traits were possible. For trait 17, combinations of one tusk crossing over the other or one tusk higher than the other, with one tusk being longer were possible.

S.No.	Trait	States	Combin
1	Ear top fold	Not folded Facing forward Folded forward Backward	R/L
2	Ear side fold	Folded forward Folded backward	R/L
3	Ear angle	Angled away from the head Not angled away	R/L
4	Ear lobe length	Pointed Average Blunt	R/L
5	Ear length	Long Medium Short	R/L
6	Ear depigmentation	Prominent None	R/L
7-10	Right ear nick, left ear nick, right ear tear, left ear tear	Before the side fold At the side fold After the side fold On the top fold None	*
11-12	Right ear hole, left ear hole	Small, before the side fold Big, before the side fold Small, at the side fold Big, at the side fold Small, after the side fold Big, after the side fold Small, on the top fold Big, on the top fold None	*
13	Tushes	Not visible Visible Prominent	R/L
14	Tusk length	Long Medium Short Tush None	R/L
15	Tusk shape	Parallel Divergent Convergent Divergent and Convergent Not applicable	R/L
16	Tusk angle	Vertical Intermediate Horizontal Not applicable	R/L
17	Tusk asymmetry	Left crossed over right Right crossed over left Right higher Left higher Right longer Left longer No asymmetry Not applicable	*
18	Back shape	Concave Flat Broken Flat and broken Humped Wavy Humped and sloping Wavy and sloping Flat broken and sloping	-
19	Tail length	Very long Long Medium Short Stumpy	-
20	Tail brush	No hair Short anterior Short posterior Short anterior short posterior Normal anterior short posterior Short anterior normal posterior Normal anterior Normal posterior Normal	-
21	Tail kink	Kinked Curved Twisted None	*
22	Warts/wounds	None Right body Left body Right foreleg Left foreleg Right hind leg Left hind leg Right of tail base Left of tail base Right side of head Left side of head Trunk	*

in males and females were the top fold of the ear, and nicks and tears in the ears. Tusk features and the presence of warts/wounds on the body were useful traits for identification of males, while tail brush and the presence of kinks in the tail were more useful in female than in male identification (Table 2). Subadults showed higher total expected P_{ID}s than adults, both amongst males and females, although this was more pronounced amongst males (see Table 2). A comparison of trait-wise P_{ID}s (excluding tusk-related traits) between the different age-sex categories of

Table 2. Expected P_{ID}s of different traits in different classes of animals (F: all females, AF: adult females, SAF: subadult females, M: all males, AM: adult males, SAM: subadult males). Values less than 0.4 are marked in bold face in the F and M columns. The total P_{ID} values, as well as the P_{ID} values excluding tusk characteristics, are shown at the end (*n* is the number of individuals sampled).

Trait	ALL	F	AF	SAF	M	AM	SAM
Ear top fold	0.238	**0.230**	0.245	0.414	**0.275**	0.299	0.273
Ear side fold	0.905	0.919	0.931	0.855	0.862	0.852	0.889
Ear angle	0.472	0.473	0.466	0.512	0.517	0.500	0.695
Ear lobe length	0.497	0.510	0.514	0.494	0.464	0.464	0.488
Ear length	0.692	0.665	0.653	0.740	0.798	0.719	1.000
Ear depigmentation	0.728	0.809	0.789	0.926	0.556	0.518	0.709
Right ear nick	0.291	**0.285**	0.256	0.509	**0.318**	0.318	0.343
Left ear nick	0.371	**0.386**	0.374	0.462	**0.331**	0.283	0.467
Right ear tear	0.321	**0.343**	0.323	0.494	**0.278**	0.205	0.599
Left ear tear	0.311	**0.331**	0.309	0.503	**0.262**	0.227	0.384
Right ear hole	0.788	0.798	0.777	0.926	0.758	0.704	0.889
Left ear hole	0.715	0.740	0.731	0.790	0.644	0.668	0.599
Tushes	0.716	0.646	0.698	0.435	0.964	0.949	1.000
Tusk length	0.588	1.000	1.000	1.000	**0.332**	0.267	0.543
Tusk shape	0.608	1.000	1.000	1.000	**0.216**	0.206	0.287
Tusk angle	0.619	1.000	1.000	1.000	0.405	0.399	0.453
Tusk asymmetry	0.595	1.000	1.000	1.000	**0.123**	0.141	0.135
Back shape	0.607	0.673	0.643	0.855	0.513	0.475	0.889
Tail length	0.563	0.617	0.618	0.612	0.441	0.400	0.557
Tail brush	0.385	**0.352**	0.340	0.429	0.514	0.472	0.696
Tail kink	0.401	**0.351**	0.341	0.417	0.652	0.691	0.585
Warts/wounds	0.512	0.585	0.553	0.787	**0.324**	0.236	0.606
n	223	168	142	26	55	38	17
Total PID (exp)	3.95E-07	3.91E-06	2.71E-06	8.41E-05	7.98E-09	1.87E-09	1.33E-06
PID excluding tusks	3.00E-06	3.91E-06	2.71E-06	8.41E-05	2.23E-06	6.02E-07	1.40E-04

animals showed a significant difference between categories (Friedman ANOVA: χ^2 [N=18, df=3] = 15.533, P=0.001). Pairwise comparisons using Wilcoxon matched-pairs tests revealed significant differences between adult and subadult females (T=26.0, Z=2.591, P=0.010), adult females and subadult males (T=27.0, Z=2.548, P=0.011), adult males and subadult females (T=34.0, Z=2.243, P=0.025), and adult and subadult males (T=16.0, Z=3.027, P=0.002). There was no difference between adult females and males (T=59.0, Z=1.154, P=0.248) or subadult females and males (T=81.0, Z=0.196, P=0.845).

We also separately examined the total number of ear marks (nicks, tears, and holes) in males and females and found an average (± 1.96 SE) of 3.63 (± 0.536) ear marks amongst females and 4.15 (± 0.868) amongst males. Although the distribution of these marks looked right-shifted in males compared to females (Fig. 11), the distributions were not statistically different from each other (Kolmogorov-Smirnov test: P>0.1) when individuals of all ages were considered.

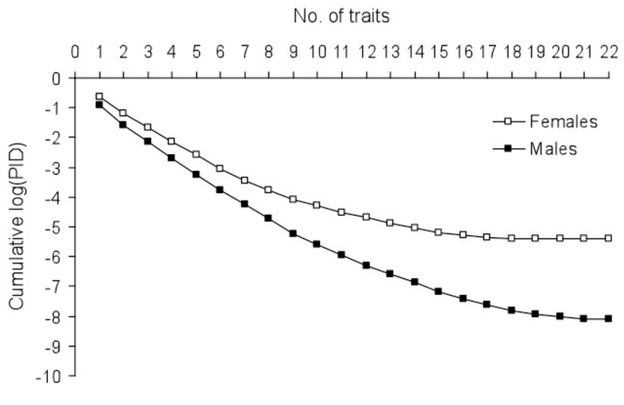

Figure 10. Cumulative log(P_{ID}) for an increasing number of traits amongst females and males. Traits were arranged in ascending order of P_{ID} (males and females separately) to calculate this.

Variability in traits across time

We calculated the rate of change of trait states based on a set of 58 individuals, accounting for a total period of 327 elephant years. However, the time span that different traits were examined for varied since all the traits could not be scored for every individual at every time point. We found that ear angle with the head, ear length, and the ear side fold were the only traits that did not change across time in our sample (Table 3). Nicks, tears, and holes were pooled together because holes could open out into nicks or into finger-like projections (tears), nicks could get enlarged into tears, and finger-like projections could, by falling off, progress to a part of the ear being missing (classified as tear again).

These ear marks showed more variability with time than other traits, with the exception of tusk characteristics and warts/wounds, but none of the traits examined changed very rapidly (Table 3). The rate of change of ear marks was 0.135 per year (for males and females together). This would amount to an expected change in ear marks of once in about 7.4 years for an animal. Tusks changed about as fast (0.209 changes/year) as ear marks (0.225 changes/year) in males. Tusk characteristics were also grouped together since a break in a tusk, for instance, could change its shape, symmetry, and angle, in addition to its length. Similarly, changes in tail length could also change the tail brush and tail kink state, and the three traits were grouped together. Although the rate of change of trait states seemed higher in males than in females (see Table 3), the difference was not statistically significant (Wilcoxon matched-pairs test: T=13.0, Z=1.478, P=0.139).

Table 3. Rate of change of various traits per elephant year. There were no males with tushes in the set of animals that we examined for changes in trait states.

Trait	All	Females	Males
Ear top fold	0.063	0.042	0.108
Ear side fold	0.000	0.000	0.000
Ear angle	0.000	0.000	0.000
Ear lobe length	0.009	0.006	0.015
Ear length	0.000	0.000	0.000
Ear depigmentation	0.015	0.005	0.038
Ear nick/tear/hole	0.135	0.089	0.225
Tushes	_	0.047	_
Tusk*	_	_	0.209
Back shape	0.011	0.005	0.022
Tail**	0.058	0.069	0.039
Warts/wounds	0.130	0.116	0.159

*Tusk length/angle/shape/symmetry
** Tail length/brush/kink

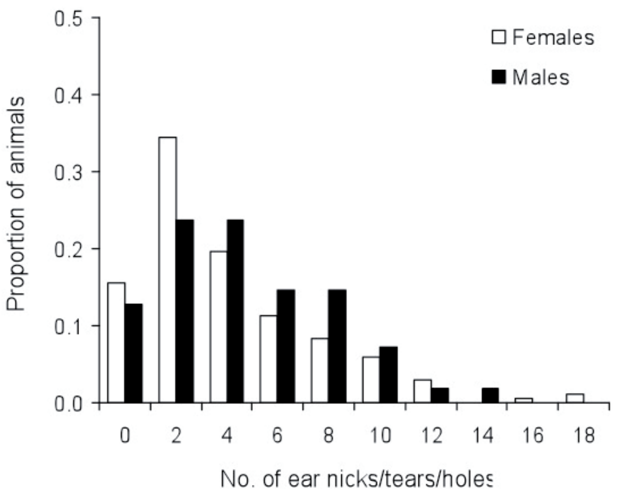

Figure 11. Proportions of females and males with different numbers of marks on their ears.

We also used Analysis of Covariance to examine the effect of sex and age on the total number of ear marks based on single-time point data of various identified animals. There was a significant effect of age ($F_{1,220}$=39.338, P<0.001) and of sex after controlling for age ($F_{1,220}$=80.778, P=0.006) on the number of ear marks (although there was no overall effect of sex on the number of marks). However, the effect of age was not very large, with R^2=0.132 (P<0.001) and 0.225 (P<0.001) for females and males, respectively (based on separate regressions for males and females), indicating a small increase in the number of marks with age (Fig. 12), and factors other than age required to better explain the number of marks. This was in keeping with the small rate of change of ear marks found (Table 3) based on multiple-time point data of identified animals.

Discussion

We were able to obtain a very low P_{ID} using a combination of traits, which makes identification of individual male and female elephants reliable. However, a large number of traits were required to achieve this (at least 14 traits in females and 9 traits in males to obtain a P_{ID} of less than 10^{-5}). We found the top fold of the ear to be informative for male and female identification. Nicks and tears in the ears were also very informative (low P_{ID}) despite the average number of ear marks per individual being low. Ear holes were, however, not very informative. Since there were six types of ear holes according to our classification (excluding the minute holes), it should have been possible to classify a large number of individuals if the frequency of individuals with holes in their ears was high (for instance, 216 possible combinations if individuals had three holes each in just the right (or left) ear, or 1296 possible combinations if individuals had four holes each in an ear). However, individuals with more than three holes on an ear were not seen and even those with three were rare. The frequency of holes in the ear would depend on the nature of the habitat and might be a more useful trait for identification of animals that live in thorn forests. Croze (1974) calculated that 15,000 distinct ear prints could possibly be obtained from marks on the ear in the Seronera elephant population. Using all the ear traits from our analysis, it would be possible to have 3.63 x 10^{13} combinations if all the trait states had an equal probability of occurrence. However, this was not the case (and is almost certainly never going to the case in any population) and, therefore, the P_{ID} values were of a much higher order of magnitude than they would have been

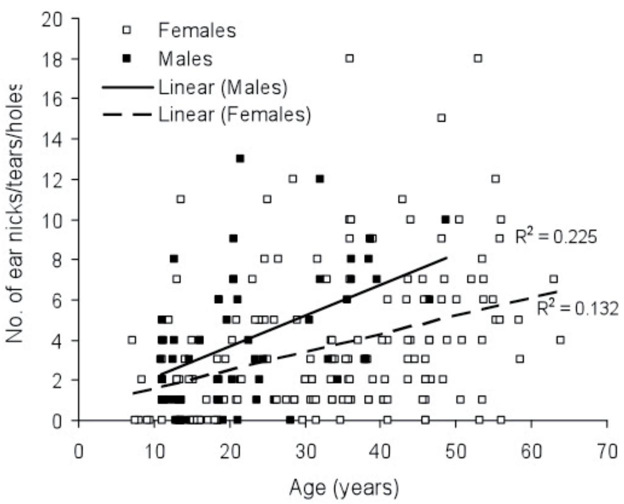

Figure 12. Number of ear marks in females and males of different ages.

if all combinations of trait states were equally likely to be seen. While the exact positions of ear marks were used for identifying individuals in the field, it was not used in our analysis of trait variability.

We found tusk characteristics also to be informative amongst males, but it must be mentioned that they can be difficult to classify in the absence of photos from different angles. This is because they can look very different from different angles, presenting a problem of 3D visualization as opposed to the 2D visualization required for classifying most ear characteristics. Broken tusks would change the length of the tusks (and were recorded as being of the respective state) and were not scored separately as being broken because tusks would appear obviously broken only when the break was recent. The same was true of bitten-off tails. The tail brush and tail kink were useful in female identification but not as much in male identification because males often bit off one another's tails, and 37% of the adult males did not have tail hair (as opposed to 18% of adult females). The presence of warts/ wounds on the body was useful for identification of males. We suggest that these informative traits listed above (ear top fold, nicks and tears, tusk traits and warts/wounds in males, and tail traits in females) be used as an initial filter if one would like to obtain a subset of animals that can then be manually identified.

Manual identification can be carried out using some qualitative traits in addition to the more objective traits listed above. As mentioned above, the top fold of the ear being folded forward could be further classified as *Folded Forward Slightly*, *Folded Forward into a Rolling Fold*, or *Folded Forward into a Flat Fold*. Similarly, depigmentation of the ears could also be classified as *None*, *Slight*, *Present*, or *Prominent*, if multiple sightings of animals in different light conditions and with their ears wet were obtained. Additional ear characteristics that were generally used for identification included the kinds of tears (for example, notches, large parts of the ear missing, tears with a small hook-like protrusions, tears with finger-like projections) and their exact positions, pleats in the ear or the lack of them, wavy or straight bottom edge of the ear, whether the entire pinna formed a single plane or whether part of the pinna was angled or formed a curved surface, small dents at the top fold (more often when the ear was not folded), thickenings at the side fold, warts, deformities, and vein patterns on the ear. Other traits that were used included depigmentation on the trunk and other parts of the body, discoloured tail hair (rare in our population), tail tip thickness (bulbous, tapered, or of the same thickness as the tail above the tip, see Fig. 8), skull shape, positions of the eyes and ears, and eye size and colour. In addition to physical traits, individual animals also often had distinct postures or behaviours, with some animals being hunched, some holding their heads high consistently, and yet others looping their tails or holding their ears in a specific way.

Apart from using the informative traits as an initial filter, the entire set of 22 traits listed can be used for more automated identification, as would be desired during mark-recapture sampling (Goswami *et al*. 2007). Using these 22 traits, we could uniquely identify each individual from our dataset of 223 animals. A division of the front of the pinna into quadrants for better positional information about ear marks would increase the number of possible combinations that could be used in automated identification.

We also found that the traits examined showed slow change across years. Previously, tusk characteristics (presence of tusks, tusk shape, angle, length, and thickness) as well as ear fold and ear lobe shape had been considered fixed traits (thought to remain unchanged over a few years or longer), and ear marks and tail characteristics had been considered variable (thought to change over the 2.5 month study) (Goswami *et al*. 2012). The use of variable traits for identification had resulted in an overestimate of elephant numbers and Goswami *et al*. (2012) had recommended the use of fixed traits for optimal individual identification. Our data show that this is not a sound strategy for identification: only ear angle, ear length, and ear side fold did not change over many years and these traits did not provide enough discrimination between individuals. More importantly, if ear marks were considered variable traits, tusk characteristics should not be considered fixed traits as they were as variable as ear marks: breakage of tusks changed their length, shape, and symmetry, and even presence/absence sometimes (when the remnant of a broken tusk fell out). The top fold of the ear was also found to change over several years. With ear marks, top ear fold, tusk characteristics, tail characteristics, and warts/wounds excluded, the total P_{ID} would be 0.032, which is useless even in a small population.

We suggest that the traits previously thought to be variable also be used for identification as they do not change on the scale of weeks/months and are, in fact, fixed traits by the previous definition. It is possible that the previous abundance overestimate resulted from incomplete marking information rather than the use of variable traits. Since marks accumulate gradually, it is not difficult to identify individuals with new/changed states. For an automated process such as that required for abundance estimation, allowing a level of mismatch between individuals that is in keeping with the rate of change of traits should be able to correct for recaptures of individuals with changes in marks. For other field studies that require individual identification, while recording a large number of trait states can be challenging, there is probably no better alternative to spending a long time getting to know the elephants, as long-term studies in Africa (for example, Moss *et al*. 2011; Turkalo *et al*. 2013) have shown.

We hope that this study will encourage researchers to carry out individual-based identification of animals in new studies, with a high degree of stringency in data collection. Since all the underlying traits being assessed are continuous, specific cut-offs are required to make their scoring objective. One would have to estimate P_{ID}s for every new population studied in order to assess the probability of making mistakes during identification. Since nicks, tears, and holes are acquired from the habitat, their frequencies may vary drastically across different populations. Attention will also have to be paid to age-specific P_{ID}s. We strongly suggest repeated measurements on multiple photos of the same animals to help to confirm various trait states.

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