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SHORT NOTE

Two new *Batracobdella* species from southern Africa and a redescription of *Batracobdella disjuncta* (Moore, 1939) *comb. nov.* (Hirudinea: Glossiphoniidae)

by
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Accepted: 20 October 1978

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ABSTRACT

Two new glossiphonids from southern Africa are described and figured. *Glossiphonia disjuncta* Moore, 1939, is redescribed and transferred to the genus *Batracobdella* Viguier.

1 INTRODUCTION

The two new *Batracobdella* species described here were discovered during an extensive survey of the freshwater leeches of the Republic of South Africa and South West Africa. Study of a large number of specimens of *Glossiphonia disjuncta* Moore revealed that this leech is closely related to the two new taxa. On the basis of, *inter alia*, having seven pairs of crop caeca and the proboscis pore in the centre of the sucker, all three species must be included in the genus *Batracobdella*. Moore's species is accordingly transferred to this genus.

The measurements given in the text are those of straight, moderately stretched, preserved specimens and are very similar to their dimensions when they were alive and at rest. For the delimitation of segments, the neuromeric standard of segment limits has been adopted: the annulus bearing the segmental sensillae externally and the nerve ganglion internally is considered to be the middle ring of the segment. In the lists of material, the number of specimens constituting a sample is indicated in brackets behind the collection registration number.

2 DESCRIPTIONS

Batracobdella cheili sp. nov.

Figs. 1—3, Map 1.

Holotype: BM (NH) 1978.20.1 in the British Museum (Natural History), London. Underneath stone in Osheshe water-hole, Cuvelai Basin, Ovamboland, South West Africa (17°56′S 16°07′E), collected by J. H. Oosthuizen, 9 July 1968. Total length (including exposed part of posterior sucker protruding beyond body) 6,8 mm, maximum width 2,0 mm, diameter of posterior sucker 0,8 mm. Collected with five other specimens (paratypes), BM (NH) 1978.20.2 to 6.

Diagnosis

Three pairs of eyes; cephalic sucker cupuliform with high, delicate walls; gonopores separated by two annuli; proboscis stout; salivary gland cells diffusely arranged; first six pairs of crop caeca each with two well developed lobes terminally; post-caeca each with about fifteen slender, lateral secondary caeca.

Description

Form: Ovate, moderately flattened, dorsum arched, venter flat. Head moderately widened beyond nuchal constriction, cephalic sucker cupuliform with high, delicate walls, rim of sucker studded with small papillae; proboscis pore large, on summit of large, dome-shaped papilla in centre of sucker. Posterior sucker small, circular, diameter less than half of maximum body width, with thick margin and cupped venter, broadly attached, directed ventrally.

Colour and pattern: General appearance either brown or green, dorsum with about 30 dark brown or dark green, narrow, broken stripes in widest region of body, number of stripes decreasing towards extremities. Striped pattern occurs from just behind ocular area to about XXV. Anterior tip, post-anal annulus and lateral edges of annuli unpigmented, thus there is a continuous, translucent edge along entire circumference of body. Ocular area, segment XXVII and dorsum of posterior sucker with irregularly distributed chromatophores. Venter uniform, more lightly coloured than dorsum.

Annulation: I and II either completely united or I/II variably developed. III biannulate, dividing furrow variably developed. IV biannulate with (a1a2) or (a1 + a2) = 2a3. V triannulate dorsally, ventrally tri- or biannulate, in the latter case a1/a2 variably developed or absent, anterior annulus forming posterior wall of sucker; a2/a3 on both sides conspicuously deeper than neighbouring furrows. VI–XXIV complete, triannulate. XXV biannulate with (a1a2) or (a1 + a2) = 2a3. XXVI and XXVII uniannulate. Anus behind XXVII, followed by one very small post-anal annulus. Annuli in complete segments about equal in length dorsally but ventrally a3>a2>a1; from about VIII caudally, a1 and a3 with shallow transverse secondary furrows.

Eyes: Three pairs, first pair in anterior half of IV, second and third pairs in anterior half of V. Pigment cups of first pair usually separated, sometimes in contact. Pigment cups of members of second and third pairs on each side usually in contact, sometimes completely coalesced, the two pigment masses so formed being well separated; distance between them variable, sometimes as great as six times their diameter. Pigment cups of first two pairs of eyes directed antero-laterally, those of third pair postero-laterally.

Nephridiopores: Fourteen pairs, in middle of a2 of VIII – X and XIV – XXIV.

Papillation: No conspicuous papillae other than the low dome-shaped sensory papillae. Sensillae very small, three series: paramedian, intermediate and supra-marginal.

Gonopores: Separated by two annuli, male at XI/XII, female at XIIa2/a3.

Digestive system: Proboscis cylindrical, stout, truncate terminally; in relaxed specimens about equal in length to total length of six segments — with retraction, may reach into XIII ventral to crop. Two bundles of protractor muscles extend forward from base of proboscis, diverge behind supra-pharyngeal ganglion and enter body wall in anterior half of VII. Retractor muscles of proboscis implanted in XII, forming together with salivary gland ductules on each side a common bundle which enters ventral lacuna in XII and is attached along side of oesophagus on its way to base of proboscis. Oesophagus distensible, shortened and deflected into a short loop ventral to crop by attached retractor muscles of proboscis. No oesophageal organ. Salivary gland cells diffusely arranged laterally to ventral lacuna, in X – XIV, more densely packed in XI and XII. Crop in XIII – XIX, seven pairs of caeca, first six pairs in XIII – XVIII bilobed, directed more or less laterally and confined to their respective segments; seventh pair in XIX elongated, deflected posteriorly and lateral to intestine, extends to about XXIV, each with about 15 slender, lateral secondary caeca. Intestinal caeca four pairs, unlobed, directed laterally, bent downwards against medial sides of post-caeca, expanded terminally, expansions particularly pronounced in first three pairs. Hind gut saccate, rectum narrow, tapering towards anus.

Reproductive systems: *Male:* Six pairs of testes, intersegmentally arranged at XIII/XIV – XVIII/XIX, much enlarged when in active state. Vas deferens enters ventral lacuna at XIIa3, expands gradually into sperm duct which forms a posteriorly directed, simple loop, both legs of loop expand to act as a seminal vesicle, loop may extend into XX at peak of male activity. Transition between recurrent limb and muscular ejaculatory duct in XIII is gradual, terminal end of duct with sharp vertical curve at XI/XII before turning sharply inwards, narrows abruptly towards junction with atrial cornu at XI/XII. Cornua muscular, strongly diverging, somewhat compressed dorso-ventrally, truncate in lateral view; atrium short, muscular, cylindrical.
Female: Ovisacs directed caudally, may extend into XXI when filled with eggs, oviducts joined dorsal to nerve and blood vessel, atrium very small, ligaments from front of system implanted in dorsal body wall in XII.

The holotype agrees with the above description in all essential details.

Remarks

Although the deep, cup-shaped cephalic sucker is a conspicuous feature in live specimens, it is often so distorted in dead animals that its typical shape is not apparent. The delicate walls of the sucker collapse very easily during fixation. The ocular pattern is fairly variable as regards both the size and arrangement of the eyes. Usually, however, a triangular pattern is clear.

Several attached spermatophores were encountered. Whereas the two halves of an empty spermatophore are cylindrical, each half of the undischarged spermatophore is fusiform in shape and terminates in a sharply-pointed projection. The halves of both undischarged and empty spermatophores are separated from each other along their entire lengths.

The largest and smallest (excluding attached young) specimens encountered measured 12,5 × 2,8 mm and 2,0 × 0,6 mm, respectively. The smallest specimen recorded with attached offspring measured 7,8 × 2,1 mm.

This leech is probably a parasite of, *inter alia*, freshwater snails. On two occasions a single, well-fed specimen was recovered from the mantle cavity of *Bulinus tropicus*. Once 21 specimens were collected from the surfaces of the plastrons of terrapins in the same body of water. It is unlikely, however, that this small leech would be able to penetrate the tough skin of these reptiles and they were probably only using them as places to hide.

Batracobdella cheili closely resembles *B. conjugata* and *B. disjuncta* with regard to colour, colour pattern and ocular pattern and it is often very difficult or even impossible to distinguish *B. cheili* from *B. disjuncta* when only external features are taken into account. However, *B. cheili* differs from the other two species in several ways. The most obvious differences are the separation in *B. cheili* of the gonopores by two annuli, compared with one in *B. conjugata*; and the lobed first six pairs of crop caeca of *B. cheili*, as opposed to unlobed caeca in *B. disjuncta*.

Other material examined

British Museum (Nat. Hist.): BM (NH) 1978.20.7 to 27 (21); 1978.20.28 to 29 (2).
Transvaal Museum, Pretoria: TM 11284 (1); 11285 (1); 11286 (10); 11287 (30).
Department of Zoology, University of Pretoria: HIR 189 (11); 341 (3).
State Museum, Windhoek: SMN 65742 (2).

Batracobdella conjugata sp. nov.

Figs. 4–6, Map 1.

Holotype: BM (NH) 1978.20.30 in the British Museum (Nat. Hist.), London. Underneath tree stump in dam at rest-camp, Daan Viljoen Game Park, Khomas Hochland, South West Africa (22°31'S 16°56'E), collected by J. H. Oosthuizen, 6 December 1970. Total length (including exposed part of posterior sucker protruding beyond body) 9,1 mm, maximum width 2,8 mm, diameter of posterior sucker 1,1 mm. Collected with 30 other specimens (paratypes), BM (NH) 1978.20.31 to 60.

Diagnosis

Three pairs of eyes; gonopores separated by one annulus or little less than length of annulus; walls of genital atria fused; proboscis stout; salivary gland cells diffusely arranged; first six pairs of crop caeca each with two small lobes terminally.

Description

Form: Ovate-lanceolate, moderately flattened, dorsum arched, venter flat. Head distinctly marked off by nuchal constriction in V, only slightly widened. Cephalic sucker scoop-shaped with deep cavity and well developed rim having numerous, minute papillae; proboscis pore large, in centre of cavity. Posterior sucker small, circular, diameter less than half of maximum body width, with deeply cupped venter and thin margin, broadly attached, directed ventrally.

Colour and pattern: General colouration either green or brown or shades thereof. Superficially situated chromatophores distributed all over body dorsally, except on narrow, marginal strips of body, greater part of head region and margins of posterior sucker. These chromatophores are either evenly distributed or are more concentrated in middle regions of annuli, the result then being a transverse, banded pattern. More deeply situated chromatophores compactly arranged into narrow, longitudinal stripes, decreasing in number towards extremities, 34 to 36 at widest region of body. Leech striped from just behind ocular area to just in front of anus. Venter much lighter in colour, without any pattern.

Annulation: I united with prostomium to form rounded, apical lip. II uniannulate or incomplete biannulate, distinctly separated from I. III complete or incomplete biannulate, annuli equal in length. IV biannulate with $(a1a2) > a3$. V triannulate dorsally, biannulate ventrally with $a1$ and $a2$ united to form buccal ring. Nuchal constriction in V. VI – XXIV complete, triannulate. XXV biannulate with $(a1a2)$ or $(a1 + a2) = 2a3$. XXVI and XXVII uniannulate. Anus at posterior margin of XXVII, one small post-anal annulus. In middle body region, $a1 < a2 < a3$ on ventral side with shallow secondary furrows on $a1$ and $a3$, more prominent on $a3$.

Eyes: Three pairs, first pair at cephalic margin of IV or just anterior to III/IV, second and third pairs in cephalic half of V. Pigment cups of first, and smallest, pair usually well separated and directed antero-laterally; pigment cups of second and third pairs much larger, members of each pair far apart but the two eyes on each side united (giving the impression that there are only four eyes). The four pigment masses are so arranged that they correspond in position to the four corners of a trapezium. Pigment cups of second pair directed antero-laterally, those of third pair postero-laterally.

Nephridiopores: Fourteen pairs, on $a2$ of VIII – X and XIV – XXIV.

Papillation: Segmental sensory papillae very small, rounded domes, almost flush with body surface, three paired series on both sides: dorsally in inner-paramedian, intermediate and supra-marginal positions; ventrally in outer-paramedian, intermediate and sub-marginal positions. Sensory papillae situated slightly within cephalic half of annuli. In addition, about 16 larger papillae present on each annulus (at their bases about equal in diameter to one quarter the length of annulus), plus numerous, much smaller ones of varying sizes, giving dorsal integument a roughened appearance. Venter also with small papillae but less numerous than dorsally.

Gonopores: Separated by one annulus or a little less than length of annulus, either both restricted to the furrows with male pore at XIIa1/a2 and female pore at XIIa2/a3; or one or both pores slightly within XIIa2.

Digestive system: Proboscis stout, sub-fusiform in lateral view, sides more or less parallel in dorsal or ventral view, truncate terminally; in relaxed specimens about the length of five segments. Two bundles of protractor muscles extend forward from base of proboscis, diverge behind supra-pharyngeal ganglion and enter body wall in VII. Retractor muscles of proboscis implanted in dorsal body wall in XII, link up with salivary gland ductules to form a stout bundle on each side which enters ventral lacuna in cephalic region of XII; bundles not attached to oesophagus, enter proboscis at its base. Oesophagus distensible, with retraction of proboscis slides together (like the bellows of a camera) attaining an annulated appearance. No oesophageal organ. Salivary gland cells diffusely arranged in IX – XIV, lateral to ventral lacuna, more densely packed in XI and XII. Crop in XII – XIX with seven pairs of caeca, one pair in each of XIII – XIX, first six pairs laterally directed, bilobed and confined to their respective segments. Seventh pair elongated, deflected posteriorly and lateral to intestine, extends to XXII, each with five or six short, lateral secondary caeca. Intestinal caeca four pairs, unlobed, directed laterally, bent downwards against medial sides of post-caeca, each terminating in a vesicular expansion, the expansion less pronounced in fourth pair. Hind gut saccate, rectal region narrow, cylindrical.

Reproductive systems: *Male:* Six pairs of testes, intersegmentally arranged at XIII/XIV – XVIII/XIX. Vas deferens enters ventral lacuna in XII, expands into sperm duct with posteriorly directed loop, at peak activity of male system loop may extend into XX. Descending limb of loop relatively narrow and of uniform width for most of its length, expands only gradually from a point near bend and towards it, recurrent limb considerably expanded, acts as seminal vesicle, joins muscular ejaculatory duct in XIII. Ejaculatory duct almost straight, proceeds obliquely outward and forward into XI, bends sharply inwards in XI to join atrial cornu at a marked constriction. Atrial cornu oblong-ovate, narrows sharply towards its junction with ejaculatory duct. Cornua strongly divergent, not vertical in orientation but directed obliquely dorsally and forward from fused atria; atrium short, truncate in anterior view.

Female: Ovisacs directed posteriorly, may extend into XIX or further when packed with eggs, oviducts directed obliquely dorsally and backward from fused atria, tubular connection between oviducts dorsal to nerve and blood vessel, atrium short. Walls of male and female atria fused over their whole lengths but there is no connection between the canals.

The holotype agrees with the above description in all essential details.

Remarks

Like its congeners discussed in this paper, this leech is quite variable as regards the arrangement and pigmentation of the eyes. Although the members of the second and third pairs of eyes are always well separated, those of the first pair are often united, resulting in a triangular ocular pattern. The second and third eyes of one or both sides may also be variably separated, in which case the symmetrical arrangement does not occur. Pigmentation was frequently absent in one or more of the eyes. As in the case of the other two species, the ocular pattern alone is, therefore, not a reliable criterion for identification.

Only two spermatophores were encountered. They consist of the usual two halves, each rather club-shaped and separated at their terminal ends. Each half terminates in a relatively stout, finger-like projection.

The largest and smallest (excluding attached young) specimens encountered measured 9,1 × 2,8 mm and 3,5 × 0,8 mm, respectively. The smallest specimen with attached offspring was 5,2 × 2,2 mm.

No information was obtained with regard to hosts. *Batracobdella conjugata* resembles *B. cheili* and *B. disjuncta*, especially as far as colouration and ocular pattern are concerned; but it is distinguishable from them externally in having the gonopores separated by not more than one annulus. Internally, the most striking differences are: the fusion of the genital atria, the oesophagus not folded into a loop with retraction of the proboscis and the retractor muscles of the proboscis not attached to the sides of the oesophagus.

Other material examined

British Museum (Nat. Hist.): BM (NH) 1978.20.61 (1); 1978.20.62 to 65 (4).

Transvaal Museum, Pretoria: TM 11288 (5); 11289 (12); 11290 (2); 11291 (4).

Department of Zoology, University of Pretoria: HIR 360 (25).

Collection of the National Institute for Water Research, Council for Scientific and Industrial Research, Pretoria: GEN. 579A (2); GEN. 658A (3); TRR. 26C (1); TRR. 39C (2).

State Museum, Windhoek: SMN 65743 (26).

Kruger National Park Museum, Skukuza: ANL—NKW 5 (23).

Batracobdella disjuncta (Moore) *comb. nov.*

Figs. 7–9, Map 1.

Glossiphonia disjuncta Moore, 1939, *Proc. Acad. nat. Sci. Philad.*, 90: 299 [type: Lake Bunyoni, Uganda; British Mus. (Nat. Hist.)]

In his preliminary examination of leeches from East Africa, Moore incorrectly identified this leech and listed it (1933) as *Glossiphonia weberi* Blanchard. Moore's later (1939) description of the leech as a new species was rather brief and there was very little information regarding characteristics that would enable one to recognise it. Apart from a photomicrograph illustrating nothing more than the body shape of the type specimen, no figures were supplied. In view of this and the fact that the original description contained erroneous information concerning a very important aspect which affects the generic status of the species, the description of this taxon must be reviewed.

Material: BM (NH) 1978.20.66 to 92 (27) in the British Museum (Nat. Hist.), London. Underneath stones in slow-flowing stream at The Fountains, Pretoria, Republic of South Africa (25°45′S 28°12′E), collected by J. H. Oosthuizen, 20 March 1963.

Diagnosis

Three pairs of eyes; dorsum of each annulus in middle body region with a transverse row of about 18 prominent papillae; gonopores separated by two annuli or a little less than length of two annuli; proboscis relatively long, slender; salivary gland cells diffusely arranged; first six pairs of crop caeca unlobed; postcaeca each with four, small lateral secondary caeca.

Description

Form: Oblong-ovate, slightly arched dorsum, flat venter. Head region perceptibly widened beyond nuchal constriction. Anterior sucker scoop-shaped; proboscis pore relatively large, at centre of sucker. Posterior sucker small, circular, diameter less than half maximum body width.

Colour and pattern: General appearance either flesh-coloured or green, all chromatophores irregularly distributed or superficially situated chromatophores arranged so as to form a finely-striped pattern dorsally, composed of about 36 longitudinal stripes at widest point of body.

Annulation: I and II united with prostomium to form rounded, apical lip, or lip with faint I/II. III uniannulate with faint furrows at margins. IV uniannulate, partially divided or biannulate. V triannulate dorsally with a1/a2 distinctly <a2/a3 or incomplete triannulate with (a1 + a2) = 2a3; biannulate ventrally with a1 and a2 united to form buccal ring. VI – XXIV complete, triannulate with a1/a2 = a2/a3 and annuli within each segment about equal in length. XXV biannulate with (a1a2) = 2a3 and a1/a2 at margins only; or (a1a2) = a3, but then no sign of a1/a2. XXVI uniannulate with incomplete dividing furrow or biannulate. XXVII uniannulate, with or without faint furrows at margins. Anus directly behind XXVII, sometimes cutting deeply into posterior margin of XXVII. One small post-anal annulus.

Eyes: Three pairs, eyes of first pair close together or coalesced, in median field in IV; those of second and third pairs widely separated from each other but the two eyes of each side close together or coalesced, in V. The three pigment masses so formed thus correspond in position to the three corners of a triangle. Pigment cups of first and second pairs directed forward and outward, those of third pair backward and outward.

Nephridiopores: Fourteen pairs, on a2 of VIII – X and XIV – XXIV.

Papillation: A transverse row of fairly large, dome-shaped papillae along middle of each annulus dorsally, best developed in middle region of body, diameter at base of largest ones about equal to one third of length of annulus; 15 – 18 per annulus in this region plus several smaller papillae (some much smaller; some minute) irregularly distributed over surface of annulus and mostly difficult to detect. Sensory papillae three series, paramedian, intermediate and supra-marginal, not readily distinguishable from other papillae, characterized by small, opaque white sensillae on summits. Venter smooth, sensory papillae very small, almost flush with surface: present in paramedian, intermediate and sub-marginal positions.

Gonopores: Either separated by two full annuli with male at XI/XII and female at XIIa2/a3; or male pore in shifted position in anterior third of XIIa1.

Digestive system: Proboscis relatively long, slender, of uniform width over whole length, truncate terminally – with retraction proximal end may reach ventral to crop into XIII and in relaxed specimens extends from VIII – XIII. Two bundles of protractor muscles from base of proboscis, they proceed forward along sides of proboscis, diverge posterior to supra-pharyngeal ganglion and enter body wall in VI. Retractor muscles of proboscis implanted in dorsal body wall at XII – XIII, join up with salivary gland ducts of each side to form two stout bundles which enter ventral lacuna in XIII; each bundle attached along side of oesophagus on its way to base of proboscis. Oesophagus flattened, short, S-shaped with retraction of proboscis, extensible. No oesophageal organ. Salivary gland cells diffusely arranged laterally in XII – XIV, more densely packed in XII – XIII. Crop in XIII – XIX, seven pairs of caeca, first six pairs in XIII – XVIII unlobed, laterally directed, each pair restricted to its segment, seventh pair elongated, deflected posteriorly along sides of intestine into XXIII, only a small lateral lobe in each of XIX – XXII. Intestine with four pairs of short, simple, tubular caeca. Hind gut sacciform, rectum narrow, tubular.

Reproductive systems: *Male:* Six pairs of testes, intersegmentally arranged at XIII/XIV to XVIII/XIX. Vas deferens on each side emerges from dorsal body wall in XIIIa1, expands into stout sperm duct forming a posteriorly directed loop which may reach into XX when system is functioning, both limbs markedly widened, act as seminal vesicle; wall of recurrent limb becomes muscular at about XIII/XIV, proceeds forward as more or less straight, thick-walled ejaculatory duct, tapers terminally before joining atrial cornu at XI/XII, no pre-atrial loop formed. Cornua muscular, short, oviform in front view, truncate in lateral view, cornua widely divergent; atrium muscular, cylindrical, dome-shaped terminally.
Female: Ovisacs posteriorly directed, in sexually mature animals may reach into XVIII when empty but into XXI when packed with ripe eggs. Oviducts with tubular connection dorsal to nerve cord and blood vessel, atrium very short, thin-walled.

Remarks

Although the annulation exhibits no special features helpful in the identification of this taxon, it is important to note that the intermetameric and intrametameric furrows at the anterior end are poorly developed in comparison with those of related forms. This often makes it impossible to see where the limits of the first three or four anterior segments are. The eyes vary greatly in size and deviations from the typical arrangement are common. Specimens without pigmentation of all the eyes were also encountered. Disarrangement of the eyes usually also affects the directional orientation of the pigment cups. The papillation, which proved to be the only diagnostic specific character mentioned in the original description, is indeed the most reliable distinguishing external feature. Its value as such lies in the pattern of distribution of the large papillae (namely in a single, transverse row) rather than in the details of their relative heights, so meticulously described by Moore (1939). He mentions that there are "... about 22 in a transverse row ..." on each annulus of the middle body region. However, the exact number is of secondary importance as it will vary according to the observer's interpretation of what papillae should be considered to be large ones.

Regarding the crop, it is important to note that in leeches that have not fed, the lateral lobes of the post-caeca may be completely collapsed; that the central part of the crop acts as the main storage place which, following dilation by food, results in shortening of the relative lengths of the first six pairs of caeca; and that in the gorged condition, the first pair of caeca may be barely visible. I initially believed that the presence of seven pairs of crop caeca in the material I studied indicated that it was representative of a new *Batracobdella* species, being quite unlike known species of the genus. Subsequently, however, I found that the leeches agreed with Moore's (1939) description of *Glossiphonia disjuncta,* except that they differed in having seven instead of six pairs of crop caeca. With the discovery of *Batracobdella cheili* and *B. conjugata*, which also agree to a large extent with Moore's description of *G. disjuncta*, the similarities between his description and the particular leeches under discussion here, was again emphasised. This raised the question of possible conspecifity of my material with Moore's species. The type [BM (NH) 1933.1.21.17] and one other specimen marked "paratype" [BM (NH) 1933.1.19.16/18] of *G. disjuncta* were, therefore, examined. After clearing in lactophenol, seven pairs of partly filled crop caeca, shaped as described above, were observed in the paratype. Although only six pairs of similarly shaped caeca were seen on the empty crop of the type, which was obviously what led to the generic allocation of this species by Moore, there is no doubt about the conspecifity of the two specimens. Difficulty in locating the first pair of caeca of an empty crop without dissection was also experienced frequently with my material. The presence of seven pairs of crop caeca indicates that this species belongs to the genus *Batracobdella*.

Altogether, 19 spermatophores were found. The spermatophores very closely resemble that of *B. cheili* and as in that species, the two halves are separated from each other over their whole lengths. In the undischarged condition, each half is fusiform with a pointed terminal projection and slender pedicel. The spindle shape is lost with ejection of the contents and each half becomes a narrow tube of uniform width.

The largest and smallest (excluding attached young) specimens encountered measured 11,6 × 2,2 mm and 2,3 × 0,5 mm, respectively. The dimensions of the smallest specimen with attached offspring were 3,6 × 1,5 mm.

This leech is apparently fairly common in permanent bodies of water. It is probably primarily a parasite of freshwater snails, although it was recorded only once on a snail (from the mantle cavity of *Bulinus tropicus*). On one occasion, a specimen was observed feeding on an unidentified insect larva. This species was also collected once each on the following: terrapin *Pelomedusa subrufa*, clawed toad *Xenopus laevis* tadpoles and a freshwater crab *Potamon* species. There is, however, no proof that these animals are actually hosts.

Batracobdella disjuncta was recorded previously from Uganda (Moore, 1933; identified as *Glossiphonia weberi*), Ethiopia (Moore, 1939) and the Transvaal, Republic of South Africa (Sciacchitano, 1963; incorrectly identified by him as *Batracobdella nilotica*). The authenticity of Sciacchitano's identifications of *B. disjuncta* from Zaïre (1952), the Republic of

South Africa (Cape Province) and South West Africa (1959), Togo (1965) and Ethiopia (1967) is questionable, because his inability to recognise *B. disjuncta* was clearly indicated by his identification of 55 specimens (19 samples) of this species as *B. nilotica* (see Sciacchitano, 1963).

Other material examined

British Museum (Nat. Hist.): BM (NH) 1978.20.93 to 103 (11); 1978.20.104 to 111 (8); 1978.20.112 to 128 (17); 1978.20.129 to 136 (8); 1978.20.137 to 149 (13).

Transvaal Museum, Pretoria: TM 11292 (9); 11293 (14); 11294 (9); 11295 (44); 11296 (39); 11297 (24); 11298 (6); 11299 (20); 11300 (1); 11301 (6); 11302 (1); 11303 (12); 11304 (2); 11305 (1); 11306 (10); 11307 (4); 11308 (6); 11309 (7); 11310 (40); 11311 (4).

Department of Zoology, University of Pretoria: HIR 135 (1); 201 (1); 206 (2); 228 (1); 246 (1); 252 (2); 259 (9); 271 (1); 288 (2); 290 (23); 301 (1); 452 (2); 469 (5); 482 (1).

Collection of the National Institute for Water Research, CSIR, Pretoria: BEN. 2E (25); CRO. 9G (9); CRO. 6T (39); CRO. 13E (5); GEN. 490A (12). The following in the same collection (which were identified by Sciacchitano (1963) as *Batracobdella nilotica*): VAL. series, numbers 616A (1); 988C (1); 1030C (3); 1052B (2); 1105A (2); 1004D (1); 1048C (14); 1051C (10); 1140B (1); 1150B (1); 909A (2); 1003A (2); 998E (3); 895F (4); 1104A (3); 346 B-C (2); 378A (1); 23B (1); 169A (1).

State Museum, Windhoek: SMN65744 (2); 65745 (9); 65746 (18).

3 DISCUSSION

The colours and colour patterns described above are those observed in live and freshly killed leeches. The colouring may become largely or even totally destroyed by preservatives, leaving only the ocular pigment.

The eyes of *Batracobdella disjuncta* are usually relatively larger than those of *B. cheili* and *B. conjugata* and normally the members of the first pair are in contact with each other. Thus, *B. disjuncta* frequently shows a more perfect triangular ocular pattern than the other two species, in which the members of the first pair are usually separated, resulting in eyes roughly arranged in the shape of a trapezium. The occurrence of variations in arrangement and sizes of eyes is common in all three species, which overlap in these respects to such a great extent that the ocular pattern alone cannot reliably be used as a distinguishing feature. A similar situation prevails with regard to general colouration and striping as criteria for distinguishing between these species, particularly in preserved material where the body pigmentation has become greatly changed. Although the exceptionally deep, cup-shaped oral sucker is a peculiarity of *B. cheili*, it is often drastically altered in appearance during fixation because of contraction of its relatively thin walls. Consequently it is not always distinct enough to enable one to recognise the species by means of this character alone.

If the positions of the gonopores cannot be determined, for separation of *B. conjugata*, the only reliable way to distinguish between the three species is by dissection, when material can be identified according to the following key:

1. First six pairs of crop caeca unlobed	*B. disjuncta*
Caeca lobed	2
2. Genital atria joined	*B. conjugata*
Atria not joined	*B. cheili*

Moore's (1939) supposition of conspecifity of his material with that identified by Harding (1932) from Ethiopia as *Glossiphonia heteroclita* is not acceptable in view of the fact that at least four African glossiphonids, one *Glossiphonia* species (Oosthuizen, 1978) and three *Batracobdella* species, are now known to have a "*heteroclita - weberi*" ocular pattern.

Although the material reported on herein was carefully compared with Augener's (1936) descriptions of *Clepsine namaquaensis* and *Clepsinides windhukensis*, I could not find any grounds for including the two new *Batracobdella* species described above in either of his two species. Moore (1939) mentioned the possibility of his *Glossiphonia disjuncta* being conspecific with *C. namaquaensis* but the available information does not justify such a supposition. The names *namaquaensis* and *windhukensis* are to be regarded as *nomina dubia* until the material on which Augener based his descriptions can be re-examined to obtain certain essential information omitted by him. Augener (1936) did not mention the repository for his material and so far I have been unable to trace its whereabouts. It seems likely that at least one of his species will prove to be conspecific with one of the three species discussed above, but since the situation is such that any one or two of the present three species may be involved, it is best, for the sake of stability, not to attempt to draw conclusions based on speculation.

4 ACKNOWLEDGEMENTS

I wish to extend my sincere thanks to the following persons and authorities: Prof. F. C. Eloff, Head of the Department of Zoology, University of Pretoria, for research facilities and for reviewing my doctoral dissertation, from part of which this paper was drafted. Mr. R. K. Brooke of the Percy FitzPatrick Institute of African Ornithology, University of Cape Town, for his assistance in choosing names for the two new species. Mr J. J. van Rensburg for inking over the

drawings. Dr. E. Joubert, Nature Conservation and Tourism Division, South West Africa Administration, who acted as my host and guide during collecting trips to South West Africa. Dr. U. de V. Pienaar and his colleagues at Skukuza, who did their utmost to take me to as many habitats as possible during my visits to the Kruger National Park. Dr. M. B. Markus, Department of Zoology, University of the Witwatersrand, who during his stay in London, arranged for the loan of the type-material of *Glossiphonia disjuncta* and for critically reviewing the manuscript. The Chief Director of National Parks and the National Parks Board for the opportunity of carrying out an extensive survey of leeches in the Kruger National Park. The Director of Nature Conservation and Tourism, South West Africa Administration, for permission to collect material in the different game parks and for making transport available. The Keeper of Zoology, British Museum (Nat. Hist.) and Mr R. W. Sims, for the loan of the type-material of *G. disjuncta*.

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6 ABBREVIATIONS

a	atrium
an	anus
br	pharyngeal ganglionic mass
c1, c2, etc.	crop caeca
cr	crop
e	eyes
ej	ejaculatory duct
f	canal for passage of nerve and vessel
fa	female atrium
g IX, X, etc.	ganglia of respective segments
go	gonopore
h	atrial cornu
hg	hind gut
i	intestine
ic	intestinal caeca
lg	ligament
ma	male atrium
n	ventral nerve
o	oesophagus
od	oviduct
os	ovisac
p	proboscis
po	proboscis pore
ps	posterior sucker
re	rectum
rm	retractor muscles
sg	salivary glands
sp	sensory papillae
t1, t2, etc.	testes
tu	tubular connection between oviducts
vs	seminal vesicle
♂ and ♀	indicate furrows in which the respective gonopores are situated.

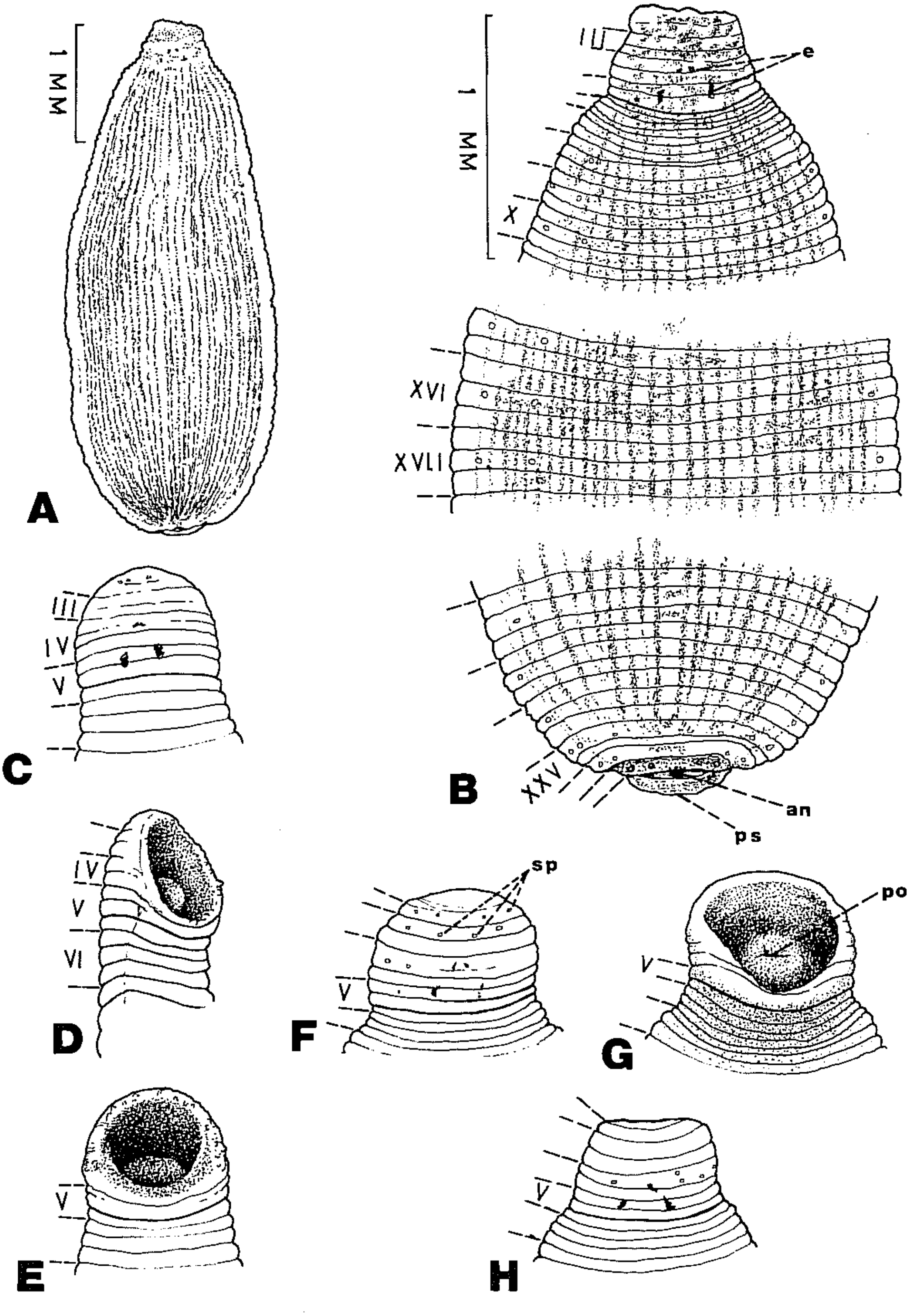


FIGURE 1: *Batracobdella cheili sp. nov.* A, General appearance of freshly preserved material, dorsal view. B, Details of dorsal striped pattern and annulation in anterior, middle and posterior regions. C, Dorsal, D, oblique-ventral and E, ventral views of ideally-preserved head region illustrating typical ocular pattern and nature of cephalic sucker. F and H, examples of variations in size and arrangement of eyes. G, Example of cephalic sucker only mildly affected by fixation, showing inward folding of its posterior wall. B — H drawn to the same scale.

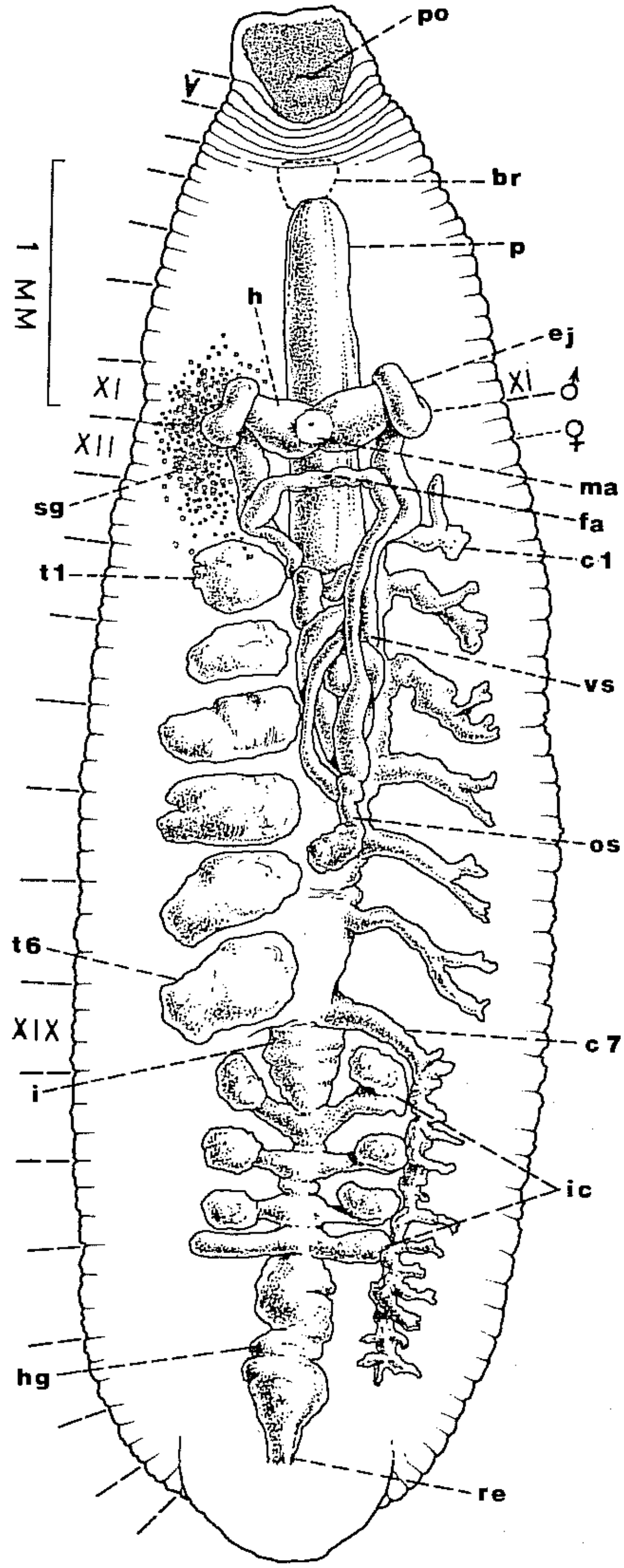


FIGURE 2: *Batracobdella cheili sp. nov.* General dissection showing major internal organs *in situ*, ventral view. Crop caeca of right side and testes of left side omitted.

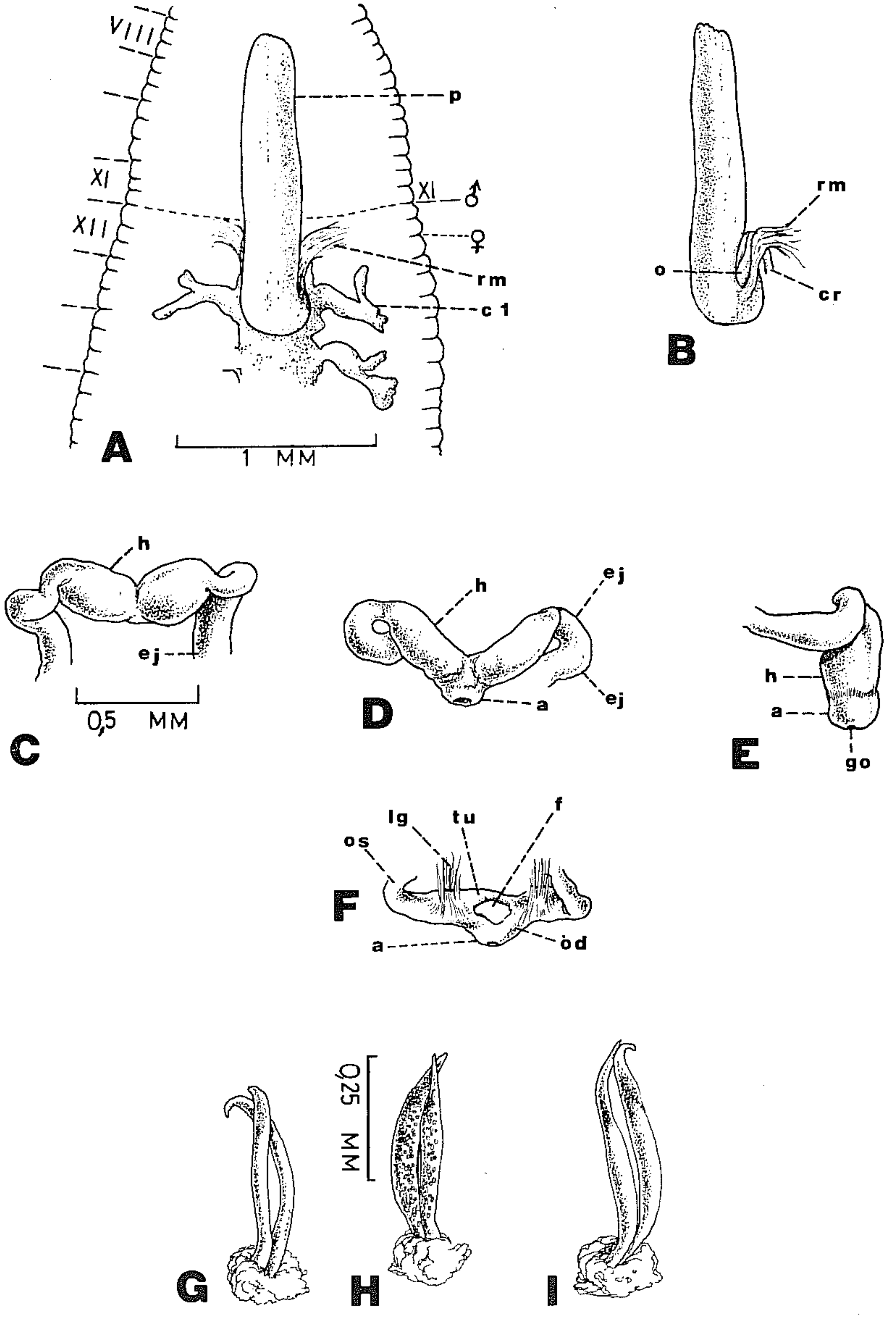


FIGURE 3: *Batracobdella cheili sp. nov.* A, Proboscis *in situ*, protractor muscles omitted, ventral view. B, Lateral view of proboscis. C, Dorsal, D, anterior and E, lateral views of terminal end of male system. F, Posterior view of terminal end of female system. G, Empty and H, I, undischarged spermatophores. A and B, C – F and G – I, respectively, drawn to the same scale.

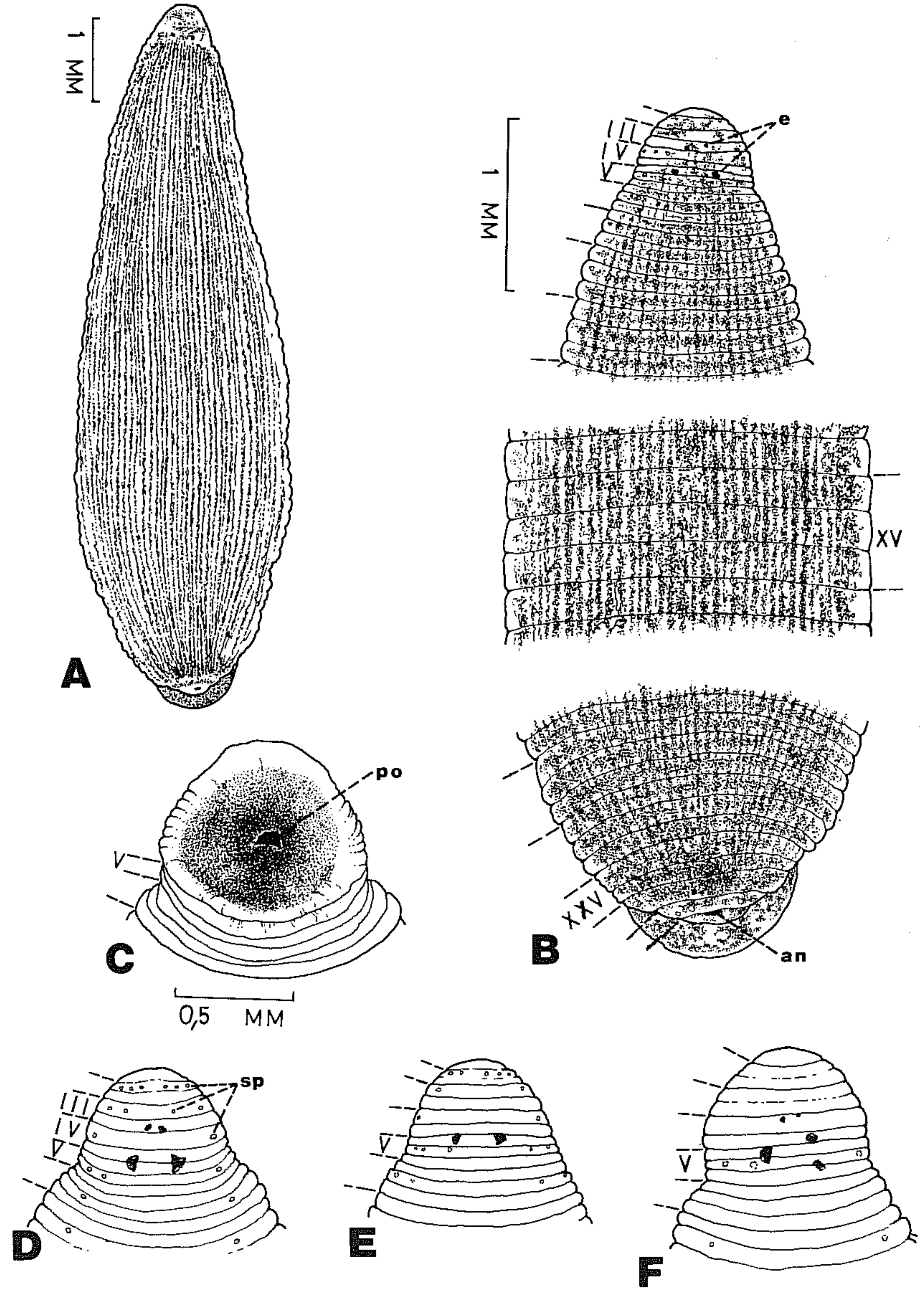


FIGURE 4: *Batracobdella conjugata sp. nov.* A, General appearance of freshly preserved material, dorsal view. B, Details of dorsal striped pattern and annulation in anterior, middle and posterior regions. C, Cephalic sucker. D, Typical and E, F, examples of variations in the ocular pattern. C — F drawn to the same scale.

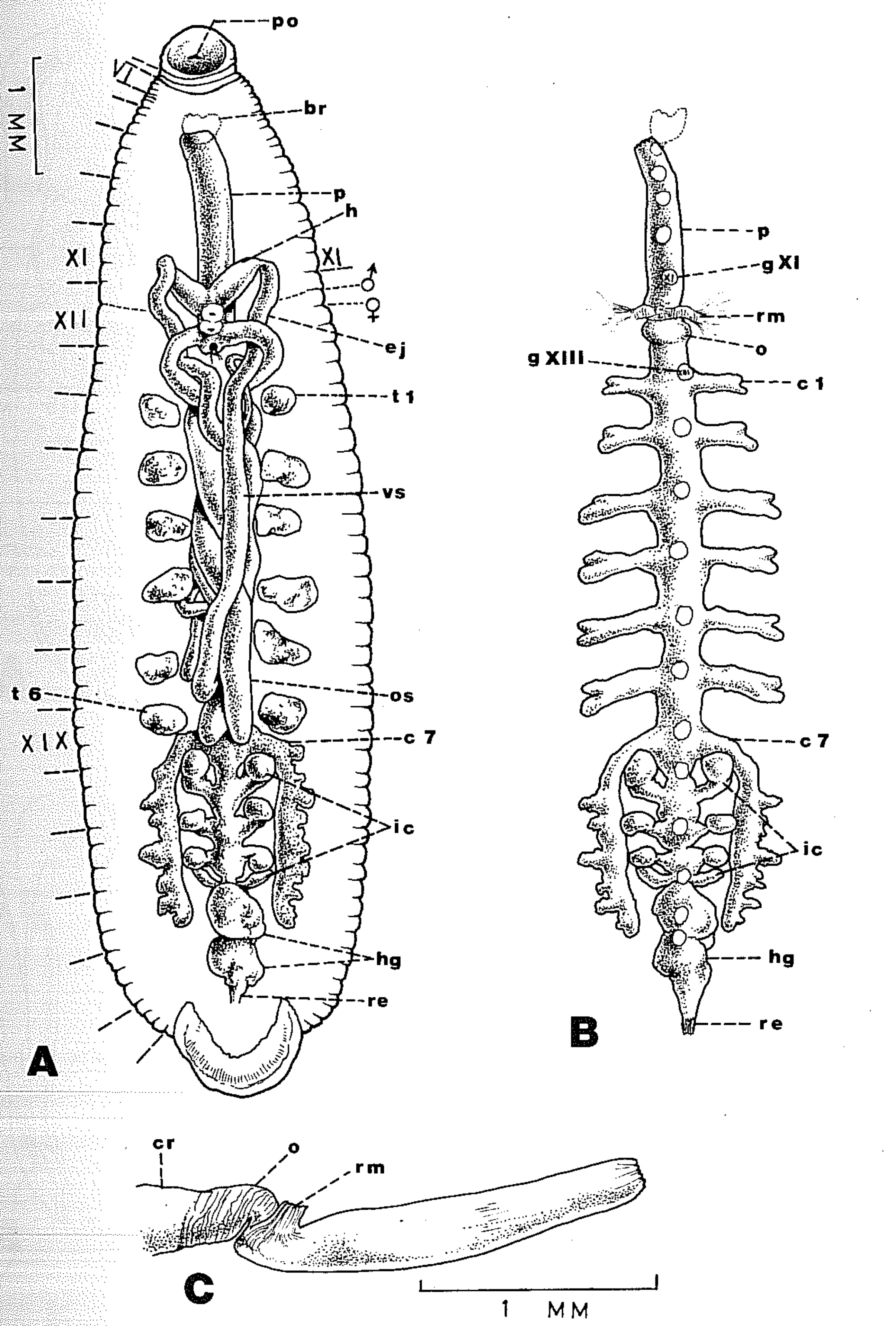


FIGURE 5: *Batracobdella conjugata sp. nov.* A, General dissection showing major internal organs *in situ*, crop largely omitted. B, complete alimentary canal, ventral view. C, Lateral view of proboscis, protractor muscles omitted. A and B drawn to the same scale.

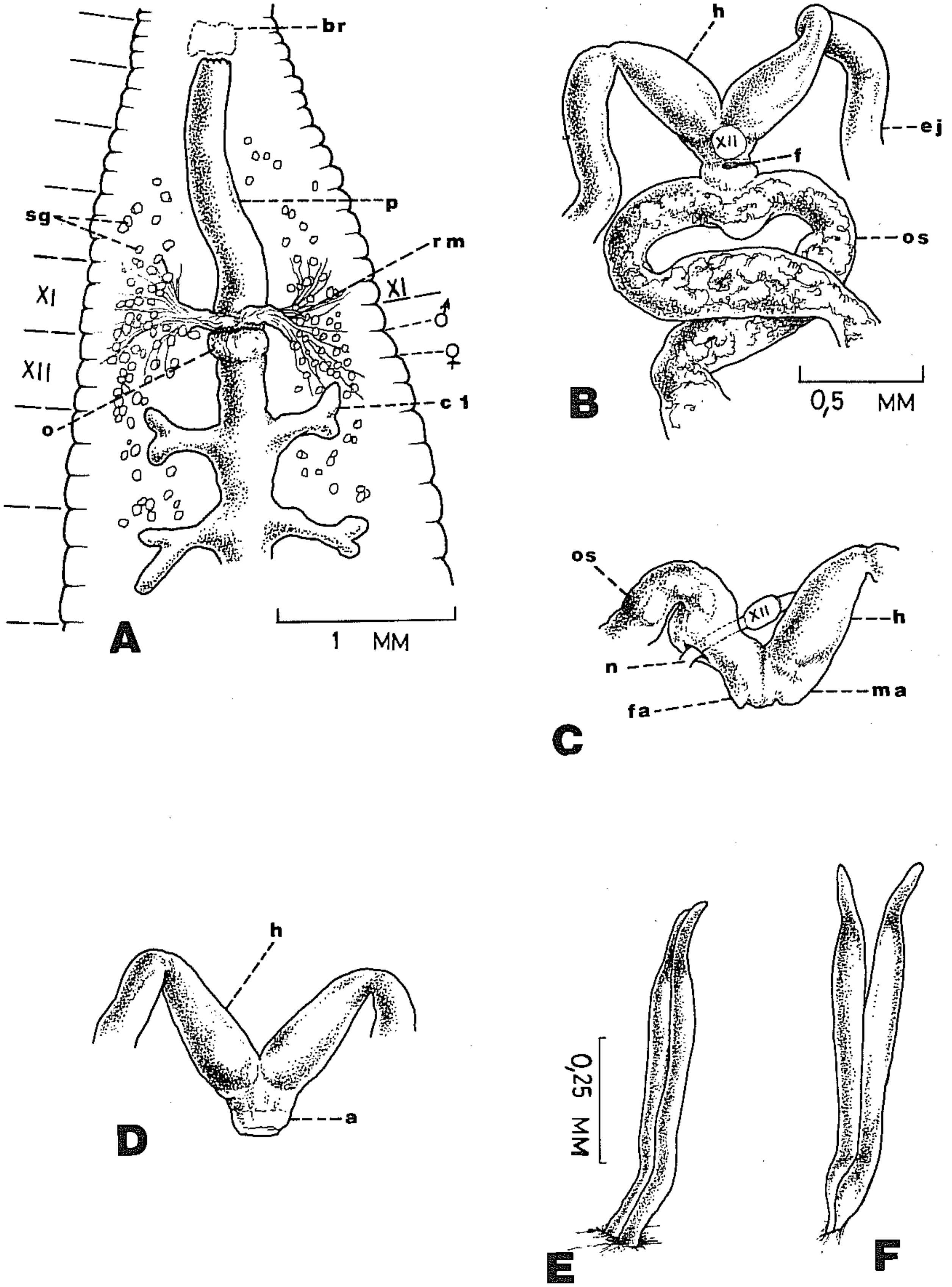


FIGURE 6: *Batracobdella conjugata sp. nov.* A, Proboscis *in situ*, protractor muscles omitted, dorsal view. B, Dorsal and C, lateral views of terminal ends of reproductive systems. D, Anterior view of terminal end of male tubes. E and F, undischarged spermatophores. B – D and E and F, respectively, drawn to the same scale.

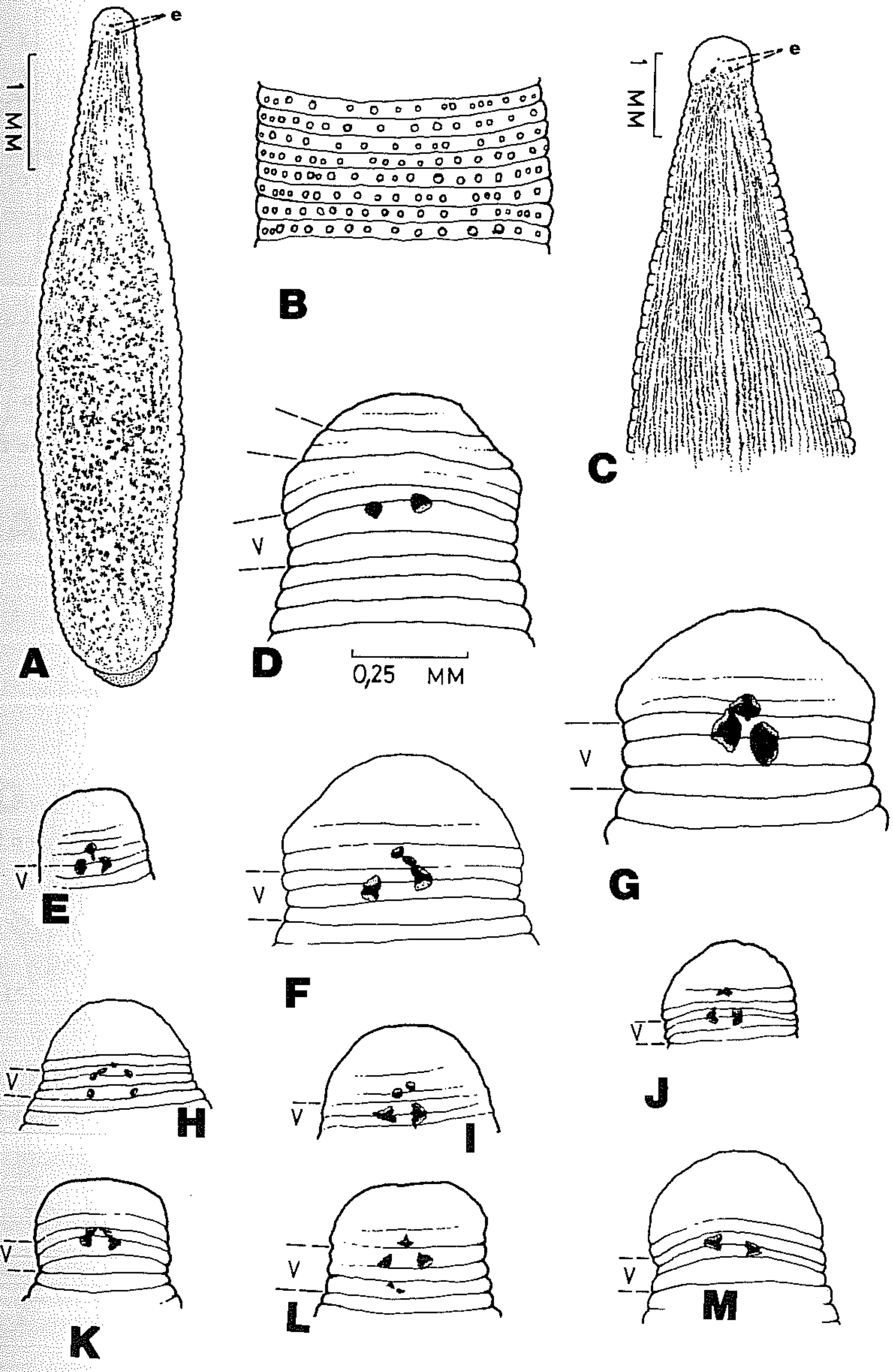


FIGURE 7: *Batracobdella disjuncta.* A and C, colour patterns, dorsal views. B, Dorsal papillation in middle body region. D – M, Annulation in head region and examples of variations in ocular pattern. A and B and D – M, respectively, drawn to the same scale.

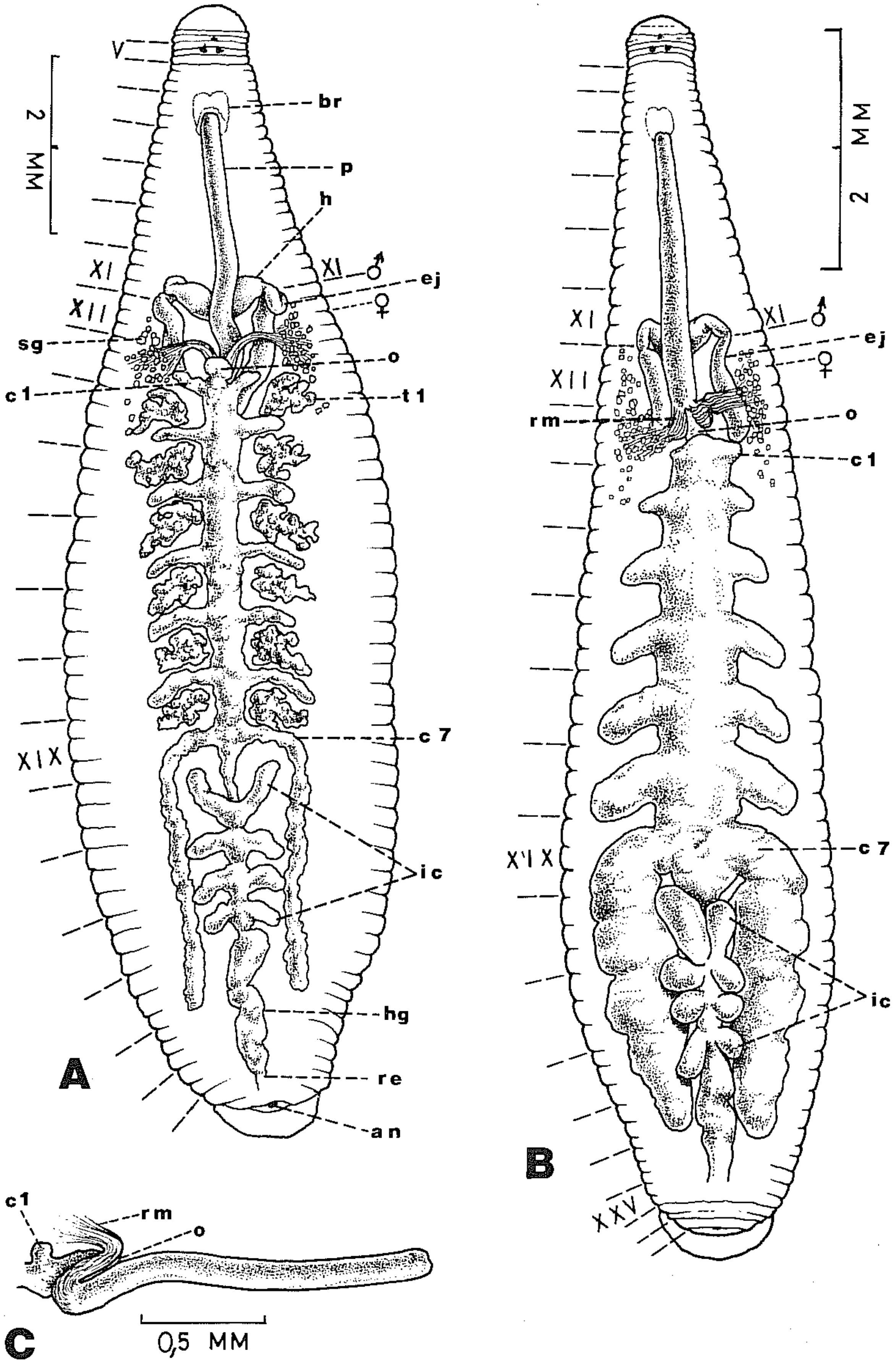


FIGURE 8: *Batracobdella disjuncta*. Alimentary canal in A, starved and B, gorged conditions, dorsal views. C, Proboscis, lateral view, protractor muscles omitted.

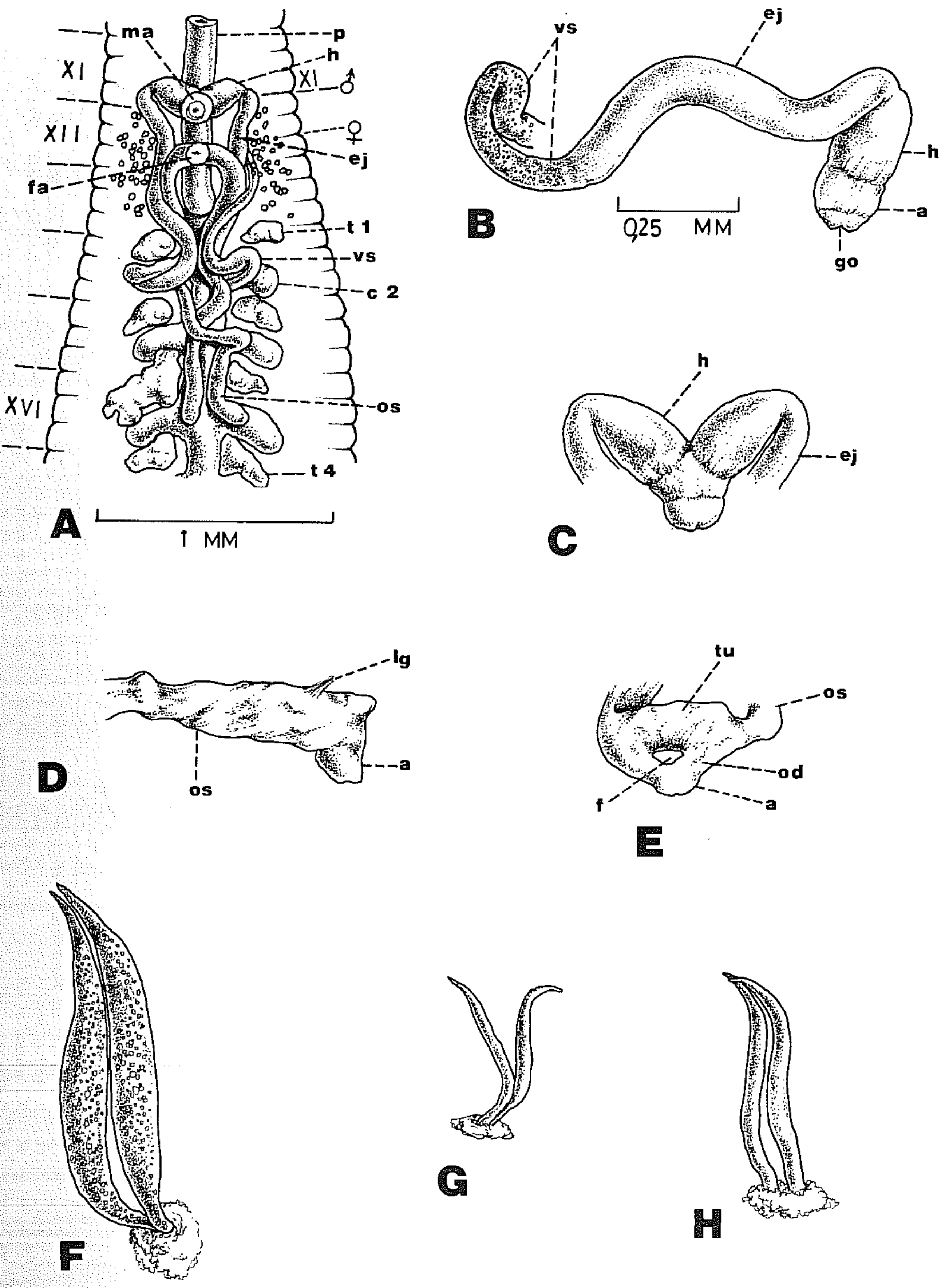
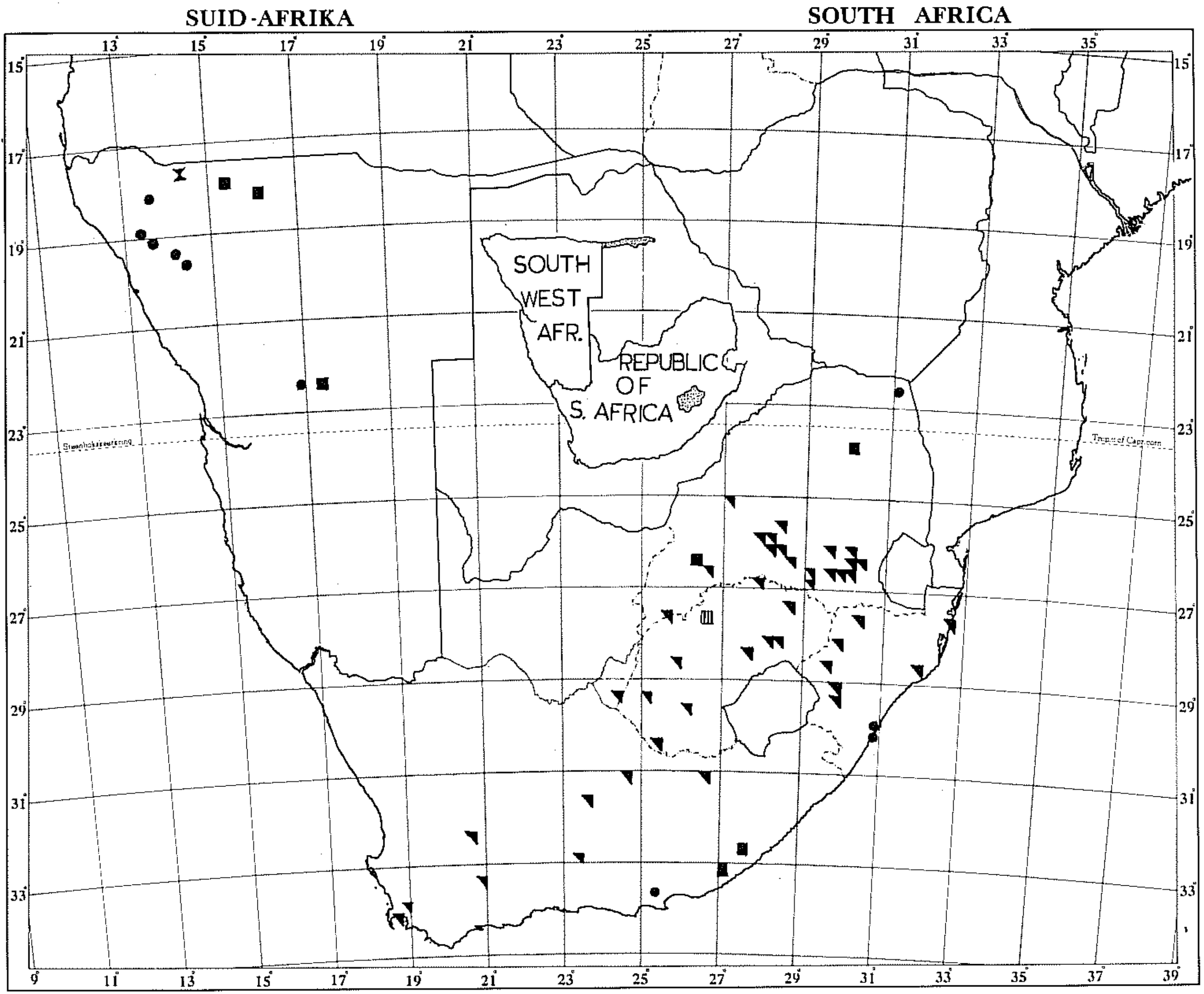


FIGURE 9: *Batracobdella disjuncta.* A, Reproductive systems *in situ,* ventral view, testes 5 — 7 not included. B, Male tubes, lateral view. C, Terminal end of male tubes, anterior view. D, lateral and E, anterior views of terminal end of female system. F, Undischarged and G, H, empty spermatophores. B — H drawn to the same scale.



MAP 1: Distribution of *Batracobdella* species.

■ : *B. cheili sp. nov.*

● : *B. conjugata sp. nov.*

◥ : *B. disjuncta*

⧗ : *B. cheili* and *B. conjugata*

▥ : *B. cheili* and *B. disjuncta*

Inset: Boundaries of geographical area covered during survey (dotted areas excluded).

Background aerosol composition at Gobabeb, South West Africa

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CONTENTS

ABSTRACT

A remote site in the Namib desert at Gobabeb, latitude 23°45′S, longitude 15°03′E, was selected for sampling background aerosols in Southern Africa. This is one of a wide network of stations spanning the Southern Hemisphere in a programme designed to measure the background concentrations of heavy elements in the atmosphere. A first series of twelve samples was collected over a fifteen week period from November 1976 to February 1977, using a single-orifice cascade impactor, which fractionated the particles into six size groups. Analysis was performed using proton induced X-ray analysis (PIXE).

The following elements were measured in all twelve samples: S, Cl, K, Ca, Ti, Mn, Fe, Br and Sr. Elements observed occasionally, generally at very low concentrations, were: V, Cr, Ni, Cu, Zn and Pb. The results over the three month period show that the aerosol in this region was stable and well mixed. No direct correlations with wind direction were observed, excluding strong local or regional sources of particles. K, Ca, Ti, Mn and Fe can be identified with a dust dispersion source. Cl, large particle S and Br, and part of the Sr are derived from sea spray. Relative to the soil components small particle K is not enriched as it normally is in regions with less scarce vegetation. V, Ni, Cu and Zn enrichments in the aerosol are lower than practically all values measured at any other location hitherto. Minimal Pb concentrations, well below 3 ng/m^3, were found, indicating that the region is free from automobile exhaust pollution and thus confirming the suitability of the site for background aerosol sampling. A bimodal size distribution of sulphur concentrations was found. The larger size fraction was assigned to an oceanic origin, while the smaller fraction is assumed to be the natural background level in the atmosphere of sulphur particulates condensed from the gaseous phase. The concentrations of the small particle sulphur, 150 ng/m^3, are among the lowest concentrations measured over an extended period anywhere in the world.

1 INTRODUCTION

In the Northern Hemisphere, the input of particulate matter to the atmosphere by human activities is already large enough to affect the atmospheric composition not only in areas close to the pollution source points but also in remote areas. Efficient long range transport of atmospheric pollutants especially of submicron aerosol particles which may have long atmospheric residence times, has indeed led to the contamination of most non-urban areas of the Northern Hemisphere, and reliably pollution-free locations for baseline measurement stations are not easily found. Yet knowledge of the natural background levels of sulphur and trace elements in atmospheric particulates is of basic importance also for urban air pollution work, since all anthropogenic atmospheric particles are imposed on the natural background, and an understanding of their relative importance is necessary to design efficient air pollution control strategies.

The Southern Hemisphere contains considerably fewer pollution sources, and the mixing time of the atmospheres of both hemispheres is well in excess of the typical atmospheric residence times of aerosols. Therefore truly remote areas of the Southern Hemisphere are potentially suitable for natural background aerosol composition studies. Recently, stations for long term aerosol collection have been installed in the Southern Hemisphere at the South Pole (Maenhaut and Zoller, 1976), the island of Samoa in the Pacific Ocean (Maenhaut *et al.*, 1978) and Fernando de Noronha in the Atlantic Ocean (Van Grieken *et al.*, 1978) and in the uplands of Central Bolivia (Adams *et al.*, 1977). Short term sampling has been carried out at several remote locations on the South American continent (Lawson and Winchester, 1978) and on shipboard sites (Darzi *et al.*, 1978).

Since no aerosol composition data from the African continent have been available hitherto, and since nowhere in the Southern Hemisphere has long term sampling been carried out in a really central desert location, where organic processes cannot add significantly to local aerosol concentrations, an aerosol sampling project was initiated in the Namib Research Institute situated at Gobabeb in the Namib desert, South West Africa. This site adequately satisfies most of the requirements for sampling background aerosols: It is reasonably accessible to qualified servicing personnel, has a mains electricity supply and laboratory facilities, yet it is remote from all possible sources of anthropogenic aerosols, specifically industrial centres and major highways, and not downwind in the prevailing wind direction from such sources.

Its situation at latitude 23°45′S, longitude 15°03′E is 100 km in direct line from the nearest town Walvis Bay (population 25 000). The only other city of any size in the region is Windhoek, which is 250 km to the north west. The relative isolation of Gobabeb from major through roads is shown in the sketch map in Map 1. Vehicle movements in the direct vicinity of the station, which is 200 m south-east of the central area of activity of the Institute, are limited to two to four per day. Geographical features of Gobabeb are its position on the ephemeral Kuiseb river, on the Northern edge of the Namib dune sea and the Southern edge of an extensive sparsely vegetated gravel plain. The closest distance to the Atlantic Ocean is 60 km. The location of Gobabeb and its climate and soils have been more fully described by Schulze (1969), Goudie (1972) and Scholz (1972).

At this location sampling was continued for 15 weeks using a six stage impactor as a size fractionating sampling tool. Elemental analyses were afterwards performed by means of proton-induced X-ray emission (PIXE). Size distribution aerosol analysis was thought to be essential in view of the objectives of this study. Knowledge of the elemental size distributions is helpful in identifying aerosol sources since large size fractions point to dispersive source processes and smaller particle sizes to condensation from a gas phase. Moreover, intelligent monitoring of ecologically harmful aerosols requires size distribution information since the penetration and deposition efficiency of particles in the respiration system strongly depends on the aerosol size distribution. Finally, important clues about long range transport and atmospheric removal of aerosols and about ageing and mixing of different aerosol populations can be derived from elemental size distributions, if one takes into account the shorter residence times of larger particles and looks for size distribution similarities between different elements.

In this paper we present initial elemental analyses of the aerosol from a central Namib Desert station, provide evidence that the site is suitable for atmospheric chemical baseline measurements, and derive preliminary information on the atmospheric chemistry of the region.

2 EXPERIMENTAL DETAILS

All samples were collected with a single orifice Battelle-type cascade impactor (Mitchell and Pilcher, 1959). The principle of the impactor is illustrated in Fig 1. The aerosol stream is drawn upward into the impactor by a pump, passes through a single orifice and impinges upon the first plate. Particles in the aerosol stream having a large enough inertia will impact upon the plate, and smaller particles will make the turn into the next stage. The orifices of the 5 successive impaction stages are carefully designed so that the aerosol is separated in size fractions of >4 μm, 4-2 μm, 2-1 μm, 1-0.5 μm and 0.5-0.25 μm aerodynamic diameter, when operating at a flow rate of 1.2 l./min. Particles smaller than 0.25 μm diameter which pass through the 5th stage are collected on a back-up filter (also called filter stage or stage 6). The impaction surfaces used in this work were thin (<4 μm) Mylar film, supported by 25 mm metal slides and made sticky by coating with a thin layer of paraffin through evaporation. A 0.4 μm pore diameter Nuclepore filter served as back-up filter.

Sampling began on 1st November 1976 and continued until 14 February 1977. Each sample was collected over a period of 126 hours extending over seven days. Since the diesel powered electricity generator was switched off during the night from 0130 to 0730 hours, these periods were not included in the sampling. As the wind was becalmed during these hours on most nights, the exclusion of these hours does not represent a serious distortion of the wind frequencies actually sampled. Sample 12 was collected over an extended period of two weeks. The results of sample 3 are not included in this report due to a loss of target material during sample preparation, while sample 14 was invalidated by a spider taking up lodging in the impactor during the collection period. The calibrated flow of the impactor was 1.2 l./min. giving a sampled volume of 9 m^3 S.T.P. over a 126 hour period.

As part of the routine meteorological observations carried out at Gobabeb, continuous recordings are taken of wind speed and direction, air temperature and relative humidity. These data were made available for the interpretation of the aerosol data. Precipitating fog occurred on an average of three nights per month at Gobabeb during the sampling period. However, the onset of the fog is usually in the early hours of the morning and it is usually completely dispersed by 1000 h. As this time span was in any case mostly excluded from the sampling period due to the electricity supply hours, the fog is not an important factor in the overall results. The collected aerosol can therefore be regarded to a good approximation as originating from desiccated air with a relative humidity of less than 50 %. Disproportionately high loadings were observed on thfilter) stage of the impactors, indicating incomplete impaction on the earlier stages. This may in part have been caused by electrostatic effects which would be accentuated in dry air. However the masses deposited on the last stages were not sufficient to seriously distort the size distributions or invalidate the conclusions based on these results.

The samples were analysed by proton-induced X-ray emission (PIXE). The PIXE technique is a non-destructive, multi-element technique, which permits fast, precise and sensitive analysis of large numbers of aerosol size fractions. Full details of the analytical procedure have been described by Johansson and Johansson (1976). The main features can be summarised as follows. A proton beam from a Van de Graaff accelerator passes through an evacuated irradiation chamber and is made uniform by means of a diffuser foil or two pairs of electrostatic deflection plates sweeping the beam in two perpendicular directions. The beam is then defined by a series of collimators and directed onto the sample. In case of a thin sample, such as a Mylar film or a Nuclepore filter, the beam passes through it and is collected in a Faraday cup connected to a beam current integrator. X-rays emitted by the sample pass out of the irradiation chamber through a thin Mylar window and are detected with a high-resolution Si(Li) detector. The pulses from the detector are analysed in a multichannel analyser. A typical X-ray spectrum thus obtained is shown in Fig 2. It consists of a number of peaks corresponding to the K_α and K_β X-rays of the elements indicated in the figure. For the heaviest elements such as lead, the L X-rays can appear in the spectrum. The number of counts in a peak is a measure of the amount of the corresponding element in the sample. In samples up to 1 mg/cm^2, the X-ray response as a function of the material being analysed was investigated and found to be linear over more than four orders of magnitude, from about 1 ng to 100 µg (Johansson *et al.*, 1975).

The PIXE analysis of the samples was carried out using the facilities available at Florida State University (Johansson *et al.*, 1975). The proton energy was 5.0 MeV. The irradiation time per sample was typically 3 to 5 min. The charge collected in each irradiation amounted to 10µC. The elemental amounts present in the samples were obtained from the X-ray spectra by means of the computer program REX (Kaufmann *et al.*, 1977). The total execution time per spectrum evaluation, including plotting and printing, was approximately 2 min.

3 RESULTS

The results of the PIXE analyses, expressed as concentrations in ng/m^3 for most elements at each stage are presented in Table 1. Also indicated in Table 1 are the concentration limits for each element. The precision of the present sampling and analysis procedure has been tested thoroughly in a previous study (Van Grieken *et al.*, 1976). A 10 % error arising from the sampler performance should be added quadratically to an analysis uncertainty of 4 to 30 %, depending on the element concentration level, to yield the overall uncertainty on the results. The accuracy of the analysis results has been proven to be in the 10 % range through the use of reference targets and the participating in interlaboratory inter-comparison runs (Johansson *et al.*, 1975). A summary of the data is presented in Fig 3, where the geometric mean of the concentrations over all samples is plotted as a function of particle size for K, Ca, Ti, Mn, Fe and Sr. The error bars shown represent standard deviations on the average, as obtained from the scatter between the different results. A similar plot for S, Cl and Br is presented in Fig 4. Data for V, Cr, Cu and Zn are not included since these elements were generally not found significantly above the detection limits. The values for Pb were below 0.50 ng/m^3 for all size fractions.

4 DISCUSSION

Inspection of Fig 3 reveals a remarkable similarity in the size distribution of K, Ca, Ti, Mn, Fe and Sr. This points clearly to a common source for all these elements. Since the size distributions are strongly skewed towards the larger particle sizes, the dominant source of these elements must be a dispersion process, namely dispersal of soil material. This assumption is further corroborated by the fact that the elemental ratios of K, Ti and Mn to Fe for those elements are always close to the corresponding ratios of average soil and crustal rock material as can be seen from Table 2. Also these ratios are independent of the particle size for these elements.

Ca, however, is significantly more abundant in the aerosol relative to average soil, but this is not unexpected for the Namib Desert which has fairly extensive outcrops of calcium carbonate minerals (Scholz, 1972). While there is some maritime contribution to the Ca, this is clearly not the only source, since the ratio Ca/Sr in the aerosol is consistently greater than 100, in contrast to a value of 50 in sea water.

It also appears from Table 2 that the Sr/Fe ratio is in excess of what could be expected for simple crustal rock dispersal, which suggests an additional Sr source, e.g. sea spray. If one assumes that the Fe in the aerosol is exclusively derived from crustal rock dispersal, while the Cl is purely of marine origin (cf. below), one can calculate the expected airborne Sr concentration in each stage from the Fe and Cl contents and from the Sr/Fe and Sr/Cl ratios in crustal rock and sea-water, since no significant Sr/Cl fractionation occurs during the sea spray generating process (Hoffman *et al.*, 1974). In this way we predicted average concentrations of 1.8, 1.8, 1.1, 0.32, 0.06 and 0.21 ng Sr/m^3 for stages 1, 2, 3, 4, 5 and 6 respectively, while values of 0.9, 1.7, 1.0, 0.28, <0.12 and <0.27 were found experimentally. This gives evidence that both sea spray and crustal material contribute to atmospheric Sr at Gobabeb.

For all these elements, the concentrations measured on stage 1 are smaller than those on stage 2, suggesting that the largest size fraction had settled by gravitation before being sampled. This indicates that the aerosol is aged, and that no strong local winds blow up coarse local dust (the average measured windspeed during the sampling period was 12.5 km/h with a one hour average maximum of 39 km/h). However it cannot be ruled out completely that the size distributions are somewhat depleted in stage 1 by bounce off of particles during impaction. The usual extreme dryness of Namib Desert air during the day, and the loading of the impactor stages after a one week collection period, might be factors enhancing bounce off errors. The resulting distortions of apparent size distributions can be minimised by using shorter sampling periods and by using a different impactor slide coating; the paraffin used in this work will be replaced by vaseline in future sampling under desert conditions.

The size distribution for K closely matches that of Fe and the K/Fe ratios are consistent with that of soil or crustal rock for all stages. Previous investigations in the sparsely inhabited area of Northern Florida (Johansson *et al.*, 1974; Van Grieken *et al.*, 1976; Johansson *et al.*, 1976) and even in Bermuda (Meinert and Winchester, 1977) have shown a distinct K/Fe enrichment in the small particle size fractions except for purely maritime air sampled at a beach location. Also in remote locations on the South American continent (Lawson and Winchester, 1977) a relatively high abundance of small particle K was noted. In all cases, forest fires or emanations from plants were postulated as probable sources. The absence of any significant small particle K enrichment in the Namib desert, which is characterised by an extremely sparse vegetation, supports this assumption.

Table 2 also lists ratios to Fe for V, Cr, Ni, Cu and Zn, calculated either from the results of the few impactor samples in which these elements were found well above blank levels or from detection limits. In spite of the small number of data points some striking preliminary conclusions can be drawn. For all these elements the ratios to Fe in the large particle fractions are very near to the average crustal rock ratios, pointing to simple soil dispersal as the dominant source. Even in small particles the ratios of these elements to Fe are comparable to those in average soil: the detection limits or the few measured concentrations, related to iron, are typically only a factor of 3 to 10 higher than expected. If one adds the data over all six impactor stages, and relates them to the total Fe-concentration, ratios to Fe of 0.004 for Zn and <0.004 for V, Cr, Ni and Cu are calculated from the present data. Comparison of these values to other published data (e.g. Adams *et al.*, 1977) shows that these values are comparable to or lower than corresponding values measured at other locations. Hitherto, Cu and Zn have generally been found to be highly enriched (up to several thousand times), and this effect has been attributed to a world-wide contamination with some anthropogenic combustion aerosol component (Dams, 1974), selective emanation from plant material (Beauford *et al.*, 1977) or selective evaporation from rocks (Goldberg, 1976). The present finding of lower enrichments might be due to greater than usual contributions of unfractionated crustal material to the aerosol or to the absence of vegetation in the Namib Desert. Final conclusions await further aerosol analyses and investigations including careful analyses of soil samples taken from the Namib Desert. Ni and V are often measured in unexpectedly high concentration, particularly close to pollution sources (Duce and Hoffman, 1976). The fact that neither V nor Ni, which are abundant in fuel-oil, are detected in enhanced concentrations at the Gobabeb station indicates that local pollution from the station's diesel generator is insignificant.

Table 2 indicates that the measured Cl/Fe ratios are very much higher than expected for a dust dispersion source, and the very high abundance of the large particle fraction as seen in Fig 4 points to sea spray as the dominant Cl source. Taking into account the elemental ratios of Cl in seawater, one calculates that, even with the present high Cl content in the aerosol, the maritime contribution for the other elements to the aerosol at Gobabeb is negligible, except for Sr (see above), large particle Br and large particle S. As can be seen from Table 2 the Br/Cl ratio in stages 1, 2 and 3 is comparable to the seawater ratio, and it might be slightly lower due to preferential Br loss from the particles. When one does not take into account the high Cl and Br levels measured on the 6th size fraction, which might be partially due to the Nuclepore blank levels not being constant or negligible, and calculates the Br/Cl ratios for the 1-0.25 µm size diameter, (stages 4 and 5), a value of 0.0084 is found. The excess Br in the small particles cannot be attributed to automobile exhaust, as is the case in less remote regions (Johansson *et al.*, 1976), because the detection limits for Pb in the present samples are such that the Pb/Br ratio at Gobabeb is certainly below 0.2, while in automobile exhaust Pb/Br is closer to 5. The low Pb content of the Namib aerosol is unusual indeed. The sum of the average detection limits for the six impactor stages points to a Pb level under 3 ng/m^3, far below most Northern Hemisphere levels (Reiter *et al.*, 1976) and below most remote station levels (Adams *et al.*, 1977).

Sulphur shows a bimodal distribution indicating two sources, probably one from dispersion of solid or liquid phase and one from condensation from the gaseous phase. The large size fraction S probably originates from sea water. The measured S/Cl ratios are consistently higher than expected for simple sea water dispersal yet comparable to the large particle S/Cl ratios of 0.18 and 0.09 measured in maritime air on Bermuda (Meinert *et al.*, 1977) and Samoa (Maenhaut *et al.*, 1977) respectively. This high S/Cl ratio may be due to preferential loss of Cl from the aerosol particles, a process that has been examined e.g. by Berg and Winchester, 1977. The small particle sulphur concentrations average 150 ng m^{-3}, and this value is among the lowest levels yet recorded. This level can be assumed to be the natural background level in the atmosphere of sulphur particles condensed from the gas phase. Other intermittent measurements on the South American continent (Lawson *et al.*, 1978) have given concentrations on a comparable level, but possible additional S sources prevented their unambiguous interpretation as background levels. A more detailed review and interpretation of atmospheric sulphur particulate measurements in the southern hemisphere is at present in preparation. To further distinguish the sources and characteristics of the components of the aerosol, the time variations of the concentrations were plotted, for comparison with the time variation of the wind distance travelled. It was assumed that Gobabeb lies at the conjunction of three distinct geographic areas defined by the coast running North to South and the Kuiseb River running West toward the coast, as shown in the inset to Figure 5. The wind direction data have been arranged to give the wind distance travelled per sampling period over each of these three regions, namely (i) maritime, (ii) dune sand and (iii) gravel plain. The wind direction data are shown in Fig 6. There is only one gross feature in the time variation of the wind travel with which to correlate concentration variations: during sampling periods 1 to 10, the wind was predominantly maritime with an average travel of 1 300 km/126 hr, while the dune sand and gravel plain continental components were small, less than 150 km/126 hr; during sampling periods 12 and 13 (wind data for period 11 not recorded) the maritime component dropped to 800 km/126 hr while the gravel plain component increased to 800 km/126 hr.

The variation in concentrations of K, Ca, Ti, Mn and Fe over the whole sampling period, shown in Fig 7, show a striking similarity, confirming a common source for these crustal elements. There was no dramatic change in the concentrations of these elements during the periods 12 and 13 when the wind travel changed from predominantly maritime to mixed maritime-gravel plain. This indicates that the additional aerosol component generated over the gravel plain North of the Kuiseb is insignificant relative to either the aged aerosol component or the component generated over the region between the coast and Gobabeb.

The variation of the Cl, S and Br concentrations are shown in Fig 8. Since S and Br showed bimodal size distributions, each size fraction was plotted to identify their possible separate origins. Up to period 12 the variations of Cl and Sr concentrations are similar to those of the crustal elements. To a lesser extent so are the variations of large fraction Br and S concentrations similar. However during period 13 the concentrations of Cl, Sr and S (large fraction) drop sharply relative to period 12: concentration (period 13)/concentration (period 12) = C_{13}/C_{12} = 0.53, 0.83, 0.60 respectively. In contrast the concentrations of all the crustal elements increased slightly: Average $C_{13}/C_{12} = 1.21 \pm 0.11$. Although the reduction in maritime component occurred already during period 12, it appears that several days are required to convert the characteristics of an air mass from maritime to continental. This time variation of concentration confirms the source of Cl, S (large fraction), and part of the Sr as of recent maritime origin. For Br (large fraction), C_{13}/C_{12} = 0.94. This value is intermediate between the ratios for the crustal elements and Cl, but not distinct enough from earlier variations to associate it unambiguously with the change in wind travel. The S (small fraction) and Br (small fraction) concentrations increase slightly during period 13; C_{13}/C_{12} = 1.11, 1.23 respectively. This indicates that these fractions were not of recent maritime origin and that they were also aged components characteristic of the atmosphere over a large region.

5 CONCLUSIONS

Gobabeb was chosen as a sampling site for remote aerosol measurements. Analysis of size fractionated impactor samples taken under varying wind conditions over a fourteen week period indicated an aerosol of combined soil and maritime origin, which was well mixed and free from local or regional anthropogenic pollution. The measurements have provided valuable baseline values of remote natural aerosol concentrations. K, Ca, Ti, Mn and Fe all showed size distributions strongly skewed towards large particles; these elements varied similarly with wind direction and their concentration ratios were close to corresponding ratios in average soil or crustal rock. These observations pointed to simple soil dispersal as the common source for these elements. The concentrations of V, Cr and Ni relative to Fe corresponded to values measured at other locations. Unexpectedly low concentrations of Cu and Zn may be related to the sparsity of vegetation in the Namib desert. High Cl/Fe ratios and the large particle predominance pointed to Cl being derived mainly from sea spray; sea salt constituted on average 20 % of the total aerosol mass at Gobabeb, assuming that Cl and Fe were derived from only average sea salt and soil respectively. Large particle Br and S were correlated with a sea spray source, based on relative concentrations, particle sizes and wind direction dependence. Small particle Br was not derived from automobile exhaust, as is found in most locations, since the Pb levels were too low to account for gasoline as a measurable source. Small particle S concentrations were amongst the lowest yet recorded.

Future work will be oriented towards expanding the statistical base of the present conclusions, and towards unambiguously separating the maritime, gravel plain and sand dune components, by combining directional control equipment with the cascade impactor for use at different locations around Gobabeb.

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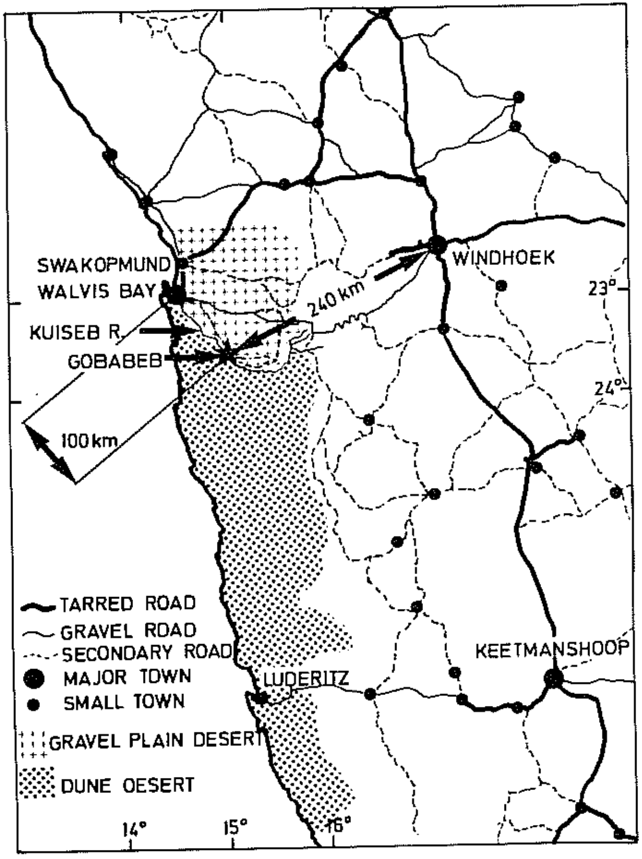
TABLE 1: Individual results (in ng/m^3) for the 12 size fractionated aerosol samples taken at Gobabeb, South West Africa

Element and stage number	Impactor run number												Geom. average	Std. dev. on the average	Average detection limit
	1	2	4	5	6	7	8	9	10	11	12	13			
S 1	66.	93.	50.	38.	35.	26.	46.	62.	70.	56.	41.	41.	49.	1.11	1.2
S 2	55.	40.	60.	43.	57.	55.	48.	64.	99.	79.	52.	21.	53.	1.12	1.1
S 3	24.	12.	30.	15.	30.	26.	44.	26.	50.	40.	40.	18.	27.	1.13	1.0
S 4	18.	9.0	37.	31.	61.	77.	32.	17.	24.	28.	61.	39.	31.	1.19	0.5
S 5	59.	22.	41.	47.	77.	57.	94.	89.	109.	114.	65.	100.	66.	1.15	0.4
S 6	67.	52.	50.	72.	82.	48.	57.	36.	63.	55.	38.	43.	54.	1.08	1.3
Cl 1	439.	742.	384.	266.	289.	188.	309.	578.	475.	451.	299.	282.	366.	1.12	1.0
Cl 2	288.	185.	403.	190.	382.	215.	176.	474.	512.	382.	317.	82.	269.	1.16	1.0
Cl 3	233.	50.	201.	25.	183.	98.	199.	257.	277.	234.	185.	43.	132.	1.26	0.8
Cl 4	63.	27.	45.	21.	35.	<0.41	46.	65.	28.	53.	15.	17.	34.	1.17	0.4
Cl 5	6.1	3.4	7.5	1.7	1.9	0.97	2.6	4.2	2.8	3.7	0.70	1.7	2.5	1.22	0.4
Cl 6	23.	24.	37.	104.	25.	12.	12.	21.	42.	15.	5.3	12.	21.	1.24	1.3
K 1	47.	66.	39.	29.	35.	21.	38.	41.	42.	32.	26.	31.	36.	1.09	1.3
K 2	42.	34.	59.	35.	67.	56.	30.	54.	81.	53.	32.	31.	45.	1.10	0.7
K 3	34.	15.	39.	14.	30.	36.	29.	36.	48.	34.	22.	20.	28.	1.12	0.6
K 4	13.	7.5	9.7	8.0	9.1	7.5	8.4	9.5	12.	13.	7.9	12.	9.6	1.06	0.3
K 5	3.7	1.6	4.0	4.2	4.8	3.7	3.3	3.8	4.3	3.4	2.0	2.5	3.3	1.10	0.3
K 6	14.	11.	16.	27.	17.	12.	5.7	6.6	12.	5.2	4.1	1.9	8.9	1.23	1.0
Ca 1	235.	311.	167.	163.	157.	99.	131.	194.	179.	143.	96.	128.	158.	1.10	0.6
Ca 2	264.	191.	308.	238.	335.	378.	159.	326.	353.	285.	147.	149.	248.	1.11	0.6
Ca 3	169.	68.	180.	79.	147.	187.	119.	180.	185.	170.	74.	80.	127.	1.13	0.6
Ca 4	52.	22.	37.	16.	29.	24.	24.	35.	30.	54.	22.	46.	31.	1.12	0.3
Ca 5	14.	5.4	13.	12.	9.6	7.2	9.8	14.	9.9	12.	5.9	9.6	9.8	1.10	0
Ca 6	54.	46.	82.	105.	49.	34.	15.	31.	40.	20.	16.	6.4	32.	1.26	0.8
Ti 1	10.	14.	7.1	5.9	6.9	4.3	7.1	6.6	9.2	6.0	4.7	7.2	7.1	1.10	0.4
Ti 2	11.	8.4	14.	8.0	14.	13.	7.5	11.	20.	12.	7.2	8.2	11.	1.10	0.4
Ti 3	9.0	3.7	12.	3.8	7.9	10.	8.0	9.8	13.	9.6	4.4	5.4	7.4	1.13	0.4
Ti 4	3.8	1.4	2.5	2.0	2.2	1.9	11.	2.9	2.4	4.2	1.7	4.1	2.8	1.17	0.2
Ti 5	0.97	0.37	1.1	0.98	0.85	0.66	0.98	1.2	0.97	0.79	0.60	1.0	0.84	1.10	0.2
Ti 6	2.8	2.2	4.0	6.4	2.9	2.2	0.80	1.9	2.4	0.65	0.97	<0.80	2.0	1.23	0.6
Mn 1	1.4	2.2	1.2	1.4	1.3	0.74	1.0	1.1	1.5	0.91	0.94	0.96	1.2	1.09	0.3
Mn 2	1.9	1.5	2.8	1.8	3.3	3.1	1.5	2.4	3.4	2.3	1.3	1.3	2.1	1.11	0.3
Mn 3	1.8	0.82	2.8	0.71	1.9	2.2	1.4	2.0	2.1	1.9	0.80	1.0	1.5	1.14	0.3
Mn 4	0.60	0.27	0.46	0.27	0.49	0.31	0.35	0.60	0.33	0.79	0.26	0.70	0.42	1.12	0.1
Mn 5	<0.21	<0.10	0.17	0.17	<0.12	0.12	0.14	0.14	<0.12	<0.19	0.10	<0.16	0.14	1.09	0.1
Mn 6	<0.46	<0.37	<0.45	0.64	<0.46	<0.40	<0.43	<0.42	<0.43	<0.37	<0.21	<0.52	—	—	0.4
Fe 1	94.	138.	43.	61.	69.	38.	69.	70.	81.	56.	49.	76.	66.	1.11	0.2
Fe 2	112.	91.	168.	87.	179.	176.	81.	142.	224.	132.	79.	85.	122.	1.11	0.2
Fe 3	106.	41.	156.	41.	110.	132.	95.	134.	150.	120.	50.	61.	90.	1.15	0.1
Fe 4	45.	16.	31.	25.	28.	23.	47.	38.	27.	52.	21.	46.	31.	1.11	0.1
Fe 5	9.9	3.6	12.	11.	9.5	7.3	8.6	11.	11.	6.8	4.9	5.8	8.0	1.11	0.1
Fe 6	33.	30.	43.	68.	30.	24.	12.	19.	26.	8.8	11.	4.6	20.	1.24	0.2
Br 1	0.51	0.93	0.39	0.41	0.27	0.23	0.53	0.83	0.95	0.45	0.48	0.61	0.50	1.14	0.1
Br 2	0.30	0.33	0.94	0.26	0.97	0.62	0.32	0.87	1.6	0.63	0.41	0.31	0.53	1.19	0.1
Br 3	0.57	0.14	0.91	0.13	0.43	0.40	0.36	0.47	0.94	0.59	0.31	0.21	0.38	1.20	0.1
Br 4	0.27	0.11	0.38	0.10	0.28	0.31	0.22	0.17	0.21	0.48	0.24	0.30	0.23	1.14	0.1
Br 5	0.24	0.15	0.27	0.09	0.31	0.17	0.45	0.30	0.37	0.49	0.20	0.24	0.25	1.15	0.04
Br 6	0.49	0.61	0.45	0.16	0.93	0.50	0.49	0.47	0.90	0.66	0.35	0.61	0.51	1.14	0.1
Sr 1	1.2	1.9	1.1	0.77	0.87	0.50	0.81	1.1	1.4	0.83	0.66	0.49	0.90	1.12	0.2
Sr 2	1.7	1.2	2.5	1.2	2.1	2.1	1.1	2.5	3.6	2.0	1.2	0.77	1.67	1.14	0.2
Sr 3	1.2	0.34	2.0	0.32	1.4	1.3	0.77	1.6	2.0	1.2	0.66	0.65	0.96	1.20	0.2
Sr 4	0.55	0.13	0.32	0.22	0.34	0.21	0.21	0.33	0.22	0.45	0.25	0.38	0.28	1.12	0.1
Sr 5	<0.13	<0.05	0.14	<0.06	0.09	0.48	0.10	0.10	0.08	0.10	<0.07	0.07	0.12	1.24	0.1
Sr 6	<0.18	0.33	0.41	0.55	0.39	<0.16	<0.14	0.21	0.30	0.23	<0.09	<0.19	0.33	1.14	0.2

TABLE 2: Elemental ratios in the aerosol as compared to the corresponding average ratios in crustal rock (Mason, 1952), soil (Vinogradov, 1959) and sea water (Riley and Skirrow, 1975).

Element	Concentration ratios to Fe							
	in the measured aerosol						in average curstal rock	in average soil
	impactor stage number: 1	2	3	4	5	6		
S	0.74	0.43	0.30	0.99	8.32	2.62	0.01	–
Cl	5.51	2.21	1.47	1.07	0.32	1.02	0.063	0.0026
K	0.54	0.37	0.31	0.31	0.41	0.43	0.52	0.36
Ca	2.38	2.03	1.41	0.98	1.23	1.58	0.73	0.36
Ti	0.11	0.09	0.08	0.09	0.11	0.10	0.088	0.12
V	0.0075*	0.0053*	0.0055*	0.0080*	<0.018	<0.026	0.0030	0.0026
Cr	<0.0047	0.0037*	0.0047*	<0.0045	<0.0188	0.038*	0.0040	0.0053
Mn	0.018	0.017	0.016	0.013	0.018*	<0.021	0.020	0.022
Ni	<0.003	<0.003	<0.001	<0.001	0.003*	0.039*	0.001	–
Cu	0.0021*	0.0012*	0.0012*	0.0006*	0.0050*	0.018	0.0014	0.0005
Zn	0.0032	0.0011	0.0014	0.0035	0.0075	0.013*	0.0025	0.0013
Br	0.008	0.004	0.004	0.007	0.031	0.025	0.00003	0.00013
Sr	0.014	0.014	0.011	0.009	0.015*	0.016*	0.006	–
Pb	<0.009	<0.006	<0.007	0.009*	0.038*	<0.028	0.0003	–
Element	**Concentration ratios to C1**							
	in the measured aerosol						**in average sea water**	
	impactor stage number: 1	**2**	**3**	**4**	**5**	**6**		
S	0.13	0.20	0.20	0.92	26	2.6	0.048	
Br	0.0014	0.0020	0.0029	0.068	0.099	0.025	0.0036	
Sr	0.0025	0.0062	0.007	0.008	0.048*	0.015*	0.004	

* includes values above detection limit only.



MAP 1: Sketch map of South West Africa showing relative isolation of the sampling site at Gobabeb from large towns and major roads.

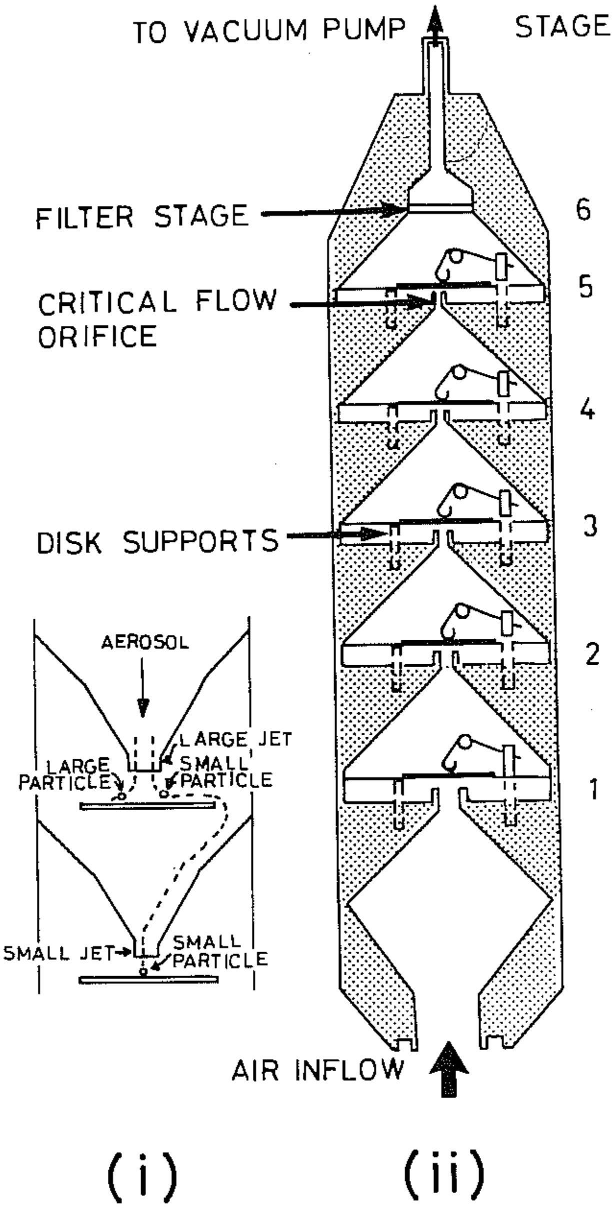


FIGURE 1: (i) Diagrammatic representation of the principle of size differential impaction of particles using a series of orifices of successively smaller diameter.

(ii) Five stage cascade impactor as used in the present project. Calibrated flow rate was 1.2 l./min.

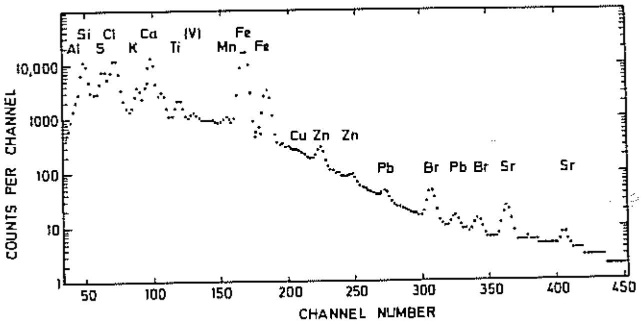


FIGURE 2: Smoothed X-ray spectrum of a Namib desert aerosol sample 11, stage 4 (0.5 to 1.0μm aerodynamic diameter particles).

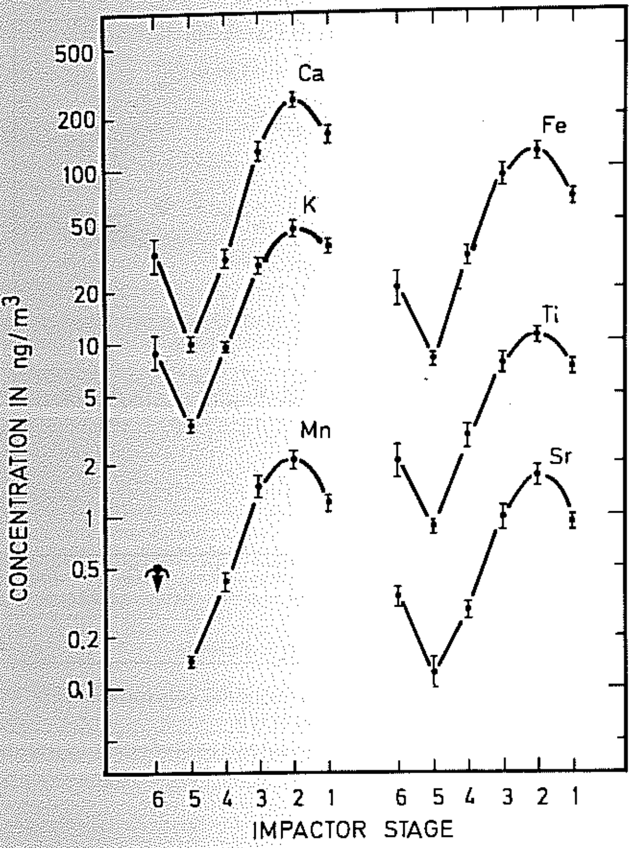


FIGURE 3: Particle size distributions of the geometrical mean elemental concentrations from twelve sets of impactor data. The horizontal scale indicates particle size on a log scale.

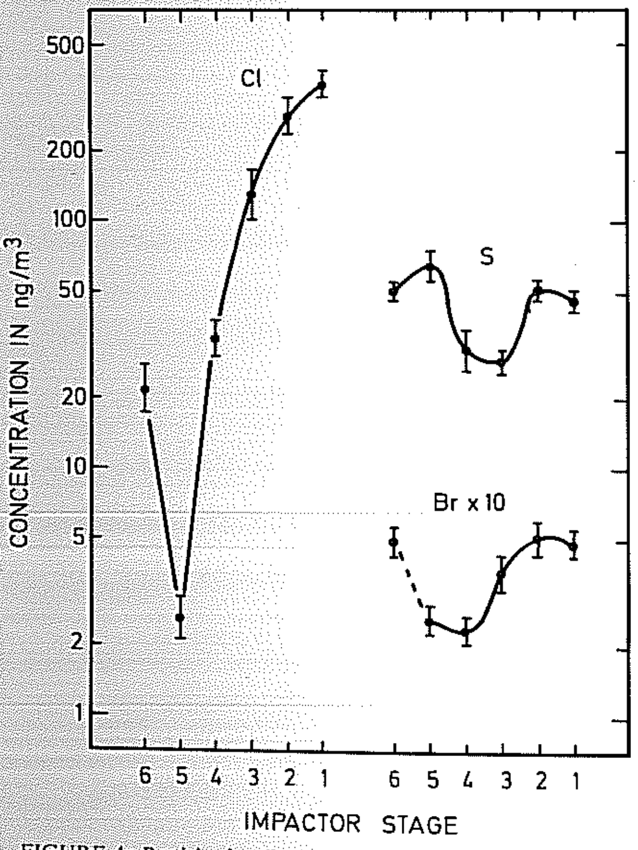


FIGURE 4: Particle size distributions of the concentrations of Cl, S and Br. Concentrations plotted are the geometrical mean of twelve impactor sets. The detection limit for Br = 0.03 ng/m^3.

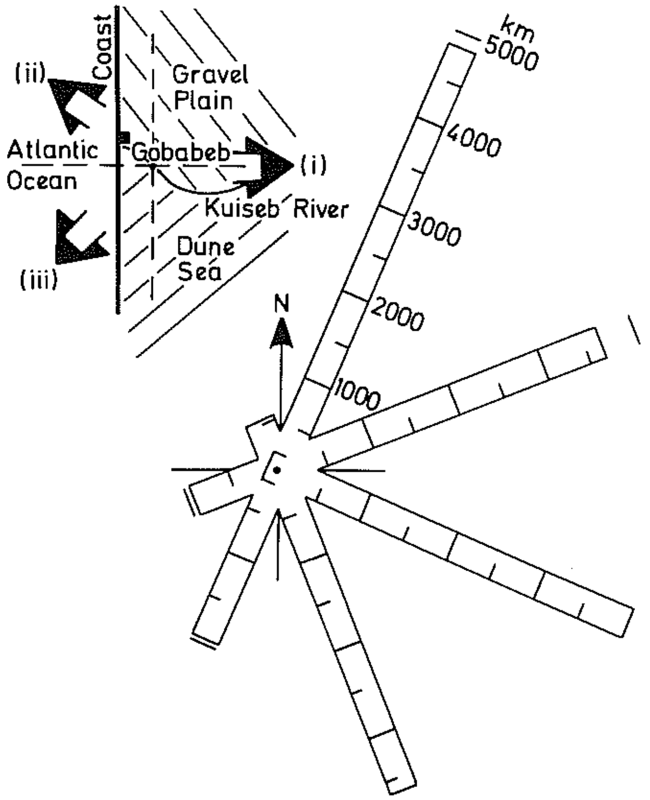


FIGURE 5: Accumulated wind distance travelled into the eight sectors indicated, during the sampling period for the twelve impactor sets e.g. 4 500 km is the distance travelled by SSW winds into the NNE sector. The approximate division of the wind reach into (i) maritime, (ii) continental (sand dune) and (iii) continental (gravel plain) regions as indicated (cf Fig. 1).

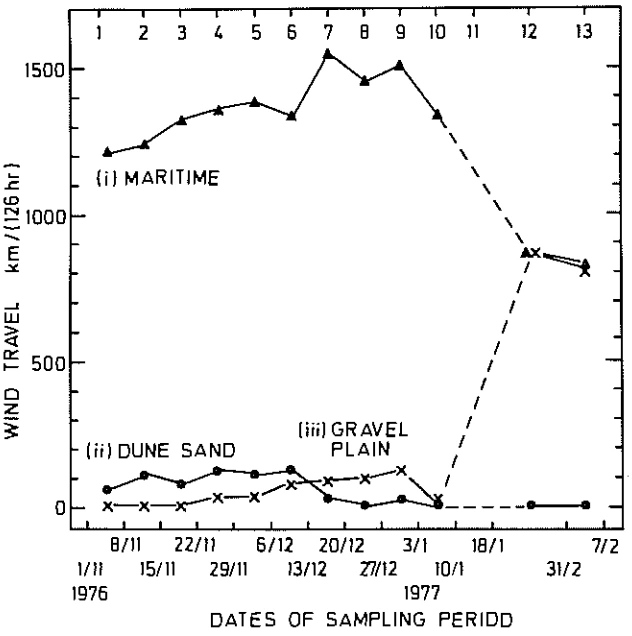


FIGURE 6: Time variation of wind travel over sampling periods in sectors corresponding to the major geographical features of the wind reach:

(i) Maritime, wind direction 180° – 360°

(ii) Continental (sand dune), 90° – 180°

(iii) Continental (gravel plain), 0° – 90°

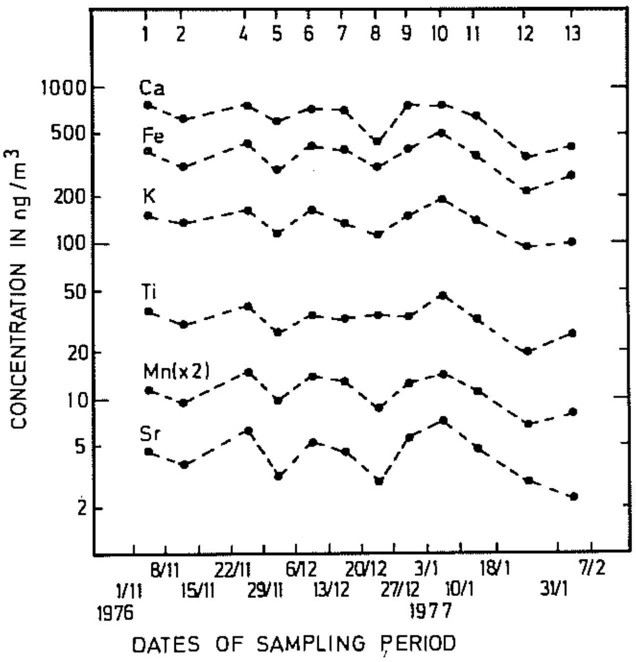


FIGURE 7: Time variation of the elemental concentrations of the aerosol, summed over all six stages.

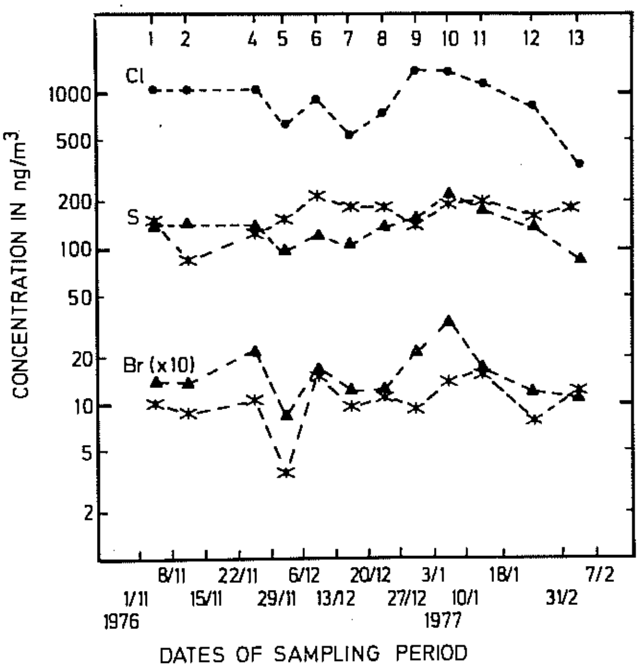


FIGURE 8: Time variation of the elemental concentrations:
(●) sum of stages 1 → 6
(▲) large fraction, sum of stages 1 – 3
(X) small fraction, sum of stages 4 – 6

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Notes on the western striped squirrel *Funisciurus congicus* (Kuhl 1820)

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CONTENTS

ABSTRACT

Information on *Funisciurus congicus congicus* was obtained during eight days spent in the field at Otjitambi (20° 15′S, 15° 15′E) and from museum records. Distribution and habitat preferences of this squirrel and the bush squirrel, *Paraxerus cepapi* are clarified. Vegetation on a study area inhabited by *F. congicus* is described, a density estimate for trees is given, and plants are listed. Nine food items are recorded together with the time spent feeding on them. Two ticks are identified to generic status; mass and measurements, range of movement and population density are given. Aspects of reproduction are mentioned and a preliminary description of activity and basic behavioural patterns (grooming, alertness, vocal and visual communication, group structure) are given. The possible use of the tail in thermoregulatory behaviour is mentioned.

1 INTRODUCTION

Two tree squirrels occur in South West Africa, both limited to the north of 21°S: *Funisciurus congicus*, the western striped tree squirrel (Shortridge 1934), or Kuhl's tree squirrel (Amtmann 1966a), hereafter referred to as the striped squirrel; and *Paraxerus cepapi*, the bush squirrel of yellow-footed squirrel. According to Amtmann (1966b), *F. congicus* includes *F. poolii*, and the subspecies *congicus*, *flavinus*, *interior*, *oenone* and *damarensis* of earlier authors are invalid. Apart from brief distributional notes and observations by early workers (Sclater 1899; Shortridge 1934; and Roberts 1951), very little is known about this squirrel. As a result the description by Sclater (1899) is here relevant: "general colour above yellowish brown, brighter on the shoulders, below very pale yellow, hairs of the back black at the base, and many of them with black tips; along the sides from shoulder to hindlimbs runs a narrow pale yellow stripe, below which is a similar dark one; an incomplete white ring around the eye; ears moderate; whiskers black; limbs pale, toes covered with long hairs nearly concealing the claws; tail a little shorter than the head and body, bushy, with hair half an inch long". Additions to this description from the present study are that the ventrum and sidestripe are white to cream rather than yellow; ears have white hairs and both ears and eyes are larger relative to head-size than those of the genus *Paraxerus* in southern Africa (the white ring around the eye makes the large eyes particularly obvious); the bands on the tail from the centre outward are: Yellow-black-yellow-black; and the tail is slightly longer than head and body calculated from museum skins, animals trapped in the field and by reference to figures in Roberts (1951) and Shortridge (1934). (See: Mass and Measurements).

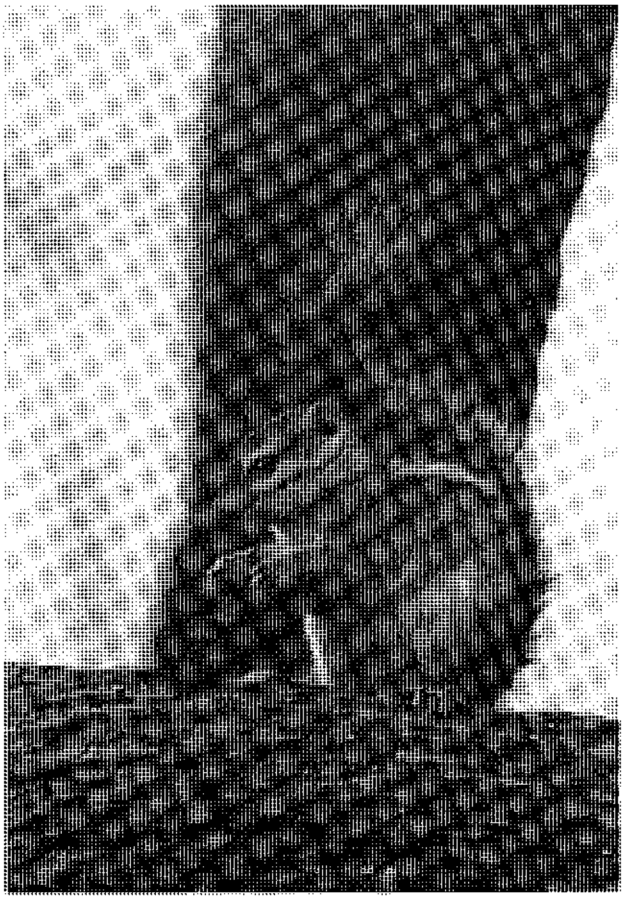

PLATE 1: *F. congicus* feeding on a mopane worm, *Gonimbrasia belina.*

Native names of bush squirrel and striped squirrel (Shortridge 1934, except where otherwise mentioned):

Paraxerus cepapi — Onjéri — Herero and Ovambo
Sipepe — Bechuana, from where the specific name

Funisciurus congicus — Onjéri-mbidiwa — Herero
Ephuku — Herero (present study)
Onjéri-shikwénga — Ovambo
Haridadob — Nama (present study)
Durus — Nama (present study)

2 MATERIAL AND METHODS

Information on distribution was obtained from specimens in the Windhoek and Transvaal Museums, as well as from various sources: Sclater (1899), Shortridge (1934), Hill and Carter (1941), Roberts (1951), Walker (1964), Amtmann (1966b), Coetzee, Schlettwein and Tinley (pers. comm.). Data on mass, standard body measurements and moult were obtained from museum specimens and records; from some of the above-quoted references, as well as from animals trapped in the field. Museum specimens were aged according to tooth wear (Viljoen 1976a) to make information more relevant. Eight days (8 April to 16 April 1978) were spent on the farm Otjitambi (20° 15′S, 15° 15′E), during which time animals were trapped along one kilometre on either side of a dry water course. Fifteen live traps (Have-a-heart type, 30 cm × 13 cm × 13 cm), baited with apple and a peanut-butter/muesli mixture, were placed on branches or rocks where the animals had been seen to move. These were attended to five times per day, every three hours from sunrise to sunset. Trapped animals were aged according to mass and external reproductive characteristics. (Females have four well-developed black inguinal nipples, adult males have enlarged scrota and often have bare chin patches). The animals were marked with Nyanzol D fur dye (Giles 1971), and ticks were collected and preserved in 70 % alcohol. Recaptures and observations on some of these squirrels enabled collection of data on their feeding, range of movement and behaviour. A vegetation transect through the study area was made (third-nearest individual method of McNeill, Kelly and Barnes (unpubl.) which they found less biased than other plotless methods in estimating density in Rhodesian woodland habitat) to give an idea of density of woody individuals (dbh more than 2,5 cm) as well as plant species present. The method entails the following: along a straight line, points are put out every 15 m where the distance to third-nearest neighbour in each of the 180° sectors along the line of travel is measured, species noted, as well as height, canopy diameter and diameter at breast height (dbh). The only difference in this instance was that the line of travel was not straight but hugged the water course at a distance of 5 m from the edge of the bank and curved with it, thereby following the distribution of the vegetation type to be sampled. In addition, a list of the plants in the study area was compiled.

3 DISTRIBUTION

The distribution of the two South West African tree squirrels has been mapped by Tinley (unpubl. manuscript 1970). He shows that the bush squirrel intrudes from the east (Botswana) reaching its most westerly distribution points at Otavi (19°45′S, 17°20′E) in the south, and at Ruacana falls (17°20′S, 14°15′E) in the north. At these two localities the bush squirrel overlaps with the striped squirrel. However, in between, the bush squirrel occurs around the east of the Etosha saline, and the striped squirrel along the west. There is a large amount of overlap in western Ovamboland, where the striped squirrel extends as far south as the forest belt between Ondongwa and Ukuambi (Shortridge 1934); and also just north of the South West African border, where the striped squirrel follows the Kunene River, and the bush squirrel occurs up to Mossamedes and Capelongo close to the coast (Hill and Carter 1941). In regions of overlap, the two species can be found in the same tree (Shortridge 1934). The bush squirrel is represented by two subspecies, the southerly population being *P. c. kalaharicus*, *vide* Smithers (1968), and the northerly pale-coloured Ovamboland population being *P. c. phalaena*, which also occurs in the south of Angola. In the Etosha National Park the bush squirrel can be seen in mopane-veld and occurs both at the Halali and Namutoni rest camps.

The genus *Funisciurus* ranges as far west as Southern Nigeria and Sierra Leone, and through the Northern Congo to Lake Tanganyika and Ruwenzori in the east; the species which concerns us here, occurs up to the Congo river where the type specimen was collected (Shortridge 1934). Amtmann (1966b) mentions them in the Katanga district of the Congo and says that they are probably to be found in eastern and north-eastern Angola. They are numerous in the west of Angola (Hill and Carter 1941) and occur right up to the seaboard as far south as Benguella and then angle south-eastwards to be distributed down the mountain range in Kaokoland to the Ugab river (20°45'S, 15°15'E) (Coetzee, pers. comm.), from there turning east, still to follow the mountain range and the *Commiphera/Kirkia* and *Colophospermum mopane* vegetation types mapped by Tinley (1969).

4 ECOLOGY

4.1 Habitat preferences

Walker (1964) notes the genus in palm groves, palm scrub, savanna and in forests up to an altitude of 2 175 m. Hill and Carter (1941) mention the striped squirrel occurring from plateau country in Angola and to the edge of the desert. Moreover, on the coast they are commonly found in palm groves, in the bushes of the savanna and also in the trees on the sides of cliffs. Shortridge (1934) notes that they prefer mopane and mixed forest, as well as dry river courses where the trees attain a larger size than elsewhere. Tinley (pers. comm.) associates them with granite outcrops, and not with open plains; and Schlettwein (pers. comm.) has also seen them frequently along dry water courses and on rocky outcrops, especially where some large trees are to be found close to these koppies. Both Schlettwein and Tinley surmise that the animals move seasonally, occurring in the wet season on the koppies and in the dry season along the river courses. All indications are that the striped squirrel requires a slightly denser vegetation type than the bush squirrel, the latter occurring both on the plains and hills, and the former not on the open plains. The bush squirrel is twice as heavy as the striped squirrel, although it is not much longer in body length, and covers large distances between patches of vegetation and trees on the ground, whereas the striped squirrel (mean adult mass of 100 g) prefers to move from twig to twig and branch to branch, even though they do spend a substantial amount of time on the ground when feeding. Frequency of sightings (n = 211) in different layers of vegetation was as follows: ground – 39 %, subcanopy (up to 2,5 m) – 42 %, and canopy (higher than 2,5 m) – 18 %. They are in the habit of jumping considerable distances between branches which *Paraxerus* prefers not to do. An additional attraction to the rocky outcrops might be a slightly warmer microclimate, which could be critical to such a small animal in winter. In addition they seem to be better able to cope with warmer conditions than the bush squirrel. (See: Behaviour).

According to the isohyet map of SWA (Tinley 1971), the striped squirrel inhabits the region between the 100 mm and 300 mm isohyets down the western length of its distribution, but in Ovamboland and also south of Etosha where they range up to Tsumeb, they cross the 400 mm and 500 mm isohyets. Giess (1971) maps mopane savanna (his vegetation type 5) and mountain savanna and karstveld (his type 6) over this region; and the more detailed description of De Sousa Correia (1976) of the Kaokoland, indicates *Colophospermum mopane/Spirostachys africana* savanna; *C. mopane/Terminalia prunioides/Acacia* spp. savanna with *Terminalia sericea*, *Lonchocarpus nelsii*, *Combretum apiculatum*, *C. imberbe* and *Kirkia acuminata*; *C. mopane/T. prunioides* savanna; sub-desert steppe with *C. mopane* and *T. prunioides*; and escarpment area with rocky hills. (His types 9, 10, 12, 13 and 14.) Overlap between the two squirrels are in his vegetation types 2, 3 and 4.

4.2 Vegetation of study area

The study area could be divided into three different habitat types namely rocky outcrops, vegetation alongside the dry river courses and open savanna. Work during the present study was limited to the former two habitat types as this had been indicated as the preferred habitat of the striped squirrel by Schlettwein and Tinley (pers. comm.). The following plants were collected from these two habitat types in the study area: (concentrating on tree species)

Dry water courses – *Acacia heteracantha*, *A. mellifera* var. *detinens*, *A. hebeclada*, *A. reficiens*, *A. tortilis*, *Boscia albitrunca*, *Colophospermum mopane*, *Combretum apiculatum*, *C. imberbe*, *Commelina* sp., *Commiphora crenatoserrata*, *C. mollis*, *C. pyracanthoides*, *Croton gratissimus* var. *subgratissimus*, *Cucumis angurea* var. *longipes*, *Dichrostachys cinerea*, *Grewia bicolor*, *G. flavescens*, *G. villosa*, *Justicia matammensis*, *Lonchocarpus nelsii*, *Maytenus senegalensis*, *Mundulea sericea*, *Terminalia prunioides*, *Ziziphus mucronata*.

Rocky outcrops – *Acacia nilotica*, *A. mellifera* var. *detinens*, *Boscia albitrunca*, *Colophospermum mopane*, *Combretum imberbe*, *C. apiculatum*, *Commiphora mollis*, *Croton gratissimus* var. *subgratissimus*, *Cardiospermum pechuylii*, *Cissus nymphaeifolius*, *Grewia* *bicolor*, *G. flavescens*, *G. villosa*, *Maytenus senegalensis*, *Mundulea sericea*, *Securinega virosa*, *Solanum* sp., *Sterculia quinqueloba*, *Steganotaenia araliacea*, *Tinnea juttae*, *Terminalia prunioides*.

The vegetation analysis is the same as that completed in the habitats of other southern African tree squirrels which will be used later for comparative purposes (Viljoen, unpubl.). From this analysis and from the lists of plants from one daily range (Table 1), the vegetational requirements of the squirrel on Otjitambi can be approximated. The vegetation density estimate (D) was 0,05 individuals/m^2

$$\left\{ D = \left(\frac{2}{\pi \times N}\right) \times \left(\sum_{i=1}^{N} \sum_{k=1}^{2} \frac{1}{r_{ik}^{2}} \right) \right\}$$

where k = 2 (the number of sectors) and N = 50, the number of points sampled

4.3 Feeding records

Squirrels fed on the following items: *Colophospermum mopane* (green seeds) *Commelina* sp. (shoot/stem), *Commiphora mollis* (fruits), *Cucumis angurea* var. *longipes* (fruit), *Grewia bicolor* (fruits and seeds), *G. flavescens* (fruit and seeds), *Gonimbrasia belina* (the mopane worm, not on the live worms but when they had been recently dead, and still soft, the exoskeleton discarded), *Justitia matammensis* (leaf/shoot), *Berchemia discolor* (fruits) and galls on trees. Time spent feeding on some of the items was as follows: *Colophospermum mopane* (n = 22), 290,45 seconds (S.D. = 97,71) taking 100 seconds to peel it first; *Commiphora mollis* (n = 5), 160 seconds (S.D. = 24,49) taking 60 seconds of this time to peel it; *Grewia bicolor*, (n = 14) 65 seconds (S.D. = 17,76); *Gonimbrasia belina* (n = 9), 360,0 seconds (S.D. = 183,10). They were twice seen to bury dry mopane seeds, so they can be expected to scatterhoard. *Grewia bicolor* stores were found on some rocks.

4.4 Trapping results

During the eight days (88 trap hours) 16 squirrels (10 adults; 6 subadults) were caught, an average of 2,0 per day (± 0,76 S.D.). Seven of the trapped squirrels were females (5 adults) and nine were males (5 adults).

4.5 Ectoparasites

No lice were collected on these animals, but ticks were found on three individuals and were identified as *Haemaphysalis* sp. and *Rhipicephalus* sp.

4.6 Mass and Measurements

Table 2 shows mass and standard measurements calcalculated separately for museum specimens (Windhoek and Transvaal Museums); reference to Shortridge (1934) and Roberts (1951); and the present study. Hindfoot measurements are *cum ungue*, and where specimens had stunted tails, the tail measurement was not used. Subadult animals in the present study (probably around six months old) had a mean mass of 75,0 g, ear length was close to adult size, but hindfoot, head-body, and especially tail length were still markedly less than those of adults. The tails measured slightly longer than head-body throughout.

4.7 Range of movement

Determination of nesting sites, observation and retrapping of marked animals and the following of a group for one whole day, enabled a calculation of six groups for a length of 1 000 m along a dry water course. The animals were not utilizing more than 10 m on either side of the river bank, i.e. where the home ranges were stretched along the length of the river (three of the groups just seemed to touch the river for about 100 m). If 20 m is then taken as the width of the range (excluding the width of the dry river), the study area included 2,0 ha, less than 0,5 ha per group. One group, followed for a whole day, moved 200 m on both sides of the river course, bringing their range of movement in one day to 0,4 ha. However, the next day they also moved 50 m in the opposite direction, so that their total home range will be somewhat more than the daily range. In another group the range calculated over the whole week's study, was slightly more than 279 m along the river, yielding a range of 0,56 ha. They certainly move over a limited area e.g. one morning at 10h00 the two subadults were still only 20 m from the nest tree and at 12h00 they were 60m off, less than for the two adults who had then already moved at least 130 m away from the nest tree.

4.8 Population density

The size of groups averaged four individuals (i.e. number of squirrels emerging from the nest in the morning) but new litters had just been added throughout the study area which would probably push the group size up to six, resulting in a variation in population size from 24 in January to 36 from April onwards (i.e. on 2 ha). Subadults of the year could be chased out of their groups by September if the social system is at all similar to that of *P. cepapi cepapi* (Viljoen, 1977). The biomass would then vary from 400 to 600 g/ha depending on the time of year. It must be emphasized that all these figures are based on a very short period of study.

4.9 Moult

The eight adult animals encountered in the study area were all moulting their tails except for one female which had a moult line between the eyes. The eight subadults displayed no moult.

5 REPRODUCTION

Shortridge (1934) records juveniles just old enough to run about in the trees, collected from March to August. According to the museum specimens, juveniles (0 – 4 months old) and young subadults (4 – 7 months old) could be collected throughout the year, but there were two peaks of occurrence, one from October to January, and the other from April to June. During the present study, subadults estimated to be six months old were caught in April and newly born litters were then again in the nest – there seemed to be birth synchronization in the study area population with all the subadults very close to 75,0 g, and the adult females lactating again. Births therefore probably occurred early in October (middle of the hot-dry season), and in March (end of the hot-wet season), i.e. if the seasons in northern SWA are considered as follows: Hot-dry from 16 August to 15 December, hot-wet from 16 December to 15 April, and cold-dry from 16 April to 15 August (Berry, pers. comm.). At Lake Kivu, Rahm (1970) also found two peaks of breeding in *F. anerythrus*, one in August/October, at the end of the dry and into the long wet season, and a small peak in April at the end of the wet season. Although the above figures are fragmentary, it does seem as if this squirrel can be expected to breed twice a year, once in the spring and once in the autumn. During the present study an adult male with small testes was caught on one occasion and scrota from museum skins also indicate that testes of adults might not always be enlarged. The measurement from just behind the penis to the posterior tip of the scrotum was 20,85 mm in the two subadult males, and 30,92 mm in the adults. However, one adult male (adult mass) measured much shorter at 21,10 mm, indicating either a degenerated or a developing testis. Litter size deduced from three nesting groups in the present study was two in each case (two litters of one male, one female, and one litter of two females).

6 BEHAVIOUR

The striped squirrel is a contact species (deduced from the large amount of allogrooming, and the contact that is kept vocally), with a cohesive group and they might therefore be territorial as found in the bush squirrel (Viljoen 1977). However, no active chasing between any squirrels was seen, only vocalisation that might signify social spacing calls, was heard. The number of squirrels seen together on 24 occasions was 1,88 (S.D. 1,03) and ranged from one to four. Even though squirrels were often seen on their own they were usually within vocal contact distance and when one moved, another would often follow it shortly afterwards. This group cohesion is necessary in an open habitat where individuals are highly vulnerable to both ground predators when crossing open stretches, and to raptors.
(See: Alarm behaviour).

6.1 Grooming

Both auto- and allogrooming could be seen at any time of the day, the former taking up twice as much time as the latter. However, not enough time was available to make any accurate assessment of grooming.

6.2 Vocalisation

This is described as a cricket-like chattering by Shortridge (1934). It consists of very high-pitched, sharp staccato sounds reminiscent of and easily mistaken for a bird, and were used in the following contexts:

1. Contact between members of groups: an adult male was once seen to move up to the two subadults (subadults were slightly smaller than adults and noticeably more playful) of the group whilst giving a series of chirps. He was answered by the one squirrel and then first went to the one subadult, and after a naso-nasal identification sniff, moved to the other individual. Subsequently, such chirps were often heard just before one squirrel would approach the others of the group. After then meeting, they would either move off on their own again, or together with one of the group. Once, shortly after releasing a male squirrel, the chattering sounds came from his direction. It therefore seems as if they 'test for company' which usually lasts for about two minutes or less and is given at six chirps per 30 seconds. This contact or maintenance call sometimes develops into a duet, once heard between an adult male and adult female sitting 20 m apart, taking turns, 37 chirps (each a double note) per minute for each individual, lasting for 18 minutes. The male had a more dominant lower frequency to his vocal quality. The chirping can be heard at 110,6 m (n = 3) when the animals are perched about 6,0 m above ground. This is a reasonable distance for an animal with 200 m length to its home range. This call also attracts other members of the group and was once given by an adult male immediately after he discovered a *Cucumis* fruit and might also serve to attract others to food. (It is sometimes given together with tailflicks, when a squirrel is about to descend onto the ground, possibly testing for hidden danger).
2. Sporadic chattering, as far as determined only given by adult males for no obvious reason. This could

be a spacing or territorial call. Once, a subadult male in a trap next to me (from a different area in which I was at that moment), answered an adult male which I was watching and caused him to continue vocalising for 13 minutes, each time responding to one another.

3. Alarm vocalisation: Once a trapped squirrel chirped when I approached it and when I picked it up, it urinated, obviously alarmed. They often seemed to vocalise shortly after suddenly noticing me such as when I came around a corner. They have been seen to mob a snake in a group (Schlettwein pers. comm.), and in the present study two subadults also once mobbed a snake. This mobbing consists of peering down to the ground, whilst tailflicking and chirping, and every now and again moving around the tree. They were also seen to mob once for 10 minutes, the calls attracting the adult male to the group, but the cause could not be determined. However, the next day a large lizard was seen in this spot, and the reptilian movement could have caused them to start calling. In response to birds of prey the chattering was of a higher frequency with almost no audible inter-pulse breaks, sounding like a whistle. This is allelo-mimetic and causes the squirrels to freeze instantly. This call is reminiscent of that of the bush squirrel alarm behaviour towards raptors (Viljoen 1977) and quite different from the situation in forest squirrels which give a low-pitched bark (Viljoen unpubl.). A scops owlet was once chased off by the adult female in the group (two subadult squirrels were with her). She rushed at it with an excited series of chirps causing it to fly off.
4. Juvenile vocalisation: A lactating female, released next to her nest tree, gave two chirps, and was answered after a few moments by juvenile barking from the drey. She immediately rushed towards the nest. These barks are very similar to those given by pups of the genus *Paraxerus* (Viljoen 1977).

6.3 Alarm and alertness

The animals are particularly tame compared to forest squirrels, both when one approaches them and when one holds them in the hand (they do not attempt to bite as squirrels of the genus *Paraxerus* do). They can move past you at 3,0 m distance, being aware of as they obviously peer at you, but do not take fright. On one occasion one was disturbed at a trap when I came to within 2,0 m of it, and when I turned and walked off to a distance of 8,0 m, he returned to the trap trying to extricate the food from the back. This might be an adaptive strategy in the particularly open habitat where they would be better off freezing where they are (they are cryptically coloured and difficult to distinguish when motionless) than to move off. Also, as regards conservation of energy in a hot environment, it would be beneficial for them to spend as little energy as possible. They are often seen on the ground, but flee to trees at the slightest disturbance. They are also very tame at nesting time, when forest squirrels are usually extremely wary and ready to move to another nest at the least disturbance. In *Funisciurus* habitat it would be impossible to have numerous nests to choose from and the best would be not to move off. When alert the hairs on the tail are spread, and the tail is flicked. Tailflicks are sporadic jerks, with the tail still in the questionmark shape.

6.4 The tail and thermo-regulatory behaviour

The animal does not carry its tail loosely as recorded by Shortridge (1934) but carries it in a questionmark reminiscent of overseas squirrels, over the head (Figure 1). When raising the tail over the back thus, the undersurface of the tail, which is very light when compared to the back, fits neatly in between the two white side-stripes presenting a light-coloured reflecting surface to the sun. It is also remarkable that the distal part of the tail very often throws a patch of shade over the animal's head. This squirrel is adapted to arid open and hot regions and the method of carrying the tail is in sharp contrast to that of *Paraxerus*, which carries it loosely and curls it around the body in cold weather (Viljoen 1975). The hairs on the tail of *Paraxerus* are also longer than those of *Funisciurus congicus*. *Xerus*, another squirrel from an arid, hot environment, is also quoted as using its tail for thermoregulatory purposes (Marsh, Louw and Berry 1978), and Golightly (1976) found that Aberts squirrels (*Sciurus aberti*) raised the tail above the body in response to elevated body temperature.

6.5 Nests

The striped squirrel differs once again from the bush squirrel and other members of the genus *Paraxerus* in utilising dreys in addition to natural holes in trees. In the study area, some squirrels were using holes in trees and others were using leaf-nests (Table 3). Perhaps they move from leaf-nests in the summer to holes in trees in winter. Nest-building was seen on one occasion in the morning when an adult lactating female moved 150 m in 23 minutes whilst she fetched bundles of nesting material from a disused drey (eight trips) and carried it each time to the hole in the tree which they were at that time using for nesting. The leaf-nests are placed in a fork in the branches, and from the outside are covered with grass and twigs. Emmons (1975) records leaves and bark fibres as nesting material for *Funisciurus* in Gabon.

6.6 Activity

Sunrise was at 07h05 and sunset at 19h00; sun rays first appeared on the trees at 07h20 on a clear day. The squirrels' emergence from nests ranged from

07h20 to 08h15 (light intensity around 1400 lux, measured with incidence dome on Luna Six 3 light meter) depending on whether it was a clear or an overcast day. They left the next tree soon after leaving the nest. They returned to the nest in the late afternoon from 18h00 to 18h53, but mostly before 18h40, well before sunset (light intensity around 700 lux).

Table 4 presents distance travelled per 15 minutes throughout the day, periods spent dozing motionless, as well as time spent feeding and temperatures throughout the day. Distance and number of times moved indicate that they were most active early in the day. However, the early mornings were already chilly and they were probably generating heat by movement. Golightly (1975) monitoring Aberts squirrels (*Scuirus aberti*) with temperature sensitive transmitters, found that the degree of hyperthermia was directly related to the intensity of activity. The relatively long time motionless early in the day was preferably spent basking in the sun and this also suggests that the striped squirrels needed heat. Time spent feeding dropped towards 16h00, as did all other measurements of activity. They could be seen or heard at any time of the day (Table 5).

7 DISCUSSION

This short project forms part of a broader comparative study of the eco-ethology of southern African tree squirrels. *F. congicus* is a west African species and differs in various respects from the only other southern African genus *Paraxerus*. The building of dreys is a habit alien to both *P. cepapi* and *P. palliatus*. It has, however been found in other species of *Funisciurus* (Walker 1964; Emmons 1975), and could have evolved in a habitat where nest-holes are at a premium. This might also hold true for the American grey squirrel, *Sciurus carolinensis* where Burger (1969) found that placement of artificial nest boxes increased the population size, indicating a shortage of natural nest-holes in certain habitats. The other southern African woodland species, *Paraxerus cepapi*, is limited to fire controlled habitat and this probably caused their exclusive nesting in natural holes in trees.

Although the behavioural contexts of vocalisation in the different squirrels are similar, the birdlike chirrups of the striped squirrel differ from the more raucous clicks and rattles of squirrels of the genus *Paraxerus*. Striped squirrel vocalisations possibly take up less energy and in open habitat these sounds will also carry over a sufficient distance, whereas the sounds of *Paraxerus* can penetrate either denser vegetation (such as in the forest species *P. palliatus*) or carry over larger distances (as in woodland species *P. cepapi*). However, the two vocal reactions of extreme alarm i.e. the raptor alarm whistle (also found in *P. cepapi*) and the alarm barks of a yet dependent pup in the nest (found in all the squirrels encountered) are very similar. This is probably parallel evolution of the most efficient survival vocalisation under these circumstances.

The carrying of the tail over the back and head indicates an animal adapted to an open hot environment. Golightly (1976) monitoring Abert's squirrels (*Sciurus aberti*) with temperature-sensitive transmitters, found that they raised the tail above the body in response to elevation of body temperature, and that the white ventral side of the tail has a higher reflectance (58 per cent at 750 nm) than the grey dorsal body pelage (10 per cent at 750 nm). He suggests that the tail is used as a shading device that moderates solar radiation striking the body.

The striped squirrel has a completely different rat-like smell from any of the other squirrels here considered. The significance of this is not clear, as very little is known of their olfactory communication.

Kingdon (1974) regards *Paraxerus* as a subgenus of *Funisciurus*. However, in the light of the abovementioned differences between *F. congicus* and two different *Paraxerus* sp. studied (Viljoen unpubl.) they are here given separate generic status. The small size of the striped squirrel, pale colour and cohesive group structure all indicate an animal adapted to an open environment. Although it does overlap with *P. cepapi* in certain areas, they still show preference for a slightly different niche. The latter animal is better adapted to moving some distance over open ground, the former to slightly denser habitat enabling them to move from twig to twig on thinner branches than *P. cepapi*. The colour of these two open habitat squirrels is very similar and sometimes, at a glance, they might even be mistaken for one another. But the pale side-stripe, white ventrum and limbs as well as the relatively large eye of the striped squirrel are distinctive. Compared to other species of the genus, *F. congicus* is also much lighter coloured. The range of movement fits the small size of the animal. The home range is slightly smaller than that of the slightly larger (142 g and 300 g respectively) *F. lemniscatus* (0,94 to 1,24 ha) and *F. pyrrhopus* (1,0 to 5,17 ha) in Gabon (Emmons 1975).

Feeding as in most other tree squirrels is opportunistic, and similar to habits found in the bush squirrel (Viljoen 1976b).

The small litter size of two is consistent with litters in other African squirrels (Emmons 1975; Viljoen 1975), and contrasts with Nearctic and Palearctic tree squirrels that have more young born in a more altricial state of development.

8 ACKNOWLEDGEMENTS

My sincere thanks are due to Dr E. Joubert and staff of the Nature Conservation Division of the SWA Administration, and in particular Mr and Mrs H. Berry for time and energy helping me to reach an appropriate study area. Also to Mr and Mrs C. A. Schlettwein for hospitality and contributing to the success of the project in various ways. Mr C. G. Coetzee and Mr I. Rautenbach allowed me access to specimens at the Windhoek and Transvaal museums respectively. Mr W. Giess, as well as the staff at the Botanical Research Institute, Pretoria, identified plant specimens, Dr I. G. Horak and Miss H. Walker at the Onderstepoort Veterinary Research Institute identified the ticks, Ken Tinley allowed reference to unpublished work. I am grateful to Prof J. D. Skinner and Mr J. Kingdon at Oxford University for their interest in the project and commenting on the manuscript and to the Wildlife Society of South Africa and the Council for Scientific and Industrial Research for grants.

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TABLE 1: Numbers of the different tree species in one daily range (4 000m^2) of a group of *F. congicus.*

Tree species	Total	Shrub	Sub-Canopy	Canopy
Acacia mellifera var. *detinens*	12	8	4	
A. reficiens	31		27	4
Boscia albitrunca	1		1	
Colophospermum mopane	179	150	5	24
Combretum apiculatum	24	11	12	1
C. imberbe	2			2
Commiphora pyracanthoides	1	1		
Croton gratissimus var. *subgratissimus*	4	4		
Dichrostachys cinerea	31	31		
Grewia bicolor	87	87		
G. flavescens	62	62		
G. villosa	7	7		
Lonchocarpus nelsii	24	8	10	6
Maytenus senegalensis	7	7		
Mundulea sericea	2	2		
Terminalia prunioides	19	17	2	
Ziziphus mucronata	6	3	3	
Total	499	398	64	37

TABLE 2: Mass (g) and standard body measurements (mm) of the western striped squirrel, *F. congicus* (mean and standard deviation).

	Head and body	Tail	Hindfoot (c.u.)	Ear	Mass
Present study:					
(April 1978)					
Subadults (n = 5)		154,80 ± 3,27	38,30 ± 1,27	14,48 ± 1,03	75,40 ± 2,88
Adults (n = 6)		160,20 ± 4,76	38,57 ± 1,04	15,12 ± 1,71	108,17 ± 5,88
Museum specimens:					
Juvenile (n = 7)	123,75 ± 8,54	140,71 ± 12,96	35,71 ± 2,75	13,29 ± 2,69	—
Subadult	140,0 ± 5,90 (n = 7)	149,33 ± 11,34 (n = 9)	39,33 ± 0,82 (n = 9)	15,33 ± 2,12 (n = 9)	66,75 ± 3,86 (n = 4)
Adult	146,91 (n = 23)	161,08 ± 9,10 (n = 26)	40,18 ± 2,13 (n = 17) 37,83 ± 2,18 (s.u.) (n = 18)	15,84 ± 2,42 (n = 45)	113,0 ± 7,78 (n = 13)
Shortridge (1934):					
Juvenile (n = 1)	98	107	31	12	
Adults (n = 49)	155,94 ± 6,63	169,90 ± 10,04	40,23 ± 1,08	16,66 ± 0,60	
Roberts (1951):					
Juveniles (n = 1)	120	130	34 (s.u.)	16	
Adults (n = 8)	148,3	169,33	38,67 (s.u.)	15,33	

TABLE 3: Description of nestholes and dreys of the western striped squirrel, *F. congicus.*

	Tree species	Height of nest-hole or drey and dimensions of drey	Direction of entrance
Nestholes	*Colophospermum mopane*	1,75 m (tree 4 m high)	West
	C. mopane	2 m (tree 9 m high)	West
Dreys	*C. mopane*	12 m (14 x 22 cm)	
	C. mopane	9 m (14 x 25 cm)	
	Lonchocarpus nelsii	5 m (15 x 20 cm)	East
	Combretum imberbe	11 m (15 x 20 cm)	

TABLE 4: Activity of striped squirrels, *F. congicus* throughout the day. (Sample size in parenthesis)

Shade temp. °C (n = 2)	Time of day	Distance travelled/ 15 minutes (metres)	No. of times move/15 minutes	Time motionless (seconds)/15 minutes	Time spent feeding (seconds)/15 minutes
13 – 19	07h00 – 09h00 (n = 9)	41,67 ± 20,05	11,75 ± 5,76	210±222,49	86,67±216,67
19 – 27,9	09h00 – 13h00 (n = 10)	25,24 ± 16,39	7,70 ± 4,66	159,43 ± 127	43,21 ± 59,35
27,9 – 29	13h00 – 16h00 (n = 12)	17,63 ± 15,21	6,25 ± 4,47	222,50 ± 376,5	175,83 ± 194,50
29 – 23,8	16h00 – 19h00 (n=6)	11,10 ± 9,90	2,29 ± 3,82	326,56 ± 398,38	46,88 ± 87,62

TABLE 5: Numbers of squirrels *F. congicus* encountered throughout the day.

Shade temp. °C (n = 2)	Time of day		Total no. of squirrels either seen or heard	Total no. of squirrels heard
13 – 19	07h00 – 09h00	(n = 7)	2,4	0,86
19 – 24,5	09h00 – 11h00	(n = 6)	2	0,17
24,5 – 27,9	11h00 – 13h00	(n = 4)	2,5	1,75
27,9 – 28,6	13h00 – 15h00	(n = 6)	1,5	1,17
28,6 – 28,4	15h00 – 17h00	(n = 7)	1,14	1,00
28,4 – 23,8	17h00 – 19h00	(n = 5)	3,0	2,00

Aspects of renal physiology, nutrition and thermoregulation in the ground squirrel *Xerus inauris*

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CONTENTS

ABSTRACT

The ground squirrel possesses very efficient kidney function which is reflected in a high urine:plasma concentration ratio, particularly during the summer months, and one of the highest relative medullary thicknesses recorded in mammals. The diet of these animals changes markedly from the wet to the dry season, as does the incidence of internal parasites. The flared, erect tail is used *inter alia* as a unique shading device as part of this species' complex thermoregulatory behavioural repertoire.

1 INTRODUCTION

The ground squirrel (Plate 1) enjoys a wide distribution in South Africa and is common in the central area, especially in the maize areas of the Orange Free State and Western Transvaal. It is also found throughout South West Africa, even occurring on the gravel plains of the Namib Desert (Coetzee, 1969).

In its natural habitat this small, diurnal mammal (300 – 500 g) excavates vast burrowing systems, an average colony consisting of 22 to 30 exit/entrance holes spread over an area of 200 to 400 m^2 (Zumpt, 1970). In fact, *Xerus* is probably the smallest diurnal mammal encountered in southern African deserts. As such it has to contend with extremely high surface soil temperatures and intense radiation without access to drinking water. Nothing, however, is known about its renal function and thermoregulatory behaviour which presumably are well adapted to the hostile environment which it inhabits.

The purpose of this study, therefore, was to assess renal efficiency in these animals by examining the morphology of the kidneys and the chemical composition of the urine and plasma. In view of the important influence of diet on water balance, this aspect was also investigated together with superficial observations on thermoregulatory behaviour.

2 PROCEDURE

2.1 Collection and analyses of plasma and urine samples

Animals were shot in the Okaukuejo area of the Etosha National Park and urine samples were collected within five minutes. Blood was removed from the jugular, the hepatic veins or the heart in a heparinized disposable syringe. The plasma was drawn off after 15 minutes of centrifuging in a clinical centrifuge and immediately cooled to -5°C in the field. Within three hours all samples were further cooled to -20°C in the laboratory. These samples were then stored at this temperature for several months until a detailed analysis could be performed. Urine was removed from

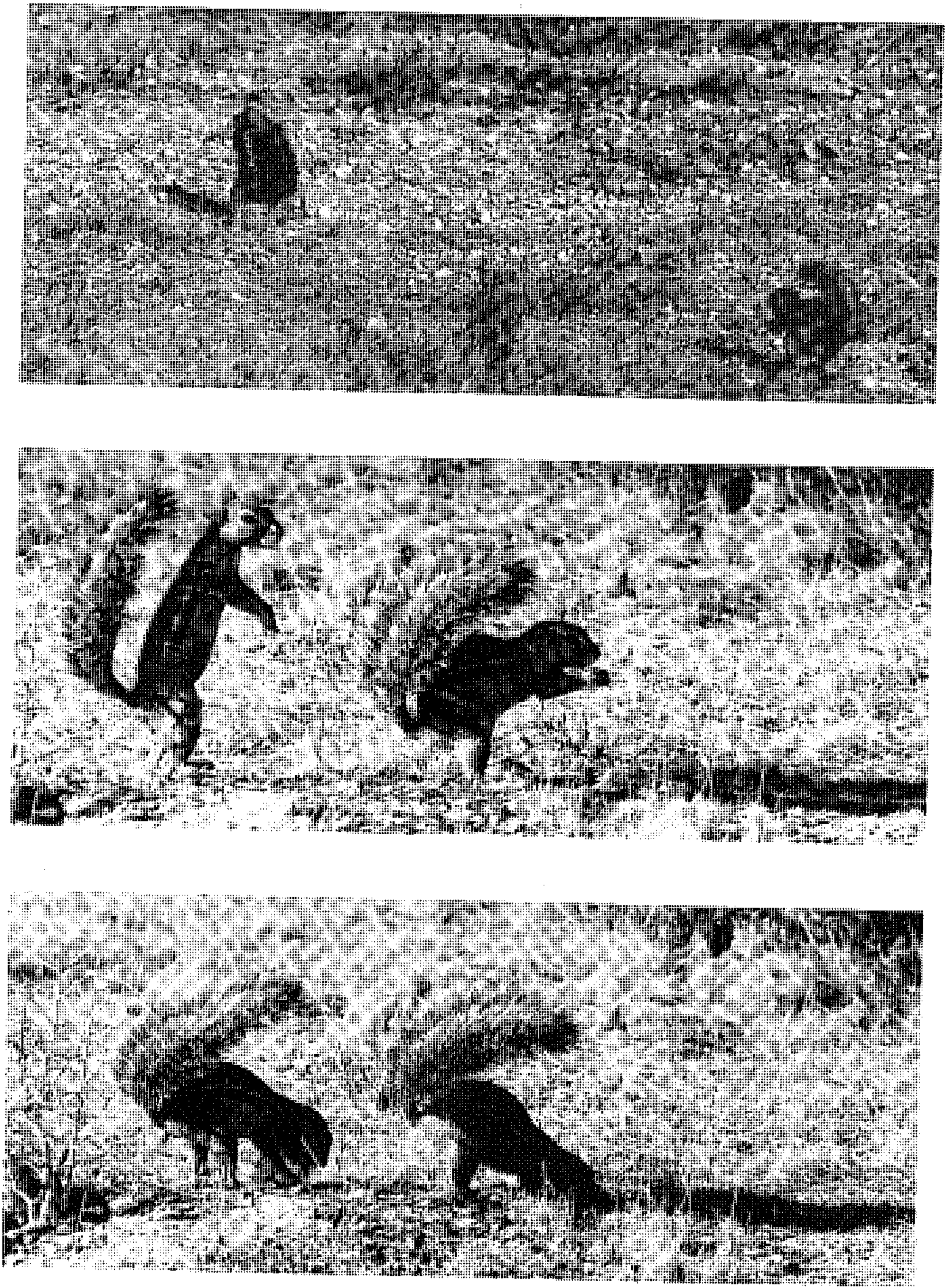

PLATE 1: Illustrating specialised thermoregulatory behaviour in *Xerus inauris*. The animals employ the flared tail for shading and orientate their bodies in the opposite direction from incoming insolation. Note the position of the shadows cast by the animals.

the bladder in a syringe and was cooled and stored in an identical manner to the plasma.

Samples were collected towards the end of February, 1976 which represents the height of the rainy season when free moisture and green vegetation are available, and at the end of August, 1976 when no free water was available and humidity was low (10 to 30 % rh).

The plasma and urine samples were analysed to determine the total osmolality as well as urea, sodium and potassium concentrations. Osmolalities were determined using an automatic osmometer (Advanced Instruments, model 6731 RAS). The concentration of urea was determined enzymatically using the method of Fawcett and Scott (1960) and a spectrophotometer at 546 nm. Sodium and potassium were determined using flame photometric techniques (Instrumentation Laboratory, IL 243).

2.2 Kidney dimensions

The mass of individual kidneys was determined. Length, width and depth dimensions were measured with a pair of calipers to the nearest mm and the kidney size was calculated as the cube root of the product of these dimensions (Sperber, 1944). The kidneys were bisected medially and the width of the cortex and the medulla were measured at 10 intervals along the periphery and the means were determined. The cortico-medullary ratio was calculated and the relative thickness of the medulla was determined using the formula:

$$\frac{\text{medulla thickness} \,.10}{\text{kidney size}} \qquad \text{(Sperber, 1944).}$$

2.3 Stomach contents

The stomach contents of ground squirrels killed in the wet and dry season were analysed under a dissecting microscope. Five sub-samples were floated in water and the percentage area of dietary items was estimated with the aid of an ocular grid. Percentages thus obtained were interpreted as being percentages of total stomach contents. The incidence of parasitism was recorded.

2.4 Food selection

Observations on the food eaten by *X. inauris* were made with a telescope in the Etosha National Park between February and March in the wet season and again in August during the dry season, in 1976.

2.5 Thermoregulatory behaviour

While observing feeding habitats of the animals, incidental observations on thermoregulatory behaviour in relation to prevailing ambient temperature were recorded.

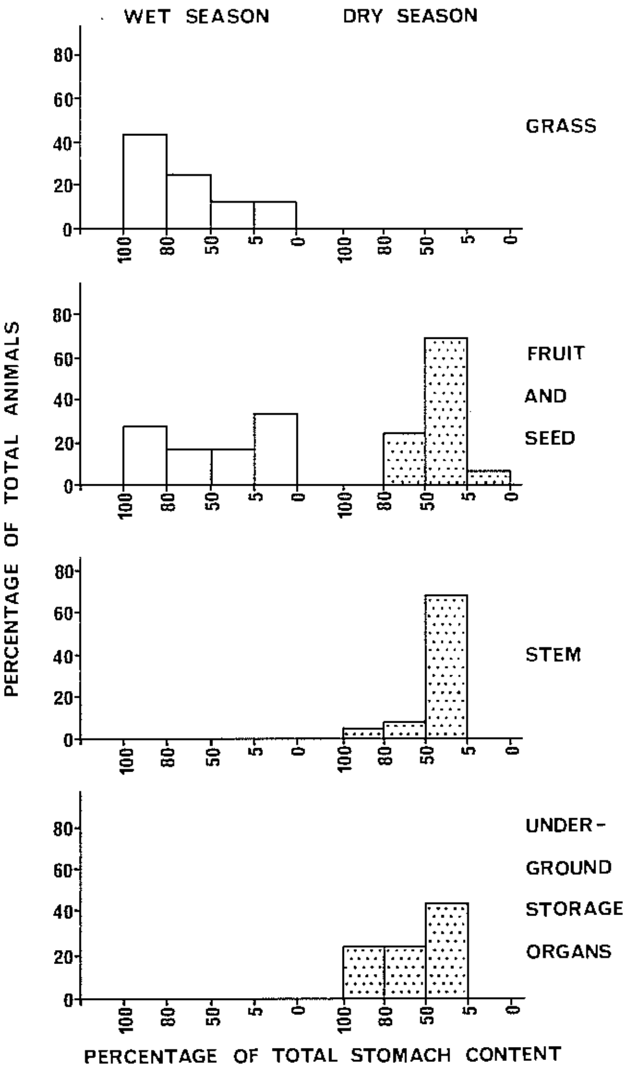

FIGURE 1: Stomach content analyses in *Xerus inauris*.

3 RESULTS

3.1 Plasma and urine analyses

The results of the plasma and urine analyses of *X. inauris* are given in Tables 1 and 2 respectively. Typical mammalian plasma characteristics are revealed. The high potassium concentrations are probably attributable to shock associated with death. The Student t-test showed that plasma urea levels increased significantly by a factor of two in the dry season ($p < 0{,}001$). Osmolality as well as sodium and potassium concentrations showed no significant seasonal variation ($p > 0{,}1$). All the urine constituents measured increased significantly in the dry season. Osmolality, potassium and urea increased by factors of 3,0; 3,6; and 3,4 respectively. These increases were all significant at $p < 0{,}001$ using the Student t-test. Sodium levels rose by a factor of 2,8 ($p < 0{,}05$).

3.2 Kidney dimensions

The kidney dimensions of *Xerus* are given in Table 3 and when these are compared with dimensions reported in the literature (Table 4), it is clear that the medullary thickness of *Xerus* is among the highest recorded to date.

3.3 *X. inauris* stomach contents

Fig. 2 is a summary of the major dietary components of *X. inauris* during the wet and in the dry seasons in the Okaukuejo area of the Etosha National Park. In the wet season grass and fruit comprise most of the diet. In 66,6 % of the animals investigated more than 50 % of the stomach contents was green grass. During the dry season, in spite of the presence of dry grass, the dietary items emphasized were underground storage organs, stem and fruit with the attendant seeds. No animal matter was detected in any of the stomachs. Thus, the Etosha National Park ground squirrels appear to be entirely herbivorous.

It is also of interest to note that the stomach of *Xerus* is capable of massive enlargement to accommodate the large intake of vegetable material. In this respect it was found that the ratio of the mass of the stomach contents to the total body mass was as high as 0,06:1. This represents 6 % of the animal's total body mass and is typical of an exclusively herbivorous animal. As would be expected, the animals possess an enlarged caecum where digestion of cellulose presumably takes place.

3.4 Food plants utilised by *X. inauris*

The vegetation favoured by *X. inauris* during February and March, 1976, is listed in Table 5. Unfortunately, it was not possible to estimate from stomach content analysis the proportion of the various plants consumed.

3.5 Stomach parasites

The incidence of parasitism fell from 75 % of the total number of animals in the wet season to 53 % in the dry season. The parasites were nematodes, belonging to the Ascaridae. Further identification was not possible. Infestation appeared to be associated with the consumption of green grass. All those individuals which had a high percentage of grass in their stomachs also contained numerous small parasites (<2 mm). The maximum number of these very small nematodes recorded from one individual was 10 000. All the nematodes found in the dry season were greater than 25 mm in length and many were about 70 mm long. The highest number found in one individual during the dry season was six.

3.6 Thermoregulatory behaviour

No attempt was made to examine thermoregulatory behaviour in detail. However, we wish to confirm an interesting behavioural mechanism, first suggested by Smithers (1971), namely the use of the flared tail as a shading device under conditions of intense solar radiation (Plate 1). In this plate it can be seen from the shadows cast by the animals that they orientate their bodies in such a way as to obtain maximum shading effect of the tails while foraging for food. This well synchronised orientation behaviour is only employed under conditions of high solar radiation when sun temperatures approach and exceed *ca.* 30°C. At lower ambient temperatures orientation is random. It should, however, be emphasized that flaring of the tail is not confined to thermoregulatory behaviour and is also frequently used as a behavioural signal during social interaction and during escape behaviour from predators. Available time, however, did not allow collection of quantitative data in regard to critical threshold temperature and wind speed at which tail shading takes place.

4 DISCUSSION

The plasma analyses of *X. inauris* revealed typical mammalian characteristics. *X. inauris* showed an increase in all blood solutes in the dry season, with the exception of potassium. The increase in urea is statistically significant (Table 1). This increase in plasma concentration could possibly improve water economy by reducing the kidney load, and would facilitate water retention by the plasma.

When the urine osmolality of *Xerus* is compared with that of other species (Table 4) it appears as if *Xerus* possesses kidneys which are among the most efficient examined to date. In the rat, cat, man, dog, kangaroo rat and jerboa the osmotic ceiling of the urine can be increased by raising the concentration of urea in the urine (Schmidt-Nielsen *et al.*, 1961b). The vast increase in urinary urea and osmolality that occurred in the dry season suggests that *X. inauris* may employ a similar strategy (Table 2).

Most plants do not accumulate sodium and chloride ions to any great extent and herbivores as a consequence tend to be chronically short of these electolytes (Potts & Parry, 1964). Mammalian homeostasis requires a high plasma level of sodium and chloride and efficient reabsorption of these electrolytes from the urine is very important. The very low levels of sodium in the urine of *X. inauris* in the wet season (Table 2) implies a low sodium level in the diet and an extremely efficient reabsorption of sodium in the kidney. As green grass was the major dietary component in the wet season, it is very likely that these grasses are exceptionally low in sodium (Fig 2).

The higher sodium in the urine in the dry season may be a result of both a higher sodium intake as well as the more efficient reabsorption of water by the kidney. Zumpt (1970) reported that the major food items of *X. inauris* from South Africa are bulbs, corms, roots, green grass, seeds and stems. The results in this investigation support this view (Fig 2, Table 5). However, he also records finding termites, beetles, locusts and other insects in *X. inauris* stomachs. This was particularly so during the breeding season between July and September. It is therefore surprising that during the wet season in the Etosha National Park, when sodium seems to be in short supply, *X. inauris* do not eat insects. This, however, may be due to the relatively small size of our sample.

The maximum renal efficiency of *Xerus* is not apparent from the blood and urine samples. However, kidney structure reflects maximum urine concentrating ability and when this is examined the position of this species, in terms of arid-adaptiveness, becomes apparent.

Table 4 shows the position of various mammals with respect to relative medullary thickness and the maximum urine concentration measured. The bontebok (*Damaliscus dorcas dorcas*) shows a similar urine concentrating ability to the domestic cat whereas the springbok (*Antidorcas marsupialis*) has a slightly lower efficiency than the white rat and is, therefore, superior to *D.d. dorcas*. *X. inauris* falls within the class of desert rodents.

Based on its exceptionally high relative medullary thickness it can be predicted that *X. inauris* should have a maximum urine concentrating ability in the region of 6 890 mOsm/l. This would be one of the highest values recorded in mammals and it would be extremely interesting to test these animals under controlled laboratory conditions to confirm this prediction. These results also suggest that the dry season at Etosha National Park is not sufficiently stressful to elicit maximum urine concentrating potential in *X. inauris*, as the maximum osmolality recorded was only 3 280 mOsm/l. Presumably preformed water in the food and metabolic water is sufficient to meet the requirements of *X. inauris* in the dry season. Moreover, efficient thermoregulatory behaviour probably minimises excessive water loss.

Research on American ground squirrels has shown that these animals employ various strategies to improve water economy in addition to efficient renal function. One of the most important strategies has been the minimisation of water loss by efficient thermoregulation in hot environments (Hudson *et al.*, 1972). This has been achieved in several ways. In North America arid-adapted ground squirrels permit their body temperature to increase to as much as 45°C before seeking thermal refuge in their burrows, where excess heat can be off-loaded by flattening the body against the cool earth. Most ground squirrels have low basal metabolic rates thus minimising endogenous heat production and, furthermore, peripheral blood circulation can be voluntarily reduced. Under extreme stress, ground squirrels pant and spread saliva over their fur. To what extent *X. inauris* employs these strategies of water conservation and the degree of saving that they would result in is not known.

5 ACKNOWLEDGEMENTS

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TABLE 1: Plasma analyses of *Xerus inauris*

SEASON	N	MEAN	S.D.	RANGE
		Osmolality (mOsm/l)		
Wet	21	240,95	±62,72	168 — 412
Dry	10	257,70	±22,29	220 — 290
		Sodium (mEq/l)		
Wet	22	183,50	±41,79	121 — 281
Dry	10	206,50	±17,81	184 — 242
		Potassium (mEq/l)		
Wet	22	16,65	± 4,68	8,3 — 23
Dry	10	14,61	± 2,81	11,5 — 21
		Urea (mg/100 ml)		
Wet	22	44,62	±16,20	10,4 — 70,4
* Dry	10	86,31	±16,69	54,2 — 105,8

* Significant difference between wet and dry season concentrations ($p < 0{,}001$)

TABLE 2: Urine analyses of *Xerus inauris*

SEASON	N	MEAN	S.D.	RANGE
		Osmolality (mOsm/l)		
Wet	18	634,1	± 442,8	180 — 1572
**Dry	9	1934,4	± 636,9	1260 — 3280
		Sodium (mEq/l)		
Wet	20	9,9	± 18,9	1 — 74
* Dry	10	27,6	± 22,3	6 — 70
		Potassium (mEq/l)		
Wet	20	152,6	± 76,8	54 — 281
**Dry	10	555,6	± 72,4	448 — 684
		Urea (mg/100ml)		
Wet	20	2526,1	±1559,9	932 — 4658
**Dry	10	8666,5	±3036,6	5721 — 13509

** Significant difference between wet and dry season concentrations ($p < 0{,}001$)

* Significant difference between wet and dry season concentrations ($p < 0{,}05$)

TABLE 3: Kidney dimensions of *Xerus inauris*

	N	MEAN	S.D.	RANGE
Mass (g)	44	1,1	±0,21	0,74 — 1,69
Size (mm)	44	12,1	±0,84	10,30 — 14,30
Medulla (%)	10	77,7	±3,60	73,10 — 83,80
Cortex (%)	10	22,3	±3,60	16,20 — 26,90
Relative medullary thickness	10	12,4	±1,16	10,70 — 14,10
Kidney size/body mass × 10^3	44	2,3		

TABLE 4: Relative medullary thickness (*) and maximum urine/plasma osmotic ratios in selected animals.

Animal	Relative medullary thickness	Maximum urine/plasma osmotic ratio
Beaver (*Aplodontia rufa*)[1]	1,3	2,7
Man (*Homo sapiens*)[2]	3,0	4,2
Cat (*Felis domesticus*)[1]	4,8	—
Bontebok (*Damaliscus dorcas dorcas*)[3]	4,9	5,4
Springbok (*Antidorcas marsupialis*)[4]	5,5	8,3
White rat (*Rattus rattus*)[2]	5,9	8,9
Jerboa (*Jaculus jaculus*)[1]	9,3	—
Gerbil (*Gerbillus gerbillus*)[2]	10,5	14,0
Ground squirrel (*Xerus inauris*)[5]	12,4	14,9**
Desert mouse (*Psammomys obesus*)[1]	12,9	17,0

* Calculated as $\frac{\text{medulla thickness (mm)} \cdot 10}{\text{kidney size}}$

Sources: Chew, 1965[1]; Gordon, 1972[2]; van Zyl, 1978[3]; Hofmeyr & Louw, 1977[4]; and present investigation[5]

** Theoretical maximum

TABLE 5: Plants eaten by *Xerus inauris* in the Etosha National Park during February to March 1976.

1. Grasses:
    - Aristida edsensionis
    - Aristida hordeacea
    - Enneapogon brachystachyus
    - Eragrostis annulata
    - Eragrostis echinochloidea
    - Eragrostis glandulosipedata
    - Monelytrum Luederitzianum
    - Setaria verticillata
    - Sporobolus tenellus
    - Tragus racemosus
    - Urochloa brachyura
2. Herbs:
    - Erucastrum arabicum
    - Geigeria odontoptera
    - Heliotropium ovalifolium
    - Hirpicium gazanioides
    - Sida hoepfneri
3. Shrubs:
    - Cyathula hereroensis
    - Leucosphaera bainesii
    - Salsola tuberculata

Waders (Charadrii) and other birds on the Namib Coast: counts and conservation priorities

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CONTENTS

ABSTRACT

Counts of waders (Charadrii) and other birds are given for a 300 km section of the coast-line of the Namib Coast, South West Africa, centred on Walvis Bay. A total of 170 000 birds (excluding cormorants) was counted in the summers 1976/77 and 1977/78. Waders totalled 83 069 of which 88,5 % were Palaearctic migrants. The most abundant wader species were sanderling *Calidris alba* and curlew sandpiper *C. ferruginea*. Terns totalled 37 000 and flamingoes 38 000. The three most important localities were Walvis Bay lagoon, Sandvis and the coast between the Swakop River and Walvis Bay.

1 INTRODUCTION

Part of the coast-line of South West Africa is at present undergoing developments for industrial and recreational use with concomitant habitat alteration. The avifauna may be unable to adapt to these changes. This paper reports on counts of waders (Charadrii) and other birds on a section of the Namib coast of South West Africa. It identifies habitats containing major wader concentrations and makes recommendations for their protection. It forms a sequel to a survey of coastal wader habitats in the south-western Cape, South Africa (Cooper *et al.* 1976, Summers *et al.* 1977).

2 STUDY AREA AND METHODS

The coast-line of South West Africa is dominated by the Namib Desert and the Benguela upwelling system. This upwelling of cold and nutrient-rich water is a result of off-shore winds. The nutrients are the basis of the food chain in the study area, and are also ultimately the source of the large pelagic fishing industry at Walvis Bay (Stander 1963). The Namib Coast is an arid environment; precipitation at Walvis Bay averages 17 mm per year (Weather Bureau: Windhoek, pers. comm.). During December 1976 and January 1977 the Western Cape Wader Study Group, with the co-operation of the Division of Nature Conservation and Tourism of the South West Africa Administration, undertook an expedition to the Namib Coast of South West Africa, and did a near-complete census of all waders and other birds on the *ca.* 250 km coastline between Cape Cross (21°45′S, 13°50′E) and Sandvis (23°22′S, 14°20′E) (Map 1). All non-passerines present which are normally associated with an aquatic environment were counted, except cormorants, *Phalacrocorax* spp. common *Sterna hirundo* and Arctic terns *S. paridisea* were not identified separately, neither were Hartlaub's *Larus hartlaubi* and grey-headed gulls *L. cirrocephalus*. These two gulls breed in mixed colonies in the area (Cooper and Clinning pers. obs.) and have been known to interbreed (Sinclair 1977).

A report on this expedition has been produced (Underhill and Whitelaw 1977). In January 1978 further censuses by the Western Cape Wader Study Group extended the counted area 48 km northwards to Durissa Bay (21°17'S, 13°49'E), and a more comprehensive census of the birds in the southern part of Sandvis was undertaken. This area had not previously been censused effectively (Underhill and Whitelaw 1977). In addition the birds of the Walvis Bay harbour area were counted. A count of Elizabeth Bay (26°51'S, 15°11'E), made on 1 December 1977 by W. R. Siegfried during a coastal survey between Lüderitz (26°38'S, 15°10'E) and the mouth of the Orange River (28°38'S, 16°26'E), has been included.

All counts were conducted in midsummer (December – January) when large fluctuations in numbers of Palaearctic waders do not occur in southern Africa (Berry and Berry 1975; Pringle and Cooper 1975, 1977). Further evidence for this within the study area is provided by the fact that of 1 040 Palaearctic waders ringed on the 1976/77 expedition, 19 out of 21 retraps were made at the place of ringing. A turnstone *Arenaria interpres* moved 20 km northwards, and a curlew sandpiper *Calidris ferruginea* moved 80 km southwards, both over four-day periods (Underhill and Whitelaw 1977).

Palaearctic terns show a variation from year to year in the sizes and localities of the flocks (pers. obs.). Flocks of common/Arctic terns *Sterna hirundo* and *S. paridisaea* were present at Sandvis in January 1977, but were encountered north of Cape Cross in January 1978 when only a small number was seen at Sandvis.

Since the 1978 counts of terns are considered the more accurate, we have subtracted 15 000 common/Arctic terns from the totals given in tables 2 and 4. This was our estimate of a single large flock at Sandvis in 1977.

The open coast-line was divided into sections, mostly 5 km in length. These were surveyed for birds either from a four-wheel drive vehicle or on foot. Two 5 km sections were surveyed by both methods. Both the total number of waders and the species composition were independent of the census method (table 1). This indicates that counts made on foot and from a vehicle are comparable, and that there is no need to make corrections for the type of count made (Underhill and Whitelaw 1977).

3 RESULTS

Summarized results of counts from Durissa Bay to Sandvis show the estimate of the wader population to be 83 069 of which 73 526 (88,5 %) were Palaearctic migrants (tables 2 and 3). The most abundant species were sanderling *Calidris alba* (25 245) and curlew sandpiper (23 192) which together account for 58,3 % of the wader population (table 3).

The non-wader population was estimated to be approximately 90 000 (table 2). Terns (37 000), flamingoes (38 000) and gulls (5 000) account for about 90 % of the non-wader population (table 2, with a treatment by species in table 4). The total population (excluding cormorants) in the study area in midsummer is about 170 000 birds (table 2). Berry (1976) found the population of Cape cormorants *Phalacrocorax capensis* in the area to fluctuate about a mean of one million birds.

The largest numbers of waders and other birds occurred at Walvis Bay lagoon (22°59'S, 14°31'E) (Fig 2) (29 533 waders and 19 818 non-waders totalling 49 351 birds), at Sandvis (map 3) (*ca.* 27 000 waders and *ca.* 33 000 non-waders totalling *ca.* 60 000 birds) and along the 30 km section of coast-line between the Swakop River (22°40'S, 14°30'E) and Walvis Bay (12 195 waders and 1 240 non-waders totalling 13 435 birds) (tables 3 and 4). Detailed counts for these three localities are given in tables 5, 6 and 7 respectively.

Counts at non-coastal localities are given in table 8. Significant numbers of birds occurred at Walvis Bay sewage works, 'Bird Paradise', (5 156 birds, including 2 420 lesser flamingo *Phoeniconaias minor* and 1 280 Cape teal *Anas capensis*), Swakopmund saltworks (5 941 birds, including 3 077 waders and 1 440 flamingoes) and pans near Cape Cross (6 794 birds, including 2 593 flamingoes and 2 187 black-necked grebe *Podiceps nigricollis*) (table 8).

Detailed counts for the 5 km sections into which the coast between Cape Cross and Sandvis was divided are given in Underhill and Whitelaw (1977). Counts made north of Cape Cross are shown in table 9, and the Elizabeth Bay census is in table 10. Table 11 shows wader densities on open shore-line for the most abundant species (birds per kilometre).

4 DISCUSSION

Walvis Bay lagoon, Sandvis and the 30 km of coast-line between the Swakop River and Walvis Bay account for 82 % of the wader population within the study area (table 4). Two non-coastal localities, Walvis Bay sewage works and the pans near Cape Cross, are important to certain species. The conservation of these localities is discussed below.

"The Ramsar Convention on Wetlands of International Importance, Especially as Waterfowl Habitat" (Carp 1972, Smart 1976) produced criteria to be used in assessing the value of wetlands as habitat for birds. Pertinent criteria are that a wetland of international importance should support more than 20 000 waders, or at least 1 % of the total world population of a single species. These criteria apply to both Walvis Bay lagoon and Sandvis.

4.1 Walvis Bay lagoon

The area below high water mark of the Walvis Bay lagoon falls under the administration of the South African Railways and Harbours, who have leased part of the southern section to a salt manufacturer. It supports 30 000 waders, 88 % of which are Palaearctic migrants, 17 000 flamingoes, and 574 white pelicans *Pelecanus onocrotalus* (table 5). Both species of flamingo and the white pelican are considered rare and vulnerable species in the Republic of South Africa (Siegfried *et al.* 1976). The total world population of the chestnut-banded plover *Charadrius pallidus* is not known, but the 2 000 found here probably comprise more than 1 % of the entire population (table 5). The importance of Walvis Bay to this species was noted by Finch-Davies (1919) who commented on Fisher's sand-plover, the former name of this species: 'This little sandplover, which is usually considered rare, is exceedingly common here, and I have secured five at one shot'. The rarity of this species elsewhere is partly borne out by the total of only 135 birds counted in the south-western Cape (Summers *et al.* 1977).

A road, built in 1971, around the present perimeter of the lagoon has resulted in the formation of barren dry salt flats in an area which was formerly inundated at spring high tides. Thus an area which compared with the very rich tidal salt flats at the southern end of Sandvis (count area D, table 6) has been destroyed as wader habitat. Wind-blown sand is increasingly being deposited in the remaining lagoon area. Map 2 shows the original boundary of inundation (Government Printer 1944) and the present boundary. Extensive salt-works development is presently taking place in the cut-off area (labelled F on Fig 2). Although this may lead to the recreation of wader habitat, the effect of the discharge of saltworks' 'bitters' (highly concentrated solution of salts which remain dissolved after the sodium chloride has crystallized out) needs to be carefully monitored, since discharge areas do not support hirds (pers. obs.).

4.2 Sandvis

Sandvis enjoys protection as part of the Namib Desert Park, administered by the Nature Conservation and Tourism Division of the South West Africa Administration. However, there is no guarantee that this protection is absolute, as is evidenced by the granting of mineral prospecting concessions within the Park. No casual visitors are allowed into the Sandvis area, and anglers require permits to fish along the beach which lies within the Park and immediately to the north of Sandvis.

Sandvis supports *ca.* 27 000 waders, 83 % of which are Palaearctic migrants, and 14 000 flamingoes (table 6). 2 600 chestnut-banded plovers here are probably well in excess of 1 % of the total population of this species (table 5). Sandvis supports 360 white pelicans, making it an important feeding area for this species. White pelicans were reported breeding until 1947 but no longer do so (Hoesch and Niethammer 1940, Rand 1952, Berry and Berry 1975). Caspian terns *S. caspia*, a rare and vulnerable species in South Africa (Siegfried *et al.* 1976), breed in small numbers (Underhill and Whitelaw 1977, Clinning 1978a).

The northern third (areas A and B, map 3) was censused for birds monthly between July 1970 and June 1972 (Berry and Berry 1975). Our census figures for the comparable area (areas A and B, table 6) are generally consistent with theirs. Sandvis is steadily undergoing changes. At the turn of the century it was a deep water harbour, nowadays, at low tide, there are extensive areas less than one metre deep (Kensley and Penrith 1977). Of the three major lagoons on the western coast-line of southern Africa, Sandvis is the only one comparatively free from pollution threats. Langebaan lagoon (33°05'S, 18°03'E), in the south-western Cape, South Africa, opens into Saldanha Bay, a major ore loading terminal and a potential industrial growth point (Siegfried 1977). Walvis Bay is the major port for South West Africa, is a major fishing industry centre and the lagoon contains extensive salt-works. During 1977 and 1978 the bay was used as a haven for unemployed oil tankers. A major pollution incident is more likely to occur at Langebaan lagoon or Walvis Bay than at Sandvis.

4.3 The coast between the Swakop River and Walvis Bay

The 30 km of coast between the Swakop River and Walvis Bay deserves special attention. It supports a total of 12 195 waders in summer (table 7), 98 % of which are Palaearctic migrants, and approximately 3 000 waders in winter (Clinning, pers. obs.). This represents a summer density of 407 birds per kilometre, of which 400 are Palaearctic migrants (table 11). This section of coast-line has large off-shore kelp beds composed of *Laminaria pallida*, and a mixture of rocky and sandy shores. In the south-western Cape, South Africa, mixed shores adjoining kelp beds support a much higher density of waders than other beaches (Summers *et al.* 1977). This area is exceptionally rich in waders compared with the rest of the coast-line surveyed (table 11). Very low densities prevail (with a few isolated exceptions) between the mouth of the Kunene River (17°15'S, 11°45'E) and Durissa Bay and from Sandvis to Oystercliffs (25°20'S, 14°47'E) (Clinning, pers. obs.). The 3 km beach at Elizabeth Bay (table 10) had a wader density of 175 birds per kilometre, a figure many times higher than that which prevailed on the remainder of the coast between Lüderitz and the mouth of the Orange River, which is considered to be a generally poor wader habitat. This beach contained much washed up kelp and large kelp beds occur off the northern part of the bay (W. R. Siegfried, pers. comm.). The average wader density on mixed shores on the west coast of the south-western Cape, South Africa, (the richest shore type in the area) was 78,5 birds per kilometre (Summers *et al.* 1977). The highest individual densities (219,5 over 4,4 km at Kommetjie (34°08′S, 18°20′E) and 198,5 over 5,9 km at St. Helenabaai (32°46′S, 18°02′E)) are in fact only approximately half the density sustained over the 30 km between the Swakop River and Walvis Bay.

Ten kilometres north of Walvis Bay is an off-shore guano platform on which white pelicans and cormorants breed (Rand 1952; Berry 1974, 1975). On 2 January 1977, 100 adult white pelicans and 60 chicks, many of which were close to fledging, were observed. On 11 January 1978 minima of 298 adult pelicans and 81 large chicks were counted on the platform from the shore. This guano platform is one of four known regular breeding sites of the white pelican in southern Africa and the only known one in existence on the South West African coast (Cooper, pers. obs.). Approximately 100 – 150 crowned cormorants *P. coronatus* breed below the platform (Berry 1974) and feed off the coast between the Swakop River and Walvis Bay (pers. obs.). This species is considered 'rare and vulnerable' in South Africa (Siegfried *et al.* 1976). This section of the coast of South West Africa is also by far the most accessible to the public. A tarred coastal road links Swakopmund and Walvis Bay. The most significant human activity along the coast is recreational angling. This in itself causes little disturbance to the birds, except that anglers collect for bait shore animals that are also taken by waders. However, many four-wheel drive vehicles are used on the beach itself and cause considerable disturbance to the birds, especially in summer, the main tourist season, when the entire beach is covered by deep vehicle tracks (pers. obs.). Since there are access roads to the major recognised angling spots, total prohibition of vehicles along the beach on this section of coast should be enforced, and should cause little or no hardship to anglers and other tourists. If necessary, further access roads could be provided. Before 1 September 1977 the area was controlled by the Nature Conservation and Tourism Division of the South West Africa Administration. The Department of Nature and Environment Conservation of the Cape Provincial Administration, South Africa, is now responsible for the administration of this area, and should patrol it. The South West Africa Administration permits no overnight camping and this prohibition should continue. No further provision of recreational facilities should take place along this section of coast.

4.4 Non-coastal localities

The Walvis Bay sewage works is the most important freshwater habitat within the study area. Its greatest ecological significance is as a source of fresh water for flamingoes, which can be observed flying between the sewage works and the nearby Walvis Bay lagoon. It also supports 53 % of the ducks and geese in the study area (tables 2 and 8). It is intended to start purifying and recycling water and control will change hands from the Walvis Bay Municipality, which proclaimed the area a municipal nature reserve, 'Bird Paradise', to the Department of Water Affairs. It is recommended that provision be made for the retention of some of the present evaporation ponds.

The pans near Cape Cross are of importance to the black-necked grebe. More than half (2 187 out of 4 264) (tables 3 and 8) of the black-necked grebes observed occurred there. This species is apparently a migrant to the coastal region from inland (Berry and Berry 1975). Since this area is apparently suitable for development as a salt reclamation works, it is recommended that no such development be permitted. The area has already been given out to mining concessions.

The Damara tern *S. balanaerum* is considered a rare and vulnerable species in South Africa (Siegfried *et al.* 1976). Its distribution, numbers and conservation in the area surveyed are discussed by Frost and Shaughnessy (1976) and Clinning (1978b).

The Caspian tern bred in a colony of 30 – 35 pairs at the Swakopmund salt works in 1975 and 1976 but not since, apparently due to disturbance by mammalian predators (Clinning 1978a). The Swakopmund salt works also supports the northernmost known breeding colony of Hartlaub's gulls. On 17 May 1978 there were 75 pairs attending nest scrapes on a small island in one of the pans (Cooper and Clinning, pers. obs.). When such colonies occur care must be taken to reduce disturbance of the breeding birds to a minimum.

5 CONSERVATION PRIORITIES

The conservation priorities may be summarised as:

5.1 Walvis Bay lagoon

(a) Protection from further encroachment by roads and salt-pans that reduce the tidal area.
(b) Protection from the side-effects of development: salt-works' 'bitters', fishing industry effluents and litter.
(c) Registration with the Ramsar Convention as a "Wetland of International Importance".

5.2 Sandvis

(a) Maintenance of present conservation status, continuing to enforce controlled public access.
(b) Registration with the Ramsar Convention as a "Wetland of International Importance".

5.3 The coast between the Swakop River and Walvis Bay

(a) The area should be patrolled by the Department of Nature and Environmental Conservation of the Cape Provincial Administration, South Africa.
(b) Prohibition of vehicles driving along the beach. If necessary, more access roads should be provided.
(c) Maintenance of the present ban on overnight camping.
(d) Nature conservation needs should be given equal priority with tourist and recreational needs in this area.
(e) Strict control of bait collecting, according to existing legislation.

5.4 Non-coastal localities

(a) Preservation of some evaporation ponds at the Walvis Bay sewage works.
(b) No further development in the pans near Cape Cross and the Swakopmund salt works should be permitted.

6 CONCLUSIONS

The breeding grounds of many of the Palaearctic waders present on the South West African coast during the northern winter are protected. Cooper *et al.* (1976) note vast nature reserves in Greenland (70 000 000 ha) and in the Taimyr Peninsula, U.S.S.R. (1 200 000 ha), which cover much of the breeding grounds of the turnstone, ringed plover *Charadrius hiaticula*, grey plover *Pluvialis squatarola*, curlew sandpiper, little stint *Calidris minuta*, sanderling and bartailed godwit *Limosa lapponica*.

Certain feeding areas used during migration have already been conserved. Iran, which lies on the migration route of the curlew sandpiper (Elliott *et al.* 1976) and of several other species (Summers and Waltner 1978), has registered 1 357 550 ha of wetlands under the Ramsar Convention (Smart 1976). The Palaearctic migrants spend up to eight months of their annual cycle in the southern hemisphere, and fidelity to the non-breeding areas has been established for most species (Elliott *et al.* 1976, Summers and Waltner 1979). Even though the birds are not breeding, they face several stress periods: recovery from migration, a complete feather moult, and the acquisition of adequate fat reserves for the return flight. Furthermore, young birds of several species spend their first two years in the southern hemisphere (Elliott *et al.* 1976, Summers and Waltner 1979). Thus the value of nature reserves in Greenland, U.S.S.R., Iran and elsewhere is reduced unless similar and adequate reserves are created throughout the southern hemisphere. South West Africa and South Africa have international responsibilities to conserve Sandvis, Walvis Bay lagoon and the coast between the Swakop River and Walvis Bay as nature reserves.

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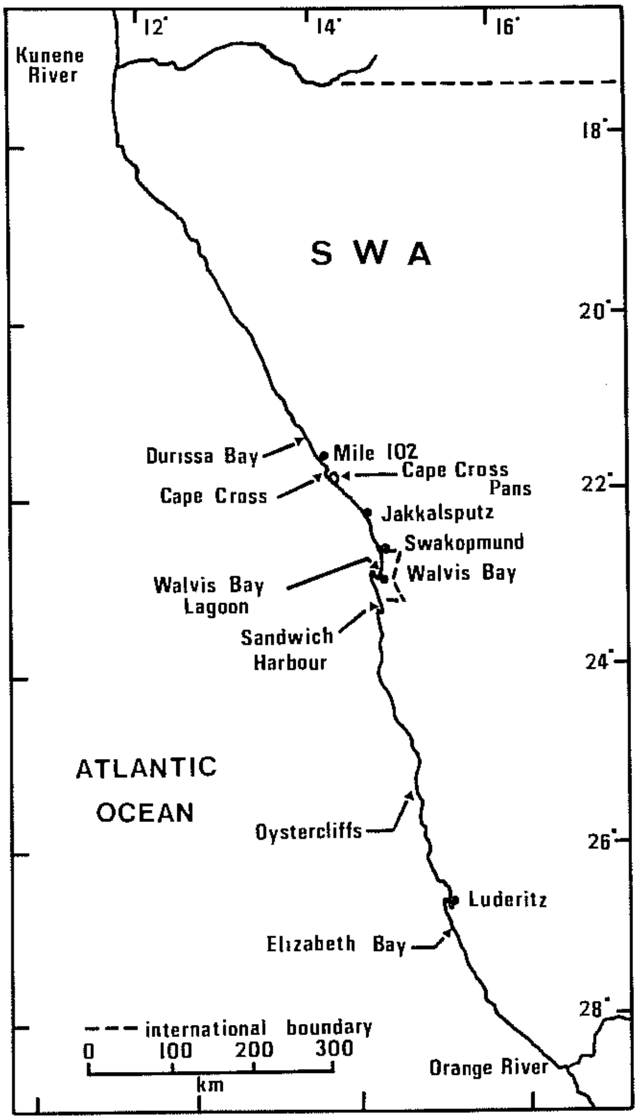
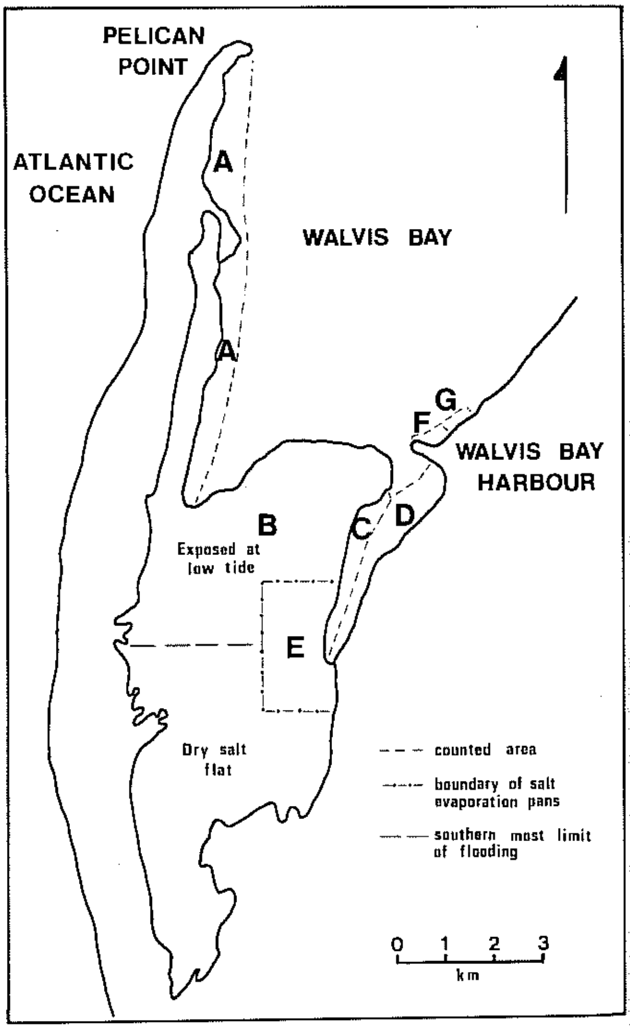
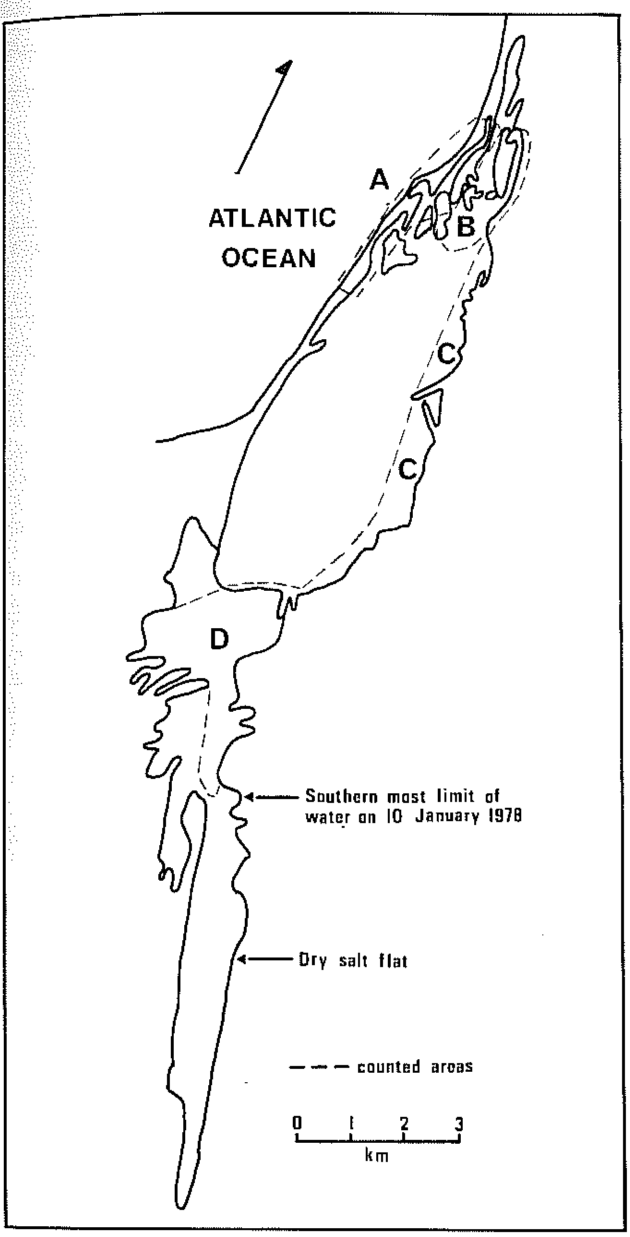


MAP 1: The coast-line of South West Africa.



MAP 2: Walvis Bay lagoon.



MAP 3: Sandvis

TABLE 1: Numbers of waders and other birds on two coastline sections surveyed on foot and by vehicle

Section	10—15 km south of Cape Cross		12—17 km north of Jakkalsputz	
Survey method	Foot	Vehicle	Foot	Vehicle
Date	31 Dec. 1976	11 Jan. 1977	9 Jan. 1977	11 Jan. 1977
White-fronted plover	24	26	20	29
Turnstone	177	115	2	1
Grey plover	15	19	9	11
Curlew sandpiper	6	19	0	0
Knot	0	5	0	0
Sanderling	305	307	138	118
Total waders	527	491	169	159
White pelican	1	2	6	1
Kelp gull	7	40	23	22
Hartlaub's/grey-headed gull	0	60	7	0
Common/ Arctic tern	0	0	1	0
Sandwich tern	0	10	0	0
Total non-waders	8	112	37	23

TABLE 2: Summarized results: Numbers of waders and other birds between Durissa Bay and Sandvis

Area	Coastline between the Swakop River and Walvis Bay (30 km)	Remainder of the coastline between Durissa Bay and Sandvis (225 km)	Non-coastal localities	Sandvis	Walvis Bay lagoon	Total
		Waders				
Non-Palaearctic	202	827	382	4 321	3 811	9 543
Palaearctic	11 993	8 834	4 728	22 249	25 722	73 526
Total waders	12 195	9 661	5 110	26 570	29 533	83 069
		Non-waders				
Grebes and dabchicks	21	0	3 109	777	488	4 395
Pelicans	199	158	161	360	574	1 452
Flamingoes	100	68	6 778	14 100	16 792	37 838
Ducks and geese	1	11	2 364	482	0	2 858
Gulls	878	1 728	885	350	1 091	4 932
Terns	40	33 291	128	17 261	834	36 554*
Other species	1	4	144	150	39	338
Total non-waders	1 240	35 260	13 569	33 480	19 818	88 367
Total no. of birds	13 435	44 921	18 679	60 050	49 351	171 436

* 15 000 have been subtracted (see Methods)

TABLE 3: Numbers of waders counted between Durissa Bay and Sandvis

Area	Durissa Bay to 8 km north of Cape Cross	Cape Cross to 8 km north	Cape Cross to Jakkalsputz (63 km)	Jakkalsputz to the Swakop River (61 km)	Swakop River to Walvis Bay (30 km)	Pelican Point to Sandvis (53 km)	Walvis Bay lagoon	Sandvis	Non-coastal localities	Totals
				Non-Palaearctic waders						
Black oyster-catcher *Haematopus moquini*	0	8	0	0	3	0	87	1	1	100
White-fronted plover *Charadrius marginatus*	45	44	219	407	194	104	1 099	800	147	3 059
Kittlitz's plover *C. pecuarius*	0	0	0	0	0	0	0	1	2	3
Three-banded plover *C. tricollaris*	0	0	0	0	0	0	0	19	35	54
Chestnut-banded plover *C. pallidus*	0	0	0	0	0	0	1 909	2 600	25	4 534
Blacksmith plover *Hoplopterus armatus*	0	0	0	0	0	0	0	0	4	4
Avocet *Recurvirostra avosetta*	0	0	0	0	5	0	716	900	117	1 738
Stilt *Himantopus himantopus*	0	0	0	0	0	0	0	0	51	51
Total	45	52	219	407	202	104	3 811	4 321	382	9 543
				Palaearctic waders						
Turnstone *Arenaria interpres*	11	723	401	940	4 277	30	698	200	613	7 893
Ringed plover *C. hiaticula*	0	1	0	0	0	0	179	200	32	412
Grey plover *Pluvialis squatarola*	40	47	106	203	612	118	2 479	900	101	4 606
Curlew sandpiper *Calidris ferruginea*	0	7	24	131	3 089	8	9 312	8 300	2 321	23 192
Knot *C. canutus*	0	0	138	1	1 528	0	1 074	600	241	3 582
Little stint	0	0	0	2	6	0	598	1 700	746	3 052

Area	Durissa Bay to 8 km north of Cape Cross	Cape Cross to 8 km north	Cape Cross to Jakkalsputz (63 km)	Jakkalsputz to the Swakop River (61 km)	Swakop River to Walvis Bay (30 km)	Pelican Point to Sandvis (53 km)	Walvis Bay lagoon	Sandvis	Non-coastal localities	Totals
C. minuta										
Sanderling *C. alba*	280	1 760	985	1 152	2 206	1 630	8 281	8 800	151	25 245
Ruff *Philomachus pugnax*	0	0	0	0	0	0	1	3	122	126
Common sandpiper *Tringa hypoleucos*	0	0	0	5	4	0	4	1	7	21
Marsh sandpiper *T. stagnatilis*	0	0	0	0	0	0	0	0	12	12
Terek sandpiper *Xenus cinereus*	0	1	0	0	0	0	0	2	2	5
Greenshank *T. nebularia*	0	0	0	0	11	0	30	110	12	163
Wood sandpiper *T. glareola*	0	0	0	0	0	0	0	0	6	6
Bar-tailed godwit *Limosa lapponica*	0	6	15	13	177	1	603	1 400	60	2 275
Curlew *Numenius arquata*	0	0	0	0	0	0	0	18	0	18
Whimbrel *N. phaeopus*	0	0	0	23	83	32	13	12	2	165
Red-necked phalarope *Phalaropus lobatus*	0	0	0	0	0	0	0	3	0	3
Total	331	2 545	1 669	2 470	11 993	1 819	23 272	22 249	4 428	70 776
Unidentified waders	0	0	0	0	0	0	2 450	0	300	2 750
Total no. waders	376	2 597	1 888	2 877	12 195	1 923	29 533	26 570	5 110	83 069

TABLE 4: Numbers of non-waders counted between Durissa Bay and Sandvis

Area	Durissa Bay to 8 km north of Cape Cross	Cape Cross to 8 km north	Cape Cross to Jakkalsputz	Jakkalsputz to the Swakop River	Swakop River to Walvis Bay	Pelican Point to Sandvis	Walvis Bay lagoon	Sandvis	Non-coastal localities	Totals
Great crested grebe *Podiceps cristatus*	0	0	0	0	0	0	0	51	0	51
Black-necked grebe *P. nigricollis*	0	0	0	0	21	0	488	720	3 035	4 264
Dabchick *Tachybaptus ruficollis*	0	0	0	0	0	0	0	6	74	80
White pelican *Pelecanus onocrotalus*	0	0	28	123	199	7	574	360	161	1 452
Cape gannet *Sula capensis*	0	0	1	0	0	0	4	3	0	8
Grey heron *Ardea cinerea*	0	0	1	0	0	0	26	60	14	101
Black-necked heron *A. melanocephala*	0	0	0	0	0	0	0	2	0	2
Little egret *Egretta garzetta*	0	0	0	0	1	0	7	50	3	61
Greater flamingo *Phoenicopterus ruber*	0	0	0	48	100	0	7 192	6 100	1 970	15 410
Lesser flamingo *Phoeniconaias minor*	0	0	1	19	0	0	9 600	8 000	4 808	22 428
Egyptian goose	0	0	0	0	0	4	0	9	48	61

Area	Durissa Bay to 8 km north of Cape Cross	Cape Cross to 8 km north	Cape Cross to Jakkalsputz	Jakkalsputz to the Swakop River	Swakop River to Walvis Bay	Pelican Point to Sandvis	Walvis Bay lagoon	Sandvis	Non-coastal localities	Totals
Alopochen aegyptiacus										
South African shelduck *Tadorna cana*	0	0	0	0	0	0	0	0	1	1
Cape shoveler *Anas smithii*	0	0	0	0	0	0	0	20	114	134
Red-billed teal *A. erythrorhyncha*	0	0	0	0	0	0	0	15	3	18
Cape teal *A. capensis*	0	0	0	7	1	0	0	400	2 114	2 522
Hottentot teal *A. hottentota*	0	0	0	0	0	0	0	0	10	10
White-faced whistling duck *Dendrocygna viduata*	0	0	0	0	0	0	0	0	8	8
Red-eyed pochard *Netta erythrophthalma*	0	0	0	0	0	0	0	2	4	6
Maccoa duck *Oxyura maccoa*	0	0	0	0	0	0	0	36	62	98
Purple gallinule *Porphyrio porphyrio*	0	0	0	0	0	0	0	0	1	1
Moorhen *Gallinula chloropus*	0	0	0	0	0	0	0	1	53	54
Red-knobbed coot *Fulica cristata*	0	0	0	0	0	0	0	33	73	106
Arctic skua *Stercorarius parasiticus*	0	0	0	2	0	0	2	1	0	5
Kelp gull *Larus dominicanus*	176	10	241	168	376	723	97	250	762	2 803
Hartlaub's/grey-headed gull *L. hartlaubi/cirrocephalus*	0	1	222	186	502	0	994	100	123	2 128
Sabine's gull *L. sabini*	1	0	0	0	0	0	0	0	0	1
Caspian tern *Sterna caspia*	0	0	0	0	1	0	31	10	4	46
Common/Arctic tern *S. hirundo/paradisaea*	29 700	1	0	0	3	0	317	17 000	45	32 066*
Sandwich tern *S. sandvicensis*	0	0	11	9	14	0	309	40	31	414
Swift tern *S. bergii*	0	1	0	2	7	0	150	0	20	180
Damara tern *S. balaenarum*	36	2	48	29	15	1	25	60	24	240
White-winged black tern *Chlidonias leucoptera*	0	0	0	0	0	0	0	150	4	154
Black tern *C. nigra*	3 200	0	0	0	0	2	2	1	0	3 205
Unidentified terns	0	0	0	249	0	0	0	0	0	249
Total no. non-waders	33 113	15	553	842	1 240	737	19 818	33 480	13 569	88 367

*15 000 have been subtraced (see Methods)

TABLE 5: Numbers of waders and other birds in Walvis Bay lagoon

Area Date	A 5 Jan 1977	B 5 Jan 1977	C 5 Jan 1977	D 5 Jan 1977	E (Walvis Bay salt works) 5 Jan 1977	F (Commercial harbour) 17 Jan 1978	G (Fishing harbour) 18 Jan 1978	Totals
Black oyster-catcher	87+	0	0	0	0	0	0	87
White-fronted plover	81	71	719	187	35	6	0	1 099
Chestnut-banded plover	2	561	385	941	20	0	0	1 909
Avocet	27	20	242	27	400	0	0	716
Turnstone	563	31	1	0	0	9	94	698
Ringed plover	12	10	131	21	5	0	0	179
Grey plover	473	1 062	893	9	1	24	17	2 479
Curlew sandpiper	1 743	1 080	3 611	2 396	477	0	5	9 312
Little stint	0	1	111	401	85	0	0	598
Knot	695	335	2	42	0	0	0	1 074
Sanderling	5 795	1 245	965	263	12	0	1	8 281
Ruff	0	0	0	0	1	0	0	1
Common sandpiper	0	0	0	0	0	2	2	4
Greenshank	10	4	2	3	11	0	0	30
Bar-tailed godwit	19	135	55	389	0	5	0	603
Whimbrel	1	0	0	0	0	7	5	13
Unidentified waders	2 000	0	40	410	0	0	0	2 450
Total waders	11 508	4 555	7 157	5 089	1 047	53	124	29 533
Black-necked grebe	351	0	35	65	0	37	0	488
White pelican	2	7	500	22	43	0	0	574
Cape gannet	4	0	0	0	0	0	0	4
Grey heron	1	0	2	0	21	0	2	26
Little egret	0	0	0	1	6	0	0	7
Greater flamingo	1 543	362	4 221	1 066	0	0	0	7 192
Lesser flamingo	1 393	834	2 665	4 708	0	0	0	9 600
Arctic skua	2	0	0	0	0	0	0	2
Kelp gull	69	11	5	3	0	2	7	97
Hartlaub's/grey-headed gull	154	0	2	54	0	665	119	994
Caspian tern	18	8	3	1	0	1	0	31
Common / Arctic tern	17	18	71	82	0	83	46	317
Sandwich tern	34	48	1	55	0	109	62	309
Swift tern	98	1	4	4	0	15	28	150
Damara tern	4	4	13	4	0	0	0	25
Black tern	2	0	0	0	0	0	0	2
Total non-waders	3 692	1 293	7 522	6 065	70	912	264	19 818
Total no. of birds	15 200	5 848	14 679	11 154	1 117	965	388	49 351

+ On 17 Jan 1978 44 Black oyster-catchers and one European oyster-catcher *Haematopus ostralegus* were present.

TABLE 6: Numbers of waders and other birds at Sandvis

Area Date	A 7 Jan 1977	B 7 Jan 1977	C 7 Jan 1977	D 10 Jan 1978	Estimate +
			Waders		
Black oyster-catcher	0	1*	0	0	1
White-fronted plover	177	0	170	104	800
Chestnut-banded plover	0	70	4	797	2 600
Kittlitz's plover	0	1	0	0	1
Three-banded plover	0	19	0	0	19
Avocet	18	585	129	129	900
Turnstone	1	3	0	72	200
Ringed plover	0	28	6	111	200
Grey plover	63	356	453	16	900
Curlew sandpiper	228	1 561	276	2 406	8 300

Area Date	A 7 Jan 1977	B 7 Jan 1977	C 7 Jan 1977	D 10 Jan 1978	Estimate +
Little stint	0	4	3	512	1 700
Knot	17	522	33	0	600
Sanderling	776	0	695	2 918	8 800
Ruff	0	0	0	3	3
Terek sandpiper	0	0	0	0	2
Common sandpiper	0	1	0	0	1
Greenshank	5	43	50	6	110
Bar-tailed godwit	713	121	455	26	1 400
Curlew	0	18	0	0	18
Whimbrel	0	9	1	0	12
Red-necked phalarope	0	0	0	0	3
Unidentified waders	0	0	0	5 350	–
Total waders	1 998	3 342	2 275	12 450	*ca.*27 000
			Non-waders		
Great crested grebe	10	6	34	1	51
Black-necked grebe	635	46	32	0	720
Dabchick	0	4	2	0	6
White pelican	47	122	139	49	360
Cape gannet	3	0	0	0	3
Black-necked heron	0	2	0	0	2
Grey heron	0	38	18	2	60
Little egret	0	28	19	0	50
Greater flamingo	2 115	163	2 225	1 073	6 100
Lesser flamingo	122	590	329	4 906	8 000
Egyptian goose	0	5	4	0	9
Cape shoveler	0	15	5	0	20
Red-billed teal	0	15	0	0	15
Cape teal	8	145	215	6	400
Red-eyed pochard	0	2	0	0	2
Maccoa duck	0	32	4	0	36
Moorhen	0	1	0	0	1
Red-knobbed coot	0	23	10	0	33
Arctic skua	0	0	0	1	1
Kelp gull	58	24	13	100	250
Hartlaub's/grey-headed gull	58	22	17	3	100
Caspian tern	2	0	0	0	10
Common/Arctic tern	15 000	0	120	35	17 000
Sandwich tern	0	3	21	1	40
Damara tern	18	11	14	9	60
White-winged black tern	0	1	90	26	150
Black tern	0	0	0	1	1
Total non-waders	18 076	1 298	3 311	6 213	*ca.*33 000
Total no. of birds	20 074	4 640	5 586	18 663	*ca.*60 000

* On 10 January 1978 six black oyster-catchers and one European oyster-catcher were present

+ The estimate is based on the assumption that area D forms 67% of the available habitat for birds on the southern salt flat. Unidentified waders in area D have been allocated to the smaller waders in the proportions: White-fronted plover 3%, chestnut-banded plover 16%, little stint 12%, sanderling 36% and curlew sandpiper 33%. The proportions are derived from counts made in area D in 1977 and 1978. Estimates are given to two significant figures.

TABLE 7: Numbers of waders and other birds between the Swakop River and Walvis Bay

Black oyster-catcher	3
White-fronted plover	194
Avocet	5
Turnstone	4 277
Grey plover	612
Curlew sandpiper	3 089
Little stint	6
Knot	1 528
Sanderling	2 206
Common sandpiper	4
Greenshank	11
Bar-tailed godwit	177
Whimbrel	83
Total waders	12 195

Black-necked grebe	21
Pelican	199*
Little egret	1
Greater flamingo	100
Cape teal	1
Kelp gull	376
Hartlaub's/grey-headed gull	502
Caspian tern	1
Common/Arctic tern	3
Sandwich tern	14
Swift tern	7
Damara tern	15
Total non-waders	1 240
Total no. of birds	13 435

* includes 100 chicks

TABLE 8: Numbers of waders and other birds at non-coastal localities

Area Date	Walvis Bay sewage works 'Bird Paradise' 2 Jan 1977	Swakop River mouth 30 Dec 1976	Swakopmund sewage works 30 Dec 1976	Swakopmund salt works 1 Jan 1977	Pans near Cape Cross 11 Jan 1977	Pan at Mile 102 12 Jan 1978	Totals
			Waders				
Black oyster-catcher	0	0	0	1	0	0	1
White-fronted plover	0	16	5	98	28	0	147
Kittlitz's plover	2	0	0	0	0	0	2
Three-banded plover	10	7	18	0	0	0	35
Chestnut-banded plover	0	0	0	25	0	0	25
Blacksmith plover	1	0	3	0	0	0	4
Avocet	33	3	1	77	3	0	117
Stilt	45	0	0	6	0	0	51
Turnstone	2	3	44	478	13	73	613
Ringed plover	1	14	11	3	3	0	32
Grey plover	13	0	0	63	15	10	101
Curlew sandpiper	99	63	66	1 496	597	0	2 321
Knot	0	0	0	236	5	0	241
Little stint	82	42	44	368	210	0	746
Sanderling	5	2	0	127	11	6	151
Ruff	31	0	56	18	17	0	122
Common sandpiper	3	0	4	0	0	0	7
Marsh sandpiper	2	1	0	9	0	0	12
Terek sandpiper	2	0	0	0	0	0	2
Greenshank	1	0	0	10	1	0	12
Wood sandpiper	2	0	4	0	0	0	6
Bar-tailed godwit	0	0	0	60	0	0	60
Whimbrel	0	0	0	2	0	0	2
Unidentified	0	0	0	0	300	0	300
Total waders	334	151	256	3 077	1 203	89	5 110
			Non-waders				
Black-necked grebe	228	0	0	620	2 187	0	3 035
Dabchick	66	0	8	0	0	0	74
White pelican	123	0	0	38	0	0	161
Grey heron	13	0	0	1	0	0	14
Little egret	0	0	0	3	0	0	3
Greater flamingo	304	0	8	500	1 158	0	1 970
Lesser flamingo	2 420	10	3	940	1 435	0	4 808
Egyptian goose	48	0	0	0	0	0	48
South African shelduck	1	0	0	0	0	0	1
Cape shoveler	108	0	6	0	0	0	114
Red-bill teal	0	0	1	2	0	0	3
Cape teal	1 280	10	73	233	518	0	2 114
Hottentot teal	10	0	0	0	0	0	10
White-faced whistling duck	8	0	0	0	0	0	8
Red-eyed pochard	3	0	1	0	0	0	4
Maccoa duck	59	0	3	0	0	0	62
Purple gallinule	0	0	1	0	0	0	1
Moorhen	30	0	23	0	0	0	53
Red-knobbed coot	67	0	6	0	0	0	73
Kelp gull	42	0	0	415	292	13	762
Hartlaub's/grey-headed gull	5	0	81	37	0	0	123
Caspian tern	3	0	0	0	1	0	4
Common/Arctic tern	0	0	0	0	0	45	45
Sandwich tern	0	0	0	31	0	0	31
Swift tern	0	0	0	20	0	0	20
Damara tern	0	0	0	24	0	0	24
White-winged black tern	4	0	0	0	0	0	4
Total non-waders	4 822	20	214	2 864	5 591	58	13 569
Total no. of birds	5 156	171	470	5 941	6 794	147	18 679

TABLE 9: Estimated numbers of waders and other birds on the coast-line between Durissa Bay and Cape Cross, 12 January 1978*

White-fronted plover	59
Turnstone	120
Grey plover	63
Curlew sandpiper	1
Sanderling	816
Terek sandpiper	1
Unidentified	1
Total waders	1 061
Hartlaub's/grey-headed gull	1
Kelp gull	186
Sabine's gull	1
Common/Arctic tern	29 700
Damara tern	36
Black tern	3 200
Total non-waders	33 124
Total no. of birds	34 185

* Estimates are based on a survey of 62 % of the coast-line

TABLE 10: Elizabeth Bay: Numbers of waders and other birds, 1 December 1977

Black oyster-catcher	9
White-fronted plover	57
Grey plover	38
Turnstone	94
Sanderling	327
Total waders	525
Kelp gull	136
Total non-waders	136
Total no. of birds	661

TABLE 11: Densities of some species of waders (birds/km) on the open coast-line between Durissa Bay and Sandvis.

Area	Durissa Bay to 8 km north of Cape Cross (48 km)	Cape Cross to Jakkalsputz (63 km)	Jakkalsputz to the Swakop River (61 km)	Swakop River to Walvis Bay (30 km)	Pelican Point to Sandvis (53 km)
White-fronted plover	1,0	3,5	6,7	6,5	2,0
Turnstone	0,2	6,4	15,4	142,6	0,6
Grey plover	0,8	1,7	3,3	20,4	2,2
Curlew sandpiper	0	0,4	2,1	103,0	0,2
Knot	0	2,2	<0,1	50,9	0
Sanderling	5,9	15,6	18,9	73,5	30,8
Bar-tailed godwit	0	0,2	0,2	5,9	<0,1
Whimbrel	0	0	0,4	2,8	0,6
All Palaearctic waders	7,0	26,5	40,5	399,8	34,3
All non-Palaearctic waders	1,0	3,5	6,7	6,7	2,0
All waders	8,0	30,0	47,2	406,5	36,3

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Relict vlei silts of the middle Kuiseb River valley, South West Africa

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CONTENTS

ABSTRACT

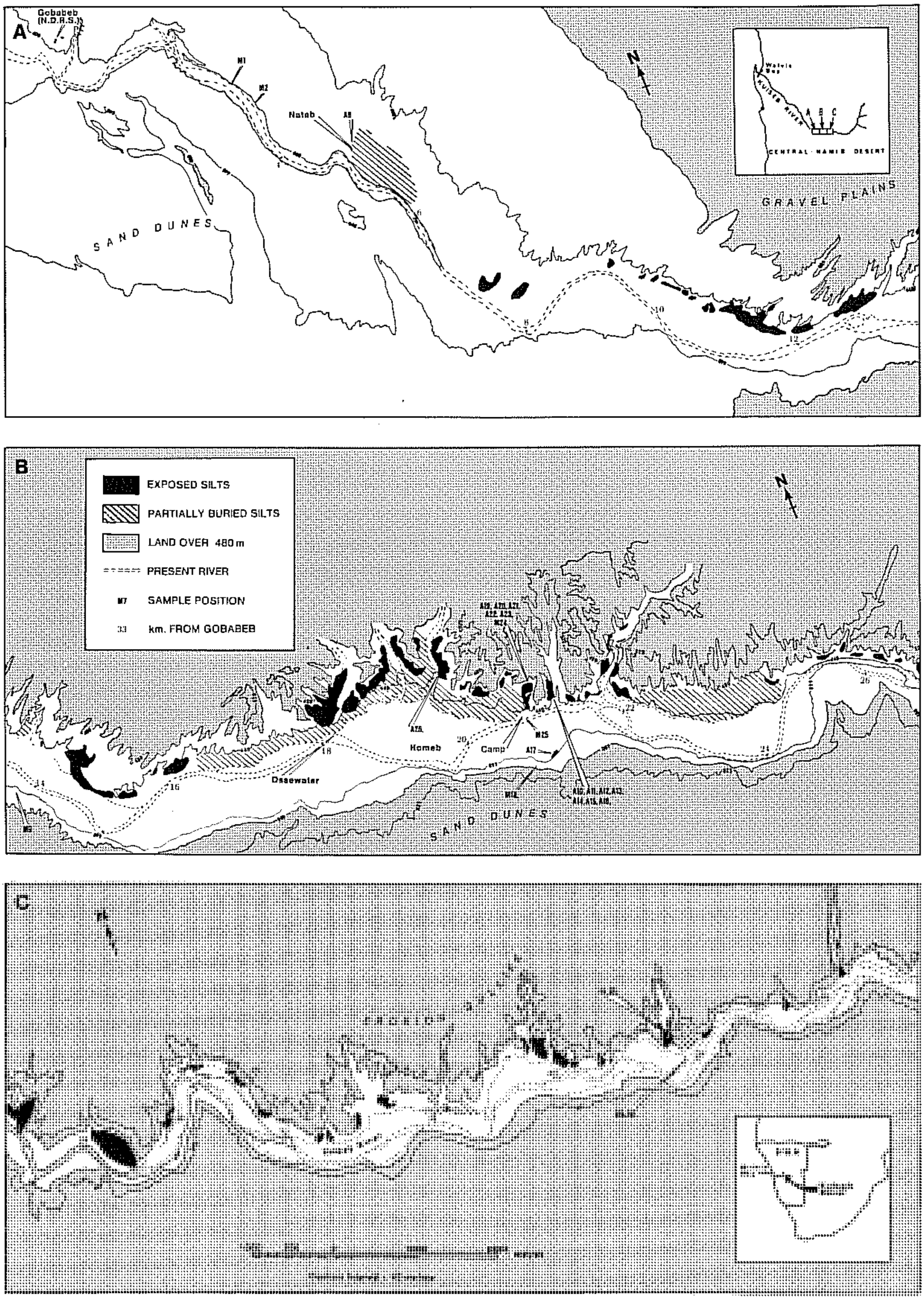
Relict fine-grained sediments have been preserved within erosion gullies (gramadullas) of the middle Kuiseb river valley in the Namib desert. These deposits are divisible into a conspicuous higher terrace and a concealed, eroded low level type. Discontinuous remnants, commonly yellowish-grey silts containing subsidiary sands, have been traced from Gobabeb 40,5 km upstream. The diverse mineralogy of the deposits reflects their metamorphic rock source. Bedding is distinct but sand and silt units are irregular in form. Sedimentary structures include cross-stratification and sun cracks. Four terrestrial gastropod species have been collected from the sparsely fossiliferous sequences. Alternation of low energy flooding and desiccation permitted fine sediment accumulation. Subsequent renewed fluvial activity incised the deposit into a double terrace. A late Quaternary age is postulated for the sediments.

1 INTRODUCTION

Relict silt-rich deposits of substantial but variable depth constitute one component of central Namib Cenozoic geomorphology, occurring in the Tsauchab, Tsondab and Kuiseb river basins. This paper discusses the location, constituents, characteristics and sedimentary history of the relict silts preserved in the middle Kuiseb valley. No details of this series have previously been published although mention has been frequent (Besler, 1972; Goudie, 1972; Rust & Wienecke, 1974; Scholtz, 1972).

The Kuiseb deposits are best preserved in the vicinity of Ossewater-Homeb, where they occur as a double terrace, the lower partially concealed by younger sands and gravels. Their present distribution is governed by factors favouring preservation from modern fluvial erosion so that the majority of silts are banked against and fill erosion gullies in the north wall of the lower Kuiseb canyon (map 1). Previous work (Goudie, 1972; Scholtz, 1972) has concentrated on the Ossewater-Homeb sediments although similar deposits have been noted at Natab (Scholtz, 1972) whilst Rust & Wienecke (1974) considered that the deposits ceased about 4 km upstream of Natab. The silts deposits are now shown to occur over a 40,5 km distance upstream of Gobabeb, isolated occurrences being believed to represent remnants of a former extensive valley fill (map 1).

These alluvial deposits are localised where the Kuiseb canyon widens into a valley incised into a basement plateau of folded, metamorphosed and faulted rocks of the Damara supergroup which have been invaded by granite and pegmatites (Martin, 1965). The basement composition is such that a very diverse mineral suite is available for incorporation into younger sediments. A further source of fines is provided by



MAP 1: The distribution of relict silts in the middle Kuiseb River valley.

Cretaceous to Holocene calcrete, gypsum and gravel and dune sand overlying the Damara rocks to the south of the Kuiseb valley.

The Kuiseb River, which rises in the better watered Khomas Highlands south of Windhoek, carries discharge in this section of its course in most years. As a result it removes blown sands emanating from the Namib dune-sea and serves to separate the dune Namib to the south from the gravel Namib to the north. The climate is hyper-arid with an annual rainfall at Gobabeb of only 16,5 mm (Seely & Stewart, 1976). Rainfall is variable and occasionally of great intensity. Fog is another source of moisture. Weathering processes are thus characteristic of desert environments with, in addition, chemical processes due mainly to the action of salt and sea mists (Scholtz, 1972).

The remnant silts are described in terms of their environment in order to add to information relating to sediment source and mode of emplacement. Demonstration of local provenance and emplacement by processes similar to the present has significance for the interpretation of the Cenozoic history of the area.

2 THE DEPOSITS

The terraced sequences of Ossewater-Homeb provide the type locality (map 1). Thick deposits preserved in north-bank erosion gullies have been incised and provide vertical sections (fig 1, plate 1). Their relatively level surface has previously been accepted as representing the level of infilling. However traces of similar materials adhering to bed-rock above the main terrace level suggest infilling may have reached a higher level (plate 1a). A lower terrace partially concealed by fan gravels of a later date forms the riverwards extension of the deposit. Such partially concealed silts are the most frequent type both upstream and downstream. The stratigraphy, even of the higher terrace, is further obscured by an external capping of hard, fine-grained material deposited by contemporary wash from material carried in suspension. These '*mud drapes*' and the intermittent preservation of the deposit complicate section correlation (plate 2a).

2.1 Composition and stratification

The most abundant sediments are yellowish-grey silts but subsidiary sands, probably of dune provenance, and darker biotite-rich silts are also incorporated. Stratification of the sediments is generally horizontal, although certain units show steeper dips (5° — 15°) unrelated to cross-stratification or tectonic deformation, their random orientation being an expression of basement irregularity. In contrast to such initial dips imposed during sedimentation, are the variable attitudes of large remnants that have collapsed following erosional undercutting. Other minor irregularities have been imposed by differential compaction and by modern creep processes. No structures of tectonic origin were observed.

Bedding is variable (fig 1 and plate 2). The best-ordered units are the dominant, laterally uniform, yellowish-grey silt beds. These vary from 10 cm to 300 cm in thickness. The darker silt beds vary from 1 cm to about 30 cm in thickness and from 10 to 60 cm in length, tending to pinch out entirely. Fine sands occur mainly in variable lenses or in thin, 1 to 3 cm beds. Rarely small sand lenses occur intermixed with finer sediments. Basal conglomerates and schist-derived sands occur as highly irregular 1 to 200 cm wedges and display poor to well-developed pebble or sand grain imbrications dipping towards the valley walls.

Bed form ranges from massive to laminated. Many massively bedded yellowish-grey silts have a well-developed fissility, indicative of micro-lamination. The darker silts are also frequently fissile and commonly display parting lineations. Their fissility may be attributed to the proportion of included platy minerals. Much of the lamination, however, results from small scale alternation of coarser silty sand with finer silt material. Graded bedding is a minor feature of the sedimentary sequences.

Although the sections are generally well-stratified, no ordered repetition of units has been recognised and it is doubtful whether the deposits can be attributed to sedimentation of a regular cyclic nature. Apart from the basal conglomerates, no preferred stratigraphic position is displayed by any particular sediment type. The irregular, non-continuous nature of the subsidiary sediments (darker silts, sands and conglomeratic schist-rich sands) seems to indicate deposition under relatively uniform conditions with local variation. The texture, good stratification, lamination and bedding variability indicates an origin within a vlei situation such as prevails at Sossus or Tsondab today, where discharge is insufficient to permit exoreic discharge.

2.2 Minor sedimentary structures

True cross-stratification is almost entirely limited to the darker silts and fine brown sands although the schist sands display a poorly developed cross-stratification (plate 3b). Cross-stratified horizons have no preferred stratigraphic position and are almost always lenticular. They appear to have resulted from ripple action in shallow waters containing a high load of suspended material. Absence of other types of cross-stratification and of directional control indicates a paucity of strong currents and of vigorous fluvial deposition. Strata in the Ossewater-Homeb area show no directional sedimentary control.

Convolute bedding caused by gravity sliding and foundering is of minor importance and occurs only

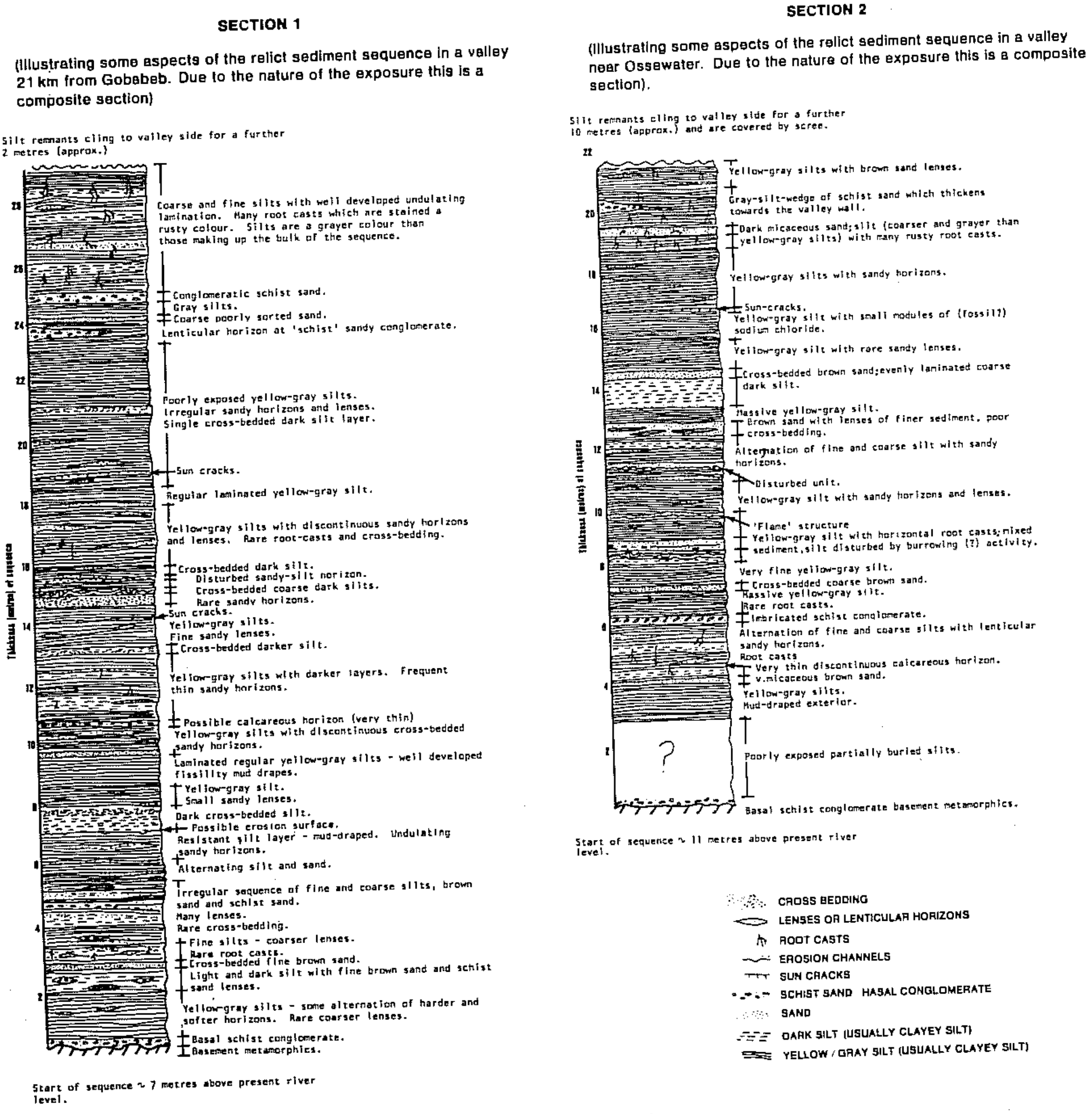


FIG. 1: Composite sedimentary sequences: (a) from Ossewater (b) from Homeb.

in silt and silty-sand beds a few centimetres thick, where it is restricted to internal bed laminations. Slump structures causing mildly deformed beds, 3 to 12 cm thick, probably arose from response to the influence of gravity on sediments deposited on a slight slope or to differential compaction over a basement high. Small faults are often associated with and restricted to these slumped beds (plate 3).

Organic structures, such as root casts, are widespread, at times transgressing up to 15 to 20 cm of silts and sands (fig 2). Most casts are weakly calcified, vertical to sub-vertical tubes 5 to 20 mm in diameter but some are uncalcified. Down-dragging of laminations in the vicinity of the root casts is ascribed to plant growth in a plastic sediment. In the upper layers many root casts are associated with an oxidised zone. Lack of oxidation in the lower layers may be due to reducing conditions at the time of deposition.

The most significant of the lesser structures are clearly discernible desiccation cracks which exhibit no preferential stratigraphic position. Crack patterns create irregular polygons varying in diameter from 10 to 100 cm, larger polygons being frequently subdivided by small cracks. The cracks are usually filled with material texturally distinct from the fine material comprising the cracked surface. Sometimes cracks are restricted to homogenous thin layers but others show well-developed fine laminations and thus transgress layers. Most cracked surfaces are overlain by very thin fine sand layers. Occasionally the presence of cracks

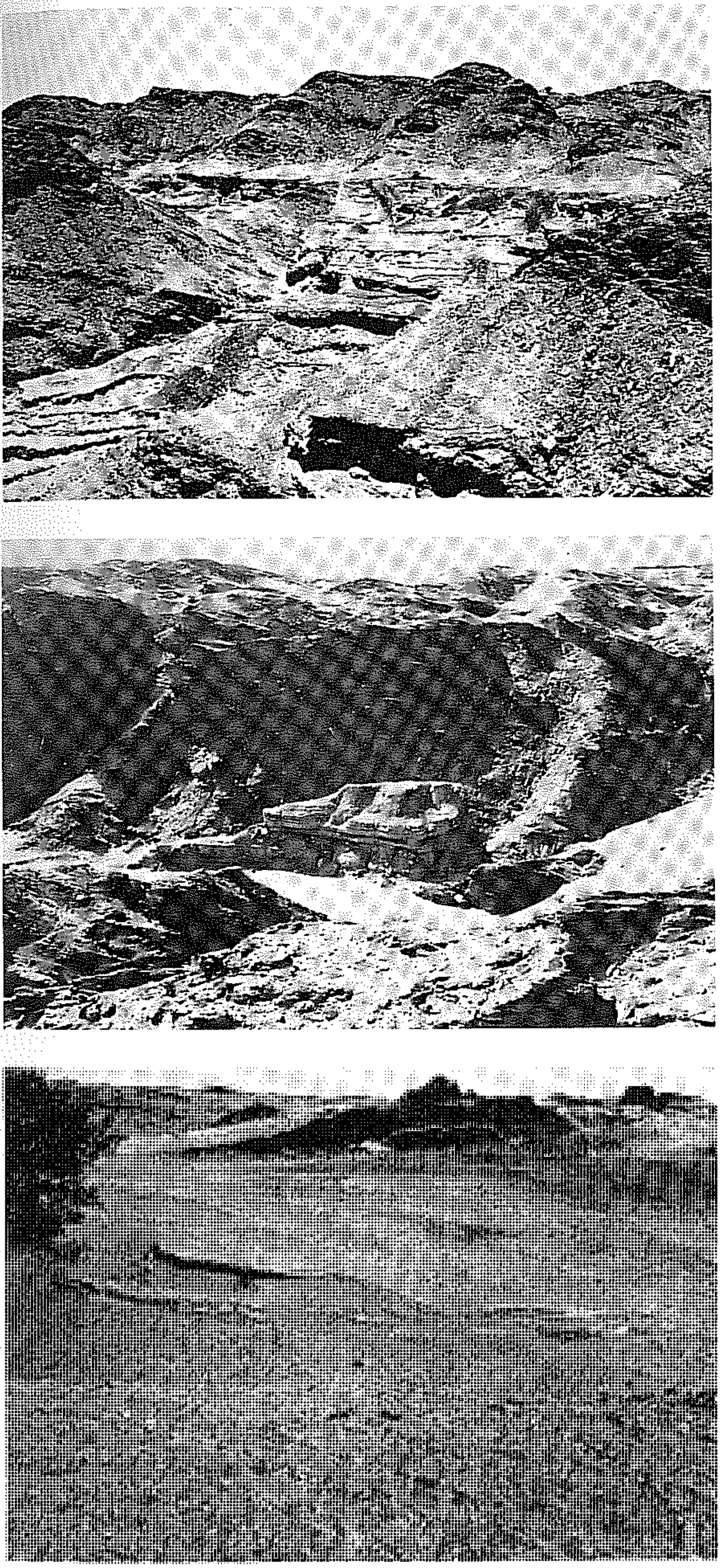
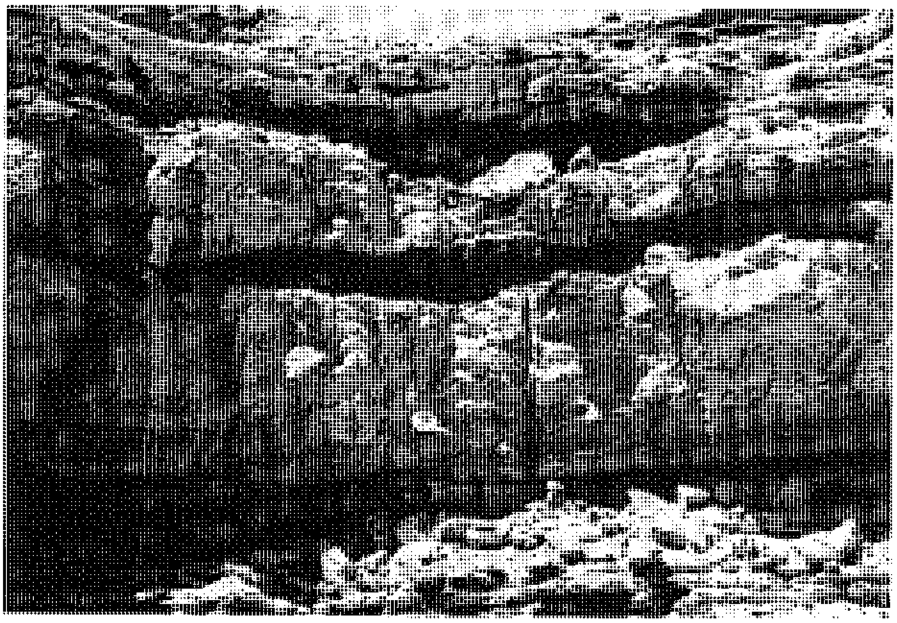


PLATE 1: Silt location:

a) terraced sediments at Homeb (note the level surface denoting the probable floor of the deposit, the silt patches adhering to basement rocks above that level and gully incision into the silts,
b) preservations of terraced silts in erosion gullies,
c) Natab concealed silts.



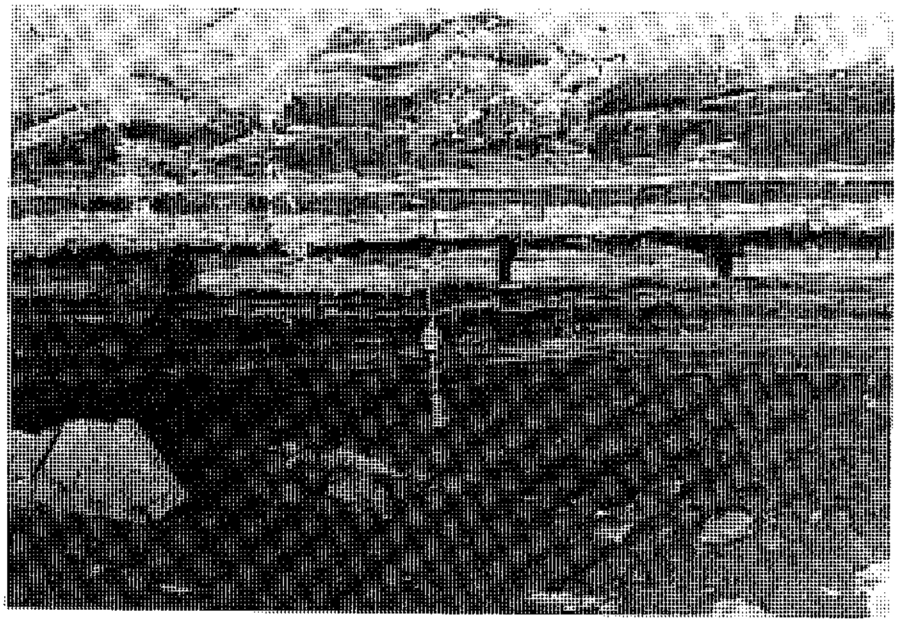


PLATE 2: Sedimentary sequences:
a) showing effect of coarse and fine layers with mud drapes,
b) relict fine-grained silts showing slumping.

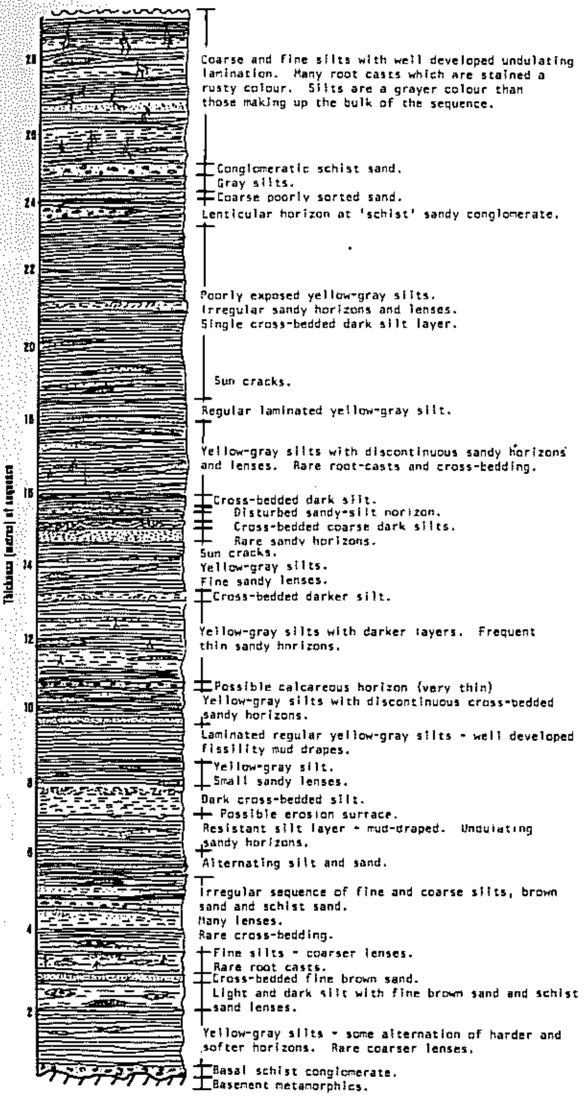
is detected only from positive casts on the bottom of overlying clayey silt beds. The cracks resemble those found in fine-grained modern sediments.

The presence of desiccation cracks implies periodic drying. The overlying sandy layer is believed to be dune-derived and is interpreted as a dry period deposit incorporated when the deposit was subsequently reflooded. Dune-derived material may also have been incorporated during flood stages to form sandy layers and lenses. Relict erosion channels are further evidence that the deposit was intermittently dry (plate 3e). The channels are all small, up to 10 to 20 cm across and 6 to 12 cm deep, and truncate any laminations in the underlying yellowish-grey silts. Channels cut into sands or pebble conglomerate were not observed. Characteristically the channels are filled with fine brown sand or darker coarse silt which may be either cross-stratified or horizontally bedded. The channels are interpreted as resulting from erosion by braided channel rivulets active when the deposit was almost dry. Sudden flooding appears not to have occurred since coarser sediments akin to the sands of the present river-bed are not found.

SECTION 1

(Illustrating some aspects of the relict sediment sequence in a valley 21 km from Gobabeb. Due to the nature of the exposure this is a composite section)

Silt remnants cling to valley side for a further 2 metres (approx.).

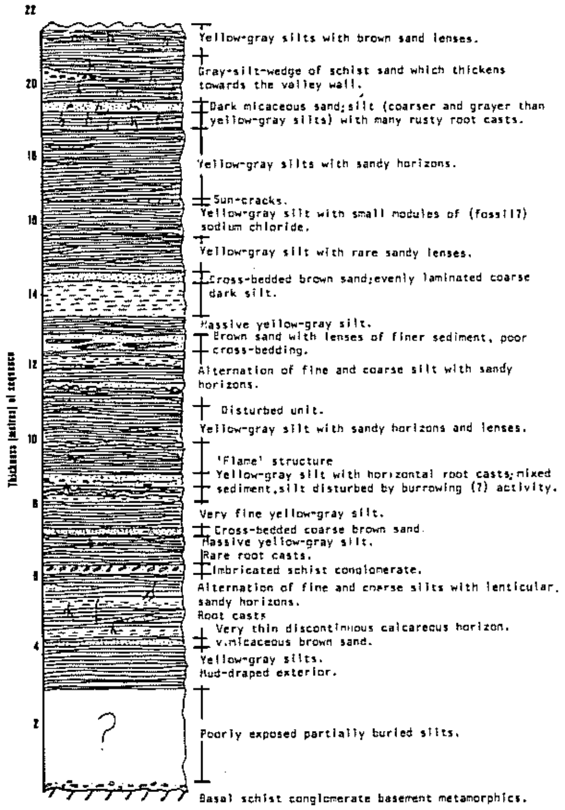


Start of sequence ~ 7 metres above present river level.

SECTION 2

(Illustrating some aspects of the relict sediment sequence in a valley near Ossewater. Due to the nature of the exposure this is a composite section).

Silt remnants cling to valley side for a further 10 metres (approx.) and are covered by scree.



Start of sequence ~ 11 metres above present river level.

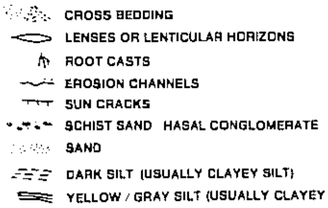


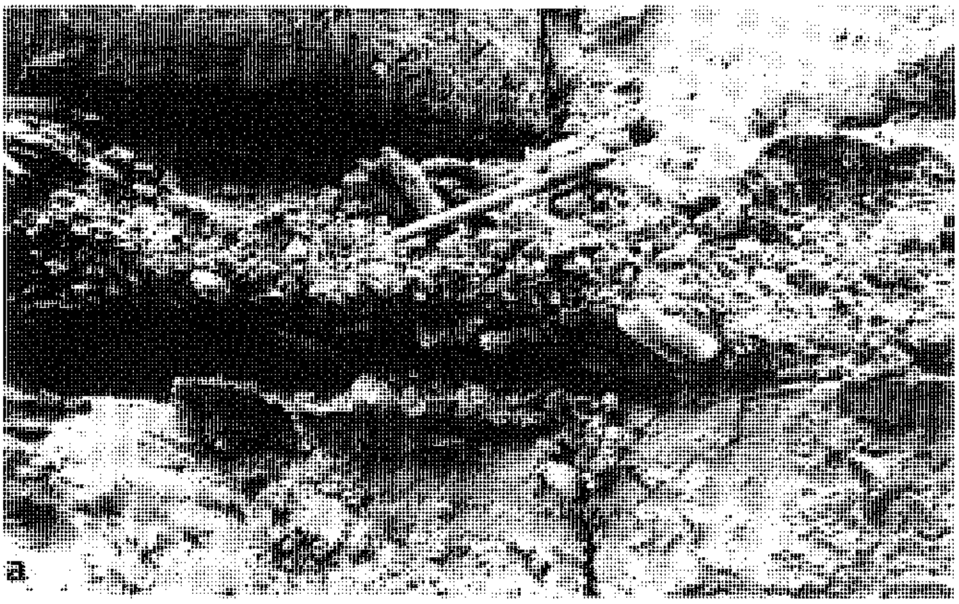
FIG. 2: Root disturbance in relict yellowish-grey silts.

2.3 Evaporites and calcretes

Most arid depositional environments favour the formation of evaporites which become incorporated into the depositional sequence. The Kuiseb valley sediments are distinguished by a relative lack of evaporites, with the exception of calcretes cementing and capping the sequence. These occur mainly as hard, dark brown fragments of irregular shape and size, sometimes joined to form continuous cappings. They never exceed a few metres in extent or 2 to 5 cm in thickness. Most of the sequences are partially cemented by carbonates with some gypsum and salt content in addition.

2.4 Palaeontology

Although the silt sequences are poorly fossiliferous, four species of gastropod have been collected. Positive identification has not yet been possible. *Bulinus (Bulinus) tropicus* and *Biomphalaria pfeifferi* were identified by Oberholzer (Institute of Zoological Re-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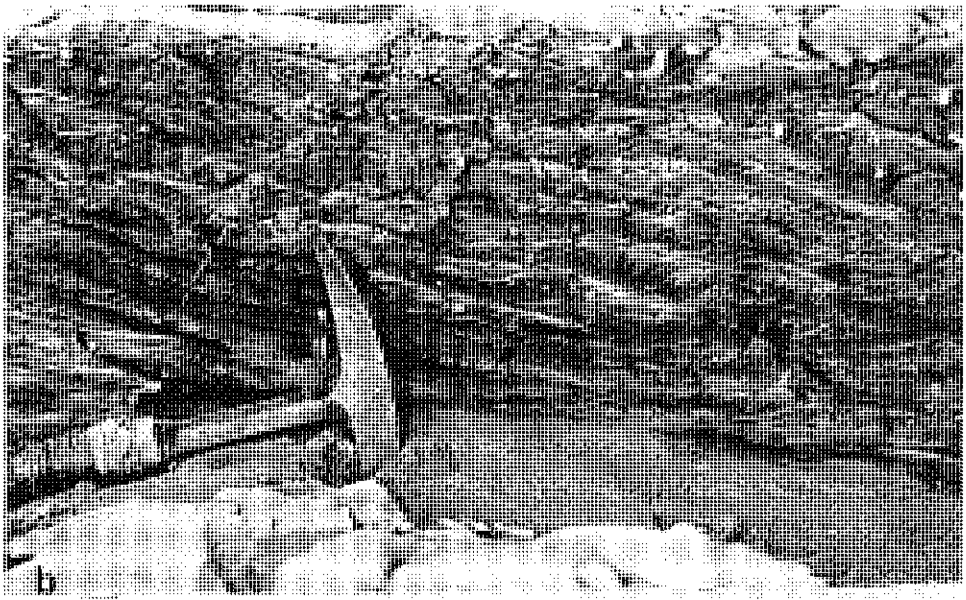
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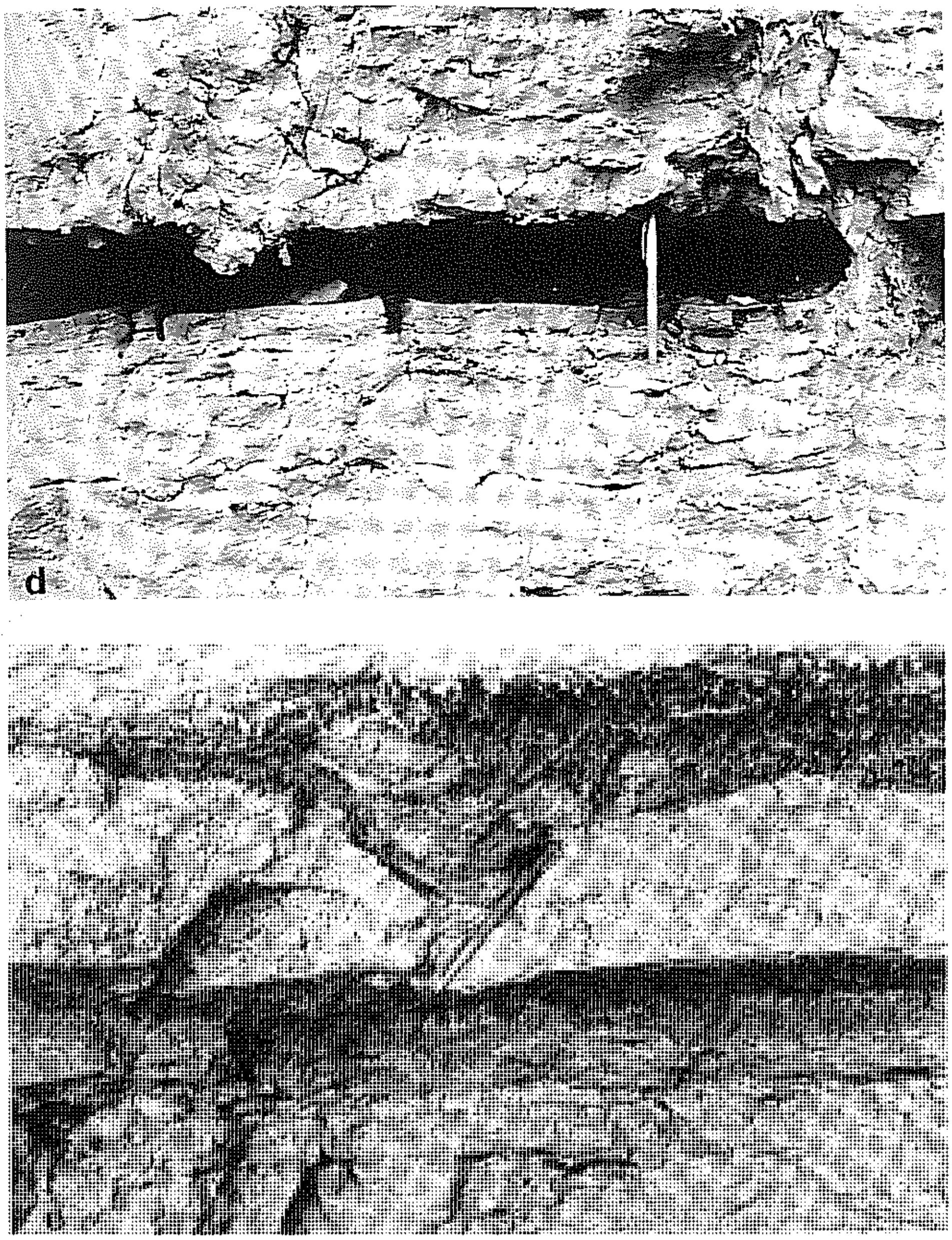

PLATE 3: Evidence of disturbance in silt sequences:
a) pebble imbrication in schist conglomerate bed
b) cross-stratification of a ripple origin
c) excellent example of flame structures
d) dessication cracks
e) erosion channel indicative of hiatus in sedimentation.

search, Potchefstroom University)* but the same specimens were classified as *Xerocerastus sp.* and as *Sculptaria sculptuici* respectively by the South African Museum. Of the other species, the South African Museum suggests *Isodora sp.* for one (fig 3). *Biomphalaria sp.* fossils have also been collected from the surface of eroding silts, 3 and 10 km west of Tsondab Vlei. All are fresh water sub-fossil snails and correspond to others collected from the Kalahari (Oberholzer, pers. comm.). Within the Kuiseb valley spatial distribution of fossils is random. No preferred stratigraphic position is apparent and fossils can be found throughout the sequences, usually embedded in yellowish-grey silts although occasional specimens occur in the coarser, darker silts. Specimens usually

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* The only information regarding biological requirements, habitat and age of the gastropods comes from comments provided by Oberholzer with his identification:
(1) *Bulinus (Bulinus) tropicus* This species is a master of aestivation and reproduction over a short period. For this reason it is frequently found in temporary water-holes.
(2) *Biomphalaria pfeifferi* Although sometimes able to survive temporary drought by sheltering in crevices and other suitable spots, drying out of the habitat adversely affects the number of individuals in that particular habitat, since this species seems to require a relatively long period in which to reproduce successive generations.

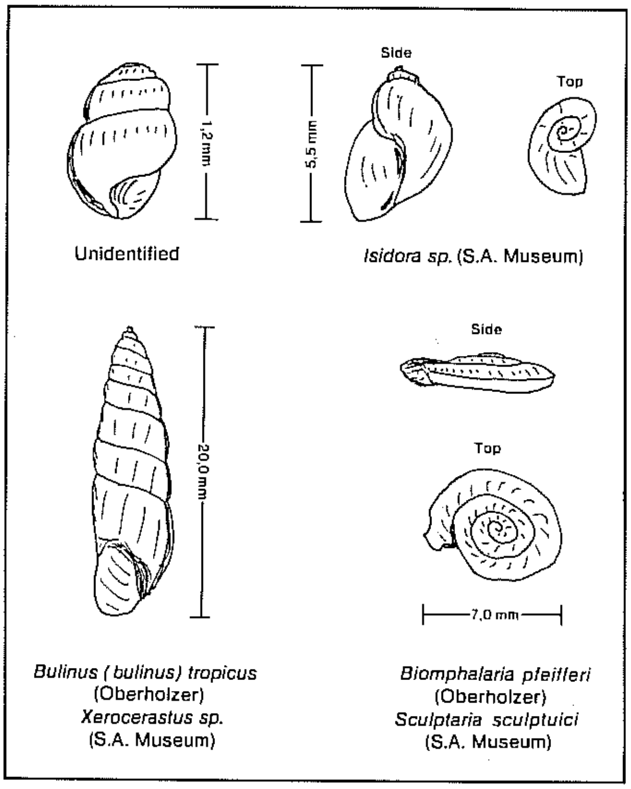

FIG. 3: Gastropods from the relict silts.

occur singly but groups of up to 5 individuals have been found. Only rarely are different species associated. The fossils are presumed to be late quaternary in age as modern forms exist and a tentative carbon fourteen date of 12 000 years Before Present has been obtained (Vogel, pers. comm.).

2.5 Sampling data characteristics

Samples taken from the deposit and from modern river sediments have been compared. Similarity in mineralogy and texture between the brown relict sands and present day-dune material is marked. The dune material is coarser and better sorted than the sands from the deposit lenses but this could be due to reworking and subaqueous mixing of the relict sediments. If the relict sands are derived from dunes, it implies that the depositional environment was then similar to that at present.

A rather tenuous size and mineralogic correlation between modern channel sands and other sand lenses of the relict deposit is also apparent. Again mixing has affected the relict deposit. The modern flood plain over bank sediments and the dark biotite rich relict silts are also similar. Bearing in mind the range within each category, there is no appreciable difference between past and present sediments. The relict sediments tend to be less sorted, probably reflecting differences in depositional environment. Modern sediments are laid down by river floods whereas the relict sediments seem to have had a quiet water environment subject to seasonal drying, and been deposited from low energy river regimes. The broad similarities between the relict sediments and the modern deposits suggest that the processes were not radically different and that those differences that exist can be explained by the difference in environmental energy.

3 CONCLUSIONS

The characteristics of the relict vlei silts of the middle Kuiseb River valley indicate a localised deposit suggestive of a vlei environment with restricted river channel and aeolian deposition. Since only minor sands occur within the dominantly silt deposit, it is deduced that the Kuiseb River then had a regime of lower energy than at present. To account for such an accumulation of still-water sediments a barrier to impede downstream flow has previously been invoked but a tectonic barrier has not been envisaged since the silts were laid down when the river was already close to or at its present base level. A model whereby dunes migrated across the river channel under conditions of greater aridity has been suggested. However under conditions of low flow, a river regime has lower energy and only suspended sediment would reach the river end-point. No dune barrier causes silt accummulation in Sossus or Tsondab Vlei today. Flow is merely insufficient to proceed further downstream. Dunes cross the river valleys following cessation of river flow.

The thickest silt deposits, up to 50 m above present channel level, are preserved in the vicinity of Ossewater-Homeb. At Gobabeb, however, the deposit appears to have a maximum thickness of only 15 m. Deposition seems to have thinned downstream. This may have resulted from progressive desiccation as the river end-point migrated upstream. No more complicated explanation is required. The following sedimentary history can thus be postulated:

1. Incision to form the Kuiseb valley and side gullies.
2. Slight climatic shift to aridity in the headwater region to reduce flow.
3. Formation of a vlei in the lower canyon with subsequent dune migration across the former river channel downstream of Gobabeb.
4. Discontinuous seasonal sedimentation with repeated flooding, depositing fine material in shallow quiet waters. Some contribution from aeolian sources and from rare local sheet wash may have occurred. Preponderance of silt would have been favoured by lower fluvial energy.
5. A return to wetter conditions with greater fluvial energy removed the dune barrier and caused incision into the sediments as the Kuiseb River cut down to its present level in two stages.

The precise date of the development of the vlei and thus the age of the sediments has not yet been determined. A late Quaternary age is postulated since the silt terraces post-date canyon re-incision through the pebble conglomerate infill (Marker, 1977). The tentative carbon fourteen date of 12 000 years Before Present provides a terminal date.

4 ACKNOWLEDGEMENTS

The fieldwork and analyses on which this paper is based were carried out by D. Müller while at the University of Cape Town. Collaboration with M. E. Marker, Fort Hare University took place during preparation for publication. D.E.R.U. staff are thanked for their help in the field and the Cartography Unit, University of the Witwatersrand for drafting of illustrations.

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TABLE 1: Sample data: size and colour characteristics (designation after Folk, 1969; and US Geol. Surv.)

DESCRIPTION	NO	COLOUR	M2	G1	Sk1	Kg	VERBAL DESCRIPTION
"Typical silts form the the bulk of the relict sediments.	A 4	Yellowish grey 5 YR 7/2	5,34	1,45	0,41	1,26	"Sandy silt" poorly sorted, fine skewed, leptokurtic
	A13	Yellowish grey 5 YR 7/1	6,76	1,92	0,08	0,78	Clayey silt, poorly sorted, near symmetrical, platykurtic
Darker than the above but otherwise similar in form of occurrence. Are important components mainly of the basal glacis deposits, but also occur less requently interbedded with yellow grey silts.	A 8	Dusky grey 5 YR 6/2	5,68	1,70	0,19	0,97	Sandy silt, poorly sorted fine skewed, mesokurtic
	A16	Dusky olive grey 5 YR 6/1	5,59	2,12	0,17	0,91	Sandy, silt, very poorly sorted, fine skewed, mesokurtic
	A17	Dusky olive grey 5 YR 6/1	5,23	1,90	0,40	1,12	Sandy silt, poorly sorted, strongly fine skewed, leptokurtic
Coarse silts — subsidiary in volume to yellow grey silts and finer dark silts. Occur in lenses as well as irregular beds. Often display good ripple cross-stratification.	A10	Dusky grey 5 YR 6/2	4,56	1,31	0,45	1,09	Sandy silt, poorly sorted, strongly fine skewed, mesokurtic
	A11	Dusky grey 5 YR 6/2	4,02	0,83	0,20	1,29	Silty sand, strongly sorted,skewed, moderately fine, leptokurtic
	A19	Dusky grey 5 YR 6/2	4,78	1,46	0,49	1,60	Sandy silt, poorly sorted, strongly fine skewed, very leptokurtic
Fine sands of darker colour — similar to the darker, coarser silts in form and also often cross-stratified.	A 5	Moderate yellowish brown 10 YR 5/2	3,77	1,02	0,44	2,51	Silty sand, poorly sorted, strongly fine skewed, very leptokurtic
	A22	Dusky grey 5 YR 6/2	3,26	0,71	0,17	1,31	Very fine sand, moderately sorted, fine skewed, leptokurtic
Fine brown sands limited almost entirely to lenses.	A12	Moderate yellowish brown 10 YR 5/5	3,49	0,81	0,29	1,53	Very fine sand, moderately sorted, fine skewed, very leptokurtic

Probably of dune (i.e. aeolian) origin, later reworked and mixed with aqueously deposited components.	A15	Light brown 5 YR 6/4	2,84	0,76	–0,32	1,82	Fine sand, moderately sorted, strongly coarse skewed, very leptokurtic
	A26	Pale brown 5 YR 5/4	3,23	0,65	0,25	2,11	Very fine sand, moderately well sorted, fine skewed, very leptokurtic.
Local basement derived deposits – can be likened to scree deposits and are very immature. Termed "schist" sands.	A21	Brownish grey 5 YR 4/1	1,50	1,52	0,07	0,76	Medium sand, poorly sorted, near symmetrical, platykurtic
	A23	Brownish grey 5 YR 4/1	1,92	1,51	–0,06	0,99	Medium sand, poorly sorted, near asymmetrical, mesokurtic
Samples from obviously "mixed" lenses – represent reworked material from different sources.	A14	Moderate yellowish brown 10 YR 5/5	2,17	1,80	–0,63	1,55	Fine sand, poorly sorted, strongly coarse skewed, very leptokurtic
	A20	Yellowish grey 5 YR 7/2	3,41	1,39	0,44	2,43	Very fine sand, poorly sorted, strongly fine skewed, very leptokurtic
Modern river overbank deposits – sometimes laminated, very frequently cross-stratified. Are similar to the other fine sands and coarser silts of the relict sequences.	M 1	Moderate yellowish 10 YR 5/2	3,22	0,79	0,14	0,99	Very fine sand, moderately sorted, fine skewed, mesokurtic
	M 2	Moderate yellowish brown 10 YR 5/2	4,46	0,87	0,20	1,06	Sandy silts, moderately sorted, fine skewed, mesokurtic
	M 7	Pale yellowish brown 10 YR 6/2	2,62	0,74	0,21	1,25	Fine sand, moderately sorted, fine skewed, leptokurtic
Modern river channel sediments. (M6 is upsteam of M25 which is slightly better sorted and finer).	M 6	Pale yellowish ish brown 10 YR 6/4	2,32	0,73	0,14	0,93	Fine sand, moderately sorted, fine skewed, mesokurtic
	M25	Greyish brown	2,43	0,56	0,15	1,02	Fine sand, moderately well sorted, fine skewed, mesokurtic
Modern gramadulla bed load material.	M24	Dusky yellow 5 YR 6/4	0,96	1,71	0,12	0,74	Coarse sand, poorly sorted, fine skewed, platykurtic
Dune sands cascading over lip into river valley at present.	M 9	Pale brown 5 YR 6/6	2,05	0,38	0,38	0,97	Fine sand, well sorted, strongly fine skewed, mesokurtic
	M18	Pale brown 5 YR 6/6	1,53	0,61	0,74	1,17	Medium sand, moderately sorted, strongly fine skewed, leptokurtic

M2 = graphic mean (phi units)
GI = inclusive graphic standard deviation (phi units)
SkI = inclusive graphic skewness
Kg = graphic kurtosis (Folk 1969)

Sample number prefix A: relict sediment
B: modern sediment

SHORT NOTE

"*Echidnopsis atlantica*" Dinter: a natural intergeneric hybrid?

by
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GREECE

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During a botanical excursion to the southern Namib, in April, 1977, the authors spent considerable time in the Klinghardt Mountains and, in particular, among the phonolite hills surrounding the Sargdeckel.

On April 13, while investigating a hill across the valley and about 2 km North East of the Sargdeckel, Barad was surprised to find a single specimen of a Stapeliad with cylindric, 8-angled, tuberculate tesselate stems, which was evidently of hybrid origin. A subsequent intensive search by both authors and by their colleagues failed to yield further similar plants.

The plant in question (Lavranos & Barad 15451) was collected and later flowered in Barad's greenhouse near Flemington, New Jersey, in the USA. This made the ensuing description possible.

Plant branching from the base; stems ascending, very succulent, rigid when turgid, 12 – 18 cm long in our unique specimen, 25 – 35 mm thick, green, mottled purplish-brown, 8-angled, the angles formed of tubercles which are slightly broader than they are long and are, when young, tipped with a soft bristle-like process. Flowers borne at the base of the tubercles, in clusters on pedicels 10 – 15 mm long; corolla chestnut brown but lemon yellow at centre, minutely pappillate, 4 cm diam., with tufts of short, dark maroon hairs in the sinuses between the lobes; corona dark maroon, the lobes fused into a cup, the outer lobes keeled and notched at the apex, their margins and apex rough and minutely tuberculate, the inner lobes short, subulate.

The only other Stapelieae collected by the authors in the same area were *Trichocaulon delaetianum* Dinter, *Stapelia ruschiana* Dinter, *Stapelia juttae* Dinter and *Caralluma winkleri* Dinter. The first two were common while the third was found only once. *C. winkleri* is obviously unrelated to *Lavr. & Barad* 15451.

It seems that *Lavr. & Barad 15451* is a natural hybrid between *Stapelia ruschiana* and *Trichocaulon delaetianum.*

It may be remembered that *S. ruschiana* has 4-angled stems, about 12 mm thick and up to 20 cm long, with rounded angles and rounded, short teeth, the flowers, some 40 mm in diam. being borne on pedicels 50 mm long. The sinuses between the corolla lobes are beset with dense tufts of dark purple, clavate hairs.

T. delaetianum has stems up to 40 cm long and 50 mm diam. with up to 18 angles formed by conical teeth each of which is tipped with a hard, black spine. The flowers are ca. 12 mm in diameter, almost sessile and free of marginal hairs.

Lavr. & Barad 15451 has flowers very similar in size, colour and tufts of purple hairs to those of *S. ruschiana*. Moreover, the *S. ruschiana* genotype appears to have contributed the rounded stem angles while that of *T. delaetianum* is responsible for the

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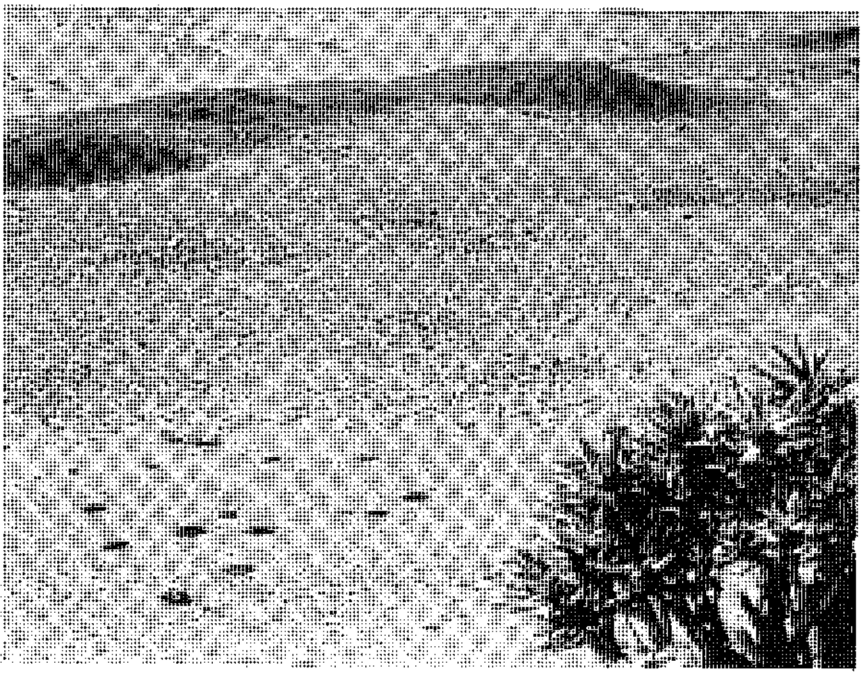

PLATE 1: View from the Sargdeckel of the low hills on which Lavranos & Barad 15451 was found
Photo: G. S. Barad

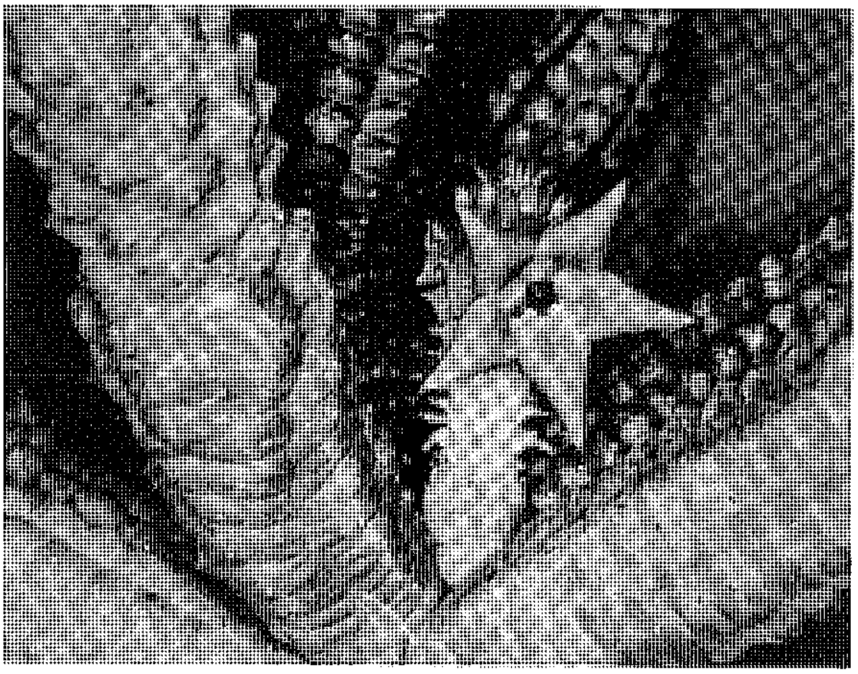

PLATE 2: Lavranos & Barad 15451: the plant in flower, note tesselations on stems and bristle-like rudimentary leaves
Photo: G. S. Barad

many-angled stems and the relatively short pedicels, which are 10 to 15 mm long.

It was in the same area that Dinter, on September 23, 1922, collected his "*Echidnopsis atlantica*", a single specimen of a plant which he described (in Fedde; Repertorium, XXX. 191 (1932)) as having "stems 40 cm long, not fully grown, 34 mm thick, at first erect, then decumbent in an arch and again erect at the tip, 10-angled, the angles formed of tubercles 8 – 10 mm wide, 7 – 8 mm long, faintly marbled over and bearing a brownish, soft apiculus. Tiny sets for flower development were appearing in fascicles between the tubercles of the same angle (not in the furrows between the angles)". Dinter's plant died before flowering. The length and form of the stems could conceivably be due to artificial conditions, in cultivation.

While *Lavr. & Barad 15451* differs from Dinter's plant in some respects, notably in its constantly 8-angled stems and in the absence of permanent bristles (apiculi) from the stem tubercles, the similarities are, nevertheless so striking that one is tempted to attribute an identical hybrid origin to "*E. atlantica*". Indeed, hybrids of the same two taxa are notoriously variable and the differences between Dinter's and our plant could be expected to fall well within the range of such variability.

Extensive searches by Dinter himself and, later, by D. T. Cole, D. C. H. Plowes and the present authors failed to produce any true *Echidnopsis* and, as Dinter's sole plant of "*E. atlantica*" died before flowering, its true nature shall remain unknown. It is, however, interesting to speculate, on the basis of the authors' evidence, that it too was a cross between *S. ruschiana* and *T. delaetianum*.

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