The elephants (*Loxodonta africana*) of Zoba Gash Barka, Eritrea: Part 3. Ecological and other data from tusks, teeth and carcasses

Yohannes Yacob,[1] Jeheskel Shoshani,[2] Yohannes Hagos[1] and Emun Kebrom[1]*

[1] Ministry of Agriculture, PO Box 1048, Asmara, Eritrea
[2] Department of Biology, University of Asmara, PO Box 1220, Asmara, Eritrea
* corresponding author e-mail: hezy@eol.com.er

Abstract

There are approximately 100 elephants in Eritrea; they survive in unprotected areas and migrate into Eritrea from Ethiopia during the dry season and return to Ethiopia during the wet season. These elephants are isolated. Their habitat consists of doum palm, ziziphus and acacias. Between 2002 and 2004, 11 elephants were found dead. Four had fallen into water wells dug by humans, two were killed by farmers; the other five died of unknown causes, although some exhibited pathological bones and teeth. There are no known cases of elephant poaching. Data obtained on tusks since 1993, although meagre, are the most comprehensive compiled thus far for Eritrea. Based on measurements of 31 tusks, average total length was 103.2 cm, average weight was 8.7 kg, and the average age at death was ~15.1 years. These and other averages can be used as bases for future comparisons with other elephant populations and to assess differences in age groups and between sexes. Weight appeared to be above the average for elephant populations in Africa but lower than the eastern Africa average. Our observations confirmed that a healthy elephant population inhabits parts of Eritrea; this population suffered a loss of approximately 5% per annum over the period of our study. Measures must be taken to prevent young elephants from falling into artificial water wells. A detailed study of the remains of dead elephants should be conducted to learn of possible causes of death and urgent steps should be taken to protect this beleaguered elephant population.

Additional key words: accidental death, ecology, elephant pathology, tusks

Résumé

Il y a approximativement 100 éléphants en Erythrée ; ils survivent dans des zones non protégées, migrent d'Ethiopie en Erythrée pendant la saison sèche et font le trajet inverse pendant la saison des pluies. Ces éléphants sont isolés. Leur habitat consiste en palmiers doum, en ziziphus et en acacia. On a trouvé onze éléphants morts entre 2002 et 2004. Quatre sont tombés dans des puits creusés par des hommes, deux ont été tués par des fermiers et les cinq autres sont morts de cause inconnue, même si certains présentaient des dents et des os pathologiquement atteints. Il n'existe pas de cas connu de braconnage d'éléphant. Les données obtenues depuis 1993 sur les défenses, quoique maigres, sont les premières pour l'Erythrée. D'après les mesures de 31 défenses, la longueur totale moyenne était de 103,2 cm, le poids moyen était de 8,7 kg et l'âge moyen au moment de la mort était d'environ 15,1 années. On peut se servir de ces moyennes, et d'autres, comme bases pour de futures comparaisons avec d'autres populations d'éléphants et pour évaluer les différences entre les groupes d'âge et entre les sexes. Le poids semblait se situer au-dessus de la moyenne générale des populations africaines mais en dessous de la moyenne d'Afrique orientale. Nos observations ont confirmé qu'une population saine d'éléphants habite certaines parties de l'Erythrée ; cette population subit une perte d'environ 5 % pendant la période de notre étude. Il faut prendre des mesures pour empêcher les jeunes éléphants de tomber dans les puits artificiels. Une étude détaillée des carcasses d'éléphants morts devrait être réalisée pour en connaître les causes possibles et il faut prendre des mesures urgentes pour protéger cette population coupée des autres.

Mots clés supplémentaires : mort accidentelle, écologie, pathologie des éléphants, défenses

Introduction

In historical times (from the 3rd century BC to the 19th century) elephants in Eritrea were observed in many parts of the country where there are no elephants today, but also in Zoba Gash Barka where they are now found. During the 20th century they were confined to Zoba Gash Barka. Approximately 100 elephants live in south-west Eritrea; they subsist in unprotected habitats consisting mostly of doum palm, ziziphus and acacia in various locations within the watersheds of the Gash and Setit Rivers. This population is fecund and appears in good physical condition.

In part 1 of our findings (Hagos et al. 2003) we focused on documenting historical records of elephants in Eritrea; in part 2 (Shoshani et al. 2004) our findings centred on elephant census and distribution, and aspects of elephant ecology and ecosystem. In this third part of our findings, we summarize nine years of ecological data retrieved from tusks and three years of data from dead elephants, and what lessons can be learned.

Habitat of current elephant distribution in south-western Eritrea

Eritrea may be divided into three phytogeographic zones: Sudanian, western lowland; Afromontane, highland; and Somalia-Masai, eastern lowland (White 1983). Further subdivisions into western lowland, western escarpment, central highland, eastern escarpment, and coastal lowland have been employed by Zinner et al. (2000). Elephants in Eritrea inhabit a portion of the Sudanian phytogeographic region. There are two rainy seasons in Eritrea, the short season, from about March to April, and the long season from about June to September. Elephant habitat in Eritrea is xeric (dry) to semi-desert with an average of up to 600 mm of rainfall per year during May and September. Zoba Gash Barka includes the only permanent river in Eritrea, the Setit (Tekezze) River, that marks the boundary between Ethiopia and Eritrea in the south-west (fig. 1). Based on previous observations (Hagos et al. 2003; Shoshani et al. 2004) elephants in Eritrea are physically and possibly genetically isolated, yet they migrate between Eritrea and Ethiopia—during the dry season from Ethiopia into Eritrea and in the reverse direction during the wet season. Elephant poaching has not been reported in Eritrea; killings by farmers were to protect farmlands.

Materials and methods

Materials

Tusks were collected from dead elephants by staff of the Ministry of Agriculture (MoA) or were brought by farmers and villagers to local authorities as from 1993. Local people were interviewed to learn about the habits and behaviour of the elephants before they died. Tusks are kept at government storehouses in Barentu, Haicota and Asmara. Bones and teeth are stored at the National Museum of Eritrea (NME), or at the University of Asmara (UoA), both in Asmara. The pathological data in this paper were drawn from field observations from elephants that died recently, and from collections at NME and UoA.

Methods

The preferred method of investigation was direct observation of dead elephants. Information from villagers and farmers was also obtained. Every datum possible was collected from carcasses (cf. Whyte 1996), including external observations, forefoot diameter and length of hind foot to calculate shoulder height and estimate age. Calculation of the shoulder height from the forefoot diameter was done by multiplying the circumference by 2.03 (following Sukumar et al. 1988). Hind foot lengths were employed to estimate ages of elephants using the formula of Western et al. (1983) and data from Lee and Moss (1995). Data on tusks were collected after Laws (1966, 1969), Pilgrim and Western (1983, 1986), Moss (1996) and Ngure (1996) (fig. 2). These measurements include tusk weight (n = 28), total length (n = 29), length at lipline (n = 24), circumference or girth at lipline (n = 24), circumference at base (n = 31), and pulp length (n = 29). Dental characters for age estimation were collected after Laws (1966) and Sikes (1971). Elephant skull measurements, as given by Groves and Grubb (1986), were also collected. All observations were documented either in field notebook or by photograph (fig. 3), or both. Data on tusks reported here include those collected since 1993 and for dead elephants since February 2002. Tissue and dung samples were collected for DNA analysis.

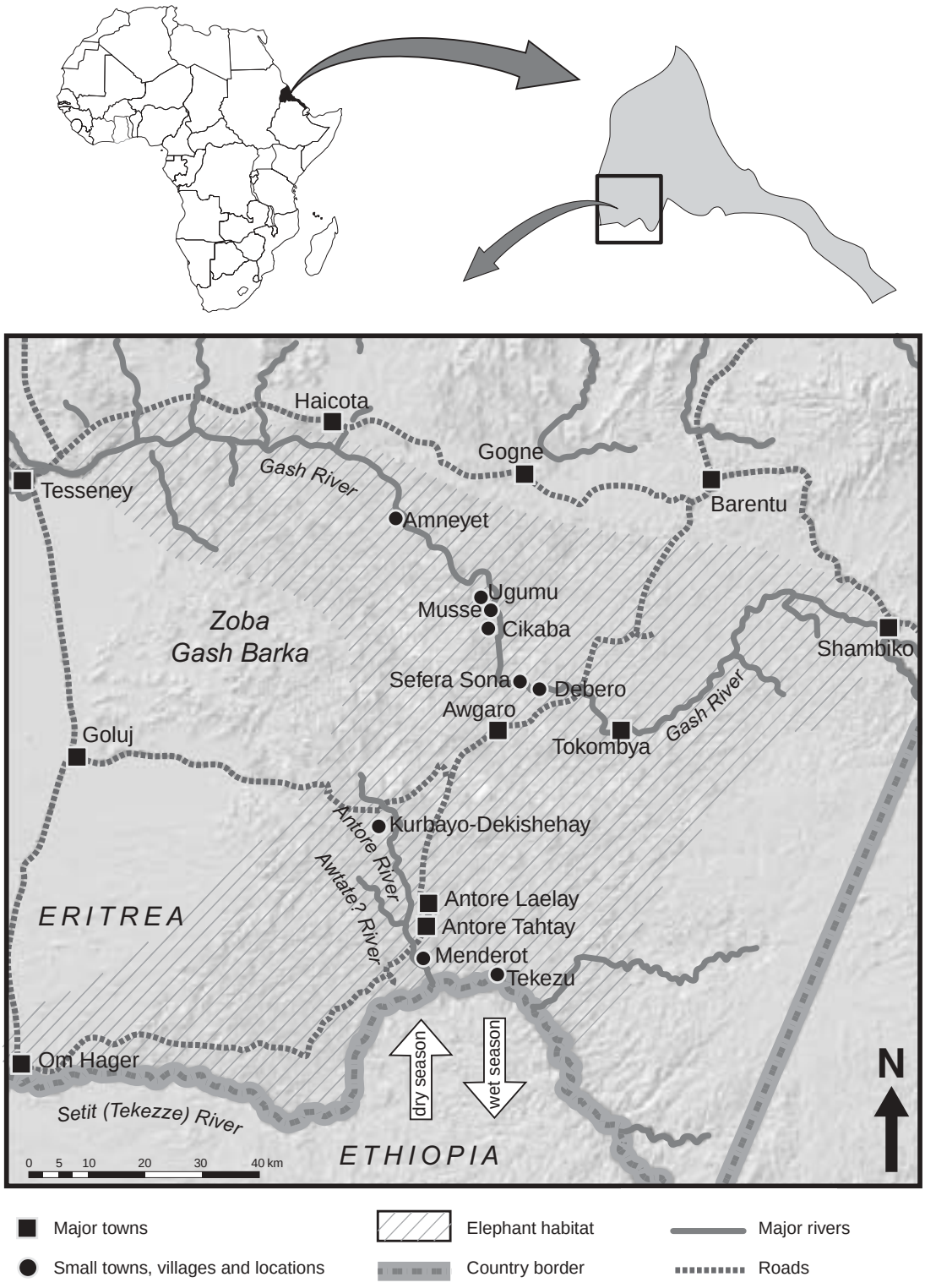

Figure 1. Distribution of elephants in Zoba Gash Barka, Eritrea, based on data presented in table 1 of Shoshani et al. (2004), and place names where elephant carcasses were found (technical and artwork by Maria Christine Hill and Philip Miyare).

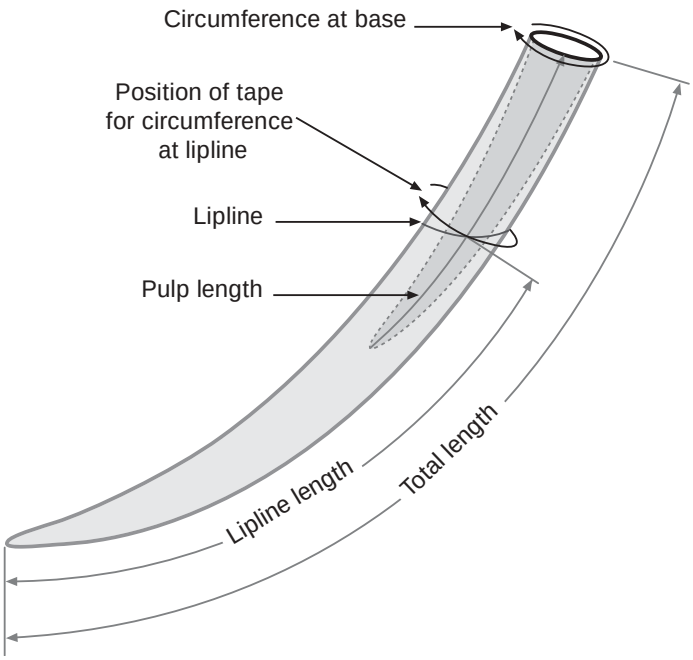

Figure 2. A simplified illustration depicting measurements given in table 2 (artwork by G.H. Marchant, modified after Ngure 1996).

Results

Reports on 11 elephants that died recently

A summary of known elephant mortality between 2 February 2002 and 20 May 2004 is given in table 1. Additional details including information on possible causes of death are provided below. Listing is chronological by date of death.

Elephant No. 1, died on 2 February 2002, near Tekezu village close to the Setit (Tekezze) River. In June 2002, we travelled to this site to collect the remains of the carcass. Before dismembering it, we noticed that its tusks were absent. We collected a short piece of one tusk (tusk no. 9, table 2) but did not find the other. Epiphyses of some of the long bones were separated and chewing marks (probably of hyenas, other carnivores and rodents) were evident. Some bones, large and small, were found at a radius of about 30 m from the carcass. There were no bird droppings

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Figure 3. Five average-sized tusks (two pairs and one odd) at Ministry of Agriculture storage, Barentu.

Table 1. Summary of information on elephant carcasses in Eritrea, February–May 2004

No.[a]	Date of death	Location	Cause of death[b]	Age(yr)/ sex[c]	Notes[d]
1	2 Feb 2002	near Tekezu village; GPS: N 14°27.30', E 37°17.17'	unknown, possibly from cholelithiasis	~ 25/M	no. 9 in table 2; tusk fragment housed at MoA, Asmara; pathological bones
2	14 Mar 2002	near Debero village; GPS: N 14°49.92', E 37°20.47'	unknown	~ 10/M	nos. 10, 11 in table 2; tusks housed at MoA, Asmara
3	13 June 2002	Cikaba near Ugumu village; GPS: N 14°54.22', E 37°17.58'	fell into a water well by the Gash River	juvenile/?	nos. 12, 13 in table 2; tusks housed at MoA, Barentu
4	8 Nov 2002	Tekezu area; GPS: N 14°26.11', E 37°19.11'	unknown	20–30/M	nos. 14, 15 in table 2; tusks housed at MoA, Barentu; pathological bones and abnormal dentition
5	22 Nov 2002	Awtate River; GPS: N 14°32.46', E 37°10.88'	unknown	~ 15/M	no. 16 in table 2; right tusk at MoA, Barentu
6	21 Apr 2003	Sefera Sona; GPS: N 14°50.47', E 37°18.55'	fell into a water well by the Gash River	~ 7/?	collected skin samples for DNA analysis
7	7 May 2003	Musse site; GPS: N 14°52.89', E 37°17.94'	fell into a water well by the Gash River	~ 2/?	collected skin and hair samples for analysis
8	26 Oct 2003	Kurbayo-Dekishehay; GPS: ~N 14°32.23', ~E 37°09.62'	killed by farmers	~ 5/?	no samples or tusks collected
9	Nov 2003	near Amnayet; GPS: N 15°04.03'', E 37°09.88''	shot by farmers	10–15/?	nos. 17, 18 in table 2, right tusk at MoA, Haicota; tissue samples collected
10	4 Feb 2004	Menderot R; GPS: N 14°27.73', E 37°11.86'	unknown	subadult/?	nos. 19, 20 in table 2; tusks
11	20 May 2004	Debri Mussa, near Ugumu; GPS: N 14°35.30', E 37°17.10'	fell into a water well along the Gash River	juvenile/?	no samples or tusks collected

[a] Listed chronologically by date of death.
[b] Additional details on possible causes of death are given in the text.
[c] M = male; ? = sex unknown
[d] Data on tusks are given in table 2 and in the text.

on the skin, although in eastern Africa droppings are often observed, as large birds (raptors and marabou storks) scavenge on the remains. A relatively large shrew, possibly a white-toothed shrew, *Crocidura ?olivieri* (Lesson, 1827) (Insectivora, Soricidae), was seen escaping from the carcass. We searched but did not find any bullets or bullet holes in the skin.

Between 21 and 22 June we removed all bones (including the hyoid apparatus), cleaned and transported them to NME in Asmara, some 400 km away. While removing putrid and decomposing flesh from the lumbar region, we noticed a large round to oval-shaped object that measured 22 x 14 cm in cross section and weighed approximately 4 kg. The internal content of this object was fine, clay-like, orange-yellow particles. Samples were sent for analysis to the USA; results on cholelithiasis are reported below. We think this elephant was a male (based on large tusk diameter, round mandibular condyle, and protruding tip of mandibular symphysis). Other unusual anatomi-

Table 2. Data on tusks and dentition of elephants from Eritrea

Tusk no.[a]	Weight (kg)[b]	Total length (cm)[c]	Length at lipline (cm)[d]	Circumference at lipline (cm)[d]	Circumference at base (cm)[e]	Pulp length (cm)[f]	Estimated or (extrapol.) age (yr)[g]
1-L	13.0	120.0	66.5	39.0	43.0	64.5[a]	(~ 20)
2-R	12.0	112.5	63.5	37.3	41.0	49.5[a]	(~ 20)
3-L	8.0	114.5	64.0	30.5	37.5	62.5[a]	(~ 12)
4-R	7.0	104.0	51.0	30.0	36.5	59.0[a]	(~ 12)
5	10.5	106.7	64.0	37.0	42.5	47.0[h]	(~ 20)
6	~ 5.0	90.0	—	—	26.5	29.0[i]	(~ 11)
7-L	~ 12.0	104.0	—	—	42.5	—[j]	(~ 20)
8-R	11.5	114.5	—	—	40.5	70.5[j]	(~ 20)
9	—	—	—	—	43.5	—[k]	~ 25
10-L	3.0	77.0	45.0	23.5	27.0	55.5[l]	~ 10
11-R	2.8	79.0	41.5	24.5	26.5	58.0[l]	~ 10
12-L	800.0[g]	49.5	21.5	15.0	17.0	23.0[m]	2–4
13-R	800.0[g]	50.5	22.5	14.5	16.5	31.3[m]	2–4
14-L	13.0	99.5	39.0	37.0	38.5	57.5[n]	20–30
15-R	10.0	106.0	39.0	32.0	36.5	65.5[n]	20–30
16	11.0	110.0	53.0	32.0	34.0	39.0[o]	~ 15
17-L	1.6	[43.0]	—	—	28.0	43.0[p]	10–15
18-R	3.0	87.5	42.0	23.0	28.0	45.0[p]	10–15
19-L	7.0	81.0	34.0	28.0	24.5	23.5[q]	(~ 12)
20-R	7.5	89.0	41.5	28.0	26.0	27.5[q]	(~ 12)
21-L	1.4	67.5	30.5	17.5	21.0	36.5[r,s]	(~ 5)
22-R	1.4	64.0	27.0	17.5	20.0	37.0[r,s]	(~ 5)
23-L	4.0	70.0	29.5	26.0	23.5	27.0[t,s]	(~ 8)
24-R	3.0	64.5	24.5	24.0	23.0	26.5[t,s]	(~ 8)
25	7.0	94.0	49.5	30.0	27.2	29.5[u,s]	(~ 12)
26-L	—	186.0	—	—	58.2	95.0[v,s]	(~ 30)
27-R	—	173.3	—	—	60.0	97.0[v,s]	(~ 30)
28-L	37.0	179.0	116.0	51.5	49.5	89.0[w]	(~ 30)
29-R	31.0	165.0	106.0	50.0	49.0	88.0[w]	(~ 30)
30-L	9.2	108.5	45.0	36.0	42.0	84.5[x]	(~ 15)
31-R	9.8	125.0	62.5	35.0	40.0	86.5[x]	(~ 15)
n =	28	29	24	24	31	29	31
Average	8.7	103.2	49.1	29.5	34.5	53.4	(~ 15.1)

Table updates data presented in Shoshani et al. (2000, p. 16)

[a]Tusks no. 1 through 4 were collected in the vicinity of Haicota in Zoba Gash Barka, as recently as December 1996. Tip of tusk no. 2 is broken (missing), data include estimation for the missing piece. Initial data for tusks no. 1–8 were collected 26 June 1997 by J. Shoshani and Y. Yacob with the help of Solomon Tewelde and others. Data for tusks no. 9–21 were collected in 2003, and for tusks no. 22 and 23 in 2001. L = left, R = right of a pair of tusks.

[b] Weights were taken with a hand-held spring scale with 200-g increments; thus the weight estimation is to the nearest 200 g. Tusks lose weight as they dry out (based on four data points, range of 5 to 15%, depending on size and storage of tusks), and since most measurements were taken in 2003, we have used these most recent weights.

[c] The longest length, measured along the outer curvature (fig. 2). Comparing data collected in previous years on weights, lengths and circumferences to those re-collected on the same tusks in 2003, we found differences, usually due to loss of moisture and to shrinkage.

[d] The length at the lipline is the exposed portion of the tusk (fig. 2)—that is, the length from the lip to the tip. Lipline on tusks removed from the cranium is identified by stained markers on the tusks (due to chemicals in the food).

[e] Measured as close to the proximal end as possible (fig. 2).

[f] Measured by inserting a stiff wire into the pulp until it stopped (fig. 2).

[g] Estimated ages (no parentheses) are based on dental data (after Laws 1966 and Sikes 1971) and epiphyseal degree of fusion (Roth 1984). Extrapolated ages (within parentheses) are based on various parameters collected from individuals whose ages are estimated.
[h] Tusk no. 5 was collected in 1996 near Hasta Sahel Province, 200 km north of Haicota, far beyond the current elephant zone in Eritrea. A small piece is missing at the tip. Circumference is estimated because base is broken. This also affected the measurement for the pulp length. Length of pulp cavity is 38.5 cm, and the estimated length is 47.0 cm.
[i] Tusk no. 6 was displayed at the Expo/Festival, Asmara, Eritrea, 6 September 1998.
[j] Data on these tusks (no. 7 and 8) were taken at the Jolly Gift Shop, Asmara, Eritrea (26 November 1999); tusks are said to have been collected in the Gash Barka area, Eritrea.
[k] Fragment of tusk no. 9 belongs to elephant no. 1 in text (Tekezu village). This fragment, measuring 30 cm long, was found near the carcass; the other tusk was not found.
[l] Tusks no. 10 and 11 belong to elephant no. 2 in text (Debero village).
[m] Tusks no. 12 and 13 belong to elephant no. 3 in text (Cikaba, near Ugumu). Tusk no. 13 (right side) has a groove at the tip.
[n] Tusks no. 14 and 15 belong to elephant no. 4 in text (Tekezu area, near Setit River). Tusks are housed at MoA in Barentu; data collected 29 December 2003.
[o] Tusk no. 16 belongs to elephant no. 5 in text (Awtate River). Only the right tusk was found; it has a longitudinal ridge. It is housed at MoA in Barentu; data collected 29 December 2003.
[p] Tusks no. 17 and 18 belong to elephant no. 9 in text (close to Amnayet). Tusks are housed at MoA in Haicota. Distal end of tusk no. 17 (left) is missing.
[q] Tusk nos. 19 and 20 belong to elephant no. 10, which died on 4 February 2004 at Menderot River, close to Antore. Tusks are housed at MoA in Barentu. Data collected 29 December 2003.
[r] Tusks no. 21 and 22 have notes on masking tape that reads: 'brought by Pawlos Estifanos'.
[s] Tusks were collected in 2002 or before.
[t] Tusks no. 23 and 24 are said to come 'from the court' (perhaps confiscated).
[u] Tusk no. 25 is a left tusk. Portion of tusk was cut with a sharp object at the alveolus above the lipline.
[v] Data on tusks no. 26 and 27 were collected by Emun Kebrom on 10 October 2001; the left tusk is the longest measured thus far. This pair of tusks is housed at the local government storage in Barentu. According to Yohannes Yacob, these tusks belong to an elephant that died about 1998 close to Alebu, Zoba Gash Barka.
[w] Tusks no. 28 and 29 are said to have been collected at about 1993. This is the heaviest pair measured thus far (data collected 29 December 2003). Tusks are housed at MoA in Haicota.
[x] Tusks no. 30 and 31 are said to have been collected during the Haile Selassie regime (about 1950s or 1960s). Data collected 14 July 2004. Tusks are in government storage in Barentu.

cal conditions are given under 'Information obtained from elephant carcasses'. The dental characters of this individual (Laws 1966; Sikes 1971), indicate that it was about 25 years old at time of death. Tests for anthrax, using the polychrome methylin glue technique, by the veterinary laboratories in Vilajo, near Asmara, were negative; cause of death is unknown (fig. 4).

Elephant no. 2 died in March; we visited the carcass on 21 April 2002 (table 1 gives details of all 11 elephant carcasses). We noted that its state of decomposition was more advanced than that of elephant no. 1, possibly because it was a younger animal, only about 10 years old. (See data from tusks no. 10 and 11 in table 2.) Separation of the epiphyses of the long bones was more extensive than in elephant no. 1, and more chewing marks of carnivores were evident on many of the bones. Bird droppings on the skin were absent. A mandibular portion of this elephant is currently being cleaned in UoA. Villagers reported that this elephant was ill before death with reddish fluid oozing from the ears, nose, mouth and anus. No signs of gunshot or spearing were found. Tests for anthrax were negative; cause of death is unknown.

Elephant no. 3 died in June 2002 near Ugumu village along the Gash River. Both tusks were collected from the carcass soon after it died (no. 12 and 13, table 2). When we visited this site on 11 January 2003, we found only a fragment of an ulna, now housed at NME. Cause of death: slipping and falling into a dug water well.

Elephant no. 4 died on November 2002 in the Tekezu area close to the Setit (Tekezze) River. Residents suspect that it had died from a contagious disease, and thus local herdsmen fenced off the carcass with thorny acacia and ziziphus to prevent domestic animals approaching it. We visited this site in January 2003 and collected the mandible (currently housed at NME), the distal portion of the left thyrohyoideum, the basihyoid, and a skin sample from the chin area. The mandible exhibits abnormal tooth eruption; therefore the age estimation (between 20 and 30 years at the time of death) is based on epiphyseal fusion on some long bones (after Roth 1984). It is noted, how-

Figure 4. Team members examine the carcass of elephant no. 1 and take samples to test for anthrax.

ever, that in addition to the abnormal dentition, some osteossed (abnormal) bones, for example, the third trochanter of the femur, was greatly ruggosed and swollen with abnormal bone and bony spikes, as observed in elephant no. 1. Cause of death is unknown.

Elephant no. 5 died in November 2002 along the Awtate River, a tributary of the Antore River. We visited this subadult to adult elephant carcass (approximately 15 years old) on 10 January 2003 and collected the mandible, currently housed at NME. Also collected were both stylohyoidea and elephant dung. Cause of death is unknown.

Elephant no. 6 died on April 2003 in the Awgaro area at Sefera Sona. It was approximately 7 years old. It fell and died in a water well dug by local people on the east side of the Gash River where the depth of water was about 100 cm below the riverbed. We visited this site on 9 May 2003 and collected skin samples from the leg area for DNA analysis. Also collected were three dung samples (large, medium and small) taken for seed analysis. Cause of death: slipping and falling into a dug water well.

Elephant no. 7 died on May 2003 in the Ugumu area near Awgaro. A calf approximately 2 years old, it fell and died in a water well along the Gash River where the depth of water was about 100 cm below the riverbed. We visited this site in May 2003 and for DNA analysis we collected skin samples from the ear and hair from the tail. Cause of death: slipping and falling into a dug water well.

Elephant no. 8 died in October 2003 near the town of Kurbayo-Dekishehay, south of Awgaro. Its death was reported in the Tigrigna newespaper Haddas Eritra on 6 November 2003. According to its report, over 40 elephants had destroyed millet crops and during that time a farmer shot and killed a five-year-old elephant (accounts of this incident were also shown on Eritrean television).

Elephant no. 9 is said to have died in early November 2003 near Amnayet, close to Haicota. We visited this site on 26 December 2003, took measurements on foot circumferences and teeth, and collected the mandible (currently housed at UoA), a complete set of hyoid bones with cartilages, and skin samples for DNA studies. This elephant was said to have been sick and was shot by a farmer. Tusks were collected on 15 November by MoA in Haicota (tusks 17 and 18, table 2). Using the dental characters described by Laws (1966) and Sikes (1971), we judged that this individual was between 10 and 15 years old.

Elephant no. 10, a subadult, died on February 2004 near the Menderot River near Antore and Tekezze Rivers. The fresh carcass was visited as part of the MIKE programme. Both tusks were collected and are housed at MoA in Barentu (tusks 19 and 20, table 2). Habitat at the site was a dense riverine forest, which included

Hyphaene thebaica and *Ziziphus spina-christi*. The cause of death is unknown, but the elephant may have been sick since an eyewitness reported seeing it isolated from other members of the herd for a few days.

Elephant no. 11 died in May 2004 near Ugumu village. This juvenile fell and died in a water well along the Gash River. It fell with its head inside the well, so it was not possible to reach the tusks. The carcass was fresh, sex unknown. Cause of death: slipping and falling into a dug water well.

Information obtained from tusks

Data on eight tusks presented by Shoshani et al. (2000, p. 16) provide some insight on the natural history of elephants in Zoba Gash Barka. Data for 31 tusks are provided in table 2. Although the data are meagre, they are the only information available and the most comprehensive compiled thus far for Eritrea. The combined average of the estimated and extrapolated age of the 31 elephants is ~15.1 years. Tusk length ranged from 49.5 to 186 cm and averaged 103.2 cm (n = 29) (tusks 12 and 26 in table 2 and fig 5). Weight ranged between 0.8 and 37 kg with an average weight of 8.7 kg (n = 28). A pair of tusks from elephant no. 2 weighed 3 kg each in April 2003; in March 2002 the same tusks had weighed 3.5 kg each—a loss of 0.5 kg per tusk in about one year. For future investigators, it would help to state when the elephant died and when the tusks were weighed. This small size is possibly due to the young age (about 10 years) of the elephant.

Other statistics calculated from the available tusks included average pulp length (n = 29), which is about 53.4 cm, and average ratio of pulp length to total length (n = 28), which is 0.5. The average tusk length inside the cranium (the unexposed, n = 24) is close to 50 cm (49.1 cm), and the ratio of exposed to unexposed tusk is about 0.5 (a 1:1 ratio).

Discussion

Tusk size and age implications

Among the elephants in Eritrea, most of the tusks measured at the lipline and those observed on live

Eritrea MoA staff

Figure 5. Apparently the heaviest tusks recorded from Eritrea, and a pair of small tusks, photographed with students, teacher (J. Shoshani, with hat), and Kabede Awole, MoA staff in Haicota, standing on left (cf. tusks no. 28 and 29, the heaviest, and tusks no. 17 and 18, the smaller tusks, in table 2).

elephants appeared to be small, about 50 cm in length from the lipline. From data given in table 2 we calculated an average of 103.2 cm in length and 8.7 kg in weight. One possible explanation for their almost uniform tusk size and weight for an age category is the homogeneous genetic make-up of the population. Observations on tusk size date to the 19th century when Baker (1871, p. 219) noted that most Abyssinian elephants have very short yet fairly thick tusks. With caution, it is possible to surmise that there is little or no variation in tusk size for a particular age class. This hypothesis may be related to isolation and inbreeding. Other information gathered from tusk and teeth include estimated and extrapolated age for 31 elephants. The average age of approximately 15.1 years, as determined by our preliminary findings, provides an indication that the age at which elephants died in Eritrea during the past five years (1998–2003) is less than half of the normal life expectancy of eastern African elephants (Moss 1996; Eltringham 2000).

The average tusk weight for elephants in Eritrea (8.7 kg, table 2) seems to be higher than average for African elephants, according to Hunter et al. (2004) who estimated an average of 6.9 kg per tusk. This average is based on data from Milliken et al. (2002), who reported an average tusk weight of 3.68 kg calculated from 7800 ivory seizure records, and Parker and Martin (1982), who reported that each elephant yields 1.88 tusks (3.68 kg x 1.88 = 6.9 kg). For comparison, the average tusk weight of African elephants in 1986 and 1988 was close to 4.5 kg (cf. Morell 1990).

Specific data on tusk weights from eastern Africa are about 14 years old (Buss 1990) or older (Laws 1966). Average tusk weight for 46 tusks from western Uganda was 5.9 kg (Laws 1966, p. 23). Using tusk data also from western Uganda, Buss (1990, p. 70) found an average tusk weight for males (n = 39) to be 5.8 kg, and for females (n = 42) 4.5 kg. Data from Laws (1966) and from Buss (1990) have similar average tusk weights, and both are lower than the current average tusk weight for elephants in Eritrea. Tusks from eastern Africa are known to be large. Shoshani et al. (1987, p. 29) provided data for four elephants from eastern Africa with large tusks with an average of 81 kg (converted from 178.6 lb) the heaviest, from near Kilimanjaro, weighed 103 kg. Laws (1970, p. 254) noted that the record tusk weight for a male elephant is 106 kg and for a female 25 kg; Moss (1996, p. 61) gave similar records: for a male 100.8 kg and for a female 29.7 kg.

Buss (1990, p. 72) pooled his data on tusk weights in relation to age, charted them with data obtained from Laws (1966), both from western Uganda, and summarized his comparisons: 'the data show clear distinction between the sexes. Both display a tusk weight to age relationship that appears to be a linear function although males seem to increase their tusk weight more rapidly than do females.'

Tusk length measurements for eastern Africa were collected by Laws (1969), Pilgrim and Western (1983, 1986), Buss (1990), and in this study. The shortest tusk measured by Buss (1990) for males (n = 39) was 98 cm, and for females (n = 41) 97.8 cm; the longest tusk for males was 101.3 cm, and for females 102.9 cm (average for males was 99.5 cm and for females 100 cm). Our data for tusk length are given in table 2. Although the averages from these data are given in the table and summarized above, they are not sufficient to draw conclusions on gender differences.

Tusk circumference at the lipline, pulp depth and volume

Data on circumference at the lipline (CALL) were collected by Laws (1969) from Tsavo National Park, Kenya; Pilgrim and Western (1983, 1986) and Buss (1990) from western Uganda; and in this study from Eritrea. All four papers cited conclude that there is a clear distinction between males and females based on their tusk CALL; those of males have higher values. Buss (1990, p. 70), measuring 39 males and 42 females, gave an average of 26.6 cm of CALL for males and 21.15 cm for females. Buss (1990) also found that pulp depth and especially pulp volume provide differences between the genders. His average pulp depth for males was 52.73 cm, and for females 33.68 cm; average pulp volume for males was 1390.7 cc, and for females 438.4 cc. We also collected data on pulp depth but not on volume (this can be estimated assuming the pulp is in the shape of a cone). It appears that it would be valuable to continue to collect these data for future comparisons.

From these studies, it emerges that certain data (for example, tusk length, weight, circumference at the lipline, pulp depth and volume) can be useful to identify whether tusks originate from male or female individuals. This conclusion was reached by Laws (1966, 1969), Pilgrim and Western (1983, 1986), and Buss (1990). Haynes (1991, p 43–45) also provides data on girth of tusks of male African elephants from Zimba-

bwe. Because our tusk data on elephants from Eritrea are meagre, it would be premature to apply the CALL and pulp volume data presented on tusks by other investigators to assign gender to elephants whose sex is unknown. However, for elephants with known sex (no. 2 and 4 in table 1) the data appear to match our measurements.

As noted by Laws (1969), Pilgrim and Western (1986), Moss (1996), and Ngure (1996), valuable data can be retrieved from elephant tusks, including estimation of age and sex, identification of individuals and populations, ecology, DNA and isotopic sampling, assessment of population trends, and possible cause of mortality. For the available tusks from Eritrea, we also calculated averages of pulp length, ratio of pulp length to total length, exposed tusk length, and the ratio of exposed to unexposed tusk length (see under 'Results'). These data can be employed as a basis for future comparison of data in other elephant populations and for assessing differences in age groups and differences between sexes. These data can also be employed for assessing more accurately the age and gender structure of this population based on observations of live elephants related to the data being collected in situ and thus contribute to improved monitoring of this particular group of elephants. In addition, tusks include a wealth of information on the life history of elephants, including timing of death, nutritional stress and possible calving periods (Fisher 1996). We have not yet maximized the potential of data retrieval from tusks in Eritrea (see however, under 'Future investigation').

Information obtained from elephant carcasses

Eritrea has been trying to conserve wildlife, in spite of economic hardship, so it is a setback to lose 11 elephants in a period of 27 months (from February 2002 to May 2004), a loss of about 5% per annum. Unfortunately it was not possible to ascertain the cause of death of all the elephants, but in addition to some basic data on tusks, it was possible to collect information on age and sex. General and skull measurements might be useful in future pathologic (based on abnormal bones and teeth) and taxonomic studies. On elephants no. 1 and 4 we found evidence of abnormal or pathological features. Data collected (after Groves and Grubb 1986) from elephants no. 1, 2, 4 and 5 are available from J. Shoshani.

An unusual anatomical condition was observed on the bones of elephant no. 1. In addition to the pathological observations noted above, we noted that the right femur was shorter by 10 cm and wider than the left, and the third trochanter as well as the distal end were osteossed and swollen with abnormal growth. It was also observed that the left tibia was shorter by 3.5 cm than the right tibia. It would seem that the body attempted to compensate for the shorter right femur by lengthening the right tibia. There was another unusual finding in this elephant: it had a large, approximately 4-kg cholelith—a concretion composed of bile alcohols, bacteria, and traces of cobalt and sulphur found in the bile duct (Agnew et al. in press). The presence of bacteria within the cholelith strongly suggests a bacterial infection of the bile duct. Such a large cholelith itself could have caused the death of the elephant from cholelithiasis.

Easily recognized sexual dimorphic osteological characters include shape of the mandibular condyle and protrusion of the mandibular symphysis. Mandibular condyles (those that articulate with the cranium) are close to round in males; in females they appear elongated or oval when the long axis is directed from side to side (latero-medially). The protrusion of the mandibular symphysis in males is distinct and longer than in females. Tusks in males are longer and have a wider base than those of females of corresponding age (Pilgrim and Western 1986; Buss 1990).

Based on the above features, it appears that four of the five elephants that died in 2002 were males. Initially a suspicion arose that the four elephants were poached for their ivory. This hypothesis was negated on at least one occasion (elephant no. 4), as soldiers watched the carcass until the authorities visited the site. The skin of elephant no. 1 was searched for any bullet holes, but none were found. The tusks that were removed by people other than staff of the MoA were probably done in opportunistic post-mortem acts.

The phenomenon of a calf or juvenile elephant dying by slipping and falling into a sandy water well dug along the Gash River has repeated itself four times in two years (elephants no. 3, 6, 7, 11; cf. table 1 and text above). Sadly, this has become a common occurrence during the hottest months, from about March to mid-June. Urgent measures need to be taken to reduce or prevent such occurrences (see under 'Recommendations').

Estimated population growth and birth rate

An important factor that contributes to population size is the available area and competition with other mammals, humans included. Zoba Gash Barka is the bread basket of Eritrea, and conflict between human and elephants for accessible land is increasing (Hagos et al. 2000; Shoshani et al. 2004). At about 4200 km^2, elephant distribution and home range in Eritrea cover less than half the size of Gash Barka. Part of this range includes passageways or narrow corridors for movement between the southern part of the range (near the Setit River) and the northern part of the range (in the Gash River between Awgaro and Haicota, fig. 1).

Various factors contribute to population growth, including birth rate, death rate, immigration and emigration (Douglas-Hamilton 1972; Smith and Smith 1998). Immigration and emigration are not known to be relevant to the elephants in Eritrea, since they are an isolated population. There are, however, few data on elephant death rate in Eritrea (and almost no data for birth rate) available for conducting a thorough analysis of population growth. As noted above, 4 of the 11 deaths during 2000–2004 were calves, a normal level among young elephants (Lee and Moss 1986). Eleven elephant deaths spread over 27 months (from February 2002 to May 2004) gives a rate of 4.9% deaths per year. This is higher than the rate of 2–3% given by Laws (1969) and Corfield (1973) based on jaws found. With poaching, however, the death rate can range from 5% to 38% (Dublin and Douglas-Hamilton 1987; Moss 1990). Estimated population growth for other populations in Africa is between 5% and 7% per annum (Hall-Martin 1992; Carbone 2003). Data on the structure of elephant population for Eritrea are beginning to emerge, although they are insufficient for estimating population growth. The fact that this transboundary elephant population migrates between Ethiopia and Eritrea makes it difficult to monitor the death rate and subsequently to estimate the population growth.

Future investigation

We will continue to collect and analyse specimens from dead elephants. Analysis will include gathering basic data, finding possible causes of death and analysing DNA to shed light on herd genetic composition compared with other populations in Africa. We will continue to search for methods to prevent young elephants from falling into artificial water wells. In addition, we plan to conduct detailed macro- and microscopic examination of tusks as described by Fisher (1996) to better understand their life history. Results from DNA extracted from tissue samples collected from dead elephants and dung samples as compared with DNA from other elephant populations will be published elsewhere (A.L. Roca, in prep.). Other aspects to be considered for future investigation include elephant density, birth rate, death rate, and population growth.

Recommendations

One of the recommendations suggested by Shoshani et al. (2004) was to install a few artificial watering sites along the path of elephant movement. Constructing these sites, we propose, should be done in a way that would allow young elephants easy access, and thereby prevent their death by slipping and falling into artificial sandy water wells. Another recommendation suggested by Shoshani et al. (2004) was, if possible, to expedite the establishment of protected areas. This becomes more imperative as this healthy elephant population is reproducing, and assuming a steady growth, soon may become a source of increasing conflict with the growing human population of the area.

Concluding remarks

Data collected during past years have added significantly to the existing pool of knowledge on elephants in Eritrea, yet much more needs to be learned. The approximately 100 elephants in Eritrea constitute a healthy, fecund and viable population, yet they are physically and possibly genetically isolated.

The elephants we observed carried tusks on average about half a metre long. Other tusk statistics, although meagre, are the first assessments of such data for Eritrea. These can be employed as a basis for future comparison with data in other elephant populations and for differences among groups and between sexes. Average tusk weight of elephants from Eritrea is higher than that for Africa as a whole but lower than the average in eastern Africa.

Currently there are no reports of poaching in Eritrea; elephants are killed only to protect human life or stop crop raiding.

A detailed study of the remains of dead elephants should be conducted to learn of possible causes of

death. Reducing the possibility of juvenile elephants slipping and falling into artificial water wells is possible by constructing artificial water sites with gently sloping entrances.

Gaining more understanding of the ecology and natural history of elephants through examining their tusks and carcasses is an additional method that can augment our pool of knowledge on this keystone species. In Eritrea, the need to protect this beleaguered elephant population is urgent. We emphasize that because of their size, by saving elephants we will automatically save large areas that protect other wildlife in the same ecosystem.

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