



Ulcerative pododermatitis in free-ranging African elephant (*Loxodonta africana*) in the Kruger National Park

D.F. KEET¹, D.G. GROBLER², J.P. RAATH², J. GOUWS³, J. CARSTENS³
and J.W. NESBIT⁴

ABSTRACT

KEET, D.F., GROBLER, D.G., RAATH, J.P., GOUWS, J., CARSTENS, J. & NESBIT, J.W. 1997. Ulcerative pododermatitis in free-ranging African elephant (*Loxodonta africana*) in the Kruger National Park. *Onderstepoort Journal of Veterinary Research*, 64:25–32

The occurrence of severe lameness in adult African elephant bulls in a shrub Mopane (*Colophospermum mopane*) ecosystem was investigated. Large ulcers in the soles of at least one front foot were seen in each of the recorded cases. Microscopically, the lesion can be described as a severe, chronic-active, ulcerative, bacterial pododermatitis (complicated by hypersensitivity/septic vasculitis). A variety of bacteria were isolated from these lesions as well as from regional lymph nodes. *Streptococcus agalactiae* was the most consistent isolate, while *Dichelobacter nodosus*, the only organism known to be involved with foot disease in domestic ruminants, was isolated from two cases. Contributory factors such as body mass, portal of entry and origin of potential pathogens may have predisposed to the development of the lesions.

Keywords: African elephant, *Colophospermum mopane*, *Dichelobacter nodosus*, Kruger National Park, lameness, *Loxodonta africana*, pododermatitis, ulcers, vasculitis

INTRODUCTION

Anecdotal evidence indicates that lameness is a relatively rare clinical entity in free-ranging African elephant (*Loxodonta africana*) in the southern African subregion in general, and in the Kruger National Park (KNP) in particular. In the rare cases investigated, the most common aetiologies are fractures of bone or bones in the distal portion of a limb (presumably of traumatic origin) and, because of the thickness of the skin of the distal extremities, partial-thickness

thermal burns of the feet after escape from encircling fires.

The African elephant has a digitigrade foot structure (Fowler 1980) and has five nails on the manis and four on the pes (Sikes 1971). Sometimes the lateral nails of the manis are absent, owing to excessive wear. The same applies to the medial and lateral nails of the pes. The bones of the phalanges are semi-planigrade, embedded in a digital cushion consisting of fibro-elastic tissue interspersed with fat and fibro-elastic cartilage (Fowler 1980). When the foot touches ground, it expands, and when lifted, it contracts elastically (Sikes 1971). The digital cushion (heel pad) functions as a shock absorber. The soles of the feet are heavily keratinized and have a distinctive mosaic of superficial cracks.

The purpose of this communication is to report the clinical and pathological findings of a relatively minor outbreak of an unusual foot lesion—involving the sole of one or more feet—which occurred exclusively in male elephant in a specific region, the Letaba Land

¹ Office of the State Veterinarian, Kruger National Park, Box 12, Skukuza, 1350 South Africa

² National Parks Board, Private Bag X402, Skukuza, 1350 South Africa

³ Department of Tropical Diseases, Faculty of Veterinary Science, Private Bag X4, Onderstepoort, 0110 South Africa

⁴ Department of Pathology, Faculty of Veterinary Science, Private Bag X4, Onderstepoort, 0110 South Africa

Accepted for publication 20 November 1996—Editor

System, in the KNP in the recent past (April 1993–October 1995). A total of 13 elephants were affected. Never before has such a high incidence of lameness occurred over a relatively short period (National Parks Board, KNP. 1903–1993 Annual Reports).

MATERIALS AND METHODS

Elephants were chemically immobilized according to the technique described by Raath (1993). Biopsy specimens were resected from the periphery and centres of ulcers and from the axillary lymph nodes and preserved in 10% buffered formalin. Specimens for culture were collected anaerobically in sterile containers. Incisions were made in the axillary area and, by a process of blunt dissection, these glands were located. The incisions were closed with continuous mattress sutures of No. 1 monofilament nylon ["Braun®" (B. Braun, Melsungen AG)].

Two elephants were euthanased by intravenous injections of suxamethonium (5 000 mg) while under anaesthesia, because of the advanced stage of their lesions and the extreme loss in body condition. Necropsies were conducted.

All bacterial isolates were identified according to standard laboratory practice based on macromorphology, and tinctorial and biochemical characteristics (Krieg & Holt 1984). Identification of *Dichelobacter nodosus* isolates was confirmed by a reference laboratory (Section of Bacteriology, Onderstepoort Veterinary Institute, Onderstepoort 0110).

RESULTS

Epidemiological aspects

An extremely lame adult male elephant was reported from the Middelvlei Windmill on the north-eastern shrub Mopane (*Colophospermum mopane*) flats (31° 32' 8"E, 23° 40,6'S) of the KNP. Loose flaps of footsole were visible as he moved. His gait was severely compromised and he was obviously experiencing severe pain. Dehiscence and consequent sloughing of the soles had taken place. There was no evidence of it having been burnt in a veld fire, nor any sign of a fracture. This animal stayed in the immediate vicinity of the windmill for a period of 4 weeks and consumed all edible vegetation in a small radius (1 km) of this water source. All four feet were found to be affected, and they exhibited varying degrees of sloughing of the soles. The two front feet were the most severely affected.

From May 1993–October 1995, 11 additional adult elephant bulls were found

to have suffered from this syndrome. Individuals were often seen in lateral recumbency, sometimes with their feet submerged in shallow water; presumably to alleviate pain. Later, we also learnt that the game ranger of Phalaborwa section had shot an extremely lame elephant bull with similar lesions at Rhidonda Pan 2 weeks prior to our investigation of case No. 2 (Arrie Schreiber, personal communication 1993). During the recording of this syndrome, no veld fires were reported from within the boundaries of the KNP.

One of the affected elephants (case No. 9) became very debilitated and eventually died of malnutrition several months later. He was virtually immobile and consumed all the available vegetation and water within the immediate vicinity. Unfortunately, the carcass was already decomposed at the time of its discovery. To our knowledge, all other cases examined, recovered after a prolonged period (6 months) of lameness.

All cases occurred on the north-eastern shrub Mopane flats on the so-called Letaba Land System (Fig. 1) (Venter 1990).

Macroscopic pathology

Foot lesions consisted of a single, focal, well-demarcated, round to oval ulcer measuring 240 x 200 mm in diameter and some 20 mm deep, and they were situated more or less in the centre of the sole of the foot. A malodorous necropurulent exudate admixed with soil and other environmental debris was attached to the surface of the ulcer which, when removed, resulted in exposure of a raw, yellowish-red, pus-crusted surface that bled readily when lightly scarified (Fig. 2a). On section, the purulent reaction was seen to extend some 2 mm below this surface. No penetrating wounds were seen in the remnants of the sole or at the base of these ulcers. In some areas, ulcers dissected between the heavily keratinized sole

TABLE 1 List of ulcerative pododermatitis cases in African elephant

No.	Locality	No. of feet affected	Necropsy	Biopsy	Bacteriology ^a
1	Rhidonda Pan	4	No	No	No
2	Middelvlei Windmill	4	No	Yes	No
3	Twanana	2, front	No	Yes	No
4	Manyeleti Dam	2, front	No	Yes	No
5	Kanniedood Dam	1, front	No	Yes	No
6	Nkulumbeni Central	1, front	No	Yes	No
7	Sirheni	1, front	No	Yes	No
8	Shingomeni	1, front	Yes	Yes	Yes
9	Nwarihangari North	1, front	No	No	No
10	Pioneer Dam	1, front	No	Yes	Yes
11	Bububu Mouth	4	Yes	Yes	Yes
12	Engelhardt Dam	1, front	No	Yes	No
13	Mooiplaas	1, front	No	Yes	Yes

^a Refer to Table 2 for specific isolates from cases

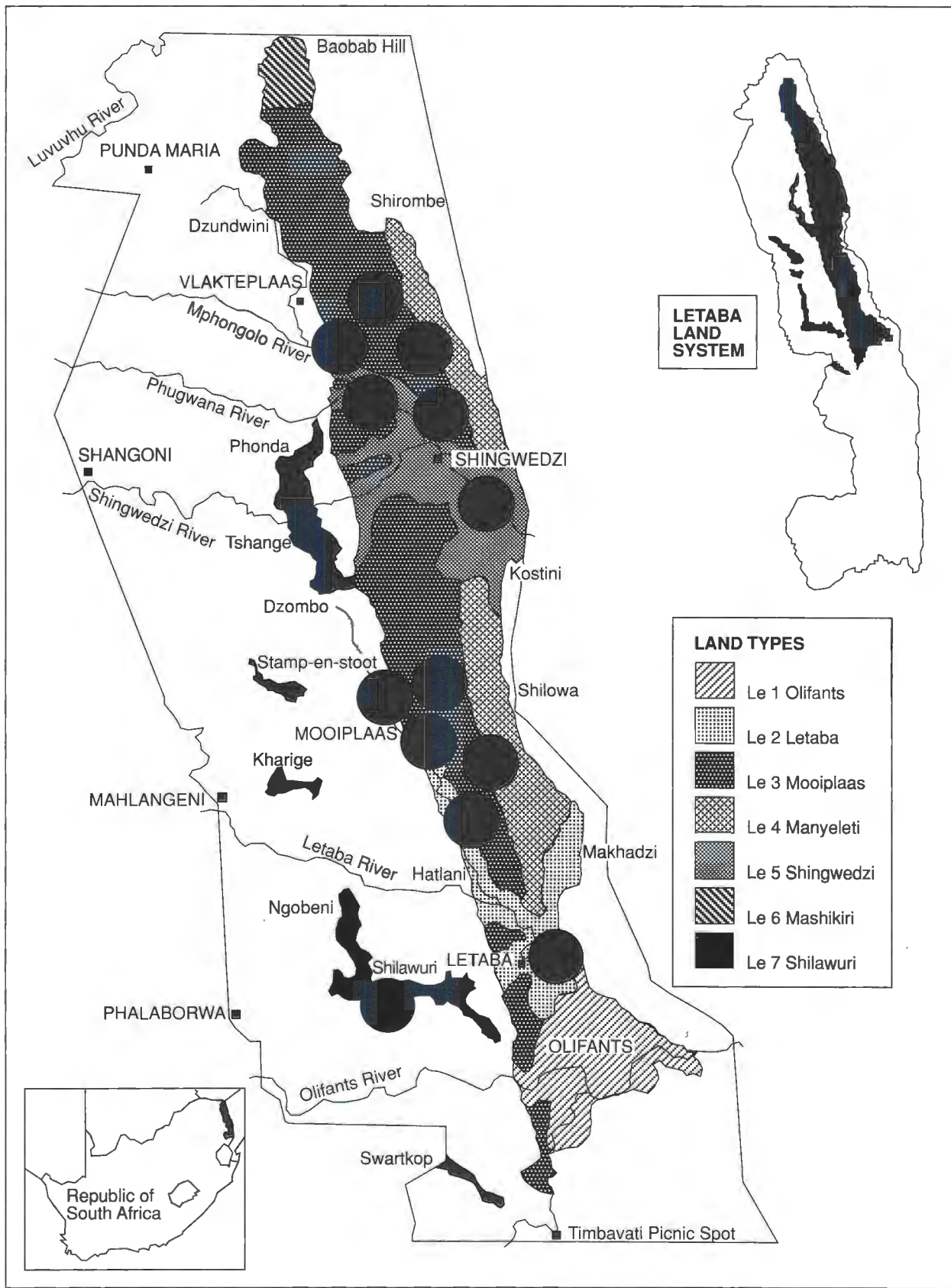


FIG. 1 Distribution of African elephant with ulcerative pododermatitis in the Letaba Land System of the Kruger National Park

TABLE 2 Infectious agents isolated from four cases of African elephant with ulcerative pododermatitis

Axillary lymph nodes	Foot lesions
<i>Dichelobacter nodosus</i> (8)* <i>Dichelobacter corrodens</i> (10)* <i>Streptococcus agalactiae</i> (10 and 11)* <i>Aeromonas hydrophila</i> (10)* <i>Bacillus cereus</i> (13)* <i>Peptostreptococcus magnus</i> (11)* <i>Corynebacterium ulcerans</i> (11)* <i>Salmonella</i> spp. (11)* <i>Bacillus</i> spp. (11)*	<i>Streptococcus agalactiae</i> (8, 10, 11 and 13)* <i>Bacillus cereus</i> (8)* <i>Corynebacterium</i> spp. (8,11 and 13)* <i>Peptostreptococcus melanogenicus</i> (8)* <i>Aeromonas hydrophila</i> (10)* <i>Pasteurella haemolytica</i> (10)* <i>Staphylococcus</i> spp. (13)* <i>Clostridium tetani</i> (13)* <i>Eubacterium lentum</i> (11)* <i>Dichelobacter nodosus</i> (11)*

* Case numbers



FIG. 2a Ulcerative pododermatitis in an African elephant bull



FIG. 3 A man-made water reservoir in the Kruger National Park. Note the drinking trough on the left



FIG. 2b The complicated hind-foot lesion of case No. 11

and the elastic cartilage cushion. These cavities were filled with moist soil, in addition to the tissue debris and exudate.

The ulcerative lesions were accompanied by distortion and overgrowth of the toe-nails of the affected foot and excessive wear of the toe-nails of the opposite front foot. In three of the cases, ulcers reached

the junction, this resulting in onychia and paronychia and ultimate loss of the affected nails. Macroscopically, some lesions appeared to be in the healing phase; the borders were rounded off and connective tissue was being laid down within the ulcer.

Draining axillary lymph nodes were enlarged and nodular (four times the size of the contralateral axillary lymph node). On section, there was bulging of the parenchyma, diminution of the corticomedullary distinction and release of blood and lymph from the cut surface. In the anaesthetized animals from which biopsies from lymph nodes were collected, it was impossible to determine whether enlargement was present.

In case No. 11, all four feet were affected. Both hind-foot ulcers had penetrated to a depth that exposed the third phalanx. This led to an ascending subcutaneous infection, resulting in severe swelling along both limbs. Septic arthritis occurred in the other phalangeal joints. Several draining sinus tracts had formed 30–70 mm proximal to the sole. The loss of skin extended about 100 mm proximally on the lateral side of the foot (Fig. 2b). The inguinal lymph node was markedly enlarged and measured 320 mm x 150 mm.

It was surrounded by a thick, fibrous capsule. The prepuce was severely swollen and oedematous.

Histopathology

The lesions observed in the various elephants were similar, with the exception of case No. 10. Lesions were sharply delineated from the unaffected epidermis. They comprised ulceration with associated necrosis and purulent exudation extending to a level deeper than the basal layer of the adjacent epidermis and overlying an extensive layer of granulation tissue. Superficial crusts consisted largely of necrotic debris in addition to degenerating neutrophils. The crusts and edges of lesions were heavily colonized by bacteria with mixed tinctorial and morphological properties, including Gram-positive cocci, coccobacilli and bacilli and Gram-negative rods and bacilli. Most of the blood vessels (arterioles and venules) at the interface of the ulcerative and granulation processes in the dermis exhibited leukocytoclastic vasculitis accompanied by fibrinoid changes of the vessel walls and, to a lesser extent, fibrinoid thrombosis. No inclusion bodies were seen in epidermal cells or cells surrounding the vessels in the inflamed and granulating dermis. Case No. 10 differed from the rest in that it had an associated eosinophilic reaction. The lesion consisted of deep ulceration with associated superficial necrosis and with subjacent neutrophilic and eosinophilic exudation overlying an extensive layer of granulation tissue. Blood vessels in the deep and contiguous subepidermal dermis manifested endothelial hyperplasia in association with perivascular cuffing by mononuclear leucocytes. Foot lesions were accompanied by reactive hyperplasia of the regional lymph nodes, characterized by follicular hyperplasia extending into the medulla, plasmacytosis of the medullary cords and histiocytosis of the medullary sinuses. Accumulation of neutrophils and macrophages occurred within the subcapsular and intermediate sinuses on a focal basis. Bacteria were not encountered in either Gram-stained or HE preparations of lymph nodes.

Bacteriology and virology

The results of the bacteriological examination in the four referred cases are presented in Table 2.

Virus isolation from tissue and blood samples was negative in every case.

DISCUSSION

Thirteen adult elephant bulls suffering from ulcerative pododermatitis were recorded over a period of 30 months. Lesions were associated with a septic vasculitis. A variety of bacteria were isolated from these lesions as well as from regional lymph nodes.

S. agalactiae was the most consistent isolate, while *D. nodosus* from two cases, was the only organism isolated known to be involved with foot disease in domestic ruminants. All these cases occurred on shrub Mopane flats.

Foot problems occur commonly in captive elephants, but are infrequently reported in the literature (Mikota, Lee Sargent & Ranglack 1994). No publications dealing with this problem in free-ranging elephant could be found. Wet and unhygienic conditions and inadequate exercise are predisposing factors in captive elephants (Evans 1910; Fowler 1993), and 50% of the captive population were found to be affected by one or more of the following conditions: cracks in the nail or cuticle; abscesses; and non-specific lesions due to trauma. The most common source of trauma was stepping on objects such as stones, nails or screws, and pieces of wire. It is important to note that only 10% of foot problems resulted in lameness. Initially, the possibility of these being natural cases of foot-and-mouth disease (FMD) was investigated. Howell, Young & Hedger (1973) experimentally infected young African elephant and described severe detachment of the soles. This differential diagnosis was ruled out serologically.

The African elephant is the largest terrestrial mammal. A mature elephant bull weighs well over 5 500 kg and up to 6 000 kg (Skinner & Smithers 1995). The range for elephant cows varies between 3 666 kg and 4 000 kg. Elephants never stop growing and the older they get, the taller and heavier they become (Hanks 1979). It is generally accepted that approximately 60–65% of the body mass of quadrupeds is carried on the forelimbs. The forelimbs are therefore subjected to more concussive and traumatic injuries than the rear limbs (Adams 1979). In elephants, this may be even more apparent, as the front legs must carry the massive head and ears with the attached ivory and trunk (Skinner & Smithers 1995).

The KNP has experienced a period of drought over the past 12 years, of which the dry season of 1991/92 was the worst in living memory (Zambatis & Biggs 1995). The northern section of the Park was more severely affected by this drought than either the central or southern section. These climatic circumstances gave rise to the die-off of a certain percentage of the woody plants. The Letaba Land System (Venter 1990) is classified into seven different land types (Fig. 1). The area is characterized mainly by extensive, flat to strongly undulating plains with clayey calcareous soils and represents 18,3% (4 000 km²) of the surface area of the KNP. A prominent common botanical feature of the land types in the Letaba Land System is the almost complete dominance of shrub Mopane in its plant communities. Even though the mopane tree is a hardy plant, some specimens did die during the drought. It is a medium to large tree, 4–18 m tall. This tree is often found on

alluvial soils, but it also tolerates alkaline and poorly drained soils. A tendency to shrubby growth is ascribed to soil condition (primarily) and veld fires (secondarily) (Van Der Schijff 1957; Van Wyk 1972). These shrub specimens are multi-stemmed and slow growing and are not resistant to cold. Wood of the mopane tree is extremely durable, hard and heavy (Van Wyk 1972; Coates Palgrave 1984).

Drought, together with constant elephant browsing, resulted in sharp, woody projections or stubble, protruding above ground level. This was found to be more apparent on the shrub Mopane flats than in the Mopane woodlands. It is reasoned that African elephant bulls, being so heavy, could feasibly develop penetrations of the foot sole when stepping on these projections, thus creating a portal of entry for secondary infection.

The Letaba Land System is not a high-density area for elephant breeding herds, but bachelor bulls frequent the area in moderate numbers ($n = 269$) (Whyte & Wood 1993). During the dry period of the year, vast numbers of numerous species visit the few remaining water sources. Elephant bulls prefer to drink from man-made water reservoirs during the dry period, as this water is clean, remains cool and is accessible only to elephants (Fig. 3). During all hours of the day and night there is constant movement of elephant bulls to these reservoirs to quench their thirst. This concentration of bulls leads to vast quantities of water being spilled from these reservoirs, creating a permanent muddy area around its immediate vicinity. The elephants also defecate and urinate around these structures, aggravating environmental contamination and creating suitable environments for the accumulation, exchange and potential entry of a variety of potential pathogens. Elephant cows and calves and other wild animals are not always tall enough to drink from these reservoirs and make use of drinking troughs near these reservoirs, or of natural water sources. Two hundred and fifty elephant cows and calves were physically examined during culling operations in the Letaba Land System during the same period, and no foot ulcers were found. In a survey to determine the prevalence of foot disorders in captive elephants, Mikota *et al.* (1994) found that disorders were most prevalent in captive Asian females, but she did not provide a reason for this observation. Captive African males were the least affected.

Although foot lesions encountered in this investigation bear some resemblance to lesions described in the feet in domestic animals and captive elephant in certain respects, the potential aetiology and nature and distribution of lesions in this series of cases appear to be unique. The finding of an association between the lesion and bacterial infection is considered significant. However, whether infection was primary or secondary, is uncertain.

Histologically, all foot lesions had a similar appearance. It was not possible to determine with absolute certainty whether foot lesions were in the initial, repair or recurrent phase of development; restriction to the epidermal layer suggests an early lesion, but the relative chronicity of the dermal and regional lymphonodular reactions suggests a chronic active process. The finding of heavier bacterial colonization of the epidermal edge as compared with the denuded surface of the ulcerative lesion, may reflect an expansile process consistent with the crateriform nature of the lesion when examined macroscopically.

The eosinophilic reaction recorded in case No. 10 may indicate a hypersensitivity ("allergic and/or parasitic") component in the pathogenesis of this specific animal's lesion. If parasitic, this may indicate a predisposing factor in elephants, analogous to one of the presumptive pathogeneses of footrot in ruminants, namely penetration of the macerated foot sole by parasitic larvae permitting ingress, colonization and infection of the region by bacteria. Round (1968) lists the internal parasites of African elephant in South Africa. Two genera of hookworms occur on this list, namely *Bunostomum brevispiculum* and *B. hamatum*, and *Grammocephalus clathratus*. Hookworm larvae are known to penetrate the skin to enter the host. This route of infestation has not been described in African elephant. Alternatively, the initial injury and portal of entry could have been no more contentious than simple trauma induced by fractured Mopane stubble.

No adequate studies have been reported on the microflora of foot infections in elephants. Organisms such as *Escherichia coli*, *Proteus* and *Pseudomonas* (Fowler 1993), *Enterobacter*, *Klebsiella*, *Staphylococcus* and *Streptococcus* (Mikota *et al.* 1994) have been isolated. As in this report, multiple isolates are common. Fowler (1993) further suggests that anaerobic bacteria such as *Dichelobacter (Bacteroides) fragilis* may be more important than aerobes because of the subsole environment and cracks and penetrations as portals of entry. Penetration and other wounds in the feet were found to lead to secondary invasion of the soles of the front feet, particularly in scrubland and mountainous areas (Sikes 1971).

Isolation of *D. nodosus* from one foot lesion and from the axillary lymph node of another case, may be important. However, the isolation of *Streptococcus agalactiae* from three foot lesions and four axillary lymph nodes, is the only consistent result of all the bacteriological examinations. The pathogenicity of this bacterium, compared with other isolates in elephant, is unknown. Apart from *D. nodosus*, none of the other organisms known to cause foot infections in cattle and sheep, was isolated.

D. nodosus is an obligate parasite of the skin of cloven-hoofed animals. It cannot survive in the environment

for longer than 14 d. The pathogenicity of the 18 different serovars varies. Virulence is correlated with thermostability, protease activity and motility. Benign and virulent strains exist, but all of them are potentially pathogenic. Isolation is extremely difficult, and Thorley's medium is suggested as a transport medium, as stringent anaerobic conditions must be maintained (Anonymous 1994).

The aetiology of infectious diseases of the feet of cattle and sheep is often multifactorial or uncertain (Venter & Van Amstel 1994). In these species, the hind legs are more often affected than the front. These diseases usually present as sporadic cases under intensive farming conditions during the rainy season and especially where muddy and unhygienic conditions prevail for prolonged periods. Infectious conditions of the feet appear to occur as a result of interrelationships between different infectious agents which are not able to invade intact skin, and can penetrate only damaged areas. The types of problems seen in domestic and non-domestic ungulates may also be seen in elephants (Mikota *et al.* 1994). Complications encountered with foot infections of captive elephant (Fowler 1993) and cattle and sheep (Venter & Van Amstel 1994) were seen in only one of the cases (case No. 11) that were examined. The extent of complicating lesions in this particular case was such that the animal could not walk.

Zinc deficiency had been incriminated as a predisposing factor to interdigital dermatitis in cattle and sheep (Venter & Van Amstel 1994). This option has not been investigated in elephant bulls. Literature regarding this subject is non-existent.

In the light of the following circumstances:

- the occurrence of the outbreak restricted to the Letaba Land System that is dominated by shrub Mopane;
- the occurrence of the outbreak during a drought which contributed, firstly, to the development of Mopane stubble and, secondly, to the congregation of large numbers of a variety of free-ranging species of wild animals around the water reservoirs, with resultant environmental bacterial contamination;
- the occurrence of the lesion restricted to adult elephant bulls; and
- the predilection of the lesion in the front feet.

It is concluded that the pathogenesis of the syndrome was related to secondary bacterial infection following traumatic injury induced by penetration of the soles of the front feet by Mopane stubble. The greater mass of an adult elephant bull, and the greater portion of the total body mass being borne mainly by the front feet, act as predisposing factors for the initiating insult. The resultant portal of entry subserved secondary bacterial infection.

ACKNOWLEDGEMENTS

Thanks are extended to the Division of Veterinary Services for permission to publish this article; game rangers Leighton Hare, Johan Oelofse, Louis Olivier and Wikus van der Walt, for reporting the cases and assisting in the collection of samples; Dr Freek Venter for providing the map of the Letaba Land System; Denis Draper for plotting cases; Ian Whyte for providing census maps of bachelor elephant bulls; the field staff of the Division of Veterinary Services for assistance rendered during the investigation; the Onderstepoort Institute for Exotic Diseases for ruling out the FMD virus differential diagnosis; Mrs Irene Grobler for assisting in the Stevenson Hamilton Memorial library; and the National Parks Board for creating the infrastructure to make research possible and making annual reports available for study.

REFERENCES

- ADAMS, O.R. 1979. *Lameness in horses*. Philadelphia: Lea & Febiger: 1–4.
- ANONYMOUS 1994. Anaerobic, gram-negative, irregular rods: Introduction, in *Infectious diseases of livestock with special reference to southern Africa*, 2, edited by J.A.W. Coetzer, G.R. Thomson & R.C. Tustin. Cape Town: Oxford University Press: 1195–1199.
- COATES PALGRAVE, K. 1984. *Trees of southern Africa*, edited by E.J. Moll. Cape Town: Struik Publishers.
- EVANS, G.H. 1910. *Elephants and their diseases*. Rangoon: Government Printing.
- FOWLER, M.E. 1980. Hoof, claw, and nail problems in nondomestic animals. *Journal of American Veterinary Medicine Association*, 177:885–893.
- FOWLER, M.E. 1993. Foot care in elephants, in *Zoo and wild animal medicine current therapy*, 3, edited by M.E. Fowler. Philadelphia: W.B. Saunders Company: 448–453.
- HANKS, J. 1979. *A struggle for survival—the elephant problem*. Cape Town: Struik Publishers.
- HOWELL, P.G., YOUNG, E. & HEDGER, R.S. 1973. Foot-and-mouth disease in the African elephant *Loxodonta africana*. *Onderstepoort Journal of Veterinary Science*, 40:41–52.
- KRIEG, N.R. & HOLT, J.G. 1984. *Bergey's manual of systematic bacteriology*. Baltimore, London: Williams and Wilkins.
- MIKOTA, S.K., LEE SARGENT, E. & RANGLACK, G.S. 1994. *Medical management of the elephant*. West Bloomfield, Michigan: Indira Publishing House: 138–150.
- NATIONAL PARKS BOARD. *Annual reports of the Kruger National Park 1903–1993*. Skukuza: National Parks Board of South Africa.
- RAATH, J.P. 1993. Chemical capture of the African elephant, in *The capture and care manual*, edited by A.A. McKenzie. Pretoria: Wildlife Decision Support Services and The South African Veterinary Foundation: 484–493.
- ROUND, M.C. 1968. *Check list of the helminth parasites of African mammals of the orders Carnivora, Tubulidentata, Proboscidae, Hyracoidea, Artiodactyla and Perisodactyla*. Technical Communication No. 38 of the Commonwealth Bureau of Helminthology, St Albans. Manchester: Richard Bates.
- SIKES, S.K. 1971. *The natural history of the African elephant*. Worcester and London: Trinity Press.
- SKINNER, J. & SMITHERS, R.H.N. 1995. *Mammals of the southern African subregion*. Pretoria: University of Pretoria.

- VAN DER SCHIJFF, H.P. 1957. *Ekologiese studie van die flora van die Nasionale Krugerwildtuin*. D.Sc. thesis, Potchefstroom. University of Potchefstroom: 153–157.
- VAN WYK, P. 1972. *Trees of the Kruger National Park*. Cape Town, Johannesburg and London: Purnell: 184–187.
- VENTER, F.J. 1990. A classification of land for management planning in the Kruger National Park. Ph.D. thesis. Pretoria: University of Pretoria.
- VENTER, B.J. & VAN AMSTEL, S.R. 1994. *Fusobacterium necrophorum*, *Dichelobacter (Bacteroides) nodosus* and *Bacteroides* spp. infections, in *Infectious diseases of livestock with special reference to southern Africa*. 2, edited by J.A.W. Coetzer, G.R. Thomson & R.C. Tustin. Cape Town: Oxford University Press: 1200–1227.
- WHYTE, I. & WOOD, C. 1993. *Aerial census of elephant and buffalo in the Kruger National Park*. Scientific Report: Pretoria: National Parks Board.
- ZAMBATIS, N. & BIGGS, H.C. 1995. Rainfall and temperatures during the 1991/92 drought in the Kruger National Park. *Koedoe*, 38:1–16.