THE COLONISATION OF FYNBOS AND DISTURBED SITES BY INDIGENOUS FOREST COMMUNITIES IN THE SOUTHERN CAPE

by

J.C. VAN DAALEN

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INTRODUCTION

The area covered by indigenous forests in the Southern Cape has been and is still diminishing as a result of road construction (for example, 28 ha of indigenous forest has recently been clearfelled for a new highway), power lines, settlements, fires (man-made and natural, for example the fires of 1869 and 1964) and agricultural activities. Furthermore, large areas are infested with exotic species such as *Acacia melanoxylon* (blackwood), *A. mearnsii* (black wattle) and different *Eucalyptus* and *Pinus* species. Although these species are useful timber and firewood species, they tend to establish themselves on disturbed patches in the indigenous forest and suppress the surrounding forest trees. The present policy of the Directorate of Forestry and Environmental Conservation of the Department of Water Affairs, Forestry and Environmental Conservation (hereafter called Forestry) regarding these forests aims at their conservation and the reconstruction of small damaged forest patches. Reconstruction is one of the five management classes for indigenous forests. The others are production, research, protection and recreation.

Especially during the last decade smaller areas were reconstructed, mainly by planting *Podocarpus falcatus* (kalander) and *Ocotea bullata* (stinkwood). Recently, other additional indigenous species are being used. A few experimental reconstruction plots have been laid out, the first one (in 1927) being the Taungya plots at

Diepwalle State Forest (Geldenhuys, 1975). Gradually certain questions arose: Does the forest colonise fynbos areas? Or is the opposite happening? What controls the forest-fynbos edge? What is the best way of reconstructing forest? Can the forest regenerate itself fast enough to colonise disturbed sites successfully? If so, what is the rate of regeneration? What can be done to accelerate regeneration? Which areas are potentially afforestable with indigenous species?

With these questions in mind, the following hypothesis has been developed: The indigenous forest colonises suitable fynbos and disturbed sites adjoining the indigenous forest successfully if the disturbing factor, for example fire, is kept out for sufficient time. A site is suitable for forest regeneration when environmental and edaphic factors, such as aspect and soil type, is comparable with those of the indigenous forest.

This hypothesis implies that the natural fynbos-forest ecotone is controlled by environmental and edaphic factors, that fynbos is a seral stage to forest (as stated by Phillips (1931)), that disturbed forest areas can be reconstructed within a reasonable time by manipulation of artificial controlling factors and that the indigenous forests of the Southern Cape are vigorous enough to withstand regular (every 30 to 100 years) disturbances, such as fire (Phillips, 1931; Section 2.1.3.1).

Secondary succession (Chapter 2) and physiography (Section ~~5~~4.3) have been discussed in much detail. Succession underlies the whole study and a sound understanding of the principles involved is necessary. To discuss the physiography of the few study sites in isolation would not have been of much value, especially where the results of the study as far as possible will be applied regionally.

CHAPTER 1

INDIGENOUS FORESTS OF THE SOUTHERN CAPE

1.1 ORIGIN

The indigenous Afromontane (White, 1978) forests of South Africa are scattered in patches of variable size along the southern and eastern coast and on the adjacent mountain ranges. It is the only type of Afromontane vegetation found in the Cape. Here increasing latitude compensates for altitude and the Afromontane forests descends locally to within about a hundred metres of sea level (White, 1978).

During periods of more favourable climate the tropical forests (in contrast to the temperate Cape flora (Bews, 1925; Phillips, 1931; Acocks, 1953)) expanded southwards. According to Axelrod and Raven (1978) forest covered most of Africa during the late Cretac-paleocene (75-55 m. years B.P.) period, with lowland rainforest covering the northern half of the continent (Figure 1a). Smaller patches of montane rainforest occurred in the middle of this area. Along the east, in a broad belt towards the west coast, subtropical rainforest occurred with temperate rainforest in the south and savanna-woodland on the central and western parts of the continent, and to the north.

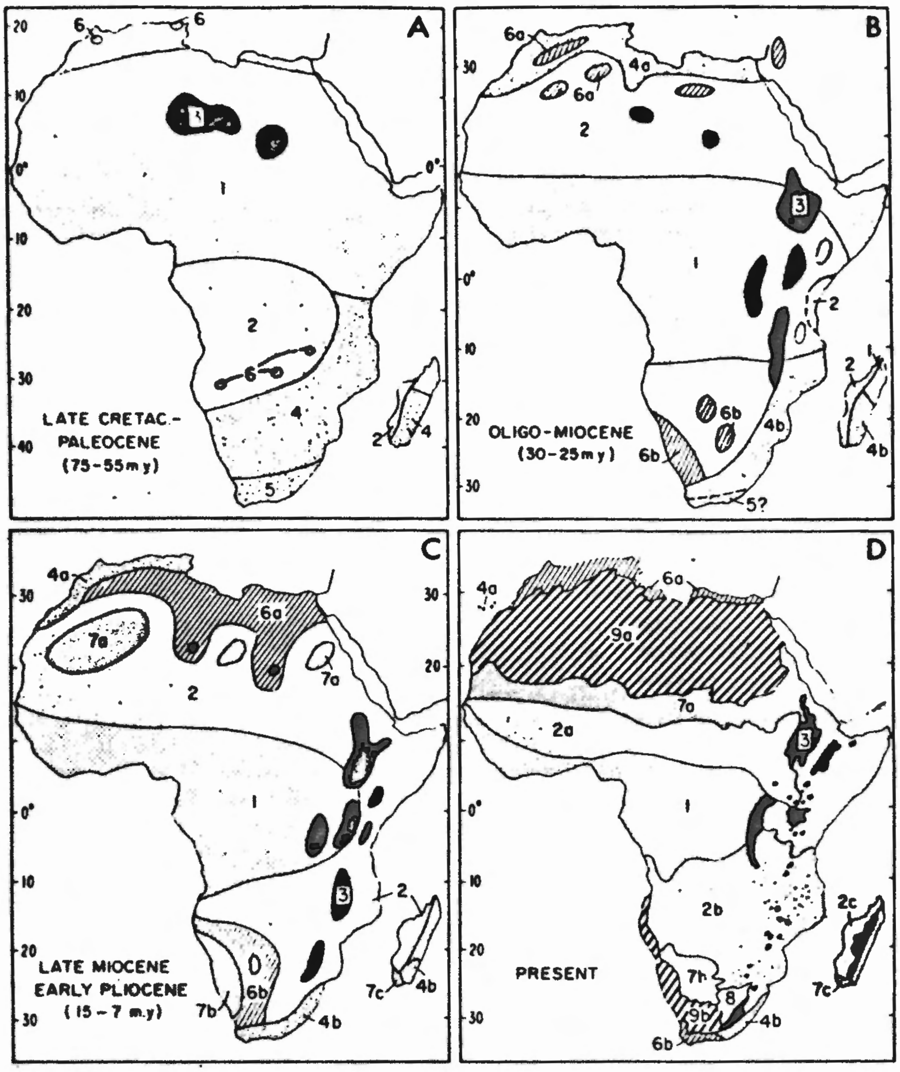


Fig. 1. Inferred distribution of vegetation. A: Late Cretaceous - Paleocene. B: Late Oligocene - Early Miocene. C: Middle - Late Miocene. D: Recent (Axelrod and Raven, 1978).

Late Cretaceous - Paleocene

1. Lowland rainforest
2. Savanna-woodland
3. Montane rainforest
4. Subtropic rainforest
5. Temperate rainforest ("austral affinities")
6. Sclerophyll woodland

Oligo-Miocene

1. Lowland rainforest
2. Savanna-woodland and thorn scrub
3. Montane rainforest
4. Subtropic laurel forest
    a. Canarian
    b. Natal
5. Temperate rainforest? ("austral affinities")
6. Sclerophyll vegetation
    a. Tethyan
    b. Cape

Fig. 1 (continued)

Late Miocene - Early Pliocene

1. Lowland rainforest
2. Savanna-woodland
3. Montane rainforest-afroalpine
4. Subtropic laurel forest
    a. Canarian
    b. Cape
5. (eliminated)
6. Sclerophyll vegetation
    a. Tethyan
    b. Cape
7. Thorn scrub - succulent woodland
    a. Sahelian
    b. Kalaharian
    c. Malgasan

Present vegetation

1. Lowland rainforest
2. Savanna-woodland
    a. Sudanian
    b. Zambesian
    c. Malgasan
3. Montane rainforest and afroalpine
4. Subtropic laurel forest
    a. Canarian
    b. Natal
5. (eliminated)
6. Sclerophyll vegetation
    a. Tethyan
    b. Cape
7. Thorn scrub-succulent woodland
    a. Sahelian
    b. Kalaharian
    c. Malgasan

(NOTE: The names of subtypes (listed under a, b or c) indicate only a general, ancestral relation to modern vegetation. All Tertiary vegetation types differed importantly from those of the present: they were far more diverse in composition. The modern communities arose as climates gradually changed, and especially rapidly in the later Pliocene and Pleistocene (Axelrod and Raven, 1978)).

During the Oligo-miocene (30-25 m. years B.P.) this whole vegetation sequence had moved further southwards, with savanna-woodland and thorn scrub covering the major part of northern Africa and central southern Africa, lowland and montane rainforest covering central Africa, sub-tropic laurel forest along the north coast and the east coast of southern Africa, temperate rainforest probably along the south coast, and sclerophyll vegetation along the west coast of southern Africa and in small patches in northern Africa (Figure 1b).

During the late Miocene and early Pliocene (15-7 m years B.P.) montane rainforest occurred along the eastern half of the continent. Savanna-woodland extended from the west to the east coast in northern Africa and from there in a broad belt along the east coast to southern Africa. Lowland rainforest covered central West-Africa, subtropical laurel forest the south-east and north coastal regions, sclerophyll vegetation a great part of North-Africa and the western inland region of southern Africa, and thorn scrub-succulent woodland the west coast of southern Africa and parts of northern Africa (Figure 1c).

Pliocene climatic conditions became unfavourable for forests and the southern flora re-advanced and forced the tropical vegetation back towards the equatorial zone. In the southern subcontinent forest survived only on favourable relic sites (Figure 1d). Today, high-forest is restricted to the most favourable sites of the original forest belt. Much of the forest has now been replaced by bush- and grassveld, fynbos and Karroo vegetation (Acocks, 1953; von Breitenbach, 1974; Axelrod and Raven, 1978).

The largest remnant of the tropical forest is in the Southern Cape and Tsitsikamma regions, against the Outeniqua mountains. During more recent times, from Quaternary onwards, this remnant was subjected to smaller climatic and depositional changes: Several aeolian depositional phases occurred. These phases are connected with periods of glaciation and lowering and rising of the sea level (Martin, 1962; Butzer and Helgren, 1972; Helgren and Butzer, 1977; Deacon, 1979).

Van Zinderen Bakker Sr. (1976, 1978) divides the glacial-interglacial cycle into four major stages and uses Post's (1946 _ex_ Van Zinderen Bakker Sr., 1978) and Iversen's (1954 _ex_ Van Zinderen Bakker Sr., 1978) terminology for them. These are the full-glacial or cryocratic stage, the protocratic stage with rising, though ocillating, temperatures which leads to the mesocratic temperature optimum of the interglacial, and finally, the telocratic stage, during which the temperature deteriorates again to glacial conditions (Figure 2). Pollen analyses obtained by Schalke (1973) and Martin (1968) provide some valuable information which can be combined with palaeontological evidence (Klein, 1974). Van Zinderen Bakker Sr. (1976, 1978) offers the following general explanation: In the Cape coastal region temperature and humidity are negatively correlated as could be concluded from the winter-rainfall climatic pattern. Evergreen forest could spread widely only during protocratic and telocratic times when temperature and humidity reached medium values. The conditions prevailed at the beginning and end of the Holocene thermal optimum. This forest dominated the coastal plain towards the end of the last interglacial. During the Early Glacial it was replaced by bush while

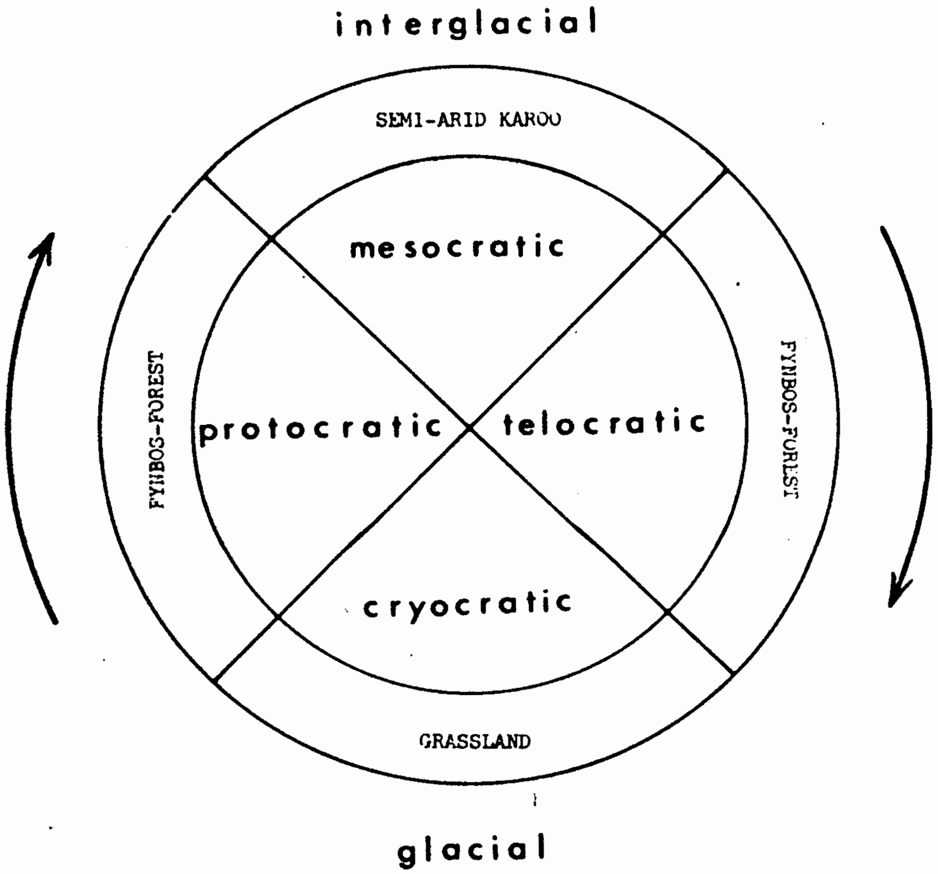


Fig. 2. Full glacial-interglacial vegetation cycle of the Cape coastal region (van Zinderen-Bakker Sr., 1978).

grassland covered the coastal region during the coldest and wettest periods of the Pleniglacial. The sudden rise in temperature round 12 400 B.P. made it possible for the fynbos, which had survived in protected mountain areas, to expand and invade the grassland. The grazing fauna was then replaced by browsing animals which were adapted to thick bush. During this protocratic period Podocarpus forest could perhaps compete with the dense fynbos in certain areas. The gradual increase in temperature, with the associated slightly drier climate, created optimal conditions from 9 000 B.P. onward for the dominance of the evergreen forest along the coast. The further increase in temperature during the drier mesocratic stage led to the encroachment of dunes in the retreating forest lands, while karroid vegetation was widespread on the coastal plain. A consequent lowering in temperature during the telocratic (present stage) times set in the reversion to forest conditions. Finally, the influence of man caused the regression of most of the evergreen forest.

According to Hopper (1979) and Macphail (1979) the glacial periods were associated with periods of major aridity in southern Australia and southern Tasmania respectively. Bowler (1976, <u>ex</u> Hopper, 1979) suggested that the causes of major aridity were to be sought in greatly intensified atmospheric circulation aided by increased continental extent corresponding to glacial low sea levels. Inter-glacials would then have been associated with wetter climates during which forests could expand.

These two opposing interpretations of the climatic patterns of the glacial-interglacial cycle both need much more proof and amplification. Only some stages have so far been verified by fossil evidence.

1.2 HISTORY

Very little is known about the Knysna region prior to the arrival of the white man. The first whites reached the George - Knysna region in 1711 (Phillips, 1931; Hartwig, 1973). Although the forests were visited in 1~~9~~727, and again between 1772 and 1775, the Dutch settlers only entered the forests in 1778 (Phillips 1931, 1963; von Breitenbach, 1974). Little evidence exists that the indigenous people, a semi-nomadic tribe of Bushmen-Hottentots (Phillips, 1931) used the forests extensively, as they were largely pastoralits (Schweitzer and Scott, 1973; Klein 1974). They did, however, burn the veld for grazing to such an extent that Vasco da Gama, in 1497, referred to the south-western Cape as "Terra de Fume" on account of dense smoke seen along the coast (Sim, 1907). These fires must certainly have affected the forest margin~~s~~. Some open patches in the forest could have been caused by smoking out of wounded animals by indigenous people. Phillips (1931) claimed that hunting pits could be found on these open patches or fynbos islands. This could provide some evidence for this theory. However, no signs of these pits could be found recently.

In 1777 a woodcutters' post was established near Swart River, in the Hoogekraal area (between George and Knysna). Commandant Mulder, with a subaltern of 15 men who attended the cutting of timber, was in charge. Soon afterwards, many more woodcutters followed and forest destruction increased. Clearing for agricultural needs also took place (Phillips 1931, 1963; von Breitenbach, 1974).

Towards the end of 1778 Governor Joachim van Plettenberg visited the region. In an attempt to bring the uncontrolled exploitation of the forest under control, he bestowed his own name onto the bay at the Keurbooms river and erected there a stone beacon with his arms and those of the Dutch East India Company and the Netherlands. Later a timber store was built and put under control of J.F. Meeding, the then commandant of the Swart River woodcutters' post. Contracts were entered into with the colonists who were to cut timber in the forests and to deliver the beams and planks to the store on payment at tariff rates. The first shipload left for Cape Town in August 1788 (Phillips, 1963; von Breitenbach, 1974).

In 1812 Meeding handed over the Knysna - Plettenberg Bay forests to the Royal Navy who opened a second timber harbour at Knysna. Although the naval authorities increased the volume of exploitation to meet the timber requirements of the Simonstown dock yards, felling operations remained comparatively well regulated. The various forests were worked in succession to allow the worked-out parts being protected and allowed to regenerate (Phillips, 1931 and 1963).

The forests to the west of Knysna were exploited more extensively, as with the founding of Graaff-Reinet in 1786 and George in 1811 the demand for timber soared, and uncontrolled exploitation and burning took place. With the beginning of the Great Trek in 1835 the demand for wagon wood and structural timber reached unprecedented heights. By 1847 the forests on the coastal plateau were so worked-out that the Government decided to sell the land for farming purposes. Only the better forests on the higher plateau and along the lower mountain slopes between the Kaaimans River and the Keurbooms River was reserved as crown land. However, very little was done to conserve these forests. As soon as a forest was worked out, it was put up for sale as agricultural land (Phillips, 1963; von Breitenbach, 1974). At about this time the forests of the Tsitsikamma, between the Keurbooms River and Witelsbos, were opened up from their eastern end and subjected to the same "fell and sell" treatment (von Breitenbach, 1974).

Urgent warnings of over-exploitation and destruction of the forests by the first Government Botanists, Dr. Karl Pappe and Dr. J.C. Brown, fell on deaf ears. It was only after the Great Fire of 1869, which swept the higher mountain slopes and lower coastal plains clean of the remnants of woody vegetation that Dr. Henry White, a member of Parliament, was able to get the "section system" approved. According to this system the state forests were subdivided into sections which were worked in rotation so as to ensure a sustained timber yield.

The George, Knysna and Tsitsikamma forests were then unified and Capt. Christopher Harison was appointed full-time forest conservator at Knysna in 1874 (Phillips, 1963).

Unfortunately, the tremendous demand for sleepers and telegraph poles for the railway lines to Kimberley and the Witwatersrand after the discovery of the diamond and gold fields caused the new forest conservation policy to collapse entirely by 1876. By then gold was discovered in the Southern Cape and portions of the Millwood forest were subsequently destroyed by miners (Phillips, 1931, 1963; von Breitenbach, 1974).

At the same time the sale of state forest land was resumed. This, together with the worldwide conservation movement, caused the public opinion to turn in favour of the perpetual preservation of the forests. In 1880 a forestry expert from France, Comte M. de Vasselot de Régné was appointed Superintendent of Woods and Forests for the whole of the Cape Colony (Phillips, 1963; von Breitenbach, 1974).

Comte de Vasselot introduced a more scientifically based management system. The forests were divided into a large number of small sections which were worked on a 40 year rotation. This system was applied from 1882 to 1890. In the majority of cases, however, its application was crude, because it was not fully understood. Numerous modifications gradually altered the very nature of the fellings and hence detracted greatly from the silvicultural value of the system. Over-exploitation was the tendency and fire continued to damage the forest margins (Phillips, 1963).

From 1891 to 1909 de Vasselot's section system was changed in many vital respects. It was a "systemless" system, never properly described or logically defined. Added to its demerits was the introduction of the "outright section system". These sections were in reality extra sections, not taken into account in de Vasselot's original management plan and much over-exploitation resulted. During this time a very arbitrary "girth-limit" appears to have been the only definite prescription in the marking of sections and even this was often ignored. Fire still did some harm along the forest margins, but less than during the previous period (Phillips, 1963).

In 1914 the existing woodcutters, of whom there were thousands between George and Humansdorp, were registered and granted the sole right to purchase trees in the forests. At an age of 65 they became entitled to old age pension and were struck off the register of bona fide woodcutters. The annual quota of 20 cubic metres which was allotted to everyone, afforded an annual income of only £25. Even this level of exploitation was much too high for the forests. A 5% stocktaking of the forest between Knysna and Humansdorp in 1927-30 showed that the legitimate yield offered only 8,5 cubic metres per year to each woodcutter. During the early 1920's forestry settlements were established to give work to unemployed, but the woodcutters were totally unwilling to give up their independence and to work for a wage (Phillips, 1963).

In the meantime a programme of afforestation with exotics, mainly pines and eucalyptus was started to combat poverty and unemployment. Roughly 40 500 ha of plantations were established in this region between 1917 and 1939 (Phillips 1963).

In 1939 the right of the woodcutters to work trees in the forests was annulled and the Woodcutters' Annuities Act provided for an annuity of £25 to each registered woodcutter (Phillips 1963; von Breitenbach, 1974).

The state-owned indigenous forests of the Southern Cape were now closed and left to heal. By 1967 the natural recovery had progressed to such an extent that the Department of Forestry was able to implement a conservation policy based on a multiple-use management system. This sound conservation based management system ensures future generations of a scientifically managed natural forest (von dem Bussche, 1974 and 1975; Geldenhuys, in press).

1.3 FOREST TYPE

There seems to be confusion about the terminology used to define foresttypes of the world, and consequently of the Southern Cape. Webb (1959) and Baur (1964) defined rainforest as a closed forest of essentially, but not exclusively, broadleaved, evergreen, hygrophilous, closely spaced trees, usually with two or more layers of trees and shrubs. The canopy level may be even or uneven. Rainforest is distinguished from other closed canopy forests by the prominence of dependent synusiae of other life forms such as epiphytes and lianas, by the absence of annual herbs on the forest floor and by its floristic complexity. Rainforest includes the characteristic vegetation of the humid tropical lowlands and those of the moist, elevated areas in the tropics and subtropics and of the somewhat oceanic climates typical of parts of the southern temperate zone. Within this broad definition numerous structural and physiognomic combinations are possible, depending upon such features as height of the community, the number of layers, the presence of a deciduous element, the most common leaf size and the nature of the epiphytes.

Webb (1959) distinguished between tropical, subtropical and temperate rainforest on the basis of mature, integrated and apparently stable Australian forest uncontaminated by other elements. The latitudinal limit~~e~~s were derived empirically using physiognomic evidence, although outliers occurred in both northern and southern directions.

Tropical rainforest is characterised by the prominence of robust woody lianes, vascular epiphytes, mostly entire leaf margins, many compound leaves of mesophyll size or larger with drip tips and pulvinii, and by a complex flora of both phanerogams and cryptogams, with some deciduous trees. The southern boundary is 21° S.

Subtropical rainforest is characterised by unique ecological features such as the prominence of notophyll leaf size and dominance by species of more temperate origin, i.e. Araucaria spp. (Agathis and podocarps in New Zealand following Dawson 1962; Robbins, 1962). The southern boundary is approximately 35° S. In comparison with tropical rainforest (Dawson, 1962), this formation has fewer species, a tendency towards local dominance of tree species, smaller leaf size, a greater abundance of tree ferns and bryophytes, denser undergrowth, a deeper humus layer in the soil, a greater accumulation of rotten logs, fewer tree species exhibiting buttressing and cauliflory, and sometimes a greater profusion of epiphytes.

Temperate rainforest is characterised by an absence or rarity of lian~~c~~es (which when they occur are slender and wiry), prominance of non-vascular epiphytes such as mosses, lichens and filmy ferns, toothed leaf margins and mostly simple leaves of microphyll size or smaller. There are few tree species, but a rich cryptogamous flora.

Phillips (1931) called the Southern Cape forests a "temperate-form subtropical forest" because climatically and floristically ~~constitutionally~~ the forests are more temperate than those of more eastern localities, while they are composed of species derived from tropical ones. Ecologically the forests also have tropical affinities, which is explained by their origin (Section 1.1). Webb (1959) regarded the Southern Cape forests following the description and suggestion by Phillips (1931) as subtropical rainforest. This forest formation occurs, according to Dawson (1962) in New Zealand, southern Queensland and New South Wales in Australia, limited montane and coastal areas in South Africa, south-east Brazil, a limited area in south Chile, southern Florida, south Japan, south and south-east China and possibly on the Canary Islands.

Baur (1964), however, regarded the term "subtropical rainforest" as of an environmental connotation, applicable to several vegetation types that are structurally and floristically related to tropical or temperate rainforest. He regarded the Southern Cape forests as temperate rainforest, as well as those in south-eastern Australia and most of the New Zealand and southern South American forests. Walter and Box (1976) classified these forests into a warm-temperate or maritime category. Strahler (1969) also classified these forests as temperate rainforest, and gives three more geographical locations where this formation occurs at higher altitudes in the equatorial and tropical zones: along eastern continental margins and on islands in the latitude belt 25° to 35° or 40°, including south-eastern South Africa, and on west coasts from 35° to 55°. Donald and Theron (in press), however, found that the forests of warm-temperate Africa have much closer affinities with tropical than with temperate origins. White (1978) classified the Knysna forests as Afromontane (see Section 1.1). A quarter of the tree species are endemic to South Africa, but all the other tree species are shared with other Afromontane regions in Africa.

The difficulties in classifying the Southern Cape forests should be clear. The uniqueness of these forests must be kept in mind when doing any research in this connection.

1.4 COMPOSITION

In spite of their origin and their basically tropical features, such as their floristic richness, 119 trees and woody shrub species (Geldenhuys, 1979), and the multistoreyed structure of the high-forest types, the Southern Cape indigenous forests are not true tropical forests.

An important characteristic of the forests is the tailing off of the species from east to west. Of the more than 300 woody species which are common to the forests of Natal and the Transkei, about 250 occur in the Eastern

Cape forests and only half of the latter occur in the Southern Cape (von Breitenbach 1972, 1974; McKenzie, 1978). A considerable number of tree and shrub species which occur in the eastern Southern Cape forests, do not occur at the western limits: Schefflera umbellifera and Brachylaena glabra are restricted to the eastern Tsitsikamma. Hippobromus pauciflorus and Canthium pauciflorum do not cross the Keurboomsriver. Maerua cafra and Cassine eucliformis disappear west of Knysna, and Fagara davyi west of Buffalo Bay. Ficus capensis, Maerua racemulosa, Clausena anisata, Pittosporum viridiflorum, Schotia latifolia, Fagara capensis, Vepris lanceolata, Ekebergia capensis, Andrachne ovalis, Rhus chirindensis, Maytenus peduncularis, Elaeodendron capense, Ochna arborea, Scolopia zeyheri, Trimeria grandifolia, Dovyalis rhamnoides, Euclea schimperi and Acocanthera oppositifolia disappear west of George (von Breitenbach, 1965, 1972, 1974; Palgrave, 1977).

A large portion of the forests is made up of tropical Afromontane rainforest species, like Apodytes dimidiata, Buddleia salviifolia, Cassine aethiopica, C. papillosa, Celtis africana, Diospyros whyteana, Ekebergia capensis, Euclea schimperi var. schimperi, Fagara davyi, Ficus capensis, Ilex mitis, Kiggelaria africana, Maytenus heterophylla, Nuxia floribunda, Pittosporum viridiflorum, Rapanea melanophloeos, Rhamnus prinoides, Rhus chirindensis, R. lucida, Scolopia zeyheri, Scutia myrtina, *Trimeria grandifolia* and *Vepris lanceolata* (Eggeling and Dale, 1951; Palgrave, 1952; Palmer and Pitman, 1972; von Breitenbach, 1974; White, 1978). Most of these species are confined to the warmer sites near the coast but species like *Rhamnus prinoides*, *Rhus lucida*, *Scutia myrtina* and *Trimeria grandifolia* occur in a subordinate position in the high forests on the cooler plateaux. *Apodytes dimidiata*, *Cassine papillosa*, *Diospyros whyteana*, *Kiggelaria africana*, *Nuxia floribunda*, *Rapanea melanophloeos* and *Ilex mitis* are more successful tropical species and counted amongst the principal species (von Breitenbach, 1974). White (1978) regards *Podocarpus* as the most characteristic genus of Afromontane forest. *Podocarpus falcatus* forms the "big trees" of the forest and outlives and outgrows all other species (Figure 3).

Some tropical species, however, survive only within very small relic habitats in the Southern Cape: *Prunus africana* at the Bloukrans Pass, *Strychnos decussata* in the Groot River valley and *Psychotria capensis* in the Gouna forest (C.J. Geldenhuys, pers. comm.; von Breitenbach, 1972).

The main portion of the forests is made up of subtropical species. These are *Olea capensis* subsp. *macrocarpa*, which is the species with the highest occurrence througout the forests (21% of all the trees at Gouna State Forest (Geldenhuys, in press)), *Ocotea bullata* (the most

Fig. 3. Structure of the indigenous forest. Note the size of the canopy emergent, Podocarpus falcatus.

valuable timber tree in the Southern Cape), Pterocelastrus tricuspidatus (12,9% of all the trees at Gouna (Geldenhuys, in press)), Olea capensis subsp. capensis, Trichocladus crinitus (the dominant undershrub of the high-forest), Burchellia bubalina, Canthium mundianum, C. obovatum, C. ventosum, Maytenus peduncularis, M. acuminata, Diospyros dichrophylla, Dovyalis rhamnoides, Ficus burtt-davyi, *Linociera foveolata* subsp. *foveolata*, *Maerua racemulosa*, *Ochna arborea*, *Rothmannia capensis*, *Olinia ventosa*, *Buddleia saligna*, *Cassine peraqua*, *Scolopia mundii*, *Cassinopsis ilicifolia* and *Alsophila capensis* (von Breitenbach, 1972, 1974).

Fig. 4. Coppice shoots of *Ocotea bullata* (stinkwood).

Platylophus trifoliatus is established along streams and on wet sites. Like Ocotea bullata (Figure 4) it regenerates vegetatively by coppicing from huge bearer stumps. Cunonia capensis is also found on the wetter sites, especially in the higher mountain forests. Virgilia oroboides serves as a short-lived pioneer. Together with Virgilia and Platylophus, Lachnostylis hirta remained confined to the Southern and Western Cape. Faurea macnaughtonii, a member of the Proteaceae, occurs only in the Lilyvlei area in the Gouna forest (Phillips, 1931; von Breitenbach, 1974).

The peripheral scrub communities are largely composed of a mixture of fynbos components, Karroo plants, tropical and subtropical bushveld elements and of local variations of the latter. Two peculiarities belong to the last group: Pterocelastrus rostratus, which appears only up to Geelhoutboomberg State Forest, west of George, and Strelitzia alba, which is found in scattered clumps in coastal scrub and forest between Harkerville State Forest and Humansdorp (von Breitenbach, 1974; Palgrave, 1977).

1.5 DISTRIBUTION

The Southern Cape indigenous forests lie in a narrow belt, 16 to 32 km wide, between the Indian Ocean and the Outeniqua mountains, roughly between Mossel Bay and the Krom River, west of Humansdorp; a strip about 240 km long (Map 1 and 2). Little forest is found on the higher mountain slopes and the lower coastal plains as most of the forest remnants on these areas were eradicated during the great fire of 1869 (Phillips, 1963).

There seems to be some disagreement about the exact area covered by indigenous forest. Von dem Bussche (1975) and Geldenhuys (in press) give a figure of about 72 000 ha of which Forestry controls 48 000 ha. Von Breitenbach (1968 and 1974) states figures of about 65 000 and 43 276 ha respectively, while the Indigenous Planning Section of Forestry in Knysna (1979) has estimates of 60 503,5 and 42 089,3 ha. Scriba (in prep.) estimated the total area of indigenous forest as 65 713 hectares, or 14,68% of the Southern Cape. (See Table 1 for a detailed comparison between von Breitenbach's and Forestry's areas). The reasons for these differences are probably different mapping scales and instruments used for determining areas, different degrees of accuracy and the lack of a clear definition of forest (or different definitions for the same concept).

Table 1. Areas covered by indigenous forest in the Southern Cape.

State Forest	Area (ha)	
	According to Forestry (1979)	According to von Breitenbach (1974) (approximate)
Ruitersbos	99,1	200
Jonkersberg	745,7	750
Witfontein (includes Geelhoutboomberg and Groenkop)	2117,9	2150
Bergplaas (includes Kleinplaat, Biervlei and Woodville)	2441,6	2550
Karatara (includes Farleigh)	2011,0	1850
Goudveld	4725,3	5150
Gouna	3556,0	3450
Diepwalle	3752,4	3200
Buffelsnek	609,0	1300
Kransbos	203,3	300
Kruisfontein (includes Concordia, Harkerville and Kaffirkop)	7779,2	7700
Keurboomsrivier	1545,1	1800
Bloukrans	3710,0	3700
Lottering	3369,6	4050
Stormsrivier	2161,1	2200
Bluelilliesbush	1581,1	1300
Witelsbos	1613,6	1300
Kromrivier	68,3	50
Total Forestry	42089,3	43000 (estimate of 1968 was 43276
Total private land	18414,2	-
Total all indigenous forest	60503,5	65000

1.6 FYNBOS ISLANDS

Within the indigenous forest areas certain sections are covered by a high, dense fynbos vegetation (Figures 5,6 and 7). These areas are known as fynbos islands and vary in size from less than 1 ha to more than 100 ha, for example Grooteiland at Kaffirkop State Forest. Uncertainty exists about the origin of the fynbos islands. Phillips (1931, 1963) attributes their origin to man, the older islands being attributed to the extinct Outeniqua tribe who were forest frequenters as is testified according to Phillips (1931), by their hunting pits within the forests. Phillips (1963) further qualifies the origin of some islands as follows: "The number of fires originating within the forests - while far lower than that of fires arising in the open - has probably been somewhat underestimated. Undoubtedly the Outeniquas were to some extent responsible for the first burning of some of the larger "eilands" now existing - a work in which they were later assisted by European and Coloured elephant, buffalo and honey hunters. Between 1856 and 1874 Harrison repeatedly commented on the serious damage wrought by these hunters, remarks which Rawbone, ten years later, was able to corroborate. Thus "Oudebrand", a large island on the edge of the Main Knysna Forest, is believed to have originated from, and to have been extended by fires kindled by early hunters, though reckless burning of grazing has undoubtedly increased this area. "Petrus

Fig. 5. 10 year old fynbos at Kleineiland.

Fig. 6. 19 year old fynbos at Kleineiland.

Fig. 7. 37 year old fynbos at Dirk se Eiland.

Brand", on the borders of the Diepwalle and Kaffirkop Forest Reserves, owes its existence to a notable old hunter, Petrus Stroebel, who set the forest alight in an endeavour to "smoke out" an elephant he had wounded and lost. The extensive wastes of Kuistervaring or Ystervaring (Gleichenia polypodioides) on the sides of Spitzkop and Jonkersberg, and such as are found in a hundred other localities in the Deepwalls forests, are attributed to honey hunters and also incendiaries aiming at burning portions of forest that they might report the damage done, and thereafter buy the burnt trees at a tariff"less than normal".

Most of the larger islands have been planted with exotics, the most recent (1974) being Petrus Brand Eiland. Some unplanted fynbos islands still exist in the largest expanse of consolidated indigenous forests, ranging from Kruisfontein through Diepwalle to Gouna State Forests. The planting plan for Dirk se Eiland was not approved as it was considered to provide grazing for wildlife, and that afforestation with exotic trees may be detrimental to the ecology of the surrounding forest. The only management done there was the removal of exotics (Cameron, 1978).

Although some fynbos islands are certainly caused by man, information on the origin and history of others is scanty. No information really exists on the interrelationship between the water relations, soil properties, floral and faunal communities and the influence these will have on succession.

CHAPTER 2

SECONDARY SUCCESSION AND SECONDARY PLANT COMMUNITIES OF THE SOUTHERN CAPE

2.1 SECONDARY SUCCESSION

2.1.1 General Review

The concept of secondary succession refers to all non-phenological vegetation changes caused by and originating from a partial disturbance in already established ecosystems (Mueller-Dombois and Ellenberg, 1974). Horn (1974) defined secondary succession as follows: It is the process of re-establishment of a reasonable facsimile of the original community after a temporary disturbance.

"The classical view of ecological succession is that, following a disturbance, several assemblages of species progressively occupy a site, each giving way to its successor until a community finally develops which is able to reproduce itself indefinitely. Implicit in this view is the assumption that each suite of species modifies the site conditions so that they become less suitable for its own persistence and more suitable for its successor, and the assumption that only the final community is at equilibrium with the prevailing environment" (Noble and Slatyer, 1978). These ideas owe their origin largely to

Clements (1916, 1936) who viewed the community as a kind of super-organism, and succession as a form of ontogeny. They have been supported by many authors, for example Phillips (1931), Odum (1969, 1971) and Golley (1977, *ex* Noble and Slatyer, 1978). Egler (1954) called this pattern of species arrival "relay floristics". He considered this pattern less widespread than normally assumed and that it may be associated mainly with the delayed entry of species communities whose composition was largely determined soon after the original disturbance.

In contrast to the relay floristics pattern, the idea of "initial floristic composition" implies the following (Egler, 1954; Drury and Nisbet, 1973): Species found in the successional stages originated on the site as seeds or vegetative propagules. Annuals are thus the quickest to obtain dominance, followed later by perennial herbs~~,~~ which are slower to react to the cessation of the disturbance. Shrubs respond more slowly and eventually trees respond. The latter two forms respond slowest due to either prolonged seed dormancy or slower seedling growth or both. Egler emphasised the importance of site occupancy by a particular species, or group of species, in restricting the subsequent entry of other species in contrast to the classical view that each group of species acts altruistically to facilitate the entry of its successor.

Although successions are generally directional rather than cyclic vegetation changes (Kershaw, 1964; Daubenmire, 1968), secondary successions can be viewed as both cyclic and directional, depending on the emphasis on the underlying time-scale (Mueller-Dombois and Ellenberg, 1974).

Horn (1976) suggested that in addition to relay floristics leading to an "obligate" pattern of succession, a competitive hierarchy between species tended to produce a directional succession in which particular species were certain to achieve final dominance. Furthermore, he proposed that in situations where there was chronic disturbance there may well be successional patterns in which almost any final community composition could result from a particular initial composition.

Connell and Slatyer (1977) suggested that most successional sequences involve three main types of pathway: The first, "facilitation pathway", is the way in which the presence of early occupants facilitates the entry of successive species groups. This is essentially the relay floristic pattern. The second, "tolerance pathway", describes the situation in which later species are successful whether or not earlier species have preceded them. They can grow on sites with lower nutrient resources and can therefore become established and grow to maturity in the presence of other species. According to the third, "inhibition pathway", later species cannot grow to maturity in the presence of earlier ones. Unless they are present on the site their entry may be inhibited by the early occupants, thereby leading to dominance by species not normally regarded as late succession species. Both the latter two pathways emphasise the importance of initial floristic composition. Implicitly, the individual is more important than the community (Noble, 1978; Noble and Slatyer, 1978).

Drury and Nisbet (1973) concluded that most of the phenomena of succession are determined by the life-history characteristics of the component species; their differential colonising ability, growth and survival. Noble and Slatyer (1977, 1978, in press, ex Noble and Slatyer, 1978) described successional sequences according to specific life-history characteristics of the key component species in a particular community and the pattern of interaction between these species with the passage of time following a disturbance. This description permits species interactions to lead to a variety of different overall successional patterns.

"To summarise, it seems that the essential requirements for the development of vegetation on a newly exposed surface, or the re-development of vegetation after a disturbance, are the availability of particular species at a particular site and their ability to become established and grow at that site. Given the relative availability.

of species at the disturbed site and in adjacent undisturbed areas, it is not surprising that the observed replacement sequences following the disturbance tend to be reproducible and frequently lead to the development of a community similar to that existing prior to the disturbance, or existing in adjacent undisturbed areas. However, the observed patterns need not reflect a form of biological determinism of the type envisaged by Clements, but rather an inevitable consequence of the relative availability of a range of species possessing certain life history strategies. This is not to say that occupancy by successive suites of species may not characterise some successions. Rather it is to emphasise that such patterns are most likely to be found when marked changes in site conditions occur during or after perturbation so that the probability of the first site occupants having the appropriate life-history characteristicts to persist under modified conditions is reduced" (Noble and Slatyer, 1978).

2.1.2 The climax concept and stability

A succession ends when the species in a community perpetuate themselves through reproduction and this is known as the climax. A climax forest must have the full complement of age class distribution in all its growth forms (Mueller-Dombois and Ellenberg, 1974).

Although in a climax community species composition should remain fairly constant over time, because of evolution, this is strictly speaking not possible. The climax concept is valid in relative stable species composition and unnoticable species population turnover. A climax community is in a dynamic equilibrium. Portions of the community are continually breaking down and being replaced by young plants. It is in equilibrium with the prevailing environmental factors of the habitat and the species are in dynamic equilibrium with one another. This may be brought about by various interactions, like niche difference in resource use, balance of competition and other disturbances, for example herbivory (Mueller-Dombois and Ellenberg, 1974). Thus the climax is a multiconditioned product of succession, its character reflecting the influence of all edaphic, aerial and biotic factors that comprise the environmental complex (Daubenmire, 1968).

Clements (1916) believed that all successions in a region lead eventually to the same climatically controlled final stage, known as the climatic climax. This is the monoclimax concept. This simplistic concept has been criticised as early as 1918 by Gams, and again in 1930 by Lüdi and Du Rietz (Mueller-Dombois and Ellenberg, 1974). It cannot be applied to mountainous regions where topography influences local climate and different communities often occur next to each other. It implies geomorphological equilibrium with the macroclimate and consequently involves complete erosion and base-levelling (Domin, 1923, _ex_ Mueller-Dombois and Ellenberg, 1974). This may take millions of years.

The polyclimax as presented by Tansley and Chipp (1926), and Domin (1923, ex Mueller-Dombois and Ellenberg, 1974) implies that there may be a variety of climax communities in dynamic equilibrium with local habitats controlled by environmental factors within a regional climate. Self-perpetuating communities may be topographic or edaphic climaxes depending on local site factors such as extreme insolation, water table, wind exposure and rainfall in contrast to the prevailing macroclimate. A polyclimax is thus a mosaic of edaphic, topographic or eco-climatically different communities one of which may be geographically dominant (Mueller-Dombois and Ellenberg, 1974).

A further development of the polyclimax concept is that different climatic climaxes may occur on a variety of soils within a region. This is the polyclimatic climax. It differs from the edaphic climax of a polyclimax in that, whereas the polyclimax concept recognises only one climatic climax in a macroclimatic region plus several environmentally controlled climaxes, the polyclimatic climax concept decrees that different parent soils will never change even when a landscape has totally aged physiographically (has attained base-levelling), and that there will always be more than one kind of well-drained soil with communities in equilibrium with the regional climate (Mueller-Dombois and Ellenberg, 1974).

Mueller-Dombois and Ellenberg (1974) state two major conceptual difficulties which need further clarification in both climax concepts viz.:

(a) The concepts of relative stability in time (climax) are not qualified in space. Spatial relationships should be strictly geographic. The stability of a formation is expected to be less than that of a vegetation region, while the stability of an association is expected to be less than that of a formation, and of a synusia less than that of an association.

(b) Community and ecosystem stability have been equated with physiographic stability, which is seldom the case, except in a dune sand succession, where the unstable substrate was the primary cause of vegetation succession. Community stability should be defined as a climax independantly of physiography to avoid controversy.

Matthews' (1979) work in Norway showed that even the idea of convergence, as explained by the polyclimax concept, is the exception, rather than the rule. He claims that as terrain age increases, the within- and between-type variability of the associated assemblage-types increases. It can therefore be inferred that a relatively varied landscape develops from a relatively monotonous successional landscape.

A logical improvement on the polyclimax concept is the climax pattern interpretation. The characteristics of the community are determined by environmental factors.

Communities intergrade as ecoclines and despite disturbances may be considered as a pattern of intergrading communities corresponding to a pattern of environmental gradients (Whittaker, 1975).

According to Daubenmire (1968) the most important measures of community stability are species composition and structure of the community. If the species composition of a community remains relatively constant over a period of several decades, one may speak of a stable community. This concept of stability allows for some fluctuation in density of individuals or in the quantities of each species comprising a community.

A natural imposed change in structure (for example, a change from closed forest to open forest or woodland) should be interpreted as instability, but if such change is reversed, as may be the case in the time following a storm, the structural change would rather be interpreted as a resistance to change, i.e. stability (Mueller-Dombois and Ellenberg, 1974).

Therefore, community stability is a stage of dynamic equilibrium persisting in terrestrial plant communities for at least several decades. During this period species composition and structure are relatively constant, measurable by structural analysis or population dynamics to predict stability. Structure and composition may vary by oscillation, fluctuation or reversible change, but not a progressive irreversible change in which case the community is unstable or fragile (Mueller-Dombois and Ellenberg, 1974).

2.1.3 Succession in the Southern Cape indigenous forests

2.1.3.1 Succession after fire

Phillips (1931) described the effect of fire on succession in the Knysna indigenous forests as follows:

(a) Ground fires: These originate in the surrounding fynbos and destroy litter, humus and trees due to root damage. All seeds, except *Virgilia oroboides* (keur), and regeneration is destroyed. Succession after the fire follows four main seral stages:

(i) Dense communities of annuals, ferns, pioneer grasses and shrubs, and coppice shoots.

(ii) Woody perennial shrubs take over and the canopy may be 3 m high in 18 months.
If keur is present the canopy may be 6 m high in the same period. Seedlings of understorey trees such as *Halleria lucida* and *Burchellia bubalina* may be present.

(iii) Many of the forest tree species invade and grow up beneath the keur canopy.

(iv) After 15 to 25 years the keur die back and the young forest trees are left to form their own canopy.

(b) Crown fires: This seldom causes any form of succession as large areas are seldom destroyed.

(c) Gleichenia invasion on burnt sites: Gleichenia often invades moist burnt sites and forms a dense mat to the exclusion of all other species, often for over 30 years. It may actively kill off perimeter trees. Only fast growing coppice or keur may quickly cover the site and exclude light, thus hampering its growth.

Phillips' Clementsian approach to forest succession appears to be wrong. The initial floristic composition might be very important, with the annuals followed by perennials and then by trees. The invasion of forest tree species beneath a keur canopy is more the exception than the rule. Noble and Slatyer's (1978) inhibition pathway most likely applies here. Dense keur stands can eliminate any invasion of forest tree species for up to 40 years. Only when the keur starts breaking down, forest species can invade.

A common phenomenon is the invasion of burnt forest sites by bracken (Pteridium aquilinum), particularly if the area is burnt successively for several years, for example, when the forest is cleared for grazing. Grasses, herbs and forest trees are excluded completely from these sites. This could possibly be the result of allelopathy. Known allelopathic chemicals from bracken have been identified by Gliessman and Muller (1978) in southern California. These are leached from the fronds into the soil by rain, to the exclusion of other plants, and eventually probably to the inhibition of the fern itself (auto-intoxication). With less phytotoxins after the reduction in density of the bracken fronds, the environment is less hostile to the establishment and development of other species. However, after a period of time the bracken could begin to re-invade the areas it previously occupied.

2.1.3.2 Succession after exploitation

Here Phillips (1931) describes the following succession after exploitation in the indigenous forests:

In large gaps (40 m diameter) insolation affects aerial and edaphic factors. Weed communities invade the site first. Due to the severe competition for moisture and space, seeds of forest trees reaching the sites are often unable to germinate and develop and regeneration is lessened.

Three principal succession stages are described after such a disturbance:

(a) Dense patches of perennial shrubs invade the area, for example *Plectranthus fruticosus*, *Helichrysum* spp., *Cliffortia* spp., *Clutia* spp., and grasses and ferns. These reduce the solar radiation at ground level and remove much moisture from the upper soil layers.

(b) Coppicing shoots of *Halleria lucida*, *Platylophus trifoliatus* and *Gonioma kamassi* grow through the dense first sere wherever these species have been felled. Together with this a variety of weak woody seed regenerating shrubs, for example *Clutia* spp., *Cassia* spp., *Podalyria* spp., *Polygala* spp., *Metalasia muricata*, *Rhamnus prinoides* and others, form a canopy of 3 to 4 m in height within 18 months of exploitation.

(c) Shoots of *Halleria*, *Platylophus*, *Burchellia*, *Ocotea*, *Curtisia* and *Gonioma* form a fairly closed canopy within 5 to 15 years. This canopy provides enough shade for forest trees to regenerate.

On sites disturbed only slightly and on smaller sites the second stage of understorey species start the seral stage and the canopy is re-established within a few years.

The presence of *Platylophus trifoliatus* in Phillips' description suggests that the successional sequence described is for a wet forest. Little evidence of this sequence on drier sites could be found.

Successions following logging and fire are not particularly evident in South Africa. This is because the artificially established plantations are seldom abandoned after clear-felling and are usually re-established very soon thereafter, before the natural succession is able to progress beyond the pioneer stage. In the plantation areas which are abandoned it is often the case that natural regeneration of the original exotics is so profuse as to exclude any form of natural indigenous secondary succession, for example, abandoned wattle, eucalyptus and poplar plantations. These may act as nurse stands for indigenous forest climax species, but as yet no conclusive evidence has been recorded.

The present methods of logging in the indigenous forests of South Africa preclude secondary succession as described above. Gaps caused are small, resulting in cyclic reproduction. Fires are not used in conjunction with logging. Where large gaps in moist forest are inadvertently caused by felling large trees the secondary succession initiated might be as described by Phillips. On medium moist and drier sites succession is much slower and Platylophus is absent.

2.1.3.3 Succession under exotic species

Laughton (1938) described this succession as follows: Exotic plantations provide enough shade to prevent the dense growth of ferns and herbs and create favourable conditions for the establishment of indigenous species. This process can be compared with succession after a fire or heavy logging, where the initial weed growth is replaced by pioneer species such as *Virgilia oroboides*, *Clutia pulchella* and *Halleria lucida*. When the growth rate and soil water requirements of the species decrease, indigenous tree species become established. A young exotic plantation has the same detrimental effect on the soil water régime as the pioneer species.

The indigenous forest is mainly growing on its own litter. The rate of recycling is much higher than under plantations, for example on Diepwalle State Forest, where most of the forest soils are shallow and infertile. Regeneration of indigenous shrubs like *Clutia pulchella*, *Halleria lucida*, *Burchellia bubalina*, *Diospyros glabra*, semi-pioneer species like *Rapanea melanophloeos*, *Pterocelastrus tricuspidatus*, *Nuxia floribunda*, *Kiggelaria africana* and climax species like *Podocarpus* spp., *Ocotea bullata*, *Olea capensis* subspp. *macrocarpa* and *capensis*, *Curtisia dentata*, *Apodytes dimidiata* and *Olinia ventosa* only occur on plantation sites with these litter characteristics. The density and composition of the regeneration largely depends on the proximity of a seed source (Laughton, 1938).

Taylor (1954) mentioned good regeneration of *Podocarpus latifolius* and *Rapanea melanophloeos* under a *Pinus radiata* stand near the indigenous forest on Karatara State Forest. On Jonkersberg and Geelhoutboomberg State Forests the understorey consists virtually exclusively of *Rapanea* on the drier sites and *Cunonia capensis* on the wetter sites, with some *Halleria lucida* and *Laurophyll~~o~~us capensis* in between.

A luxuriant growth of *Pterocelastrus tricuspidatus* often occurs under *Eucalyptus* belts, for example, on Groenkop State Forest. On Witelsbos State Forest some *Eucalyptus* stands have a rather dense understorey of *Ocotea bullata*.

2.1.3.4 Succession of exotic species

This type of secondary succession is often found on islands. Areas of the same habitat may have different plant communities which are not essentially different succession stages. Man introduced species may cause new floristic patterns within these stages. These new invaders may have a dominant community structure in one part of the island, but may not have invaded other parts as yet. Thus, as the exotic species invades, secondary succession may change periodically and not allow the reversible floristic pattern found usually in floristically saturated continental areas (Mueller-Dombois and Ellenberg, 1974).

Where exotic species have become established in natural vegetation any disturbance, especially burning, may cause a complete invasion by the exotic in the area. This is particularly true of the pioneer exotics such as *Hakea* sericea, Acacia melanoxylon and A. mearnsii. These species are adapted to fire and their seed is stimulated thereby. Thus a fire reduces natural vegetation competition, stimulates their seed and the exotic invades rapidly. Once established they compete fiercely with the vegetation, for example fynbos, which is soon almost eliminated (Wicht and Kruger, 1973).

Wherever large gaps in the Southern Cape indigenous forest occur Acacia melanoxylon is able to establish itself if a seed source is nearby, to the exclusion of the natural forest species. Being shade-intolerant it cannot establish under a dense canopy and seed must lay dormant until stimulated by fire and/or solar radiation in gaps caused naturally or by man.

2.2 SECONDARY PLANT COMMUNITIES OF THE SOUTHERN CAPE

Apart from Phillips (1931), and recently Taylor (1978) and Kruger (1979) little has been published about the non-forest secondary plant communities of the Southern Cape. The fynbos, however, despite its uniqueness and scientific interest, has not yet been classified into detailed structural or floristic units partly because the main botanical effort has hitherto been directed towards solving the manifold taxonomic problems and partly because of the complexity of the vegetation. Also, since fynbos does not possess the economic potential of grassland or forest, the practical need for vegetation studies has not hitherto been felt (Taylor, 1978).

Acocks (1953) recognised four vegetation types in the Southern Cape, viz. Knysna forest (veld type 4), false macchia (veld type 70), some coastal renosterbosveld (veld type 46), with a tiny patch of valley bushveld (veld type 23) round Mossel Bay (Figure 8). The valley bushveld is found in the valleys of the Klein and Great Brak Rivers. These valleys are hot and receive less rain than the intervening ridges. The coastal renosterbosveld is found between Mossel Bay and George, an area which is extensively cultivated, and in a narrow belt along the coast from George to Goukama, west of Buffalo Bay. According to Acocks, this vegetation type has replaced the natural vegetation which appears to have been dense thorny scrub with Olea africana and Sideroxylon inerme being the dominant trees. The lower parts of the valleys may have had a drier, semi-succulent scrub, while the upper parts of the valleys probably had a scrub which was transitional to forest. Relics of the original scrub are scarce and in poor condition.

Acocks (1953) dealt extremely briefly with the sclerophyllous bush types, dividing them into two types: macchia and false macchia. Macchia, also known as fynbos, is the

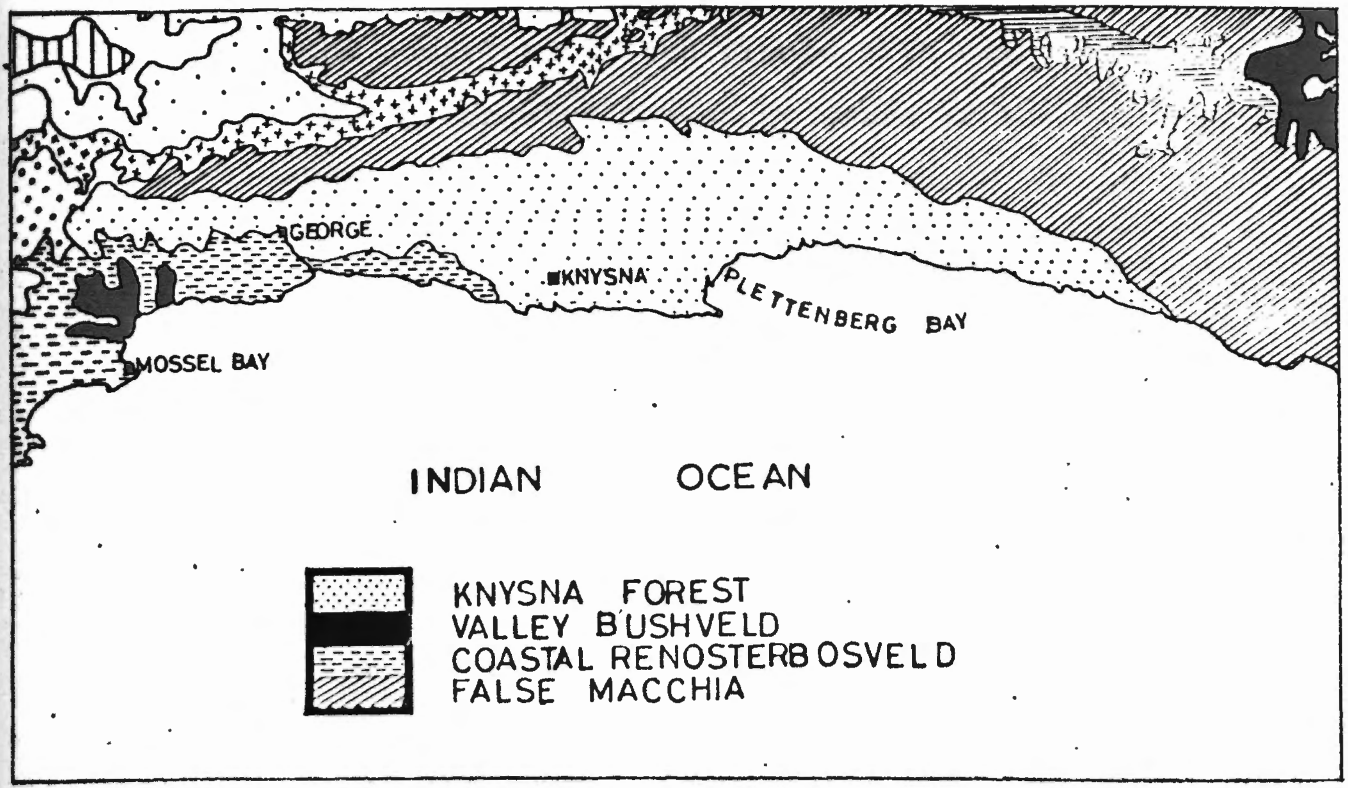


Fig. 8. Vegetation types of the Southern Cape (Acocks, 1953).

southern vegetation and is different in origin and nature to the tropical vegetation of South Africa; but today is very mixed with it. According to Acocks false macchia is today indistinquishable from macchia, but contains indications that in its natural condition it would have been transitional from sourveld to macchia. Taylor (1978) divided the fynbos in three sub-sections: mountain fynbos, arid fynbos and coastal fynbos. Of these, mountain and coastal fynbos are represented in the Southern Cape south of the crest of the Outeniqua Mountains. Taylor identified three physiognomic characteristics of fynbos:

(i) The restioid element, which is always present and comprises tufted plants with near-leafless tubular or wiry non-woody stems of the Restionaceae and some Cyperaceae.

(ii) The ericoid element, which is also constant and comprises dwarf and low, evergreen ericoid shrubs with small, narrow, often rolled leaves.

(iii) The proteoid element, which is a frequent but not constant feature, comprising taller sclerophyllous shrubs with moderate-sized hard leaves with a dull surface.

(a) Mountain fynbos: This occurs on the cool moist and upper mountain slopes (Kruger, 1979). It is 0,2 to 2,5 m tall and even taller on wet sites or where it contains a tall proteoid component. Cover may vary from 50 to 85%, approaching 100% on wet and mature sites. Within this type Taylor (1978) includes the hygrophilous fynbos where plentiful soil moisture is a unifying factor. This occurs along river and stream banks, seepage and drainage lines, marshes, swamps, pans and on moist flats. Phillips (1931) regards the hygrophilous fynbos as a seral stage to evergreen forest. According to him the floristic and structural composition varies from one locality to the next: The number of dominants on an area may vary from several to many and the height varies from less than 1 m to more than 3 m. The stands are closed;

the density being a feature of the particular dominants and sub-dominants present. In its taller portions it greatly influences the atmospheric conditions - air humidity is increased; air temperature and evaporation are decreased and light intensities are reduced.

Although sclerophyllous species remain prominant, soft leaves are prevalent, for example of such members as Brunia, Berzelia, some Erica species and low forbs. The most striking features of these formations are, however, their stature, their extreme density, indefinite stratification and great diversity of species and growth forms (Kruger, 1979). Kruger further subdivided this fynbos as follows:

(i) Mixed sclerophyllous scrub: These are very dense, vigorous and relatively uniform communities. The upper stratum, with a cover of 50 to 70%, is normally 3 to 4 m tall, but can reach 7 m if protected for 20 to 30 years. It is dominated by a mixture of broad-sclerophylls such as Leucadendron eucalyptifolium and Laurophyllous capensis and narrow sclerophyll Bruniaceae such as Berzelia intermedia. The middle layer consists of thickets of tall and mid-height shrubs, such as Erica, Penaea and Phylica, and tall graminoid herbs such as Restio foliosus, Cannomois virgata, Tetraria bromoides and T. involucrata. This layer is 1,5 to 2,5 m tall, although it may reach 3 to 4 m in old communities. Tufted hemicryptophytes, low shrubs and herbs form the bottom layer and maintain a cover of 10 to 25%.

This formation occurs in a belt between about 250 m and 600 m on south slopes, but can extent to 900 m on drier aspects. It alternates with dry broad-sclerophyllous scrub with changes in aspect and the soil moisture régime.

(ii) Broad-sclerophyllous scrub: Most of these scrub communities occur on steep cool slopes at and near drainage lines, especially on shales, and level perennially moist erosion surfaces on the coastal platform. Protea lacticolor, P. longiflora, P. mundii and P. punctata dominate these communities. These shrubs are relatively long-lived and P. mundii can reach a height of 6 to 8 m at an age of 40 to 50 years. In old stands the lower strata are suppressed.

(iii) Tall narrow-sclerophyllous heath: This formation occurs on the upper mountain slopes and succeeds the zone of broad-sclerophylls. These tall heath communities have a dense upper stratum of tufted and multi-stemmed Ericaceae, Bruniaceae, Penaeaceae and Cliffortia about 1 to

1,5 m tall. Cyperaceae and Restionaceae form dense and poorly stratified lower layers.

(b) Coastal fynbos: This fynbos type is restricted in the Southern Cape to small areas round Mossel Bay and at Goukama, mainly on limestone. Taylor (1978) noted that it has many more grass species and annuals than mountain fynbos. Sparse to dense stands of Proteaceae form the upper layer. Beneath this layer, which may be 1 to 2 m high, ericoids and restioids occur (Taylor, 1978). Structurally this formation represents some mountain fynbos communities and includes some species typical of the latter vegetation, such as Erica plukeneti and Hypodiscus striatus, but also a complement of strictly coastal fynbos species such as Protea obtusifolia, the other Erica spp., Chascanum cernuum and Thamnochortus fraternus (Kruger, 1979). Phillips (1931) notes that where it occurs on white and grey marine sands, it is much gnarled, twisted and stunted as result of wind action. On better sites, climatically and edaphically, and where it receives a fair supply of scrub and bush germinules, it can develop into scrub or bush.

(c) Lithophilous fynbos: Phillips (1931) recognised this formation which occurs on rocky sites along mountain summits and upper slopes, and on portions of the foothills. On these sites this vegetation remains climax. He claims that it can develop into scrub, bush or even forest on suitable sites. Its structure differs from the abovementioned fynbos types in that it is of a lesser height and luxuriance, and is more open. In addition, it contains more grasses. On the warmer and drier sites *Themeda triandra* can form an extensive cover.

(d) *Scrub*: Two scrub types are identified by Phillips (1931): littoral or coastal scrub and inland scrub. The former is more stunted, more gnarled and more slow-growing, while the foliage is usually more succulent and the leaves smaller than the latter. On the whole the littoral scrub is denser and possesses a closer, less interrupted canopy than the inland type. The height of both types varies from 1 m at the coast and on the hottest, driest and most shallow inland sites, to 5 m. Due to the adverse climatic and edaphic conditions on these sites the community remains stunted, despite the fact that the component species are capable of growing to large dimensions under favourable conditions. The most important features are as follows:

(i) The large number of subtropical species present.

(ii) The abundance of true woody shrubs and stunted trees; the development of spines, the increase in numbers of lianes as compared with fynbos and the occasional occurrence of succulents.

(iii) The impenetrable, densely-massed nature of the vegetation.

(iv) The rarity of regeneration of typical scrub shrubs, but the gradual increase in number, in high scrub and of seedlings of pioneer forest trees.

(v) The general absence of dominance, except over exceedingly small areas. The shrubs and stunted trees are generally mixed.

(vi) Some of the important canopy-forming species are as follows: *Euclea schimperi*, *E. racemosa*, *Pterocelastrus tricuspidatus*, *Scolopia zeyheri*, *Apodytes dimidiata*, *Maytenus heterophylla*, *M. acuminata*, *Rhus lucida*, *R. longispina*, *Pittosporum viridiflorum*, *Carissa bispinosa*, *Scutia myrtina*, *Grewia occidentalis*, *Capparis sepiaria*, *Heteromorpha arborescens*, *Ekebergia capensis*, *Tarchonanthus camphoratus*, *Buddleia salviifolia* and others. Between the shrubs appear species such as *Elytropappus rhinocerotis*, *Stoebe* spp., *Passerina filiformis*, *Erica canaliculata*, *Tetragonia* spp., *Mesembryanthemum* spp. and xerophytic grasses and under the shrubs species such as *Hypoetes* spp., *Knowltonia* spp., *Haemanthus* spp. and *Pellaea viridis*.

(e) *Bush*: Bush is more luxuriant than scrub and can be considered a transition between scrub and forest. As development proceeds, more and more climax forest species appear. The general height of the canopy varies from 6 to 9 m. More species and individuals of ferns, lianes and epiphytes are present than in scrub. As in the case of scrub, there are two well-defined bush types: the littoral bush of the sea and the inland bush of the plateaux and foothills of the interior. The differences between the two types are almost entirely structural. The inland type is usually better grown, less gnarled, grows faster and is more luxuriant than the littoral type (Phillips, 1931).

(f) Forest: This formation occupies the best sites in the Southern Cape. The type of forest and the composition has already been discussed in Chapter 1.

Locally it has been divided into six site classes, viz. very dry, dry, medium moist, moist, wet and very wet. Only the medium moist and moist types, which forms about 20% of the forest, are used for production. These two classes also have the highest canopy: 16 to 22 m for the medium moist and 20 to 30 m for the moist forest (von Breitenbach, 1968). The rest of the forest is managed for research, protection, reconstruction and recreation.

CHAPTER 3

SOILS AND VEGETATION

With the exception of research on exotic plantation species, very little work has been done on the influence of site factors on forest development in South Africa. More work in this connection has been done in foreign countries, the classic one being that from Morison et al (1948) in the south-western part of the Anglo-Egyptian Sudan (southern Sudan), although this study was on the relation between soil and savannah-woodland.

Forests are dependent on the soil for their sustenance (Youngberg, 1965). Morison et al (1948) claims that the development of the soil on any site is mainly determined by the local topography through its effect on water movement. Jenny (1941, ex Mew, 1975) adds parent material, climate, time and organisms to topography as soil forming factors. Organisms include vegetation, mesofauna and human activities. Of these five factors topography, parent material and organisms will be the major ones affecting the soil in such a way that it might control the forest-fynbos ecotone in the Southern Cape. Climate and time, as geology and geomorphology, can be considered constant when looking at a specific forest-fynbos or forest-disturbed site ecotone. These factors may, however, play important roles in the regional forest distribution.

3.1 MUTUAL INFLUENCE

According to Hall (1977) much of the variation in the Nigerian high forest is associated with soil differences. A primary division of the forest could be made according to the underlying soil type: Ferrallitic and Ferruginous Tropical (presumably the latter soil is a plinthic soil). Forest on Ferruginous Tropical soils could usefully be subdivided according to rainfall, while the forest on Ferralitic soils could by subdivided on a geographical basis; mainly reflecting the influence of factors other than rainfall.

On the other hand Eyre (1968), considering a world picture of vegetation and soils, came to the conclusion that in the case of tropical soils which are subjected to seasonal drought, very little correlation exists between soil types and vegetation types. No clear distinction between grassland soils and forest soils could be made, partly because of the vast extent of various grades of savanna and grassy woodland.

Whittaker (1970) stated: "A number of trends or progressive developments underlie most successional processes. There is usually progressive development of the soil, with increasing depth, increasing organic content, and increasing differentiation of layers or horizons towards the mature soil of the final community ....". The time scale within which this progressive soil development takes place has seldom been specified explicitly. But it clearly implied that development of a mature soil profile is contemporaneously with succession, and is therefore measured rather in thousands of years than in centuries or decades (Drury and Nisbet, 1973). This implies that during secondary succession, which comprises a relative limited period, normally no significant soil development takes place as a result of the changes in vegetation (primary succession does result in soil development, but is of no interest for the present study). However, the opposite normally is applicable, viz. that the type of soil has a significant influence on the type of vegetation developing (Drury and Nisbet, 1971; Pritchett, 1979).

Sometimes the vegetation does have a drastic influence on soil development, but normally only where it causes acidification of the soil. The classic example are the heathlands in England and Europe. After the oak forests were cleared during Napoleonic times, heath developed in its place and no regeneration of the oak occurred. Probably these trees, with their deep roots, obtained their nutrients directly from the weathering parent material. These nutrients were then re-cycled through litter fall. When the trees were removed, the source of this humus was removed and a mor soil developed, mainly as a result of the litter of the heath and the acidifying grasses. Thus, podzolisation took place. Some brown forest soils are probably converted to podzols in this way after deforestation or the podzol characteristics of podzolic soils were made more prominent. Thus, an E (A_2) horizon developed or increased, and iron illuviated into the B_1 horizon. In some cases this resulted in a hardened B_1 horizon as a result of sementation of the iron. This, in turn, limited root and even water penetration (Bunting, 1965; Eyre, 1968).

Another example of podzolisation is in New Zealand where Agathis australis (Kauri pine) produces a very acid litter which causes podzol formation to proceed more vigorously near the tree to form the so-called "egg cup" podzol beneath the tree. A similar phenomenon develops in some luvosols (red yellow podzolic soil) in southeastern Asia where a thick luvon (red yellow leached horizon) is associated with Gymnostoma nobile (a species of casuarina) (Fitzpatrick, 1971). Nothofagus solandri var. solandri (black beech) in New Zealand caused more leaching of a site with a similar climate, topography and climate than of an adjacent one under Podocarpus/broad-leaved forest (Cowie, 1965, ex Mew, 1975).

A similar soil development can be expected on sites in the Southern Cape where the indigenous forest has been eradicated and replaced by fynbos, with its acidifying characteristics.

Whether the vegetation has acidifying properties or not depends largely on the uptake of nutrients. Coniferous trees have a low demand for bases, and leaf fall of these plants results in an accumulation of acid residues. Moreover, because these plants have low demands for bases such as calcium and magnesium, the solum is likely to become impoverished of bases as leaching occurs. Trees, however, vary in their demand for basic elements. In general, deciduous forests have higher demands for bases than coniferous forests, but forests as a whole have lower demands for bases than grasses (Thompson, 1957). Fynbos occurs on acid, infertile soils. Thus, it must have a low demand for bases and the leaf litter will be acid too. Fertilizer experiments on the Australian heathlands showed that expecially high levels of phosphate, and sometimes of nitrogen caused certain species to die earlier, and virtually all seedling growth was inhibited (Heddle and Specht, 1974; Groves and Keraites, 1976).

On the short term it is not so much the physical soil properties that are influenced by the vegetation, but more the chemical properties, and thus the soil fertility.

In the Southern Cape the vegetation may influence the soil to such an extent that the retrogression of forest to fynbos is irreversible.

Other, less drastic, roles of vegetation in soil development is of importance too. Tree roots grow into fissures and aid in the breakdown of bedrock. They may penetrate some compacted layers and improve aeration, soil structure, water infiltration and retention, and nutrient-supplying capacity. In addition to tree roots, the associated and other living organisms in the soil are responsible for organic matter additions and decomposition, accretion of nitrogen and structural stability. Furthermore, protection of the soil from erosion may be afforded by a vegetative ground cover. A forest cover can significantly modify the temperature and moisture condition of the soil by its influence on the amount of water that reaches the soil surface, by a reduction of runoff and an increase in percolation, and by an increase in water loss as a result of evapotranspiration (Lyford and MacLean, 1966, ex Pritchett, 1979).

3.2 INFLUENCE OF TOPOGRAPHY

Topography can have a profound local influence on soil development. Soil relief affects development mainly through its influence on soil moisture, soil temperature, leaching, erosion and on plant cover. For example, in most coastal plains small variations in elevation can have a pronounced effect on drainage. Water in soils with restricted drainage often becomes stagnant because micro-organisms and plant roots use dissolved oxygen faster than it can be restored. Under anaerobic conditions, Fe, Al, Mn and other heavy metals are reduced to a more soluble condition. Under reduced conditions these metals move in the soil solution until they eventually oxidise and precipitate. Such precipitation produces gleyed conditions that are often characterised by a grey to greyish-brown matrix sprinkled with yellow, brown or red mottles or concretions in the B horizon. Subsoil colours are generally reliable guides to drainage conditions, ranging from blueish-grey for very poorly drained reduced conditions to yellows and reds for better drained areas (Pritchett, 1979).

Steep slopes have more runoff and less water percolating through the soil than occur on more gentle slopes. With less water percolating in the soil on steep slopes there may be shallow rooting of plants. Furthermore, less vegetation is supported on steeper slopes because of the limitations of water. Steeper slopes also suffer more geological erosion, and the more strongly weathered material is gradually eroded away, exposing fresh or less weathered materials (Figure 9). Steeper slopes have better aeration as a result of less water held in pore spaces; and as a consequence of better aeration, organic matter decomposes more rapidly on steeper slopes. There is more desiccation on steeper slopes and more dehydration of iron hydroxide, resulting in redder colours, or if the organic matter content is relatively high, in browner colours (Thompson, 1957). Steinbreuner (1965) found that the site index of Douglas-fir (*Pseudotsuga*

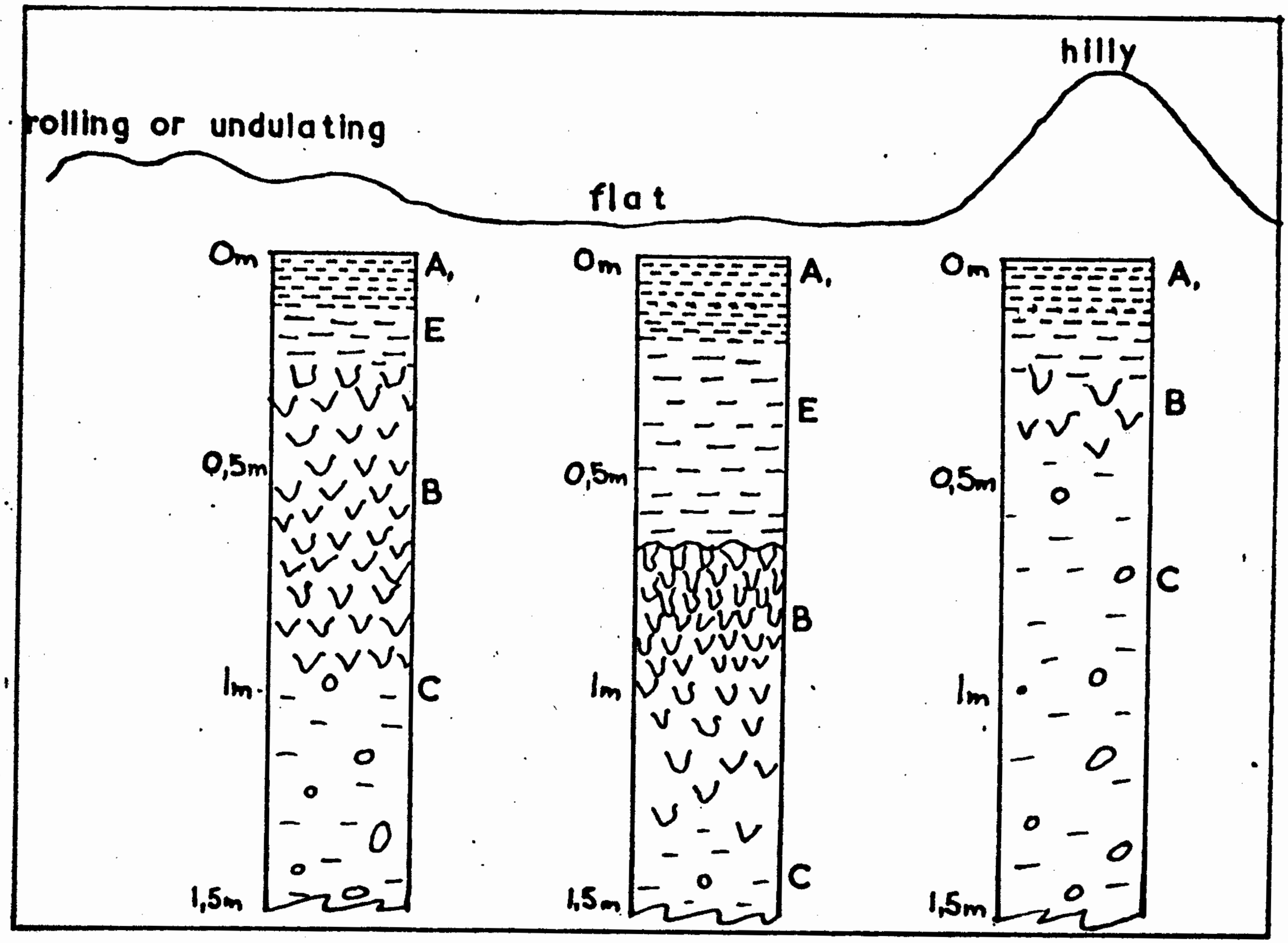


Fig. 9. A schematic diagram showing the effect of slope on the depth and degree of horizon differentiation of soils developed from similar parent materials (Thompson, 1957).

menziesii) in Western Washington decreased on slopes steeper than 30%. Significant negative relations could, however, only be found on elevations above 330 m.

Equator-facing slopes are much warmer than pole-facing slopes and have a greater degree of weathering and more decomposition of organic matter. The cooler (pole-facing) slopes have less evaporation of water than the warmer slopes, which may cause more vegetation to be produced and a greater accumulation of soil organic matter (Thompson, 1957). The site index for oak in Arkansas was found to be significantly higher on pole-facing slopes than on equator-facing slopes (Graney, 1974). In the Southern Cape the indigenous forests occur mainly on the southern (pole-facing) slopes, particularly in the marginal areas. In both cases these are the more moist, cooler slopes associated with higher site indexes.

The form of the slope can be important too. Concave slopes are usually much wetter than convex slopes (Graney, 1974). On gentle slopes below steeper slopes there may be some accumulation of soil that erodes from higher places. This causes a thicker topsoil to occur than might be found on gentle slopes above steep slopes.

The position of the water table has a major influence on profile differentiation on flat topography. If the water table is very near the surface, there is a minimum of percolation of water through the solum to cause differentiation. The most strongly differentiated profile can be expected in humid regions where the water table is low enough to cause more downward movement of soil water, other conditions being equal with respect to parent material, relief, rainfall etc. (Figure 10). In warm dry climates a high water table may increase the rate of weathering compared to soils with no water table near the surface. The higher moisture content resulting from capillary rise from the water table favours chemical decomposition of minerals of the soil. Furthermore, the organic matter content of the soil may be higher in the soil with a high water table, but the likelihood of downward movement of clay from the A to the B horizon is small under such conditions. The B horizon with a higher clay content than the A horizon in an arid soil with a high water table might be explained by greater weathering in the B horizon, which would be more moist than the A horizon most of the time (Thompson, 1957).

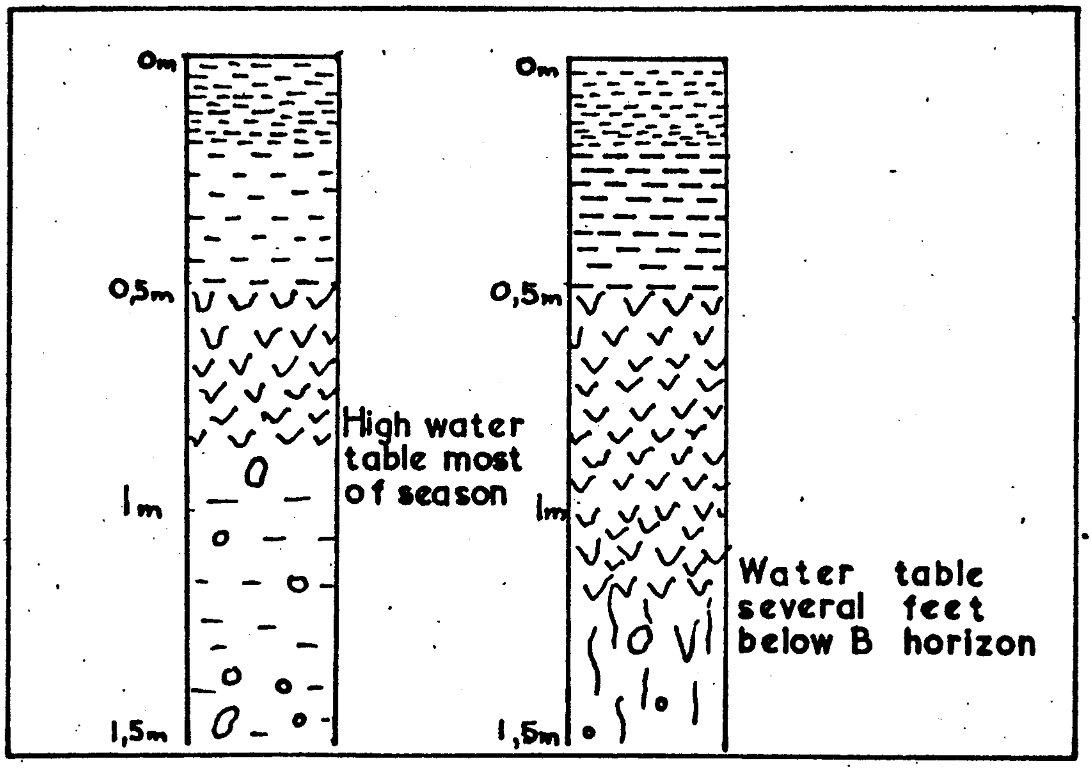


Fig. 10. The influence of a high water table on profile development (Thompson, 1957).

3.3 INFLUENCE OF PARENT MATERIAL

The principal characteristics of parent material that affect soil development are texture and mineralogical composition.

3.3.1 Texture

The texture of a soil horizon is one of its most, if not the most, permanent characteristics (Soil Survey Staff, 1951). The texture of the parent material determines the water and aeration relations of the developing soil and influences its productivity. Thus it may determine the type of vegetation that will occupy the soil. Sands are usually high in quartz although they do contain other minerals, such as feldspars. They usually represent resistant minerals, and their rates of weathering are also slow because of the low surface area in relation to their weight and volume. Consequently sands are poor sources of nutrients; they do not hold much water and organic matter does not accumulate as much in sandy soils compared to fine-textured soils (Thompson, 1957).

Deep, coarse sandy soils often support relatively poor coniferous stands and other species that have low requirements for moisture and nutrients. The productivity of sandy soils increases as the proportion of material smaller than 0,05 mm (silt and clay particles) increases to an optimum level. Because of this relationship loams and clay soils often support trees of high moisture and nutrient requirements, such as many hardwood species (Fitzpatrick, 1971; Pritchett, 1979).

Steinbrenner (1965) found a curvilinear positive relationship between the clay content of the B horizon and the site index of Douglas-fir in Western Washington. According to Page (1976) the site index for _Abies balsamea_ and _Picea mariana_ in Newfoundland was better on well-drained apedal and podzolic soils than on the poorly drained clayey, gleyed or peaty soils. However, if the soils are too coarse and sandy, like the shallow mountain soils on sandstone, the site index decreases, like that for _Quercus rubra_ and _Q. alba_ in Arkansas (Graney, 1974). The same holds for the site index of _Picea mariana_ in eastern Canada, but there the highest site index is on fine textured silty or heavy clay soils (Lowry, 1975).

If all other things are equal, deeper solums are associated with coarse textured materials low in clay content, while shallow solums develop from materials with a high proportion of clay (Figure 11).

The importance of the indirect influence of texture on tree growth is often masked by more critical factors. Texture _per se_ has little effect on tree growth as long as moisture, nutrients and aeration is adequate. In coastal plains, changes in soil moisture conditions

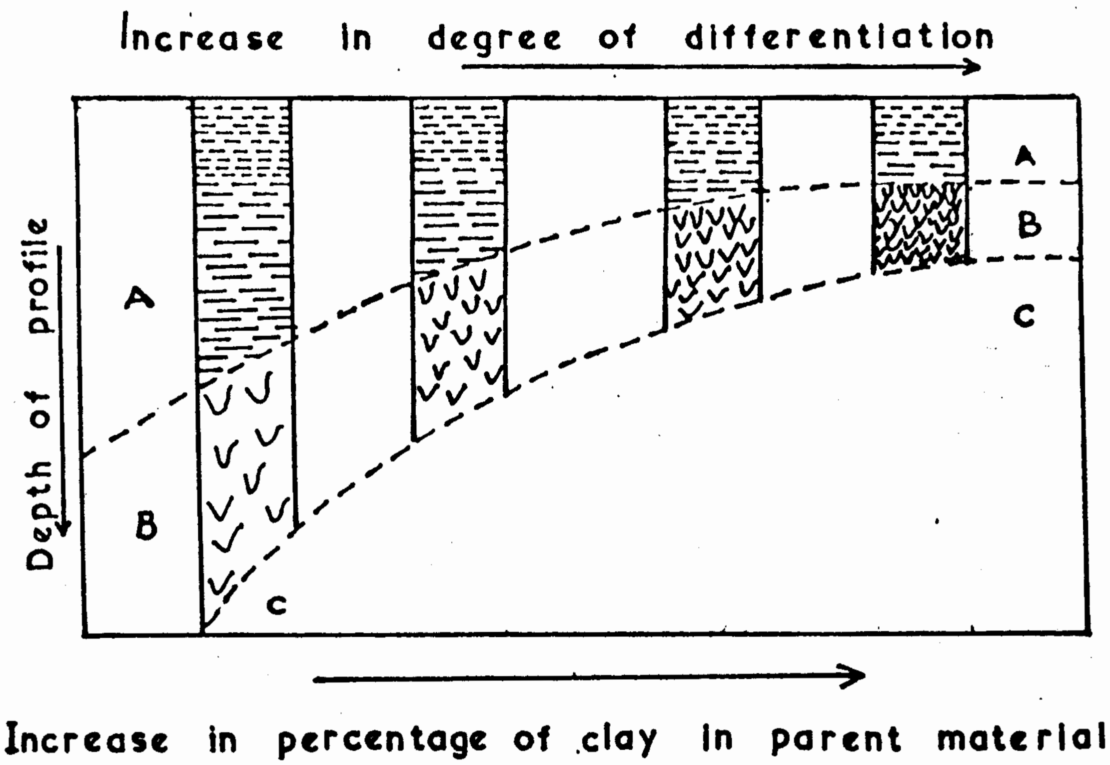


Fig. 11. The effect of texture of parent material on profile development (Smith, Allaway and Riecken, 1950, ex Thompson, 1957).

brought about by small differences in elevation may completely overshadow textural effects. Fertilisation of moist, sandy soils can overcome the low capacity of these soils to retain nutrients. Furthermore, a forest stand tends to modify its environment to the extent that texture of the soil is of minor importance. Through species succession, soil conditions may be gradually changed so that they more nearly meet the requirements of the trees in the stands. In this way, pioneer trees create conditions for the establishment of more exacting climax species by increasing organic content, thus minimising the effect of soil texture on establishment of growth (Pritchett, 1979).

3.3.2 Mineralogical content

The mineralogical content of parent materials is of particular significance in determining the fertility level of the soil. Youthful and fertile soil is associated with the presence of a high proportion of calcium-magnesium minerals and a high content of total phosphorus. As weathering of materials proceed, the calcuim-magnesium mineral content decreases and the easily weathered potassuim minerals disappear. The older and more strongly weathered materials are a poor source of plant nutrients, and they support only plant species with low base requirements. Conifers are found to predominate on the more strongly weathered soils while the hardwoods occupy the more fertile younger soils in the United States of America. In the forest-grassland transition, the grasses generally occupy the soils with the higher base status while forests generally occur on the soils with less bases (Thompson, 1957).

Where one particular type of vegetation, for example grasses, exists on a variety of associated soil series, the organic matter content may be positively correlated with the fertility level of the soil (Thompson, 1957).

3.4 INFLUENCE OF OTHER SOIL FACTORS

3.4.1 Structure

The most important factors influencing soil structure are the nature and origin of parent materials and the physical and biochemical processes of soil formation. The presence of salts, growth and decay of roots, freezing and thawing, wetting and drying, and the activity of soil organisms are important too. Soil texture has considerable influence on the development of aggregates. Sandy soils often have a single grain structure, while clay soils exibit a wide variety of structural types. Fires may increase the formation of aggregates in fine-textured soils due to dehydration of the soil colloid. Mesofauna, such as earthworms and millipedes, cause the formation of crumb structure in the surface soil by ingestion of mineral matter along with organic material. Aggregates are stabilised by the temporary binding action of micro-organisms, such as mycelia and fungi, the intermediate products of microbial synthesis and decay, and the cementing action of the more resistant humus components that form complexes with soil clays. These stabilisers are associated with forests (Fitzpatrick, 1971; Pritchett, 1979). Thus, a vigorous forest cover favours the maintenance of good soil structure, which in turn favours the forest.

3.4.2 Soil depth

The volume of soil available to tree roots, as dictated by soil depth, influences tree growth to the extent that it affects nutrient and moisture supplies and root development and anchorage against windthrow. Trees growing on shallow soils are generally less well supplied with water and nutrients than trees on deep soils (Pritchett, 1979). Steinbrenner (1965) found a strong linear relationship between soil depth and the site index of Doublas-fir (*Pseudotsuga menziesii*) in Western Washington.

The absolute and effective depth of a soil are not necessarily the same, because a high water table, toxic substances, or an impervious layer may completely restrict root penetration in a soil that would otherwise permit deep rooting. Strong linear relationships between effective soil depth and the site indexes of *Pinus echinata* in Arkansas and Doublas-fir in Western Washington have been found by Graney (1974) and Steinbrenner (1965) respectively. According to Jackson (1973) the productivity of trees in New Zealand are generally higher on soils with greater effective depths than those on shallow soils. Excessive soil moisture becomes an inhibiting factor on shallow soils in moist areas.

A common feature of the Southern Cape indigenous forests is the shallow rooting of the trees, a mechanism which enable the trees to utilise the nutrients in the biomass as soon as they are released by decomposition of the litter on the forest floor. This makes these forests to a great extent indepent of soil depth.

The depth of the E (A_2) horizon can have a pronounced influence on site quality. Steinbrenner (1965) found that when he included the E horizon in his calculations, he could explain more of the variation in the site index of Douglas-fir. He found a positive relationship between the depth of the E horizon and the site index, probably as a result of better drainage. This influence decreased as the depth of the A_1 horizon increased. Lowry (1975), on the other hand, found that the site index of *Picea mariana* decreased when the depth of the E horizon increased, probably as a result of leaching of nutrients.

3.4.3 Gravel content

Gravels may occupy a considerable percentage of the total soil volume - space that would otherwise be occupied by soil, air or moisture. A reasonable amount of rock in a fine-textured soil may favour tree growth. The coarse fragments may increase penetration of air and water and increase soil temperatures during the growing season. Nevertheless, a coarse skeleton dilutes the soil and can be detrimental to tree growth if it occupies a significant volume of sandy soils. It reduces the already low waterholding and exchange capacities of these soils

(Pritchett, 1979). Steinbrenner (1965) found that the site index for Douglas-fir decreased as gravel content of the soil increased, but the rate of decrease became less at higher gravel contents.

CHAPTER 4

STUDY AREA

4.1 LOCALITY

In the study six areas were sampled, i.e. parts of Kleineiland (33°58'S, 23°13'E) and Grooteiland (33°57'S, 23°13'E) both on Kaffirkop State Forest, Dirk se Eiland (33°56'S, 23°13'E) on Diepwalle State Forest, Ysternek Nature Reserve (33°54'S, 23°10'E) between Diepwalle and Buffelsnek State Forests, and Forest Creek Concession area (33°54'S, 22°52'E) and a fynbos island in Ratelbos (33°53'S, 22°53'E) both on Goudveld State Forest (Figure 12). The first four areas were sampled by means of a grid system, while the two areas at Goudveld were only sampled by means of a short transect. Kleineiland, Grooteiland and Dirk se Eiland are all at an elevation of 330 m, Ysternek at 670 m, Forest Creek Concession area at 305 m and the fynbos island in Ratelbos (which will be referred to as Ratelbos Island) at 395 m.

4.2 CLIMATE

The Southern Cape is that part of South Africa which experiences an all seasons rainfall régime. It lies between the Cape winter rainfall area to the west and the summer rainfall area to the east. The climate is characterised.

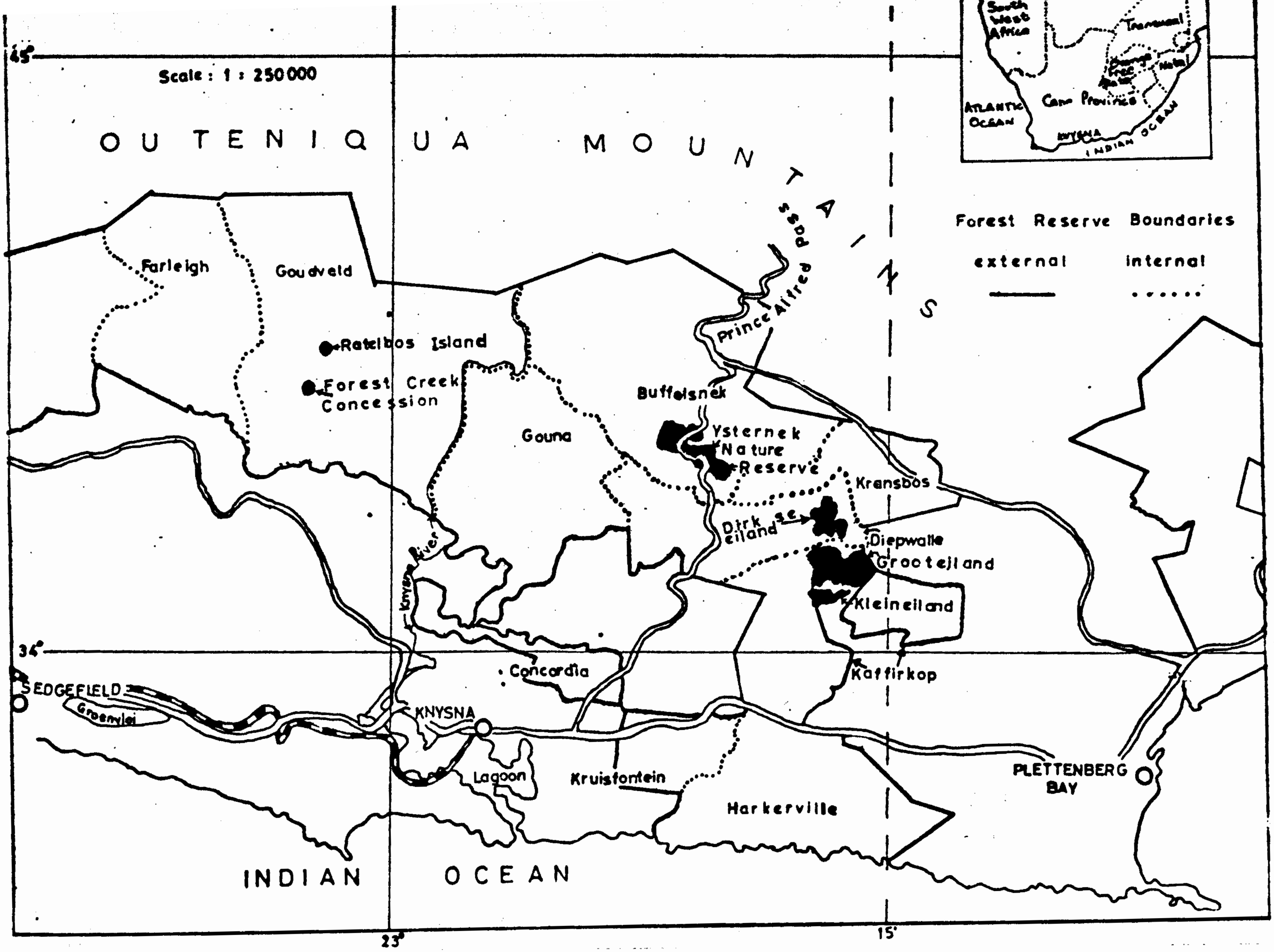


Fig. 12. Map of study areas

by the high incidence of cloud, frequent light rain and changeable weather.

The weather of the Southern Cape, like the rest of Southern Africa, is dominated by the general circulation of subtropical anti-cyclones. Circumpolar westerly winds originate far to the south of Southern Africa and take the form of a succession of eastward moving cyclones and anti-cyclones, bringing rain to the south and south-eastern coasts. This rain may extend far inland. Frosts are associated with the cyclones, warm fronts being diffuse and cold fronts being more usual (Jackson and Tyson, 1971).

The Outeniqua mountains act as a barrier to the inland penetration of shallow weather systems, thus producing frequent and often highly localised orographic mist and rain, and controlling the local airflow on fine days and nights (Tyson, 1971).

Spring is the wettest season, while winter is the driest (Table 2). The mean annual rainfall for the whole region is 994 mm, but owing to the nature of the topography, it varies considerably with altitude and shows a tendency to increase towards the east. On the mountain ranges annual amounts may reach 1 200 mm, whereas the coastal area around Mossel Bay receive barely 500 mm annually (Map 3).

Table 2. Mean annual and seasonal rainfall (mm) and number of rainy days for selected stations in the Southern Cape (Weather Bureau, 1970 and 1977)

Station	Co-ordinates		Height (m)	Period of measurement (years)	Mean Annual		Main Seasonal							
							Rainfall (mm)				Rainy days			
	S	E			Rainfall (mm)	Rainy days	Dec.-Febr.	Mar.-May	June-Aug.	Sept-Nov.	Dec.-Febr.	Mar.-May	June-Aug.	Sept-Nov.
Jonkersberg	33°55'	22°14'	457	56	1019,8	99	280,6	266,6	183,6	289,0	26	25	20	28
Geelhoutboomberg	33°55'	22°22'	460	43	815,5	98	219,2	205,9	158,0	232,4	26	25	18	29
Witfontein	33°55'	22°26'	610	21	932,9	91	259,8	264,9	167,4	240,8	25	24	18	24
George	33°58'	22°25'	229	98	868,8	122	236,0	225,0	163,4	244,4	32	31	25	34
Saasveld	33°58'	22°32'	223	43	850,7	91	220,8	220,4	169,8	239,7	23	23	19	26
Goudveld	33°55'	22°57'	216	88	815,9	106	214,4	205,3	163,2	233,0	27	27	21	31
Millwood	33°53'	22°59'	457	83	1058,0	122	286,3	263,3	197,6	310,8	33	30	23	36
Gouna	33°58'	23°03'	305	52	933,4	104	239,5	226,6	200,2	267,1	27	26	21	30
Diepwalle	33°57'	23°10'	519	36	1192,9	126	307,5	270,2	265,4	349,8	34	29	26	37
Kaffirkop	34°00'	23°13'	396	53	878,0	105	197,7	214,1	214,9	251,3	27	26	23	29
Bloukrans	33°57'	23°38'	243	94	1001,9	101	271,5	244,7	197,7	288,0	27	24	21	29
Lottering	33°57'	23°47'	229	78	1115,0	101	286,1	274,4	238,3	316,2	26	24	22	29
Stormsrivier	33°58'	23°53'	243	92	1118,8	116	270,7	273,1	250,2	324,8	31	28	25	32
Bluelilliesbush	34°00'	23°57'	300	26	1149,4	107	253,2	283,8	291,9	320,5	27	27	23	30
Witelsbos	33°59'	24°07'	227	81	1155,8	100	274,2	277,9	275,3	328,4	26	24	22	28
		Mean of all stations			993,8	105,9	254,5	247,7	209,1	282,4	27,8	26,2	21,8	30,1
		Mean % of all stations					25,6%	24,9%	21,0%	28,4%				

Precipitation most commonly occurs as light rain. Thunderstorms, hail and weather disturbances which produce high intensity rainfall occur on about ten occasions per year, almost exclusively in summer (Schulze, 1965; Tyson, 1971).

The warmest weather is associated with pre-frontal conditions and with "bergwinds" which often precede winter cyclones when dry subsiding air moves off the interior plateaux in response to strong coastward pressure gradients. The coldest, and usually wettest, weather results from post-frontal outbursts of cold polar or subpolar air from the southwest (Tyson, 1964 and 1971). (See Table 3 for more detailed temperature data).

Walter-Lieth climate diagrams, which were drawn for four stations (Figure 13), gave no indication of moisture stress periods for the forests. A good indication of this was obtained by using Thornthwaite's potential evapotranspiration (PE) (Thornthwaite, 1948). Although his method for calculating PE has certain shortcomings (Schulze and McGee, 1978), it only requires latitude and mean monthly temperature as data inputs. More comprehensive weather data, which is necessary for Penman's method, for example, are not available.

Actual evapotranspiration is the difference between the water supply (as precipitation) and the PE. Thus, in months where rainfall exceeds PE, there will be a moisture surplus which will either be lost as runoff or used to recharge depleted soil moisture.

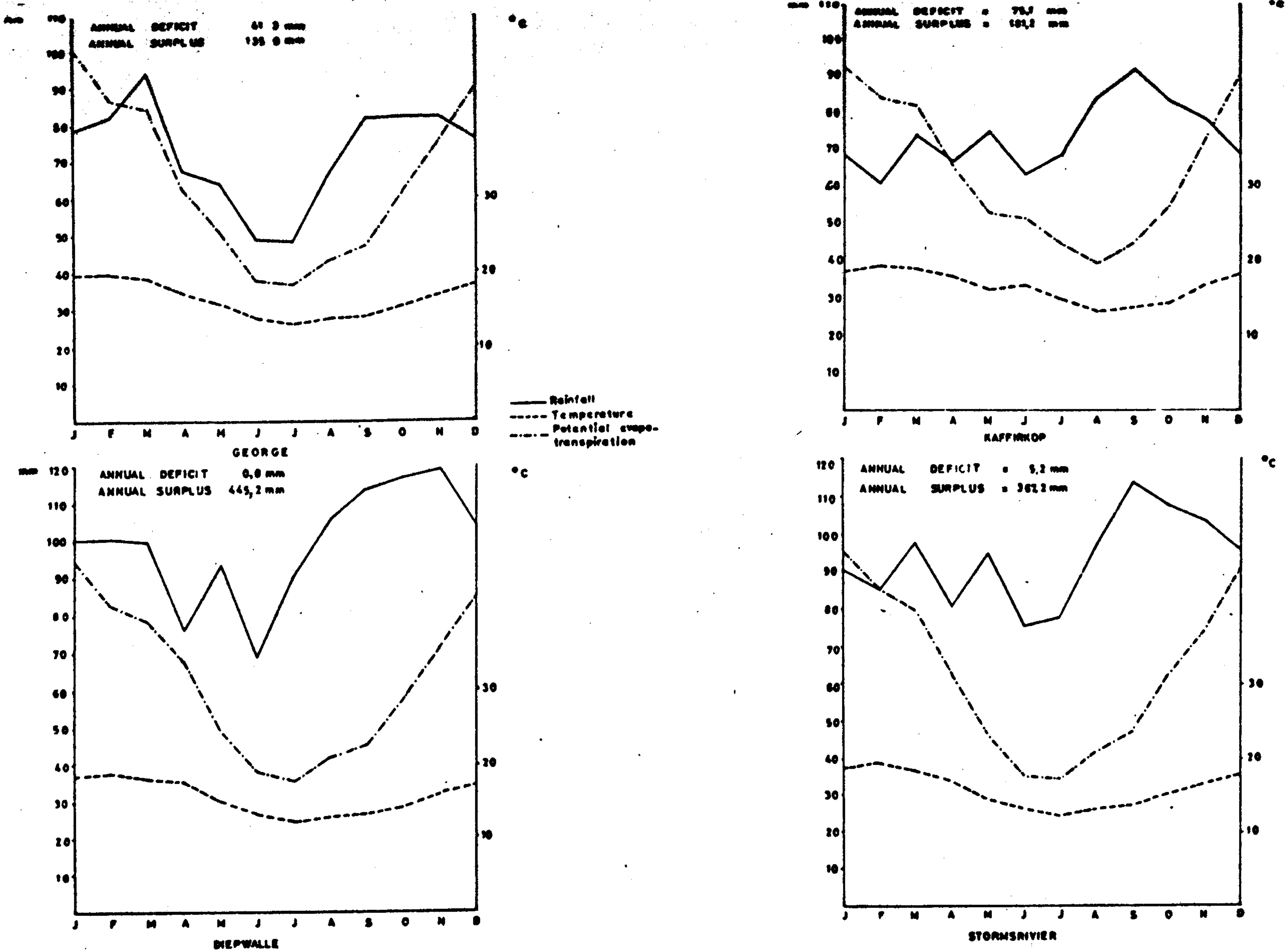


Fig. 13. Climate diagrams, with Thornthwaite's potential evapotranspiration superimposed onto them, for four selected stations.

Table 3. Mean and extreme temperatures (°C) and relative humidity (%) for George, Diepwalle, Kaffirkop and Stormsrivier (Weather Bureau, 1954 and 1977)

	Air temperature (°C)										Relative humidity (%)			
	Means of						Extremes							
	Daily max.	Daily min.	Mean daily $(\frac{max-min}{2})$	Range (max-min)	Monthly max.	Monthly min.	Absolute max.	Absolute min.	Average at 08h00	Average at 14h00	Average at 08h00	Max. at 08h00	Average at 14h00	Min. at 14h00
George (33°58'S, 22°25'E)														
P	10	10	10	10	10	10	10	10	8	8	8	8	8	8
an.	24,5	14,7	19,6	9,8	33,2	10,5	41,3	8,9	19,2	23,0	77	80	64	57
ebr.	24,4	15,2	19,8	9,2	32,6	10,5	37,2	8,3	18,8	23,2	83	86	66	59
ar.	24,0	14,4	19,2	9,6	34,1	9,3	41,2	8,2	17,6	22,3	82	86	66	57
pril	22,4	12,0	17,2	10,4	33,0	7,8	38,7	4,7	15,2	20,8	80	85	61	53
ay	21,1	10,3	15,7	10,8	29,7	5,5	32,9	3,6	13,8	19,6	73	82	58	53
une	19,4	8,2	13,8	11,2	27,6	4,2	30,6	3,3	11,7	17,9	68	77	54	43
uly	18,6	7,4	13,0	11,2	27,8	3,3	30,2	1,3	10,3	16,9	73	77	53	45
ug.	19,2	8,1	13,7	11,1	29,6	3,4	31,9	2,2	11,1	17,3	74	79	57	54
ept.	19,1	8,9	14,0	10,2	30,8	4,5	34,6	3,3	12,8	17,2	78	82	66	56
ct.	20,0	10,5	15,3	9,5	29,7	6,0	37,9	4,1	14,6	17,9	77	81	69	59
ov.	21,7	12,1	16,9	9,6	29,9	7,8	33,5	6,4	16,9	19,8	75	82	67	60
Dec.	23,0	13,3	18,1	9,7	32,0	8,1	38,9	4,4	18,1	21,2	73	79	66	57
ear	21,5	11,3	16,4	10,2	-	-	41,3	1,3	15,0	19,8	76	-	62	-
Diepwalle (33°57'S, 23°10'E)														
P	20	20	20	20	20	20	28	28	20	-	20	20	-	-
Jan.	23,2	13,8	18,5	9,4	33,3	9,6	40,4	5,6	17,7	-	83	87	-	-
Febr.	23,4	14,3	18,9	9,1	33,6	10,1	39,9	5,6	17,6	-	87	92	-	-
Mar.	22,6	13,7	18,1	8,9	33,2	9,3	38,6	5,0	16,6	-	82	90	-	-
April	21,1	12,2	17,7	8,9	32,1	7,0	35,6	3,7	14,5	-	78	83	-	-
May	19,3	10,7	15,0	8,6	29,0	4,9	34,4	0,1	12,9	-	74	83	-	-
June	17,9	8,9	13,4	9,0	25,3	3,8	29,4	-0,2	11,6	-	69	80	-	-
July	16,6	8,1	12,3	8,5	24,9	3,0	27,5	0,3	9,5	-	75	85	-	-
Aug.	17,7	8,3	13,0	9,4	28,7	3,3	32,6	-0,4	10,1	-	77	88	-	-
Sept.	18,0	8,7	13,3	9,3	30,9	3,5	36,7	0,0	11,7	-	77	90	-	-
Oct.	18,9	9,7	14,3	9,2	29,7	5,2	38,1	0,9	12,9	-	80	91	-	-
Nov.	20,5	11,5	16,0	9,0	31,3	6,9	39,2	4,4	15,1	-	82	95	-	-
Dec.	21,8	12,3	17,1	9,5	30,9	7,6	36,8	5,2	16,2	-	81	89	-	-
Year	20,1	11,0	15,5	9,1	-	-	40,4	-0,4	13,9	-	79	-	-	-
Kaffirkop (34°00'S, 23°13'E)														
P	9	9	9	9	9	9	9	9						
Jan.	22,8	13,9	18,6	8,9	33,0	11,0	37,5	9,4						
Febr.	23,5	15,2	19,4	8,3	34,1	11,4	37,2	10,3						
Mar.	23,3	14,6	18,9	8,7	32,5	10,3	37,2	7,2						
April	22,6	13,1	17,8	9,5	35,3	8,8	37,6	5,1						
May	20,3	11,9	16,1	8,4	29,6	6,2	31,7	4,2						
June	19,4	10,2	16,7	9,2	26,3	4,7	28,3	2,8						
July	17,8	8,8	14,8	9,0	26,1	2,6	28,3	1,7						
Aug.	18,9	8,6	13,1	10,3	28,3	4,9	32,8	3,9						
Sept.	18,9	9,6	13,7	9,3	30,4	5,2	35,6	2,5						
Oct.	19,3	10,8	14,3	8,5	29,4	6,3	34,4	5,0						
Nov.	20,8	12,7	16,7	1,8	27,0	8,3	35,6	6,7						
Dec.	22,6	13,7	18,1	8,9	31,2	9,2	35,0	7,5						
Year	20,8	11,9	16,4	8,9	-	-	37,6	1,7						
Stormsrivier (33°58'S, 23°53'E)														
P	68	68	68	68	68	68	68	68						
Jan.	23,7	13,7	18,7	10,0	34,5	9,4	41,7	5,6						
Febr.	24,3	14,3	19,3	10,3	34,7	9,4	41,9	4,7						
Mar.	23,1	13,6	18,3	9,5	34,7	7,9	41,9	4,4						
April	22,5	11,5	17,0	11,0	33,8	6,1	37,8	-0,6						
May	20,1	9,1	14,6	11,0	30,0	4,3	34,9	0,8						
June	18,8	7,3	13,2	11,5	27,1	2,4	31,1	-2,8						
July	17,6	7,0	12,3	10,6	27,3	2,2	36,4	-0,4						
Aug.	18,8	7,3	13,1	11,5	29,4	2,7	34,2	-0,3						
Sept.	18,7	8,6	13,7	10,1	31,9	3,5	38,6	-0,6						
Oct.	20,2	10,1	15,1	10,1	31,4	4,5	37,1	0,0						
Nov.	21,5	11,6	16,5	9,9	32,3	6,8	39,7	3,9						
Dec.	22,9	12,9	17,9	10,9	35,9	8,6	40,3	5,6						
Year	21,0	10,6	15,8	10,4	-	-	41,9	-2,8						

P = period in years

Diepwalle is the only place (of the four used in Figure 13) which experiences no summer moisture deficit, although the deficit at Stormsrivier is very small. Noteworthy is the fact that the annual (summer) deficit at Kaffirkop is higher than at George, in spite of the higher annual rainfall. However, the nett surplus (surplus minus deficit) at Kaffirkop is higher than at George. This stresses the importance of the topographical influence on the rainfall pattern of the Southern Cape, which is reflected to a certain extent in the type of forest in the different areas.

Relative humidity is always fairly high, with an average of 76% and 62% at 08h00 and 14h00 respectively at George and 79% at 08h00 at Diepwalle. During summer the relative humidity is higher than in winter, with the highest 08h00 average of 83% at George and 87% at Diepwalle, both in February. The lowest 08h00 average occurred in June, being 68% and 69% for George and Diepwalle respectively. The highest and lowest 14h00 averages at George are 69% in October and 53% in July respectively. No 14h00 data for Diepwalle are available (Table 3).

Frost is virtually unknown. Snow only occurs on the higher mountains above 1 000 m, but only persists on the highest peaks of the Outeniqua range.

The local pattern of air movement on the coastal foreland is dominated by the occurrence of both land and sea breezes (induced by the land - sea juxtaposition) and anabatic and katabatic winds (induced by the Outeniqua mountains and adjacent coastal foreland). The onshore sea breeze and upslope anabatic wind during the day, and the offshore land breeze and downslope katabatic wind by night act together to produce strengthened local winds (Figure 14). By day in January the combined onshore east-south-easterly and sout-easterly anabatic wind and sea breeze is pronounced and contributes greatly to total air movement in this direction. By night the onshore component is weak, with the katabatic wind and land breeze increasing in

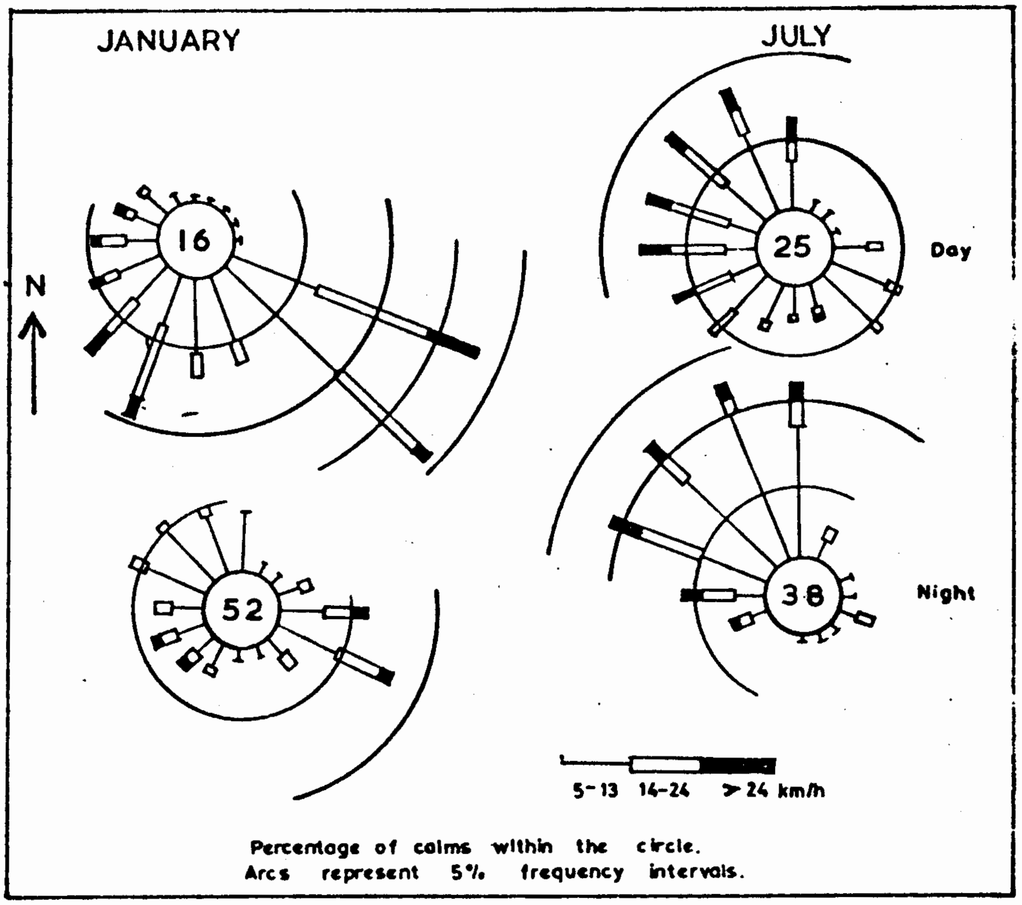


Fig. 14. January and July wind roses for George (Weather Bureau, 1960; Tyson, 1971)

frequency of occurrence. In winter the situation is the reverse with the onshore daytime component being noticeable weaker and the offshore nocturnal component strengthened.

In January there is a marked diurnal variation of both wind speed and direction at George (Figure 15). Onshore movement begins between 09h00 and 13h00 and ceases after 21h00. Off-shore movement prevails between 21h00 and 7h00. In July, the diurnal variation is much less, and the local on-shore component is negligible, while the

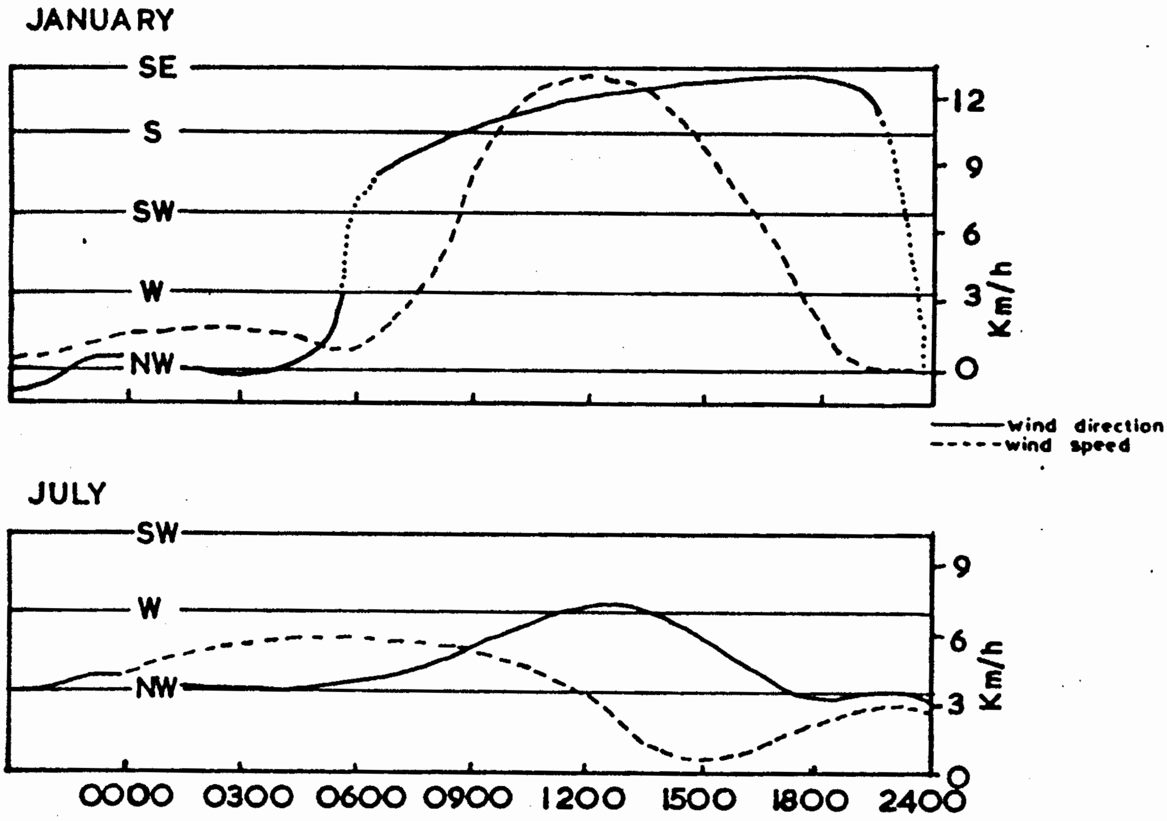


Fig. 15. Diurnal variation of wind speed at George (Tyson, 1971)

light northwesterly off-shore winds prevail from about 21h00 to 10h00.

4.3 PHYSIOGRAPHY

4.3.1 Topography

The Southern Cape is dominated by east-west striking ridges of the Cape Fold Ranges. This folding occurred during the middle Mesozoic (about 120 m.y. B.P.) era. It is composed essentially of Table Mountain Sandstone (Ordovician to Silurian age) and shales of the Bokkeveld Series (Devonian age). The first mountain range extends to above 1 500 m and ridge crests further north above 2 000 m (Schafer, in prep.).

The coastal belt is made up of a series of plateaux, commencing about 200 m beneath the Indian Ocean and rising gradually as it proceeds inland. Of these plateaux the more important ones are the following:

(i) The plateau submerged about 200 m and extending a few kilometres into the sea. The edge is known as the Agulhas Bank (Phillips, 1931).

(ii) On the coast line the second plateau rises abruptly to a height of between 120 and 180 m (Figure 16). For the most part its seaward end is a cliff-faced terrace, rising immediately from the surf. The entire plateau is between 5 and 16 km wide and extends to about

Fig. 16. The coast line east of Knysna. The Uplands or coastal plateau rises abruptly to a height of between 120 and 180 m. The whitish TMS of the coastal plateau is of the Peninsula Formation, while the brownish Tchando Formation remnants can be seen at sea level.

300 m above sea level. Phillips (1931) called this plateau the Uplands Plateau, while Tyson (1971) and Schafer (in prep.) refer to it as the coastal platform. It has been created by major eustatic seal level fluctuations (Tertiary and Quaternary) followed by planation (through wave action) and sedimentation. Uplift and downcutting created the deeply incised valleys found throughout the plateau - an indication of a relative young topography associated with a

lowering of the sea level. Rivers that cut through this platform are the Brak, Kaaimans, Swart, Touw, Homtini, Goukama, Karatara, Knysna, Keurbooms rivers and others (Tyson, 1971; Toerien, 1976; Schafer, in prep.).

Part of this plateau, or lying between the plateau and the sea, are the coastal dune plateau just east of Knysna (Harkerville, Kaffirkop area), the dunes between the Kaaimans river and Gericke Point, west of Knysna, and the Wilderness lakes. The coastal dune plateau is undulating to rolling. Slopes are convex, sloping to moderately steep. Drainage patterns are dendritic and bottomlands are strongly concave and narrow (Schafer, in prep.). The dunes between Gericke Point and the Kaaimans river are 100 m and higher and comprise of calcareous sand ridges and unconsolidated superficial deposits. The ridges loose height westwards from Knysna. The older inland ones trend east-southeast to west-northwest, whereas the younger seaward ridges are aligned east-northeast to west-southwest and are truncated by the present coastline (Tyson, 1971). Between these two dune ridges are the Wilderness lakes. They are all connected with the sea, except the most easterly one, Groenvlei, which is 2 m above sea level (Martin, 1962).

(iii) The third plateau, called the De Vlugt plateau by Phillips (1931) and the foothills zone by Tyson (1971) occurs only west of the Keurbooms river. East of this river it gradually disappears.

> "The narrow and often indistinct plateau at 335-396 m is cut indiscriminately across Table Mountain Sandstone and rocks of the basement complex, indicating its likely erosional origin. This zone is particularly narrow west of George, but reaches its maximum extent on the Woodville granites, near Bergplaas and Diepwalle in the headwaters of the Diep and Knysna rivers. Being developed to a large extent on granite and drained by youthful incised streams, the slopes are generally convex and the actual surface is somewhat irregular" (Tyson, 1971).

4.3.2 Geology

Sandstone, quartzite, shales and phyllites of the Table Mountain and Bokkeveld Groups underlie the greater part of the Southern Cape. Exceptions are the relative small areas near the coast underlain by pre-Cape rocks comprising the Maalgaten Granite (600 to 650 m.y. B.P.), and a variety of sedimentary and metamorphic rocks belonging to the Kaaimans Formation, the unconsolidated surface deposits, conglomerates and sands of Tertiary to recent age (Map 4) (van Eeden, 1972; Geological Survey, 1979; Toerien, 1979).

The Table Mountain Group consists of supermature quartz sandstone and minor shale layers. This can be up to 3 500 m deep. The Bokkeveld Group consists of up to 1 700 m of shale and subordinate sandstone. Marine invertebrates are common in the shales of the lower half of the Bokkeveld Group (Toerien, 1979), for example at Nature's Valley.

"All the pre-Cretac~~i~~eous strata were subjected to severe north-south orientated compressive stresses producing the so-called Cape Fold Belt with the more resistant strata forming prominent mountain ranges running east-west. Overfolding is common, and reverse faults are present in places. Also present are normal faults, largely post-Cretaceous in age, and downthrown to the south by up to a few thousand metres" (Toerien, 1979).

The sediments of the Kaaimans Formation are metamorphosed to some extent by the Maalgaten and related granites. Phyllite, quartsite, grit, hornfels and schist are among the sedimentary deposits of the seven members of this formation (Geological Survey, 1979; Toerien, 1979).

The Table Mountain Group comprises the Peninsula, Cedarberg, Tchando, Kouga and Baviaanskloof Formations. The Peninsula, Tchando and Kouga Formations constitute .

the mountain ranges of the Cape Fold Belt and are probably of marine origin. Although rare in the Peninsula Formation, Trilobite trails (?) and Scolithus are more abundant upwards in the succession (Toerien, 1979).

The Peninsula forms the basis of the Table Mountain Sandstone (TMS) Group, is the thickest and most massive formation and builds the highest ranges. It is a whitish-weathering quartz sandstone, medium to coarse grained, quartzitic and massive, with indistinct cross bedding and shale bands less than a metre thick (Figure 16). It contains randomly imbedded, very rounded to egg-shaped quartz pebbles (Geological Survey, 1979; Toerien, 1979; Schafer, in prep.).

The Cedarberg Formation is a black shale band of 35 to 55 m thick, directly overlying the Peninsula sandstone and often intermixed with thin sandstone bands. Due to more rapid weathering, it usually forms areas of negative relief (Toerien, 1979; Schafer, in prep.).

Next in the sequence is the Tchando Formation. It is a brownish-weathering sandstone, fine to coarse grained, containing iron and manganese and frequent subordinate shale bands (Figure 16). It creates topography of a negative relief (Johnson, 1976; Schafer, in prep.).

The Kouga Formation is the most prominently cross-bedded, and is distinguished from the Tchando by its whiter appearance. It is medium to coarse grained, quartzitic, feldspathic near the top, with subordinate shale and is much more resistant to weathering than the Tchando Formation (Johnson, 1976; Toerien, 1979).

The Baviaanskloof Formation consists of two dark-grey impure sandstones, massive or bioturbated, separated by a pale feldspathic zone. Brachiopods and gastropods appear at the top where the formation is terminated by a few thin alternating sandstone and shale layers (Johnson, 1976; Toerien, 1979).

The Table Mountain Group ranges from Early Ordovician to Early Devonian in age.

The Gydo Formation is the first of the sequence of alternating shale and sandstone bands that directly overlie the TMS Group and is the only formation of the Bokkeveld Group on the southern side of the Outeniqua mountains. It is an Early Devonian, usually yellowish-brown, finely laminated shale that resembles in colour the phyllites that occur around Saasveld. The formation contains fossils and shells, though they are not very distinguishable due to deformation and weathering of the shales. As with the other argillaceous formations, the Gydo weathers to areas of negative releif (Schafer, in prep.).

Cretaceous deposits occur on the coastal plain at Mossel Bay, Knysna and Plettenberg Bay. They are generally deposited in structural basins underlain by the less resistant Bokkeveld sediments. These deposits, which belong to the Enon Formation, are fairly well-consolidated, containing the minimum of interstitial material and consist of coarse arenaceous conglomerates which, over much of the area are composed of closely packed, well-rounded TMS boulders. At Phantom Pass (Figure 17), near Knysna it reaches a thickness of 180 m. The Knysna lagoon has eroded into these deposits (Figure 18) (Miller, 1963; Tyson, 1971; Toerien, 1979). According to Butzer and Helgren (1972) and Helgren and Butzer (1977) these deposits have been reworked during Tertiary times and are therefore different from the Enon Beds around Oudtshoorn. They called it the Keurbooms Formation.

During late Tertiary and Early Quaternary times pebbles and gravels were deposited at various altitudes up to 40 m on marine and estuarine terraces. They are now wholly

Fig. 17. Enon Formation at Phantom Pass, near Knysna

Fig. 18. Enon at the Knysna lagoon

or partly covered by sand. These terraces can be seen in the river estuaries at Plettenberg Bay (Miller, 1963; Toerien, 1979).

During later Quaternary times aeolian sand was deposited on the coastal plain at various stages. Along the entire coast is submerged dune rock which was formed at a lower sea level. On land younger, now vegetation-bound settled dunes largely overlie this dune rock. North and west of Knysna the dunes reach far inland on the Tertiary plain. Along the coast, in a narrow strip, these fixed dunes are overlain by young migrating dunes which partly or entirely bars some river mouths, creating the Wilderness lakes. Thick surface limestone forming a small ridge on the Tertiary peneplain from Mossel Bay westward is also largely sand covered (Toerien, 1979).

All the sampling areas are underlain by TMS (Map 4; Figure 12). Those at Ysternek Nature Reserve, Grooteiland and Kleineiland are on the Kouga Formation, those at Dirk se Eiland and Ratelbos on the Tchando Formation and the one at Forest Creek Concession area on the Peninsula Formation.

4.3.3 Geomorphology

"Numerous features indicative of both coastal emergence and submergence are to be seen in close proximity in the George - Knysna area. The ubiquitous marine platform is deeply dissected, rivers are drowned and their estuaries are filled with alluvium. Raised beaches and sea caves are to be found above present sea level along the coast, while drowned extensions of the coastal sand ridges are distinctive submarine features. All this suggests a complicated geomorphological history" (Tyson, 1971). Some of the foreland and coastal features have been caused in part by down-warping of the crust (King, 1963), while others have been caused by faulting (MacFarlane, 1958).

Sometime during the Cainozoic (= Cenozoic), the sea level stood about 180 to 240 m above the present level. An almost ubiquitous planation surface, the coastal platform (Phillips' (1931) Upland Plateau) is associated with this sea level. After a long period of stillstand the sea level oscillated considerably, dropping irregularly to a level at least 55 m below the present one. This happened probably during the Miocene. Incision of rivers into the marine platform to below their present base levels took place. Borings show that in the case of the Goukama river solid rock occurs at a depth of 26 m 4 km inland. At Swartvlei Lagoon bedrock is at 41 m depth, while at the Little Brak river recent alluvium, overlying the Enon (Keurbooms) Conglomerate, is 31 m deep (Tyson, 1971; Butzer and Helgren, 1972).

Planation of ridge summits and the formation of wave-cut features appear to have taken place widely during the Quaternary. During this period, sea level fluctuated considerably as a result of glacio-eustatic changes in the levels of the oceans, cutting several surfaces or raised beaches (Tyson, 1971). With the steadily falling sea level during the Pleistocene a series of dune ridges developed, ponding behind them the protolakes of Bo-Langvlei, the Swartvlei complex, and Groenvlei. During the first transgression (increase in sea level of about 5 m - Pleistocene) Swartvlei and Groenvlei were flooded, some high dunes were being formed inland and considerable erosion of the seaward ridges took place. The second marine regression (Pleistocene) caused a connecting channel to be cut between Groenvlei and Swartvlei. Onder-Langvlei probably developed during this regression as a ponded drainage behind a developing dune ridge and Rondevlei originated due to flooding of a deflation hollow. The second transgression (Pleistocene) produced brackish water in those lakes invaded by the sea. Groenvlei was turned into an isolated lagoon during this time as a result of the closing of the Groenvlei-Swartvlei channel. Interdunal depressions were broadened and deepened by rivers deflected into the intervening valleys as the sea level dropped. During the Holocene the low-lying regions were floaded during the third transgression. Since 4 000 years B.P. the sea has slowly withdrawn to its present day level (Rust, 1979).

4.4 SOILS

The Southern Cape soils are complex and difficult to classify. Although Phillips (1931) claimed that most soils are in situ on the parent material, duplex soils are abundant. Colluvial and alluvial depositions, particularly near the mountains and near the sea, is apparent. The so-called plateau clays or clay beds, overlying the large areas of TMS and dune rock areas have high salt concentrates, although the topsoil is acid (pH in H_2O = 3,5 to 6) and infertile.

These clays would appear to have been deposited during the Oligocene (H.J. Deacon, 1979, pers. comm.). This suggests that they are not marine originated. The Enon Conglomerates have been deposited on the marine cut platform during the Late Cretacious and Early Tertiary times, after the regression of the sea. Thus, being younger than the Enon, marine deposition of these clays is not possible.

Schafer (in prep.) postualtes that during the Oligocene vast alluvial movement took place from the mountains in the form of periodic flooding and sediments accumulated in a shore lagoon environment, protected by barrier beaches, as is happening today on a smaller, less intense scale with Ruigtevlei and Groenvlei. The rare, rounded pebbles that occur within these clays, also suggest fluvial deposition. The high saline conditions of the clays would be due to the strongly impermeable character along with the minimal lateral drainage, rather than salts relict from a marine environment.

According to the Soils and Irrigation Research Institute's (in prep.) land-type classification, the following soils occur on and around the study sites:

(i) Dirk se Eiland, Grooteiland and Kleineiland:

The dominant terrain units are crests (1) and middle slope (3), comprising 40% and 50% respectively of the land-type (Figure 19). The rock/Mispah complex is the dominant soil-type (55% of the land-type) with Cartref (14%) and Glenrosa (7%) being second and third most abundant. Most of these soils are stony, shallow and infertile. However, deeper, more clayey soils, such as dry Westleighs, were also found on the study sites.

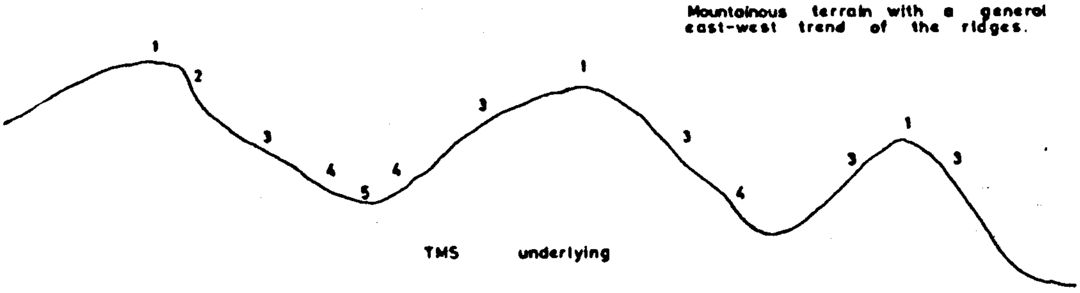
(ii) Ratelbos Island and Forest Creek Concession area:

The soils and terrain forms of this land-type are virtually the same as those of the one above (Figure 20).

The boundary between these two land-types indicates a change in macroclimate. Thus, soils are also stony and inherently infertile; the rock/Mispah complex still dominates, followed by Cartref, but the Houwhoek form (10%) replaces Glenrosa as the third most abundant, although the Glenrosa still covers 7% of the land-type.

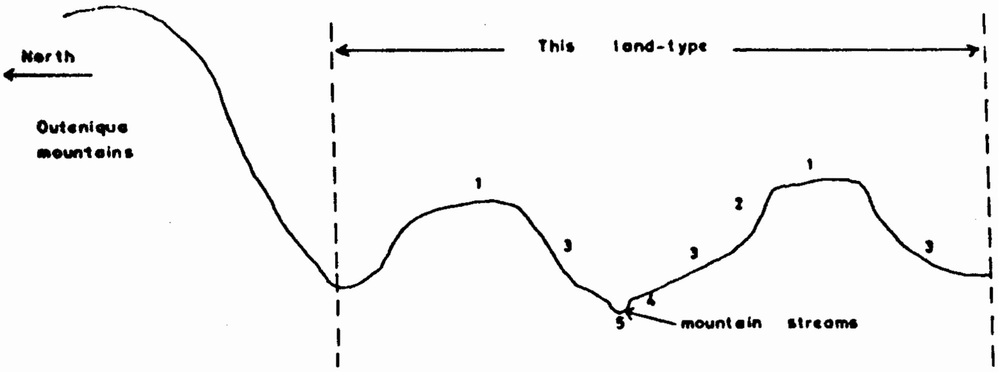
(iii) Ysternek Nature Reserve:

Although physically not part of the main Outeniqua range, Ysternek Nature Reserve has been classified with the upper mountain land-type (Figure 21). By far the greater part of this land-type is covered by open rock (65%), followed by a Mispah/Nomanci/talus complex (20%) and shallow sandy soils of various other soil forms (15%).



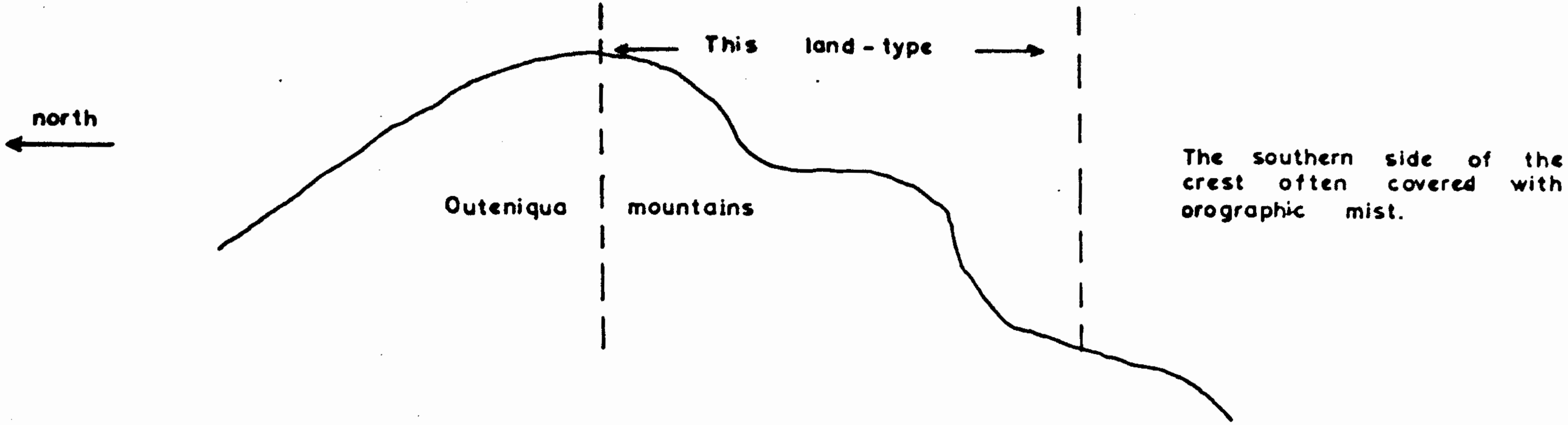
Terrain unit	% of land-type	% of terrain unit	Soil forms
1	40	75 10 5 3 2 5	Rock/Mispah complex Cartref Glenrosa Nomanci Houwhoek Talus and other soils
2	1	100	Rock/Mispah complex
3	50	45 17 10 8 5 4 4 7	Rock/Mispah complex Cartref Griffin and Hutton Glenrosa Clovelly Houwhoek Nomanci Talus and other soils
4	6	25 20 15 10 10 5 5 5 3 2	Cartref Rock/Mispah complex Griffin and Hutton Clovelly Glenrosa Nomanci Talus gravels Houwhoek Westleigh and Longlands Other
5	3	70 20 10	Oakleaf and Dundee Westleigh and Longlands Other

Fig. 19. Soil forms at and around Dirk se Eiland, Grooteiland and Kleineiland (Soils and Irrigation Research Institute, in prep.).



Terrain unit	% of land-type	% of terrain unit	Soil form
1	40	70	Rock/Mispah complex
		10	Cartref
		7	Houwhoek
		5	Glenrosa
		3	Nomanci
		5	Talus and other soils
2	2	100	Rock/Mispah complex
3	50	35	Rock/Mispah complex
		17	Cartref
		14	Houwhoek
		10	Griffin and Hutton
		8	Glenrosa
		5	Clovelly
		4	Nomanci
		7	Talus and other soils
4	5	25	Cartref
		20	Rock/Mispah complex
		15	Griffin and Hutton
		10	Clovelly
		10	Glenrosa
		5	Houwhoek
		5	Nomanci
		3	Westleigh and Longlands
		7	Talus and other soils
5	3	70	Oakleaf and Dundee
		20	Westleigh and Longlands
		10	Other soils

Fig. 20. Soil forms at and around Ratelbos Island and Forest Creek Concession area (Soils and Irrigation Research Institute, in prep.).



The southern side of the crest often covered with orographic mist.

% of land-type	Soil form
65	Rock
20	Mispah/Nomanci/talus complex
15	Generally shallow sandy soils (<15% clay) of the following soil forms: Nomanci Clovelly Hutton Houwhoek Griffin Lamotte Cartref Kroonstad

Fig. 21. Soil forms at and around Ysternek Nature Reserve (Soils and Irrigation Research Institute, in prep.).

4.5 VEGETATION

Indigenous forest occurs on all these soils. The underlying rock only influences the type of forest significantly if it is not far beneath the root systems of the trees. In most cases factors limiting root penetration into the B horizon are more important. The fynbos, which also grows on all these soils, is likewise influenced by the substrate, but less than the forest (see Appendix 1 for a checklist of the species found on the study sites).

Generally the forest and fynbos on soils underlain by TMS less than 4 m deep, are wetter, more vigorous and have a better regeneration as those on soils underlain by Bokkeveld Shales (Phillips, 1931). A possible reason for this is the higher clay content of the B horizon compared to soils derived from TMS. The ground water in the B horizon is kept by a greater moisture stress, the difference between field water capacity and permanent wilting point is less, resulting in less water being available to the plants than in sandy soils. Furthermore, root penetration into the B horizon is inhibited, particularly during wet periods, forcing the plant to depend on the shallow A horizon for its water requirements.

According to Phillips (1931) well-drained, dry to medium moist forest types occur on the TMS, as well as poorly drained, very wet types. This, he claims, can be attributed to the slope of the underlying TMS - horizontal .

or near-horizontal bedrock underlies the wet type, while the steep sloping rock underlies the drier types. However, whether or not this phenomenon is of real significance, is not clear.

CHAPTER 5

METHODS

5.1 SAMPLING DESIGN

The forest edges at Kleineiland, Grooteiland, Dirk se Eiland and Ysternek were sampled using a grid system (Figure 22). A maximum of five lines per sampling area, orientated at right angles to the existing forest edge were laid down. The position of the first line was located at random. Thereafter the lines were 100 m apart and parallel. Plots of variable size were established at 25 m intervals along the lines, which varied in length. For collection of the required data 25 m was considered the maximum possible distance between plots on a steep gradient like the forest-fynbos ecotone. The 100 m between lines was chosen arbitrarily. At Forest Creek Concession area and Ratelbos Island only one transect per site was laid down. Here circular plots, confined to 40 m^2 (3,57 m radius) for trees and 10 m^2 (1,78 m radius) for the other vegetation, were used.

The first plot was established well within the forest, before any edge effect could be seen, and sampling continued across the forest margin until the vegetation was dominated by fynbos species only. A total of 132 plots were sampled as follows: Kleineiland 28, Grooteiland 33,

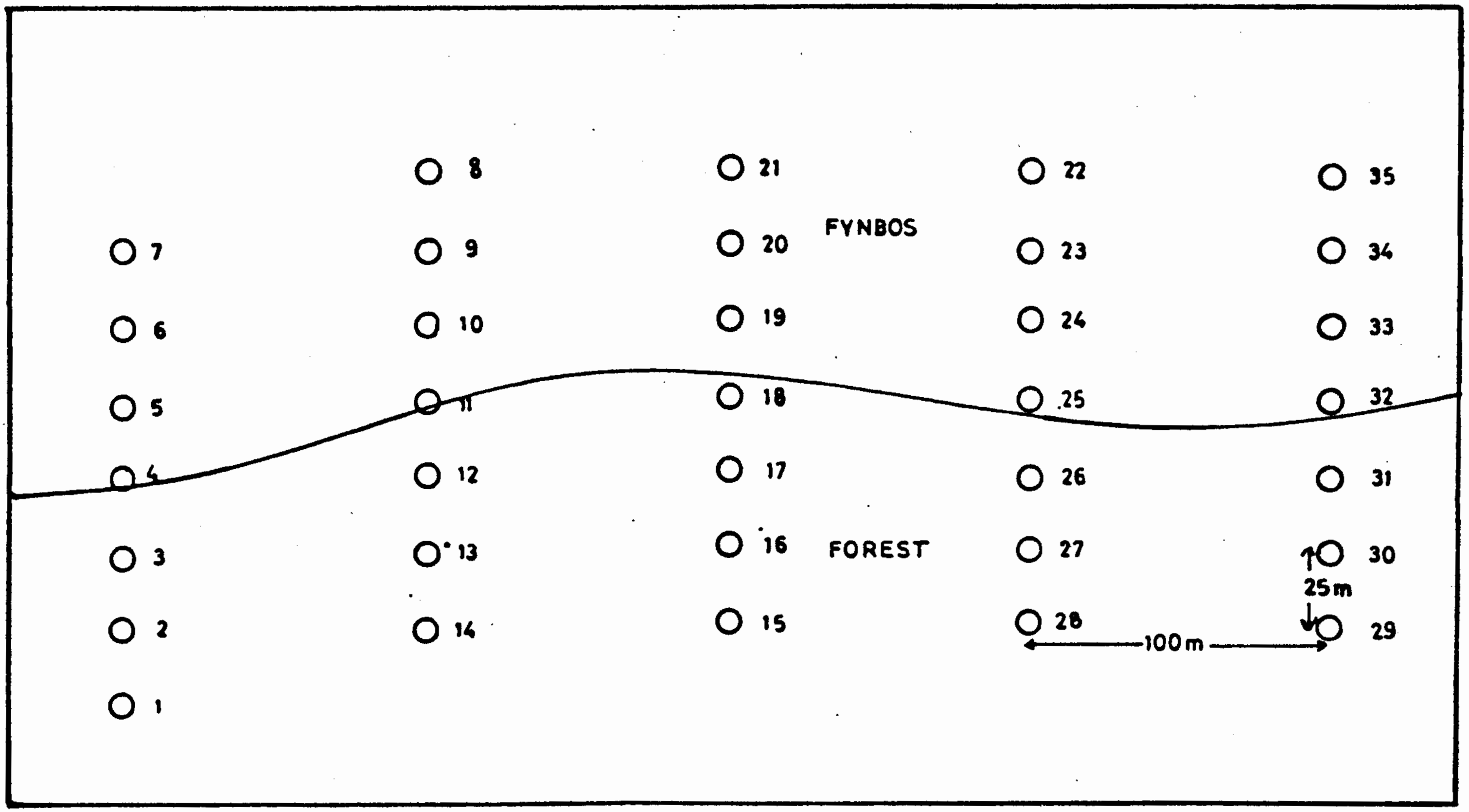


Fig. 22. Distribution of plots and sampling design

Dirk se Eiland 43, Ysternek 17, Forest Creek Area 6 and Ratelbos Island 5. Physiographic and edaphic factors were recorded at the plot centre. Species parameters were described at variable distances from the plot centre, i.e. 2 to 4 m from the plot centre, except at Forest Creek Area and Ratelbos Island, where non-tree species were described up to 1,78 m and trees up to 3,57 m from the plot centre. The vegetation near and at the forest fringe is normally extremely dense and often thorny, reducing sight to 2 to 3 m and making movement very difficult. Under these circumstances laying out confined plots is very time consuming and thus expensive. It is quicker to record heights of the different species and estimate cover on a plot bigger than the minimum plot size (i.e. 10 m^2) than laying out confined circular or squared plots. Minimum plot size was determined as described by Werger (1972), using a log transformation for the plot size (x-axis). 500 m^2, which is the biggest plot possible when sampling every 25 m, was taken as the 100% level of information, regarding the number of species as amount of information. 50% information was considered sufficient. Due to criticism from various people, who questioned the validity of statistical analyses of data from open plots, plot sizes at Forest Creek Area and Ratelbos Island were confined.

Later, after completion of the mathematical analyses, physiographic and edaphic factors were recorded at five more plots at Dirk se Eiland (plots 44 to 48 - Figure 31). These were used to confirm the results.

5.2 DATA RECORDED

5.2.1 Physiographic factors

Elevation - an average per sample area, taken from a 1:50 000 topo cadastral map.

The following information was recorded at each point:

(i) Slope (in degrees).

(ii) Aspect (classified into eight classes). Slope and aspect were combined into a radiation index (Frank and Lee, 1966) (see Appendix 2).

(iii) Terrain morphological unit (Young, 1972):
crest = 1 (0° - 4°)
free face = 2 (more than 40°)
mid-slope = 3 (12° - 35°)
footslope = 4 (0° - 8°)
flood plane/river valley = 5

(iv) Position on slope
top slope = 1
middle slope = 2
lower slope = 3

5.2.2 Soil factors

Soil factors were determined by means of soil pits, supplemented by augering. The following factors were recorded at each plot centre:

(i) Total soil depth (cm).

(ii) Effective soil depth (i.e. depth of root penetration, being the depth of soil used by plants) (cm).

(iii) Depth of A_1 horizon (cm).

(iv) Mottles - contrast (only Fe-mottles occurred):
clear = 1
diffuse = 2

(v) Texture of A_1 and B_{21} horizon:
sand = 1
loamy sand = 2
sandy loam = 3
sandy clay loam = 4
clay loam = 5
sandy clay = 6
clay = 7

Silt was left out on purpose, because the S.A. binomial soil classification system only uses percentage clay and sand and it is difficult to estimate silt content when the organic matter content is high.

(vi) Clay content of A_1 and B_{21} horizon (%).

(vii) Consistency of A_1 and B_{21} horizon:

dry	moist	
loose	loose	= 1
soft	very friable	= 2
slightly hard	friable	= 3
hard	firm	= 4
very hard	very firm	= 5

(viii) Structure of A_1 and B_{21} horizon

Prismatic = 1
columnar = 2
blocky = 3
single grained = 4
massive = 5
apedal = 6

(ix) Concretions - horizon in which they occurred

non = 0
A_1 horizon = 1
B_{21} horizon = 2
both = 3

(x) Abundance, size and form of stones in A_1 and B_{21} horizon

abundance: none = 0
rare = 1
frequent = 2
abundant = 3

size: 0 - 5 cm = 1
5 - 10 cm = 2
10 - 15 cm = 3
15 - 20 cm = 4
20 - 30 cm = 5

bigger than 30 cm = 6

form: angular = 1

rounded = 2

(xi) Abundance and size of roots in A_1 and B_{21} horizon - abundance:

none = 0

rare = 1

frequent = 2

abundant = 3

size:

fine = 1

medium = 2

coarse = 3

(xii) pH (in H_2O) of the A_1 horizon.

(xiii) % organic matter in the A_{11} horizon (by low temperature (375°C) ignition - average of three determinations).

The latter two parameters were measured in the laboratory.

The above-mentioned parameters were used for the factor analyses (Section 5.3.2).

The following soil factors were determined on a lower sampling intensity (Figures 25, 28, 30, 33, 35 and 36):

(i) Rate of water absorption: Five drops of water were added to the same spot on a soil sample. Absorption classes were determined as follows (Loxton, 1966):

(1) very rapid - each drop disapperas immediately

(2) rapid - free water disappears within one second

(3) moderate - free water disappears within one to five seconds

(4) slow - free water disappears within five to fifteen seconds

(5) very slow - free water disappears within fifteen to sixty seconds

(6) extremely slow - free water is not absorped within one minute.

(ii) Bulk density: This was done by a simplified version of the excavation method (Black et al, 1965): Each horizon of a number of selected profiles inside and outside the indigenous forests was opened successively and the top cleaned of all loose sand. An ordinary planting trowel was used to excavate a hole with a diameter of 10 to 15 cm and a depth of 10 to 12 cm, tapering towards the bottom. All soil, stones and roots from the hole was put into a plastic bag. Building sand, air dried and sifted through a 250 mm sieve (=US and British No. 60 and French No. 25 sieve) was used to fill the hole. The volume of the sand used, which was equivalent to the volume of soil excavated, was measured by means of a 250 ml plastic beaker, graduated in 10 ml intervals. The surface of the sand in the hole was levelled by carefully spraying the sand. It was not scraped level or touched by hand. Of the 46 horizons sampled, 17 were sampled three times repetitively. The soil collected was oven dried at 105°C. The stones, roots and soil of each sample were separated and weighed. Randomly selected subsamples were used to determine average densities of the stones and roots. This was done by weighing them and measuring their volume by liquid displacement. Water was used in the case of stones and methanol (S.G. = about 0,8) in the case of roots. The average densities were used to calculate the volume of stones and roots in each sample. Only the soil was used to estimate bulk density. In order to check the variation in the sand volume due to errors in measurement and possible differences in sand compaction, the 250 ml beaker was filled 19 times and weighed.

(iii) The following analyses were done by the Saasveld Forestry Research Station's soils laboratory:

(a) pH in H_2O and $CaCl_2$ (0,01M), 1:2 soil:liquid ratio, measured in the supernatent using a combination glass electrode and calibrated with two buffer solutions, pH

3 and 7. Waiting time is one hour after initial mixing.

(b) Particle size analyses, determined by the hydrometer method (Day, 1965). All soils were pretreated by H_2O_2 to remove the organic matter.

(iv) The following were done by D.R. de Wet Forestry Research Station:

(a) Organic matter and carbon of the A_1 horizons. Organic carbon was determined by the Walkley-Black method, using a correction factor of 1,33 for recovery, and organic matter content was calculated by use of the Van Bemmelen factor.

(b) Exchangeable cations (K, Ca, Mg, Na): The determination was made on a 1N NH_4Cl extract of the less than 2 mm fine earth by atomic absorption spectrophotometry.
The S-value per 100 g clay was calculated.

(c) Exchangeable acidity was determined on a 1N KCl extract by titration with NaOH.

(d) For exchangeable aluminium the latter titrate was back titrated with HCl following the addition of NaF.

(e) Available phosphorus was determined colorimetrically by the molybdenum blue procedure on a Bray No. 2 extract.

Total phosphorus using perchloric acid digestion, cation exchange capacity, and nitrogen as determined by the micro-kjehldahl digestion/distillation technique was requested, but could not be completed in time.

5.2.3 Vegetation

The following vegetation data was recorded:

(i) Non-tree species: The average height and the occurrence (cover on the Braun-Blanquet scale) were recorded for each species. The midpoint of each class was used in the analyses.

(ii) Tree species:

(a) Seedlings, defined as tree species less than 25 cm high. The cover of each species was recorded.

(b) Saplings, i.e. tree species from 25 cm in height and less than 10 cm D.B.H. The cover of each species and one average height for all the saplings (all species) were recorded.

(c) Trees, i.e. tree species from 10 cm D.B.H. The cover of each species and the average canopy height were recorded.

5.3 ANALYSIS

In detailed floristic or environmental description, two major approaches can be distinguished. These are, the relevé analysis for classification and the continuum analysis for ordination. "A classification aims at grouping individual stands into categories. The stands that are closely similar with one another form one class, which is separated from other classes that also consist of similar stands. The properties common to a group of similar stands in a class are then abstracted to serve as a description of that class. In contrast, an ordination aims at portraying the individuality of each stand. This is done by demonstrating the similarity or dissimilarity of all stands to one another in the form of geometric models" (Mueller-Dombois and Ellenberg, 1974).

As a method to summarise results from a survey, ordination has two major advantages (Kruger, 1974).

(i) It avoids the necessity of an arbitrary selected set of criteria for defining the classes.

(ii) No assumption that the classes are hierarchically related, is necessary.

Classification tends to stress the discontinuity, while ordination only indicates the real similarities and dissimilarities between communities (Greig-Smith, 1964).

Ordination and classification are not necessarily incompatible techniques (McIntosh, 1967; Nichols, 1977). Classification may lead to ordination, and an ordination can be arbitrarily classified into classes of high similarity. In fact, the two techniques can be complementary in the description of the variation of the environment within the space of a classification unit (Shimwell, 1971; Hall and Swaine, 1976).

Both above-mentioned approaches are used in multivariate analysis. This is the branch of statistical analysis which is concerned with the relationships of sets of dependent variates (Kendall, 1965). (A variate is a quantity which may take any one of the values of a specified set with a specified relative frequency or probability, for example, a set of measured values of some property in which there is more or less random variation (Jeffers, 1978; Webster, 1979)).

Figure 23 gives a simple classification of multivariate models. Broadly, these models can be divided into descriptive and predictive models. In the latter some variates are used to predict others, while in the former no attempt is made to predict one set from the other. In this study, descriptive models were used. These models can be further subdivided into those in which all the inputs are quantitative and which include factor analysis, principal component analysis and cluster analysis, and those for which at least some of the inputs are qualitative, rather than quantitative. For the latter, the reciprocal averaging model is the more appropriate.

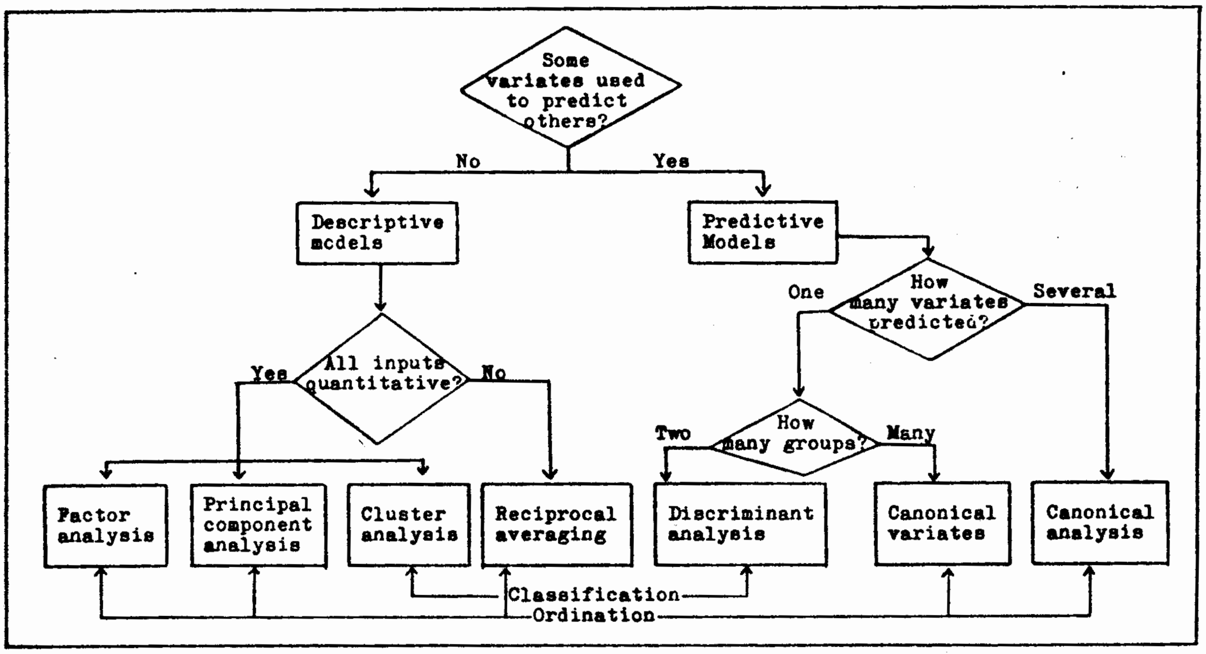


Figure 23. Classification of some multivariate models (modified from Jeffers, 1978).

5.3.1 Reciprocal averaging

The vegetation data was analysed by means of reciprocal averaging (RA) (Hill, 1973; Gauch, 1975). This was done for each of Grooteiland, Kleineiland, Dirk se Eiland and Ysternek. The cover value of each species was multiplied with its height. These products were used for the RA analyses. In this way provision was made for the heterogeneity of the vegetation. In the forest the height of the different species is more important, while cover becomes more important in the fynbos.

The model is especially appropriate for presence - absence data which are commonly found in ecology, as in the recording of the presence or absence of particular species in quadrats (Jeffers, 1978).

The method uses a scheme of successive approximations during which the individuals are given an arbitrarily chosen set of starting scores, ideally chosen to represent some gradient suspected *a priori* as being reflected in the data. For example, from the forest-fynbos gradient, the species are divided into forest and fynbos species. The initial gradient analysis of plots can be obtained by allocating a score of 0 to fynbos species and 100 to forest species, and by using average species scores, defining plot scores. A plot containing only fynbos species will score 0 and a plot with only forest species 100. A plot containing half and half will score 50 and so on. Average scores are then computed for each variate (plot) from which new, rescaled averages are calculated for the species. For the above example species which occur mainly in fynbos plots will have a low score, whereas species which occur mainly in forest plots will have a high score. Intermediate and ubiquitous species will have an intermediate score. If the new species scores are rescaled from 0 to 100, the process can be repeated and the plots recalibrated. After a sufficient number of iterations, the final variate scores converge to the same row vector, and the eigenvalue of the first axis is a measure of how much the range of the scores contracts in one iteration. The process is called "reciprocal averaging" because the species scores are averages of the stand scores and reciprocally the stand scores are averages of the species scores. In the iterative process the final scores do not depend on the initial scores, although the number of iterations required to reach them does. A good initial guess will reduce the number of iterations needed (Hill, 1973; Gauch, 1977; Jeffers, 1978).

When the first axis is obtained, the second is considered. A good starting point for the scores of the axis is obtained by using a set of scores which were fairly close to the final ones for the first axis. Before iteration, however, these scores have to be adjusted by subtracting a multiple of the final first axis. An example of the computations is given by Hill (1973).

Diagrams of the different RA scores on axis 1 against scores on axis, as well as axis 1 against axis 3 were drawn. This was done for the species as well as the plot scores. In this way forest, fynbos and fringe (intermediate) species and plots were separated. Furthermore, by using the same scale for the species and plot scores, and by making overlays of the species scores, possible indicator species were selected (Hill, 1973; Gauch, 1975).

The whole procedure is mathematically very similar to facor analysis (FA) or principal components analysis (PCA). The main advantage of RA is that it gives good species ordinations to go with the plot ordinations, not that it gives markedly better plot ordinations. The rationale of the method is close to that of gradient analysis (Whittaker, 1967), so that it is more suitable than PCA or Fa for displaying strong floristic gradients (Hill, 1973) like the forest-fynbos ecotone. It is resistant to involution even at high beta diversities. Data with species distributions departing from the Gaussian form, can, however, cause involution (Austin, 1976). Often, reciprocal averaging distorts the major axis of sample variation into an arch in the second axis of ordination, but is, despite this effect, superior to FA or PCA at high beta diversities and on the whole preferable to FA or PCA at low beta diversities when analysing vegetative data (Gauch <u>et al</u>, 1977).

5.3.2 Factor analysis

For the environmental data factor analysis (FA) (SPSS program), based on Pearson's correlation coefficient, was used (Child, 1970; Kim, 1975). Again, the data for the four above-mentioned areas were analysed separately. Ex-.

cept for pH (in water), organic matter of the A_{11} horizon and particle sizes as estimated in the field, the results of the chemical soil analyses, bulk densities and water absorption rates were not included in the FA analyses. No analyses of the combined data of the four above-mentioned areas were done. Not only would the results have been confusing, for each of the four different forest-fynbos gradients has its own intrinsic variance, but the FA program used could not handle such a big data matrix. Of greater use was a comparison of the results of the different areas.

A second FA, using a SAS-program (Barr et al, 1976), and without variables with a Poisson distribution (see Appendix 3), was done. However, due to dubious program procedures, the results, which appeared inconsistent and unreliable, could not be used.

No attempt will be made to explain the mathematical models or computational procedures underlying FA. This is discussed in detail in numerous handbooks, for example, Kendall (1965), Comrey (1973), Gorsuch (1974), Orlóci (1975), Mather (1976) and others. The basic principles, advantages and limitations of FA and PCA will be discussed briefly.

FA is based fundamentally on the faith that the observed correlations are mainly the results of some underlying regularity in the data. It is assumed that the observed variable is influenced by various determinants, some of which are shared by other variables in the set while others are not shared by any other variable. The part of a variable that is influenced by the shared determinants is usually called common, and the part that is influenced by idiosyncratic determinants is usually called unique. Under this assumption, the unique part of a variable does not contribute to relationships among variables. Thus, the observed correlations must be the result of the correlated variables sharing some of the common determinants. These common determinants or factors will be smaller in number than the variables and can be viewed as descriptive concepts, summarising the behaviour of a set of variables. FA is a technique by which a minimum number of hypothetical variables are specified in such a way that after controlling for these hypothetical variables, all the remaining correlations between the variables would become zero (Gorsuch, 1974; Kim, 1975; Mather, 1976).

The unique variance, which does not contribute to the intercorrelations of the variables, is not known; it has to be estimated from the given data. The determination of the unique variance, or its complement, communality, is one of the most difficult and ambiguous tasks in FA. The main diagonal of the correlation matrix is replaced by the communality estimates. Thus, the unique variance is taken out and only the remaining portions of the variables are analysed (Child, 1970; Comrey, 1973; Kim, 1975).

In this study, an iteration procedure was used to improve the estimates of communality. First the number of factors to be extracted from the original or unreduced correlation matrix was determined. The main diagonal elements of the correlation matrix was then replaced with initial estimates of communalities. Next, the same number of factors were extracted from this reduced matrix, and the variances accounted for by these factors became new communality estimates. The diagonal estimates were then replaced with these new communalities. The process continued until the differences between two successive communality estimates were negligible. The diagonal element had to be less than unity (1,0) and greater than zero. Thus the communality is only that proportion, expressed as a fraction, of the variable which is decomposed into factors (Kim, 1975). Other factoring procedures, for example, Alpha factoring, Image factoring, and others, are available, but will not be discussed.

It is generally agreed upon that the unrotated factors do not generally represent useful scientific factor constructs and that it is usually necessary to rotate when there are two or more extracted factors. All rotated solutions are mathematically equivalent to each other and to the unrotated solution in that all of them account for the original correlation matrix equally well. The rotated and unrotated factor solutions merely represent different basis systems (or sets of co-ordinate axes) for the same vector space (Comrey, 1973).

The main choice to be made before rotation is between an orthogonal (where the factors are assumed uncorrelated) and oblique (where the factors may be correlated) rotational method. Orthogonal factors are mathematically simpler to handle, while the oblique factors are empirically more realistic (Kim, 1975). In this study, the orthogonal rotation, "Varimax", (Kim, 1975) was used. It centers on simplifying the columns of a factor matrix.

The Burt-Banks formula (Burt, 1952) was used to find the significance of the parameters (factor loadings) on the different factors:

$$\left(\begin{array}{c}\text{significant value}\\ \text{of loading}\end{array}\right) = \left(\begin{array}{c}\text{significant value}\\ \text{of correlation}\end{array}\right)\left(\sqrt{\frac{n}{n+1-m}}\right)$$

where

n = numer of variables

m = number of factor.

A R-type factor analysis is based on the correlations between variables, while the Q-type is based on correlations between plots (Shimwell, 1971). A Q-type analysis was tried, but was for some unknown reason unsuccessful. Three-dimensional scatter diagrams of the plots were then constructed from the R-type analyses. The position of a plot along an axis was determined by the standardised (between 0 and 1) sum of the products of the eigenvector and parameter vector for the plot (Ross and Morris, 1971). On these diagrams forest, fynbos and transition plots as selected with RA (only present vegetation taken into account) were marked. From the correspondence of the vegetational divisions with the environmental groupings deductions about the forest-fynbos ecotone were made. The three-dimensional diagrams proved to be much more informative than the two-dimensional ones. This was because three factors, in stead of two, were taken into account simultaneously.

Factor analysis is useful in those situations in which the relationships among the elements of a multivariate system are being scrutinised. Prior knowledge of the system is necessary, however, to provide criteria against which the outcome of the analysis can be evaluated. Although the assumption of normality of the observed variables is not always explicitly required, the interpretation of the factor pattern may be affected by non-normality since the range of the correlation coefficients may be restricted, for example, due to the effects of skewed distributions (see Section 6.2). The size of the correlation coefficients have a direct bearing on the size of the factor pattern coefficients (Mather, 1976).

5.3.3 Principal components analysis

PCA can be seen as a variation of FA. There are, however, some important differences, and the two techniques must not be confused.

PCA is a relatively straight forward method of transforming a given set of variables into a new set of composite variables or principal components. Each principal component is a linear combination of the observed variables, and these linear functions are chosen to be orthogonal. The first one is the best summary of linear relationships exhibited in the data. The second component is defined as the second best linear combination of variables, under the condition that this component is orthogonal to the first. To satisfy this condition, the second one must account for the proportion of the variance not accounted for by the first one. Thus, the second component may be defined as the linear combination of variables that account for the most residual variance after the effect of the first component is removed from the data. Subsequent components are defined similarly until all the variance in the data is exhausted. Unless at least one variable is perfectly determined by the rest of the variables in the data, the principal component solution requires as many components as there are variables. However, since each successive component is the best linear summary of the (remaining) variance, most of the variance is normally accounted for by the first few components. Only these components are normally retained for further rotation (Gorsuch, 1974; Kim, 1975; Mather, 1976).

In PCA the division of the variance into a unique and common component is ignored. The total variation is taken into account. Therefore unity (1,0) is used in the main diagonal of the correlation matrix. The principal components extracted are exact mathematical transformations of the original variables. This method does not require any assumptions about the general structure of the variables (Child, 1970; Gorsuch, 1974; Kim, 1975).

As a result of the standardisation of the variance (unity in the main diagonal of the correlation matrix), variables with a low occurrence must be left out, otherwise they get an unjustifiable importance relative to the other variables (Nichols, 1977). The choice of variables is the crux of issue. The variables should, as far as possible, cover the whole field of interest, and should not be concentrated on one or two easily-measured facets (Mather, 1976).

The eigenvalues associated with each component represent the amount of total variance accounted for, and the importance of a component may therefore be evaluated by examining the proportion of the total variance accounted for (Gorsuch, 1974; Kim, 1975).

PCA is a robust technique and especially suitable for direct gradient analyses. Its mathematical structure limits its application for indirect gradient analysis to a large extent (Austin and Noy-Meir, 1970; Mather, 1976; Nichols, 1977).

In this study the majority of the communalities of the FA laid between 0,70000 and 0,99999 (Appendix 4). Thus the unique variance was very small and would not have caused large differences between the FA and a PCA, should the same data have been analysed with PCA (F. Franz, 1978, pers. comm.).

CHAPTER 6

RESULTS AND DISCUSSION

6.1 KLEINEILAND

The first factor of the FA (Figure 24) accounted for 27,9% of the common variance (see Section 5.3.2). The texture and clay content of the A_1 (7-25% clay) and B_{21} horizon (8-38% clay) caused significant positive loadings on this factor (see Appendix 3 for the data matrixes and Appendix 4 for the rotated factor matrixes). The soil became more clayey and wetter towards the fynbos. The underlying gradient in this factor seems to be soil moisture. Forest occurred towards the drier end of the gradient and fynbos towards the wetter end.

Factor 2 accounted for 23,1% of the common variance. The significant positive loading was caused by soil mottles (contrast) of the B_{21} horizon (see Appendix 4). This is caused by a fluctuating water table; drainage being the underlying gradient.

The third factor accounted for 17,5% of the common variance. Significant positive loadings were caused by the terrain morphological unit, total and effective depths of the soil and abundance of roots in the A_1 horizon. Radiation index caused a significant negative loading and

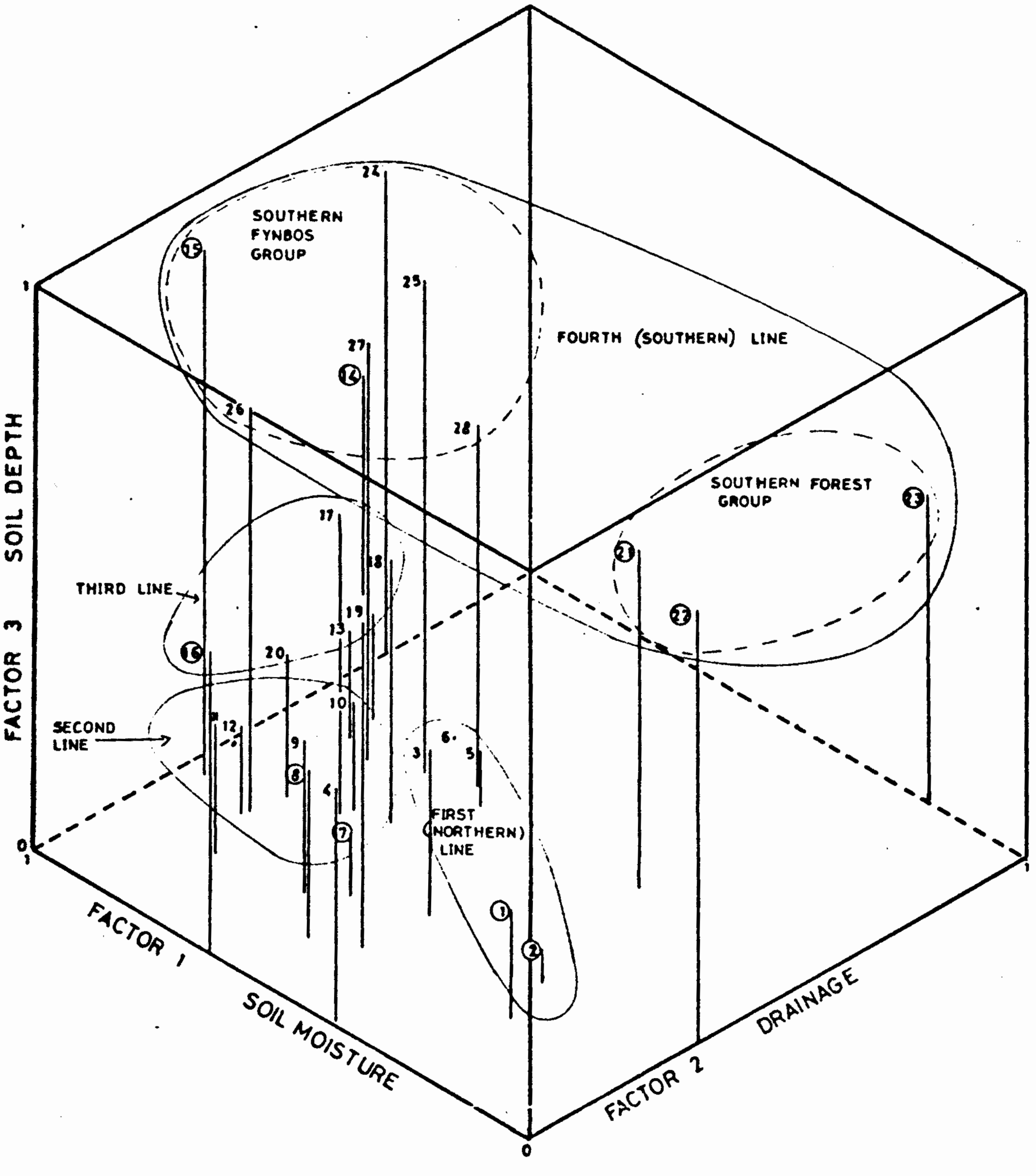


Fig. 24. Factor diagram of Kleineiland

is thus negatively correlated with the above-mentioned parameters. The underlying gradient here seems to be soil depth, the deeper soils occurring on the lower southern slopes.

The forest plots (according to the RA) are all encircled. Comparing the grouping of plots in Figure 24 with their distribution in the field (Figure 25) it is clear that the main grouping is north-south across the slight east-west running ridge, and not east-west across the forest edge. With a few exceptions the plots of each of the four transects grouped together. This indicates the importance of aspect as the main grouping factor. The most southerly transect (plots 21 to 28) did group into fynbos and forest plots, but the inclusion of plots 14 and 15 (forest plots) in the fynbos group indicate that the soils of the fynbos plots are potentially suitable for forest.

Mottling occurred in nine fynbos plots, i.e. plots 5, 6, 13, 17, 18, 19, 24, 27 and 28, against two forest plots, i.e. plots 21 and 23. Although this trend was expected as a result of the restricted drainage in the more clayey fynbos soils, causing reduction, oxidisation and hydration necessary for the creation of mottles, it was not strong enough to cause a significant east-west grouping.

From these results one can conclude that the fynbos-forest transition is an artificial phenomenon, probably caused by fires. Kleineiland was burnt from time to

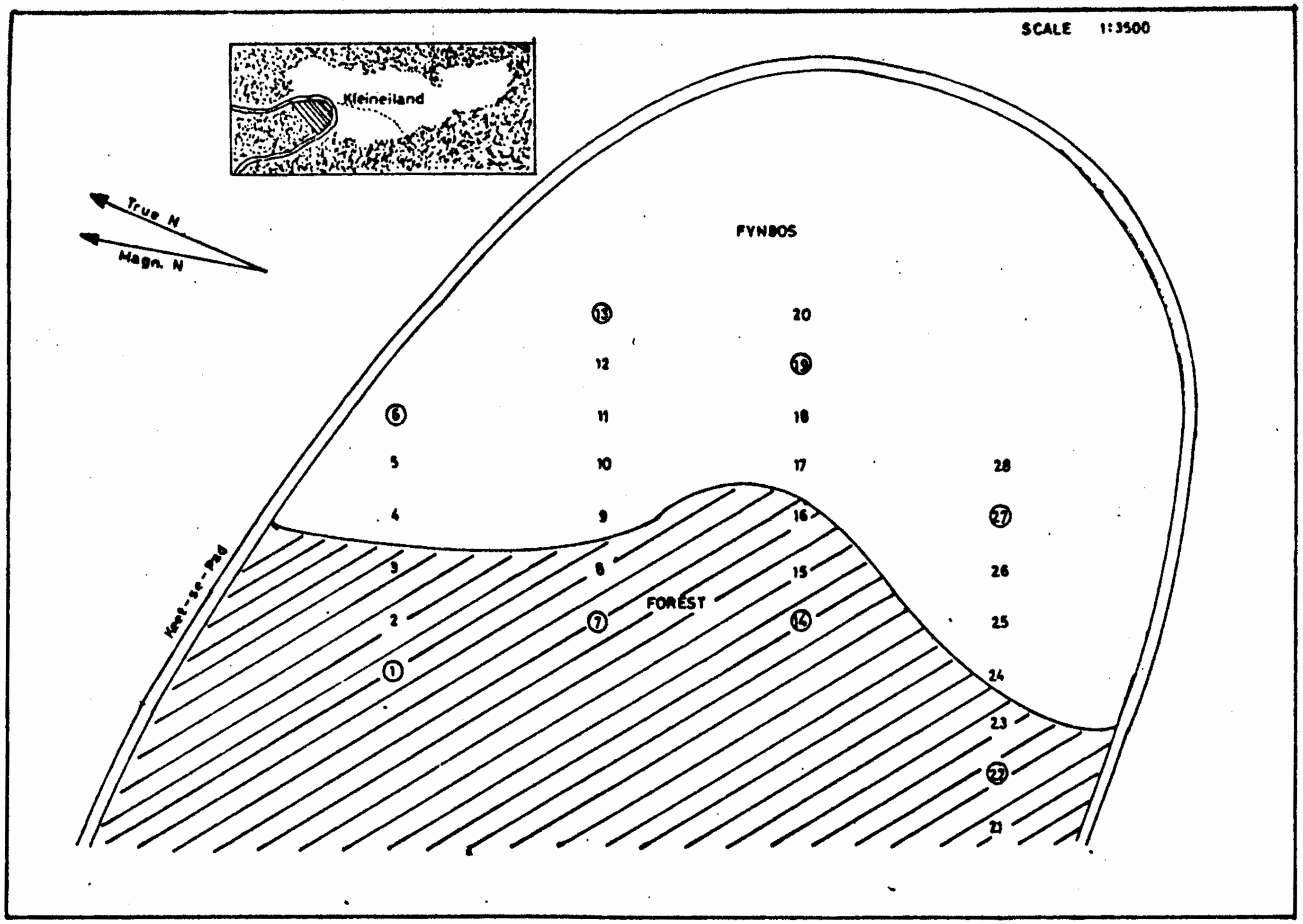


Fig. 25. Distribution of plots at Kleineiland. Samples for chemical and physical soil analyses of the encircled plots were taken.

time for grazing and fire control purposes. Accidental fires occurred too, the last one in 1970 (von dem Bussche, G.H., 1978, pers. comm.). The effect is clearly visible as no natural forest fringe is left - the canopy drops suddenly (Figure 26).

Fig. 26. The abrupt forest edge at Kleineiland. Note the person standing in the fynbos.

6.2 GROOTEILAND

Factors 1, 3 and 4 were used to draw the diagram in Figure 27. Factor 1 accounted for 36,4% of the common variance and had significant negative loadings for texture, clay content and consistency of the A_1 horizon, and significant positive loadings for abundance and size of stones in the A_1 horizon (see Appendix 4). The soil became more clayey, with a higher consistency towards the fynbos, while the abundance and size of stones decreased. Soil moisture of the A_1 horizon seems to be the underlying gradient, fynbos occurring on the wetter and forest on the drier soils.

Factor 3 accounted for 15,4% of the common variance. Here total soil depth, and texture, clay content and consistency of the B_{21} horizon caused significant loadings. As in the case with the A_1 horizon, the B_{21} horizon became more clayey, with a higher consistency towards the fynbos. Total depth had no visible pattern. This time the underlying gradient seems to be the soil moisture of the B_{21} horizon.

Factor 4 accounted for only 8% of the common variance, but gives a good indication of the occurrence of stones in the B_{21} horizon. The abundance, size and form of stones had the highest loadings on this factor. A further significant loading was caused by the structure of the B_{21} horizon, and significant negative loadings by the occurrence of concretions and the clay content of the A_1 horizon. The most likely underlying gradient here is stoniness of the B_{21} horizon. The more stones, the less clay and the less iron mottling.

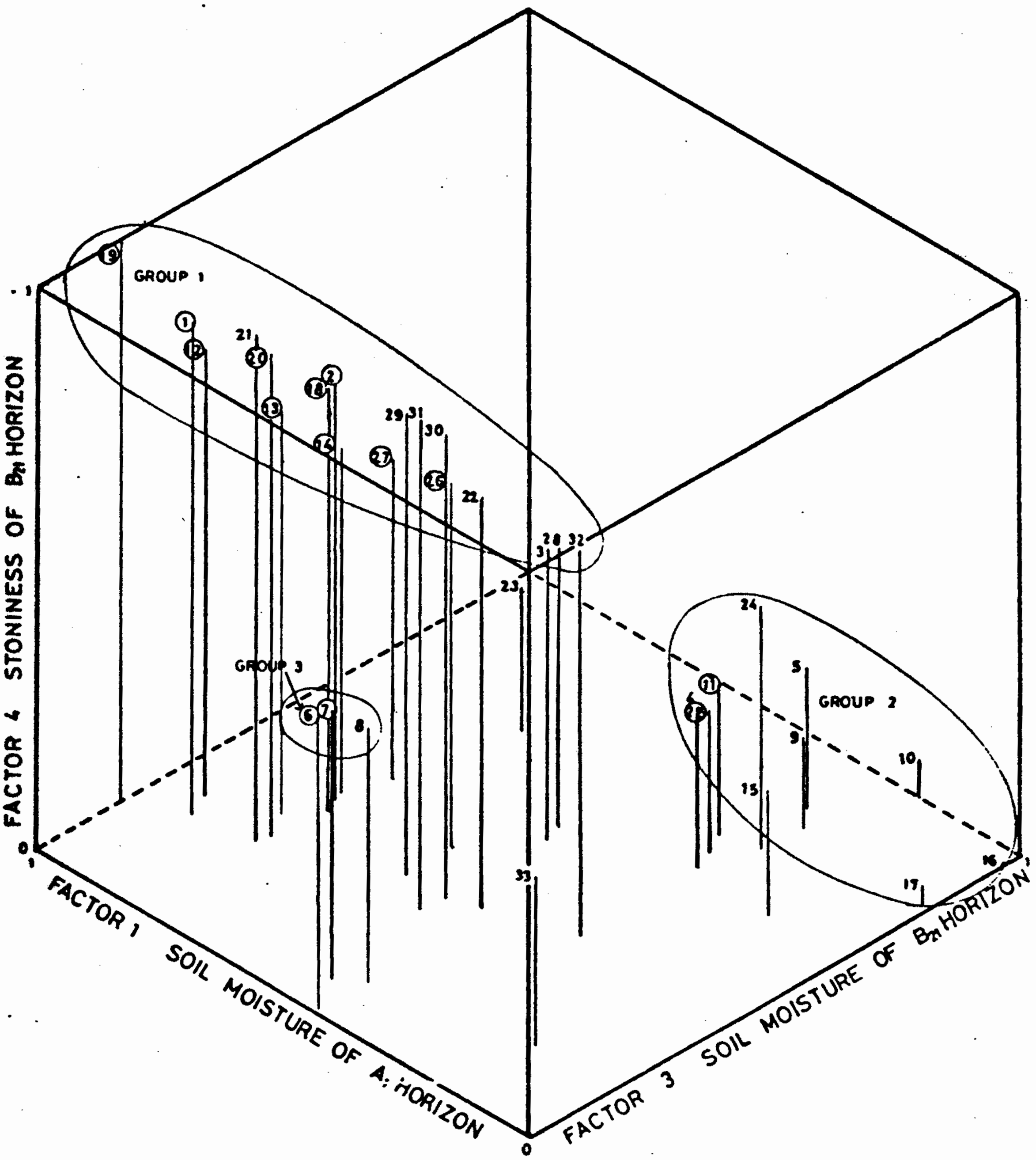


Fig. 27. Factor diagram of Grooteiland

Factor 2 was left out on purpose. It accounted for 20,2% of the common variance, but mottling which was the only significant parameter, occurred only on four of the thirty-three plots, causing a Poisson distribution. FA is based on finding linear combinations of variables (factors) with large variances. Although it is not always possible to satisfy the principle of linearity, even through transformation, it is dangerous to use variables distributed in a Poisson way (Shimwell, 1971; F. Franz, 1978, pers. comm.). Undoubtedly, if this FA was repeated without mottles as a parameter, the percentages of the variances accounted for by the different factors, as mentioned above, will change somewhat. The sequence of the factors, however, will stay the same, excluding factor 2 of course.

No grouping of forest and fynbos plots occurred (Figure 27 and 28). The stony plots formed a separate group (group 1). The only non-stony plot in this group, plot 32 (see Appendix 3), is loaded high on factor 3 by a combination of insignificant factor loadings (eigenvectors). The fynbos plots in this group tend to group towards the wetter ends of factors 1 and 2. (The moisture related variables of factor 1 had significant negative loadings, causing the wetter plots to load low on factor 1). The plots of group 2 all had clayey B_{21} horizons, while plot 33 and those of group 3 had no B horizons, or very rocky B horizons. These plots should, strictly speaking, be

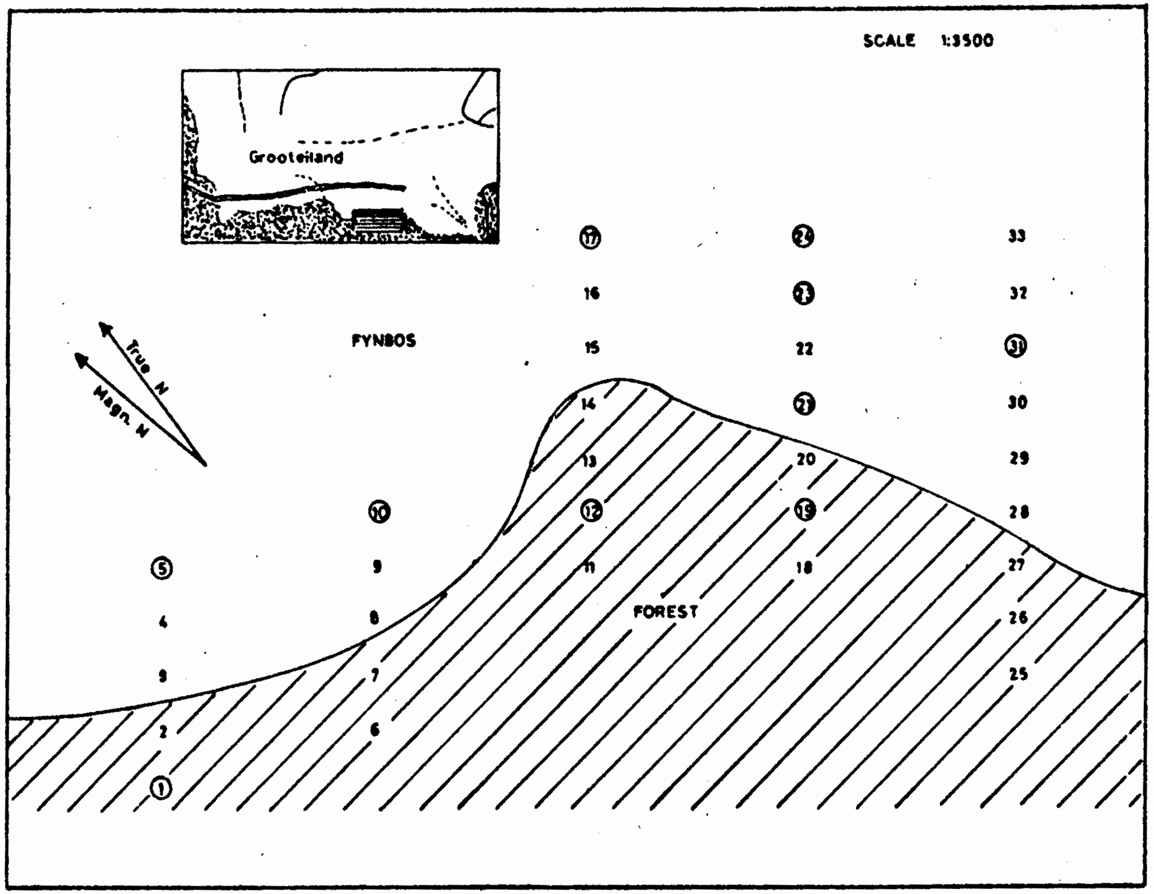


Fig. 28. Distribution of plots at Grooteiland. Samples for chemical and physical soil analyses of the encircled plots were taken.

part of group 1. Most of these plots classified as Glenrosa, with lithocutanic B_{21} horizons. It was, however, not possible to dig a proper soil pit at every plot. ~~On~~ In many plots only small pits of 50 x 50 cm were dug, and where the B horizon could not be opened as a result of rockiness, it was considered absent.

As at Kleineiland, the forest edge seems to be artificial. It is clear that the area had been burnt. Pieces of charcoal were found in the soil profiles. Fires probably started on the northern end of the island, where the soils are very shallow and fynbos possibly occurred naturally, and died naturally when the southern downward slope increased (Figure 29). Unfortunately no records of any fires at Grooteiland exists. Judging by the age of the keur (*Virgilia oroboides*), which started falling over, and by counts of the nodes and internodes of the *Leucadendron eucalyptifolium* the last fire must have been at least 38 years ago.

6.3 DIRK SE EILAND

The data used for this FA came from two separate areas on Dirk se Eiland, one on the western boundary and one on the south-eastern boundary of the main part of the island (Figure 31). The data were analysed together.

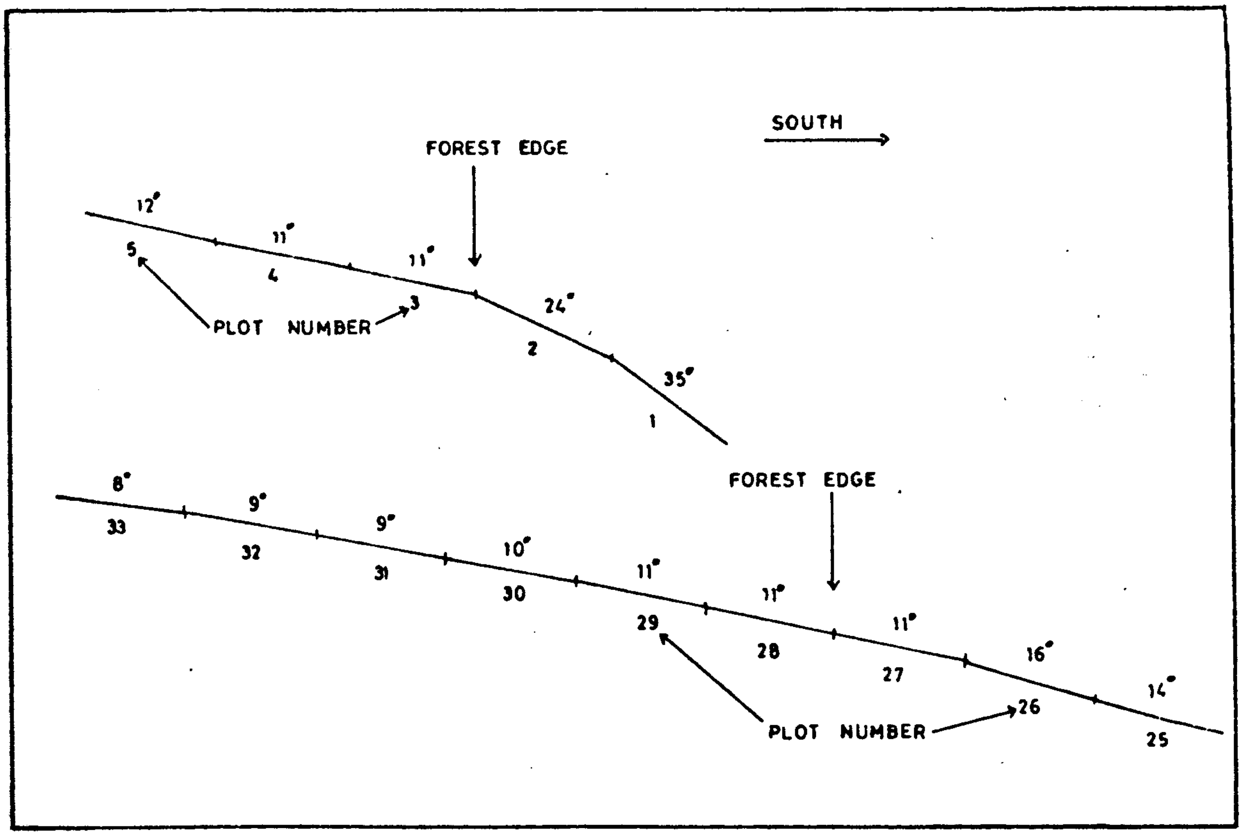


Fig. 29. Topography along the first (top profile) and fifth (bottom profile) line at Grooteiland

Factor 1 accounted for 28,5% of the common variance, factor 2 for 22,7% and factor 3 for 22,4% (Figure 30). Both factors 1 and 2 had numerous significant loadings: On factor 1 terrain morphology, total and effective soil depth, clay content of the B_{21} horizon and radiation index caused significant positive loadings. Significant negative loadings were caused by soil structure, abundance of roots and pH of the A_1 horizon (see Appendix 4). On factor 2 texture, consistency, structure and abundance of size and roots in the B_{21} horizon all caused significant

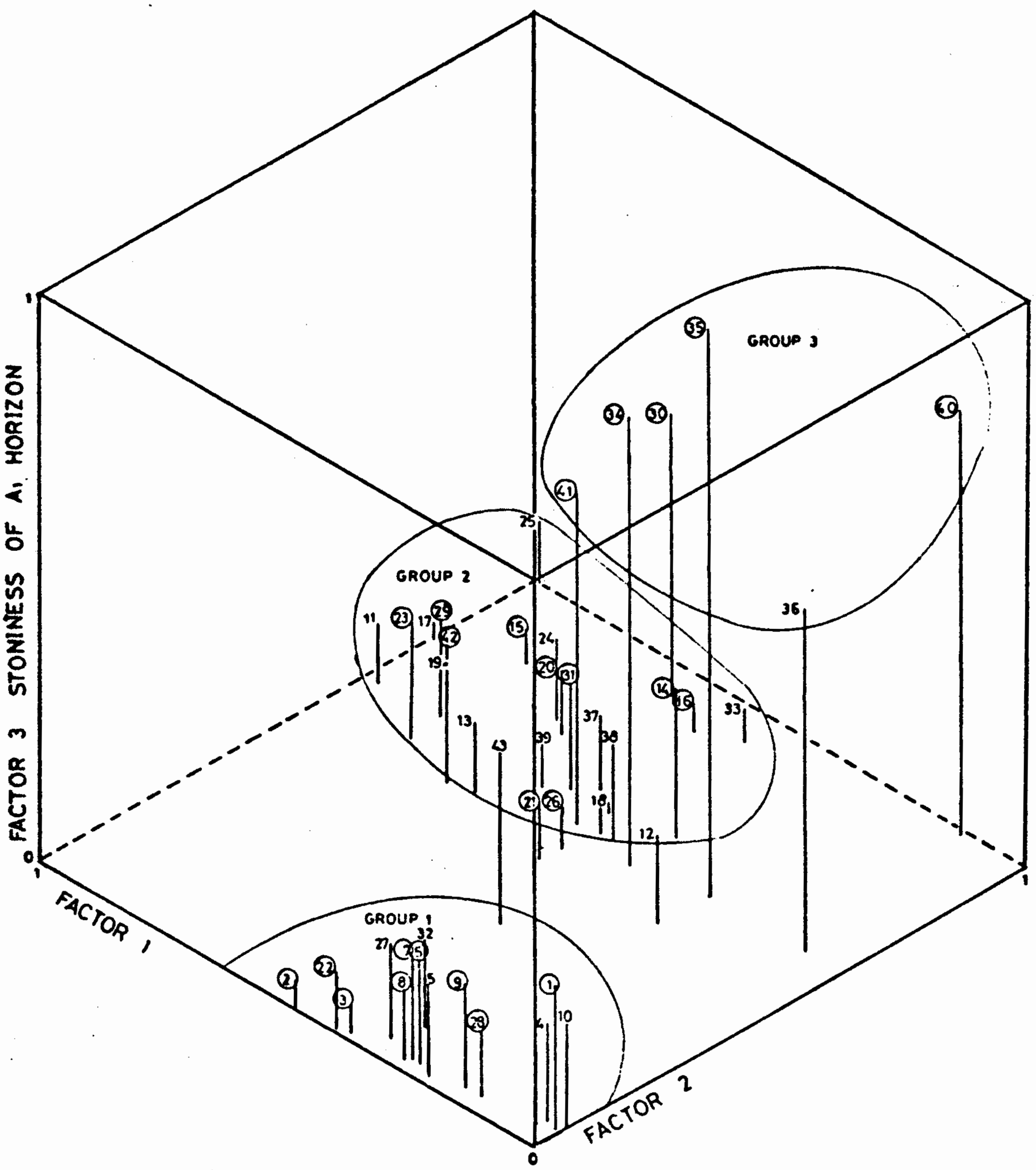


Fig. 30. Factor diagram of Dirk se Eiland

positive loadings. None of these parameters showed any pattern between forest and fynbos and the underlying gradients, if any, are not clear.

The abundance, size and form of stones in the A_1 horizon, and the organic matter in the A_{11} horizon caused significant positive loadings on factor 3. The underlying gradient seems to be stoniness of the A_1 horizon, with the forest plots from the sampling area on the south-eastern boundary of the island loading high on the gradient (group 3 on Figure 30).

The plots of group 3 are all on a very steep rocky south-eastern slope. Group 1 loaded low on all three factors, while the separation of group 2 was mainly due to a high loading on factor 2.

No grouping between the forest and fynbos groups occurred. Again the forest edge seems to be artificial. Supplementary sampling (plots 44 to 48 on Figure 31) showed no significant difference in soil type from the other plots on the island. Plot 48 (on the northern side) was the only exception with a shallow soil and the fynbos resembling that of Ysternek Nature Reserve in structure and species composition (Figure 32) (see Section 6.4). Most probably this part was a natural patch of fynbos from where fires started which resulted in the gradual increase of the size of the island. Judging from counts of the

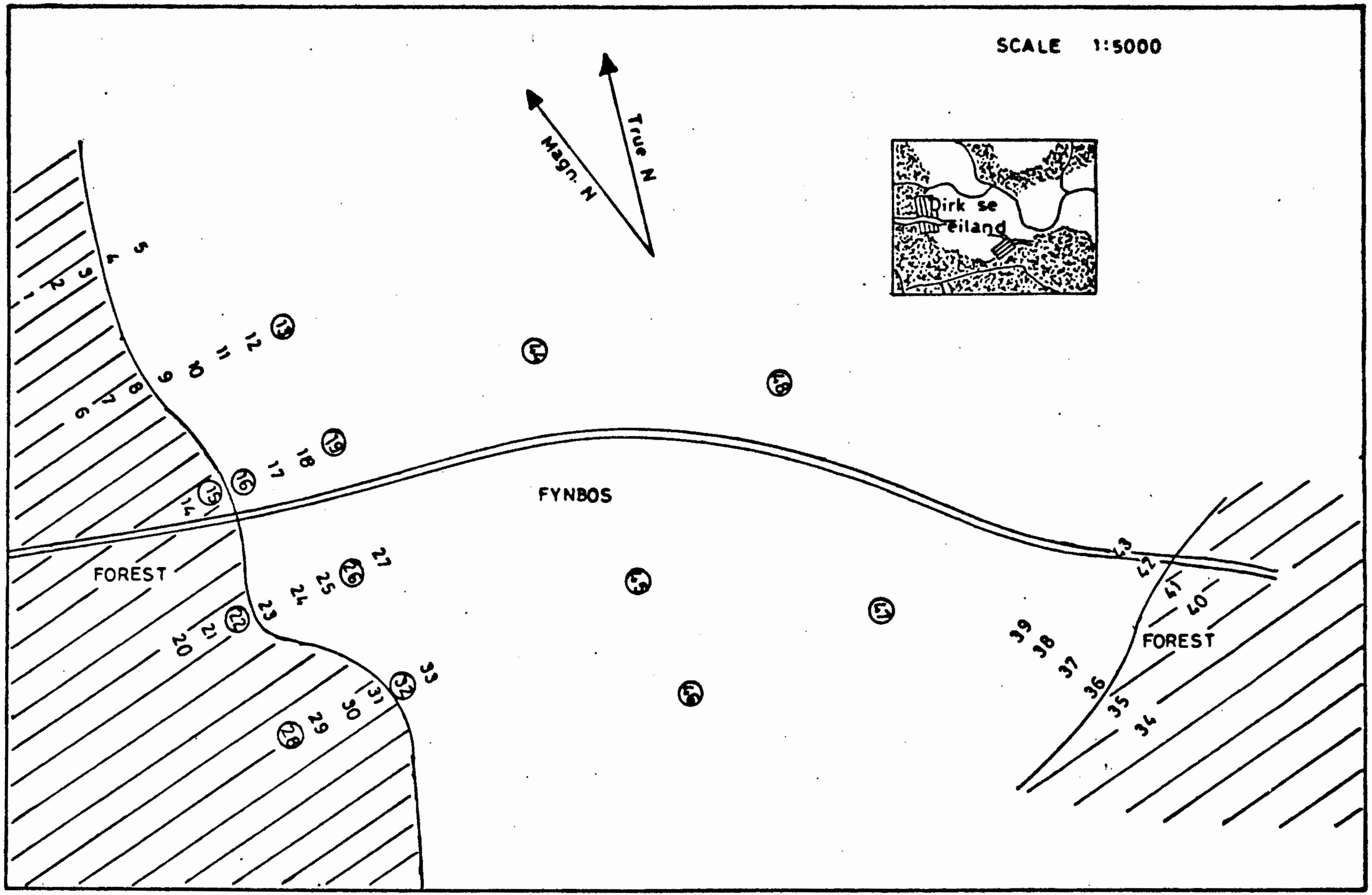


Fig. 31. Distribution of plots at Dirk se Eiland. Samples for chemical and physical soil analyses of the encircled plots were taken.

Fig. 32. Low fynbos on the northern part of Dirk se Eiland can be seen in the foreground, with the dense high fynbos on the adjoining Takkieseiland on the right. Note the abrupt forest edge

nodes and internodes of Proteaceae, the vegetation on the northern side of the island is at least 37 years old (Figure 7) and on the southern side 51 years.

6.4 YSTERNEK NATURE RESERVE

The area sampled was on a east-west running ridge with fynbos on the northern and forest on the southern slope (Figure 34). This appears to be a natural boundary between forest and fynbos and was chosen to test the methods.

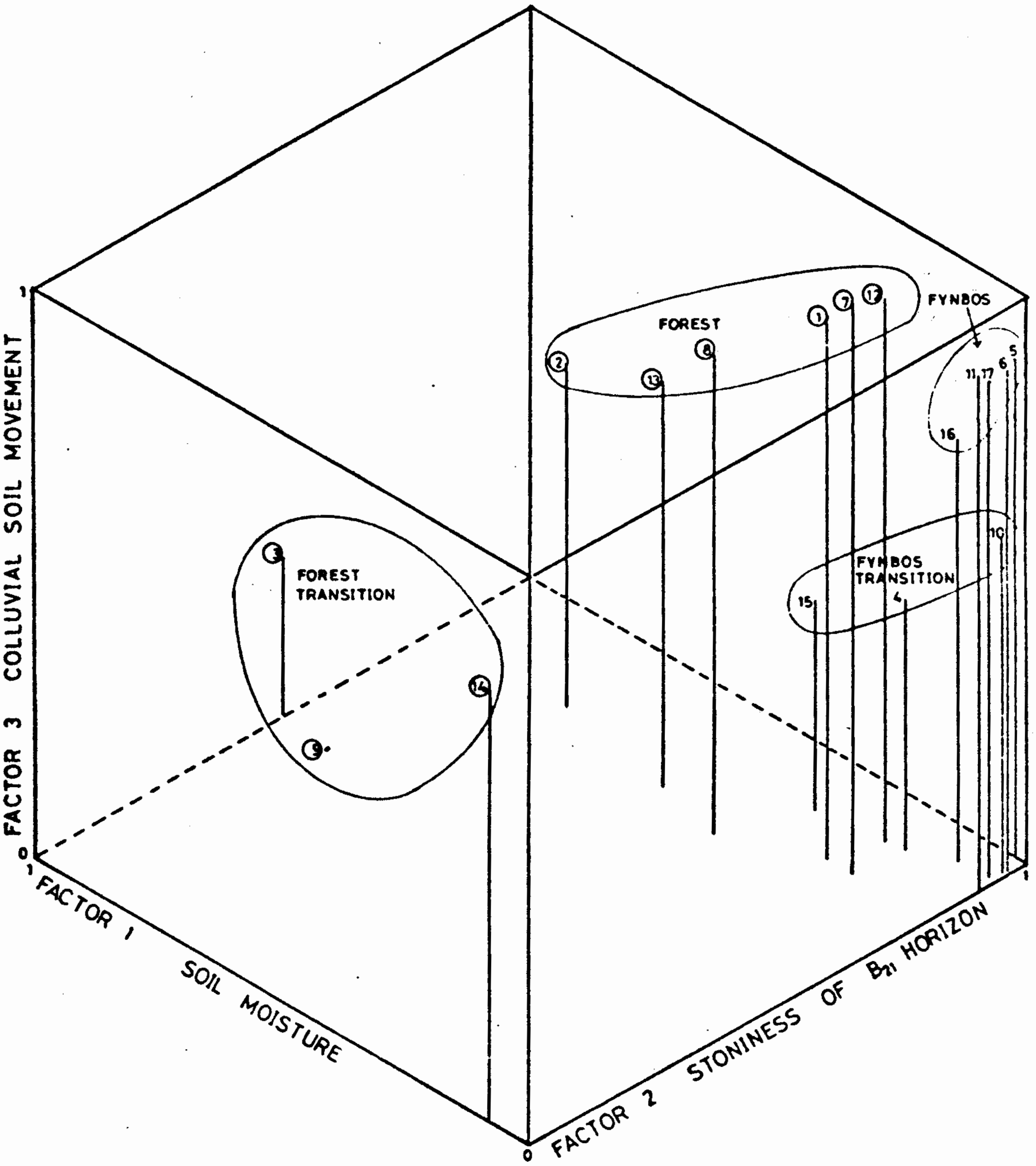


Fig. 33. Factor diagram of Ysternek Nature Reserve

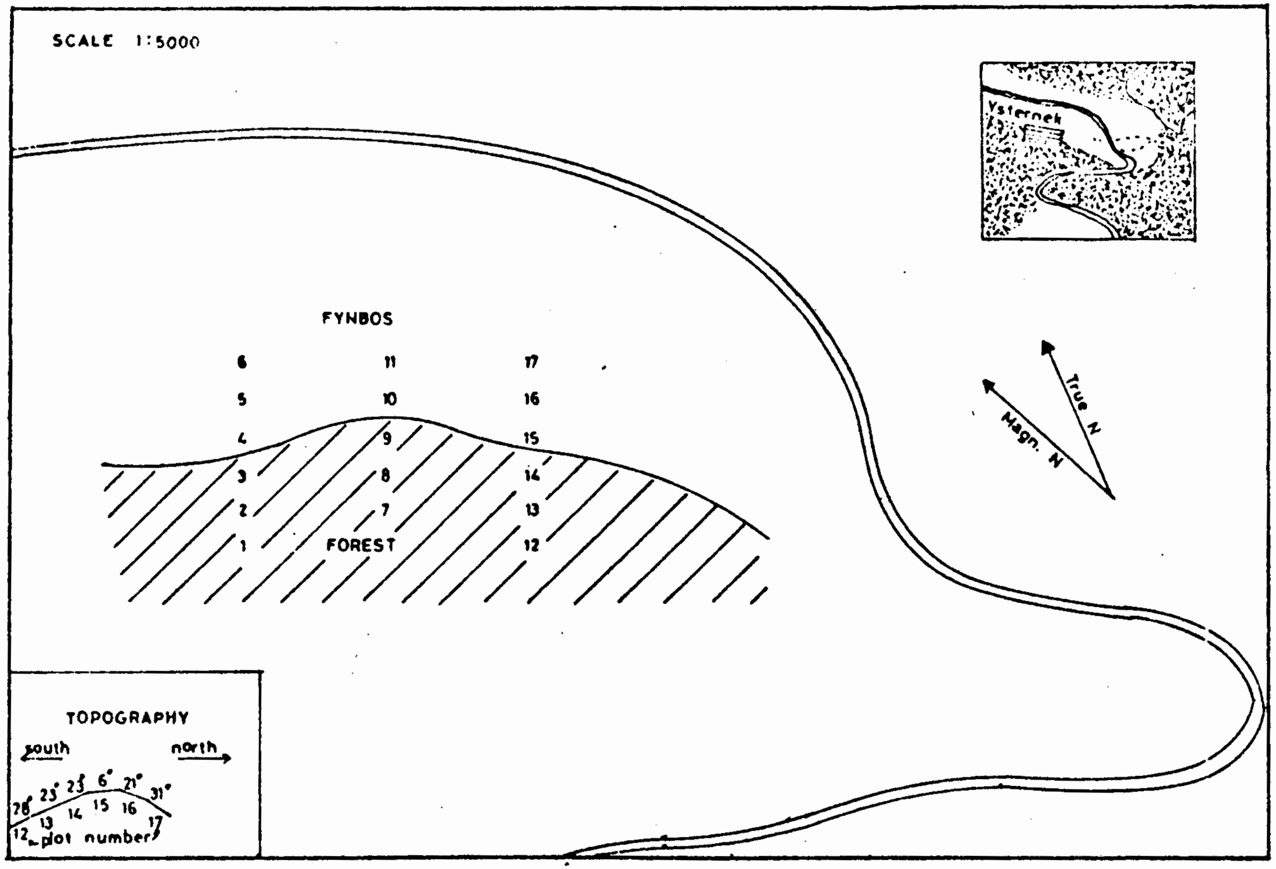


Fig. 34. Distribution of plots at Ysternek Nature Reserve. No chemical or physical analyses of these soils were made.

Factor 1 accounted for 44,9% of the common variance, factor 2 for 27,8% and factor 3 for 12,0% (Figure 33). Significant positive loadings on factor 1 were caused by total and effective soil depth of the A_1 horizon and texture and clay content of the A_1 and B_{21} horizons (see Appendix 4). Abundance of stones in the B_{21} horizon caused a significant negative loading. As in the case of both Groot- and Kleineiland, the underlying gradient seems to be soil moisture. On factor 2 consistency, abundance and size of stones and abundance of roots in the B_{21} horizon caused significant positive loadings. The underlying gradient here might be the stoniness of the B_{21} horizon. Significant positive loadings on factor 3 were caused by terrain morphology, and abundance and size of stones and pH of the A_1 horizon. The more stony plots, with a higher pH, occurred on the lower slopes; the underlying gradient probably being colluvial soil movement.

On top of the ridge deep loamy soils were found against expectation. Root penetration in these soils was limited mainly to the deep A_1 horizon. On both northern and southern slopes, however, the soils were shallower and more stony, and root penetration through the shallow A_1 horizon into the stony B_{21} horizon was much more frequent. Thus, the underlying gradient in factor 2 had little to do with the forest-fynbos gradient. This factor also had little influence on the grouping in Figure 33. It only separated the forest transition group from the other plots.

Most of the grouping was caused by a combination of factors 1 and 3. The drier fynbos plots on the northern slope all loaded very low on factor 1 (soil moisture), while both the fynbos and forest plots loaded high on factor 3 (colluvial soil movement). The forest plots loaded higher on factor 1, an indication of the wetter southern slope. The fynbos transition group grouped between the latter two mentioned groups on factor 1, and about halfway lower on factor 3. This corresponds to deeper soils found on the forest-fynbos transition.

The results confirm that the forest-fynbos ecotone at Ysternek is natural; aspect, and consequently soil moisture, is the controlling factor. The fynbos is different from that on the fynbos islands. It is much richer in species, much lower in stature and with a much more dominant component of Proteaceae.

6.5 GOUDVELD

The two areas at Goudveld, Forest Creek Area and Ratelbos Island (Figures 35 and 36), were used to verify results and conclusions made from the study sites at Kaffirkop and Diepwalle State Forests. Forest Creek Area (10 ha) was clearfelled in 1907/8 (refer Section 1.2) for mining

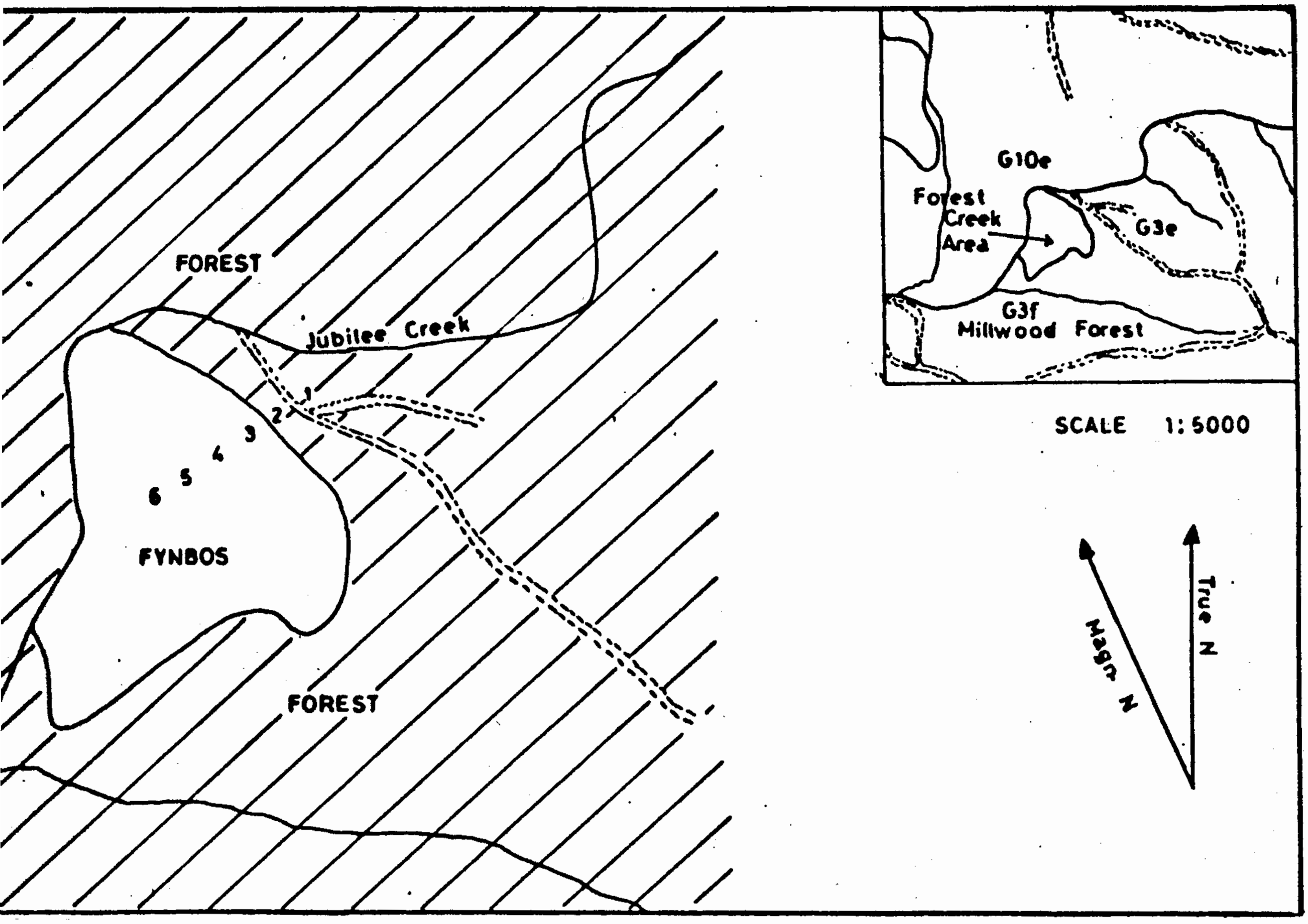


Fig. 35. Distribution of plots at Forest Creek Concession area. Samples for chemical and physical analyses of the soils at each plot were taken.

timber. It has not been burnt. The surrounding forest is a dry type on a northern slope. Ratelbos Island is a wet fynbos island on a southern slope, partly surrounded by moist forest. It appears to be fire induced. According to the number of nodes and internodes on Leucadendron eucalyptifolium the fynbos is at least 37 years old.

The fynbos at Forest Creek Area resembles very much that of Dirk se Eiland in species composition and structure.

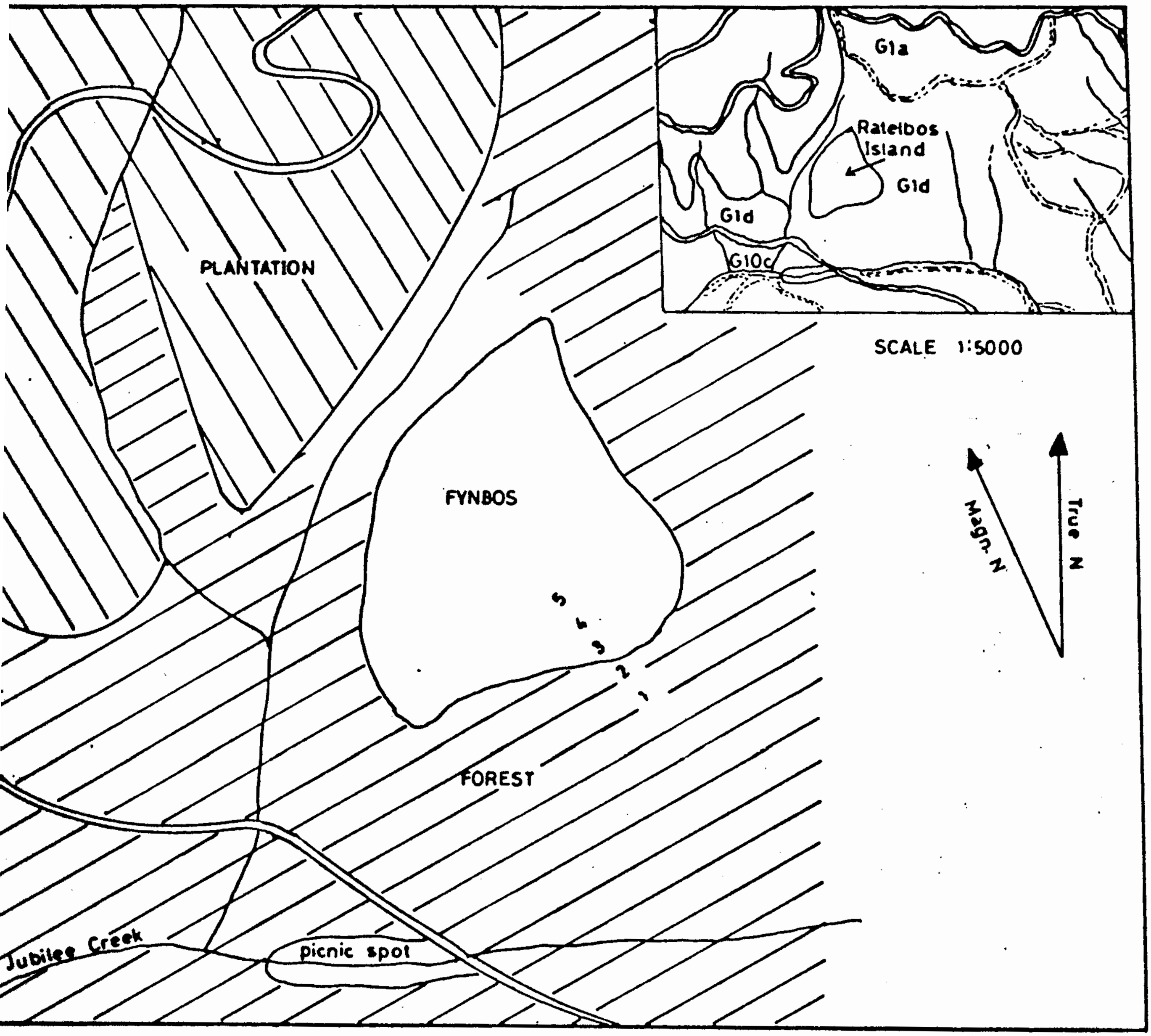


Fig. 36. Distribution of plots at Ratelbos Island. Samples for chemical and physical analyses of the soils at each plot were taken.

Virtually no forest regeneration is present. The only exception is in the immediate vicinity of a few indigenous trees which were unsuitable for mining timber and left standing.

Ratelbos Island is much more infested with Gleichenia polypodioides than the other sites. Other ferns are not uncommon. Only a few scattered tree saplings are present, but no seedlings.

The soils directly overlie TMS. The very heavy B_{22} horizon and gravel layer between the B_{21} and B_{22} horizons so abundant on Kleineiland, Grooteiland and Dirk se Eiland, is not present. However, very few differences in the mineral content (Table 6), and no differences in texture of the A_1 and B_{21} horizons between these Goudveld and the other sites appeared, and the conclusions made from the latter sites could be confirmed.

6.6 BULK DENSITY, WATER ABSORPTION RATE AND TEXTURE

The results of the bulk density determinations are summarized in Tables 3 and 4. Except for the B_{21} horizon of soil profile 1 (Westleigh), 3 and 4 (both Wasbank) and the B_{22} horizon of soil profile 6 (Clovelly) all the coefficients of variation (CV) are below 10% (Table 4). The high CV of the latter three had been expected. It is ex~~s~~tremely difficult to excavate the hard plinthic B_{21} horizon of the Wasbank soil form or the very coarse gravelly B_{22} horizon of soil profile 6. The high CV of soil profile 1 is probably due to some sampling error.

With only three replications it is informative that the CV is so consistently low (Gregoire and Barrett, 1979). Possible error sources are, however, numerous. Due to stoniness of a horizon, it is not always possible to level the top of a horizon completely before excavating. When excavating some compaction of the side walls of the hole takes place due to the shovelling action of the planting trowel. Lastly, errors in measuring the volume of sand and different packing of the sand particles can cause considerable variation. The 5% confidence interval for the mass of a plastic beaker containing 250 ml sand was 378,38 ±13,73 g. In extreme cases this can result in about a ±0,4 g/cm^3 difference in bulk density estimates. This could have been the reason for the high CV of the B_{21} horizon of soil profile 1.

No significant differences among bulk densities of soils inside and outside the forest could be found (Table 5). Bulk densities of the B_{21} horizons, compared to A_1 horizons are significantly higher. Note that the exclusion of the above-mentioned outliers (horizons with a high CV) had little influence on the significance of the F-values.

Table 4. Bulk densities (g/cm^3) of soils inside and outside the indigenous forests

Profile No.	Soil form	Sample No.	Horizon				Vegetation
			A_1	E	B_{21}	B_{22}	
1	Westleigh (dry)	1	0,6967		1,2585		forest
		2	0,6283		1,6820		
		3	0,6304		1,3897		
CV (coefficient of variation)			5,94%		15,02%		
2	Glenrosa	1	1,2669		1,2466		dry forest
		2	1,1004		1,1678		
		3	1,2790		1,1366		
CV			8,23%		4,78%		
3	Wasbank	1	0,8452	1,5432	1,0438		forest
		2	0,8330	1,6146	1,1658		
		3	0,8459	1,5421	0,8858		
CV			1,19%	2,63%	13,60%		
4	Wasbank	1	1,0444	1,2468	3,3539		fynbos
		2	1,1062	1,3064	1,6032		
		3	1,1148	1,4311	1,0084		
CV			3,56%	7,06%	61,32%		
5	Oakleaf	1	0,8133		1,5555		fynbos
		2	0,8931		1,4766		
		3	0,8669		1,5415		
CV			4,81%		2,78%		
6	Clovelly (B_{22} very gravelly)	1	1,2499		1,3461	1,1369	fynbos
		2	1,2161		1,3781	2,3311	
		3	1,3147		1,3277	1,1781	
CV			3,97%		1,96%	43,77%	
7	Clovelly	1	1,4470		1,6812		fynbos
		2	1,3119		1,7720		
		3	1,4301		1,7781		
CV			5,26%		3,09%		
8	Westleigh (dry)	1	0,9992		1,1331		forest
9	Clovelly (stony)	1	0,8672		1,4807		dry forest
10	Houwhoek (talus phase)	1	0,9442	1,0327	1,1328		dry forest
11	Westleigh (dry)	1	1,1994		1,4043		forest
12	Glenrosa	1	0,7996		0,9016		dry forest
13	Clovelly	1	0,8856		0,8768		forest
14	Westleigh	1	0,9135		1,0151		fynbos
15	Westleigh	1	0,8892		1,4776		
16	Oakleaf	1	1,0027		1,4195		
17	Westleigh (dry)	1	1,0583		1,2879		
18	Westleigh (dry)	1	1,0825		1,7966		
19	Westleigh	1	0,8065		1,5384		
20	Glenrosa	1	0,9505		1,2382		
21	Clovelly	1	0,8579		1,0306		wet fynbos

Table 5. F-values for analyses of variance of bulk densities (g/cm^3), using values of profiles 1 to 7

Source of variation	Degrees of freedom	F-value
Forest-fynbos (all horizons)	1:44	3,78
Forest-fynbos (A_1 horizons)	1:19	1,03
Forest-fynbos (B_{21} horizons, including outliers)	1:19	5,40
Forest-fynbos (B_{21} horizons, excluding outliers)	1:17	3,31
A/B_{21} (all profiles)	1:40	22,00**
Differences among horizons sampled repetitively (including outliers)	16:34	2,87*
Differences among horizons sampled repetitively (excluding outliers)	13:28	43,78**

*significant at a 5% level
**significant at a 1% level

To calculate the required sample size for a given probability that the average value lies between set limits, the following formula was used (Snedecor and Cohran, 1967):

$$n = Z_\alpha^2 \, S^2/L^2$$

where

n = sample size

Z_α = 1,96 for a probability of 95% and 2,58 for a probability of 99%

S^2 = sample variance, an estimate of the population variance

L = absolute value of limit

For L = 0,1 and a probability of 95%, n = 3,8 for the A_1 horizon of profile 2 (with a CV of 8,23%). For the A_1 horizon of profile 3 (CV = 1,19%), n = 0,04. A sample size of three seems adequate for most horizons. Required sample sizes for the hard plinthic horizons and very gravelly or stony (more than 50% of the soil volume) soils range from 8 to 571, and the results obtained from three samples are not reliable in these cases.

Although this method has not been tested against other sampling methods, it seems suitable for comparative bulk density estimates.

Water absorption rates of the A_1 horizons were invariably extremely slow when the soils were dry. This water repellency has been observed throughout the Southern Cape, and is caused by organic hydrophobic substances in the soil (De Bano, 1969). Burning of chaparral in California (De Bano and Krammes, 1966, <u>ex</u> Richardson and Hole, 1978) and forests in the Pacific Northwest (Dyrness, 1976, <u>ex</u> Richardson and Hole, 1978), increased the water repellency markedly. Richardson and Hole (1978) found that mor horizons, with abundant observable fungal mycelia are more repellent than mull horizons. They also found that B horizons, like in the Southern Cape, are not consistently water repellent.

This phenomenon apparently causes no surface runoff. The water has been observed running down the soil in wetting fronts, both in the forest and fynbos adjoining the forest.

No significant differences in texture between the different study sites could be found. The B_{21} horizons are much heavier than the A_1 horizons, with a doubling of the clay content from 11 to 21%. Silt content is high: 26% in the A_1 horizon and 21% in the B_{21} horizon. This indicates a possible strong fluvial and/or wind action in the geomorphological history of the Southern Cape.

6.7 CHEMICAL SOIL ANALYSES

Of the elements and parameters determined, only pH, potassium, calcium and aluminium showed significant differences between forest and fynbos (Table 6, Appendix 5).

Mean pH (in H_2O and $CaCl_2$) of the B_{21} horizons of the forest was lower than that of the fynbos B_{21} horizons. This might be correlated with the 65% higher aluminium content of the forest B_{21} horizons compared to the fynbos B_{21} horizons, affecting the pH through the increased hydrolysis associated with an increase in aluminium (Etherington, 1975). The higher aluminium content can also be an indication of a better moisture régime in the forest, leaching down more aluminium into the B horizon. There is a 55% decrease in aluminium of the A_1 horizon from fynbos to forest, with no noticeable effect on pH. Usually, the aluminium - pH relation in the A horizon is complicated by litterfall, nutrient circulation and the type of vegetation (D.C. Grey, 1980, pers. comm.).

On the whole, pH in H_2O seems more sensitive than pH in $CaCl_2$. Normally $CaCl_2$ is regarded a better medium where pH is measured in very different soils. Where soils are fairly similar, as in this case, H_2O is preferable to $CaCl_2$, for it gives a better picture of what the plant roots have to deal with in the soil water solution.

Significant differences in pH were found between fynbos A_1 and B_{21} horizons, the B_{21} horizons having a higher pH. The differences in A_1 horizons between sites might merely be an indication of the age of the soil, the younger soils of the Goudveld sites being less leached than the older plateau soils with a heavy subsoil (Figures 37 and 38). This was, however, not confirmed by significant differences of other elements.

Potassium showed a 100% decrease from forest to fynbos, and also from the A_1 to the B_{21} horizon. It was previously concluded that all these sites have artificially induced forest-fynbos edges; thus the differences in nutrients are vegetation induced. A possible explanation for the above-mentioned decreases then is that most of the potassium is locked up in the vegetative biomass. The forest, with its higher biomass, will keep more potassium than the fynbos. Alternatively, the fynbos might take up less potassium per biomass unit. When a forest is destroyed, more potassium is available than can be utilised by the fynbos invaders, with a consequent leaching of this mobile element (Etherington, 1975). This theory is confirmed by the results of Brasell <u>et al</u>

Fig. 37. Typical soil profile at Dirk se Eiland. The A_1 horizon normally shows signs of leaching, while the E horizon might be very thin or absent

(1980). They found a higher potassium content in the litter of the more fertile rainforest and <u>Araucaria cunninghamii</u> plantation sites than on the less fertile sites.

Calcium decreased from forest to fynbos only in the A_1 horizon. The same arguments as for potassium might be

grey A_1 horizon

lithocutanic B_{21} horizon

Fig. 38. Typical soil profile at Forest Creek Area. Note the dense root mat in the A_{11} horizon. The heavy subsoil (Figure 37) is absent.

applicable. Again biocycling of calcium is important in restricting leaching loss by returning calcium to the soil surface (Etherington, 1975). As with potassium, Brasell <u>et al</u> (1980) found a higher calcium content in the litter of the more fertile forest sites than on less fertile sites. Although calcium is not immobilised in organic matter, it does show chelation with a number of organic acids, for example, citric and gluconic (Stevenson, 1967, ex Etherington, 1975). This can restrict leaching of calcium out of the soil profile.

On the whole, the calcium/magnesium ratio did not show the imbalance observed in some areas of the Southern Cape. Average ratios varied from 1,7 to 4,2.

With the exception of two values, all the S-values/100 g clay for the B_{21} horizons are in the mesotrophic range. The S-values for the A_1 horizons are not very informative. They vary tremendously, especially where the clay content is low.

Although the calcium/aluminium ratio decreased significantly from forest to fynbos, it was not a very sensitive forest or fynbos site indicator, probably as a result of the inaccurate aluminium determinations. Laboratory standard samples included in the analyses, showed coefficients of variation of 36% and 28% for the A and B horizons respectively.

Organic matter and carbon was consistently higher in the forest than in the fynbos, although not significantly so. A larger sample size will be needed to confirm this result.

Brasell et al (1980) found significantly higher concentrations of total phosphorus (determined by the colorimetric method of Murphy and Riley (1962, ex Brasell et al, 1980) using a perchloric-nitric acid digest) and nitrogen in the litter of rainforest than in that of Araucaria cunninghamii plantation. These elements are often in short supply for exotic plantation trees in the Southern Cape. The insignificance of differences in phosphorus concentrations in forest and fynbos soils and A_1 and B_{21} horizons again might be due to inaccuracy of the determinations. Laboratory standard samples had coefficients of variation of 43% and 20% for A and B horizons respectively. A repitition of these analyses, perhaps with a stronger extractant than the Bray No. 2 extract, might be useful. Nitrogen determinations might likewise be informative.

6.8 INDICATOR SPECIES

As mentioned in Section 5.3.1 indicator species were selected by drawing two-dimensional diagrams of the RA plot scores and making overlays of the species scores (for example, Figure 38). All non-tree species (indigenous tree species occurring on sites next to the indigenous forest are indicators automatically) that occurred in two or more ecotone areas as possible indicators, were selected as indicators of potential forest area. These were:

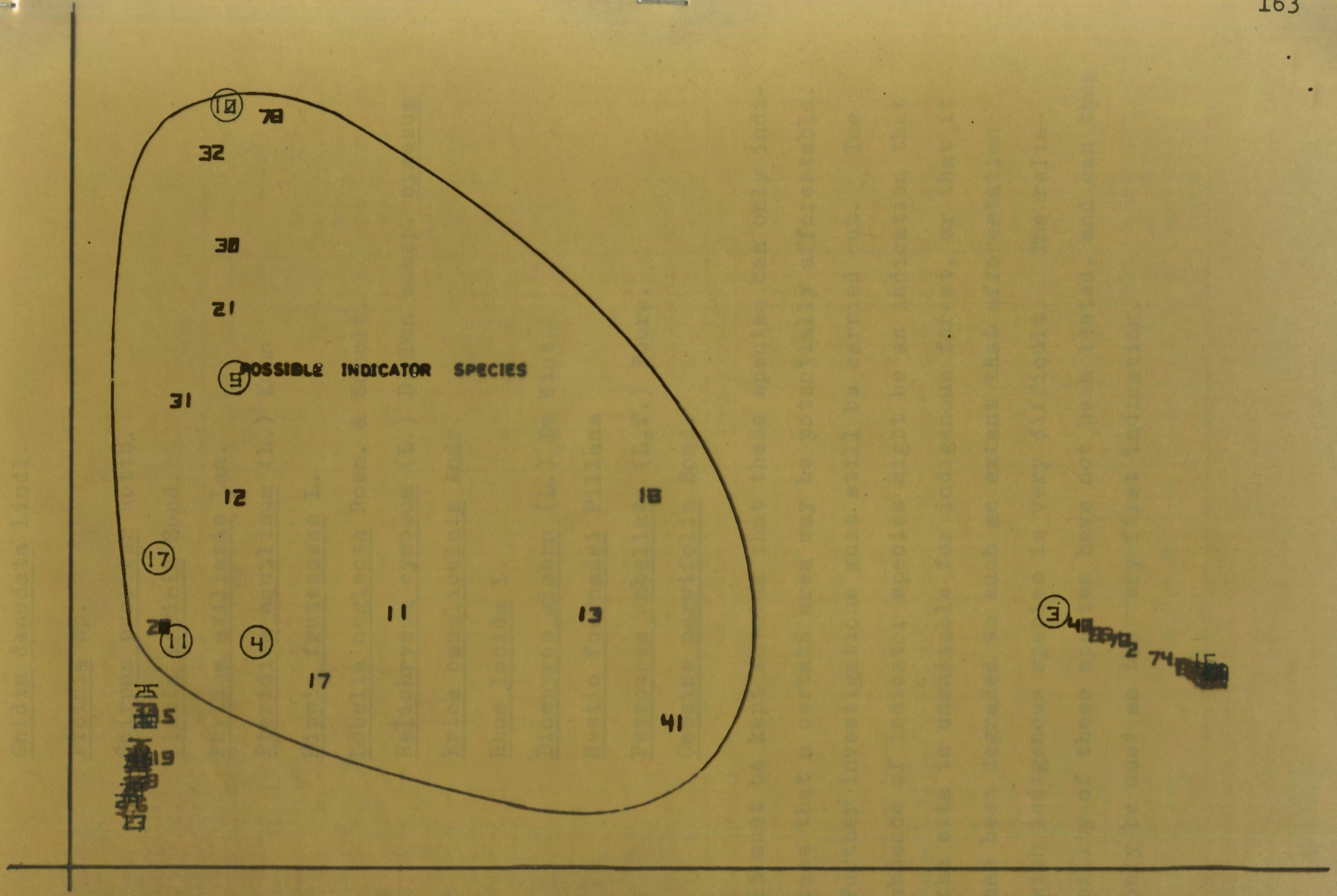


Fig. 38. Selection of possible indicator species from the reciprocal averaging of the data from Kleineiland. An overlay of species scores over plot scores was used.

Gnidia denudata Lindl.

Ficinia sp.
Scirpus prolifer Rottb.
Clutia affinis Sond.
Phylica axillaris Lam.
Pteridium aquilinum (L.) Kuhn
Hippia frutescens L.
Lobelia neglecta Roem. & Schult.
Helichrysum cymosum (L.) D. Don subsp. *cymosum*
Erica canaliculata Andr.
Rhus lucida L.
Diospyros glabra (L.) De Wint.
Restio fourcadei Pillans
Peyrousea umbellata (L.f.) Fourc.
Cassine parvifolia Sond.

It must be kept in mind that these species can only indicate that a certain area may be potentially afforestable. Further investigations must still be carried out. The absence of indicator species might be an indication that the site is unsuitable for indigenous forest, or that it has been degraded to such an extent that afforestation with indigenous species is very difficult. The reliability of these species have not been tested, and can thus only be used as the very first indication.

Table 6. Means and F-values for analyses of variance of chemical soil analyses

Source of variation	pH (H_2O)			pH ($CaCl_2$)			P (ppm)		
	mean	F	df	mean	F	df	mean	F	df
Forest - fynbos									
Kleineiland A_1 hor.	4,4/4,4	0,16	1:6	3,9/3,6	1,70	1:6	9/10	0,14	1:6
B_{21} hor.	4,4/4,9	57,80**	1:6	3,7/4,0	10,71*	1:6	11/11	0,00	1:6
Grooteiland A_1 hor.	4,1/4,1	0,00	1:8	3,6/3,4	0,69	1:8	8/8	0,00	1:8
B_{21} hor.	4,4/4,6	3,11	1:7	3,8/3,8	0,03	1:7	10/5	6,70	1:7
Dirk se eiland A_1 hor.	4,4/4,4	0,02	1:11	4,0/3,6	1,55	1:11	7/6	0,04	1:11
B_{21} hor.	4,3/5,0	19,33**	1:9	3,9/4,2	3,35	1:9	5/4	1,08	1:9
Forest Creek A_1 hor.	3,8/3,5	2,10	1:4	3,1/2,9	1,83	1:4	13/12	0,07	1:4
Ratelbos A_1 hor.	3,8/3,8	0,02	1:3	3,4/3,4	0,01	1:3	9/3	2,98	1:3
B_{21} hor.	4,1/4,4	1,94	1:3	3,7/3,9	0,79	1:3			
Combined A_1 hor.	4,1/4,1	0,04	1:40	3,6/3,4	2,39	1:40	9/7	0,69	1:40
B_{21} hor.	4,4/4,8	19,38**	1:33	3,8/4,0	8,35**	1:33	7/6	0,68	1:29
Forest : A_1 - B_{21} hor.	4,1/4,4	3,76	1:25	3,6/3,8	1,02	1:24	9/7	1,00	1:24
Fynbos : A_1 - B_{21} hor.	4,1/4,8	36,39**	1:49	3,4/4,0	34,59**	1:49	7/6	1,36	1:45
Between Sites:									
[2]**Kaffirkop/Goudveld:**									
Forest A_1 hor.	4,3/3,8	6,92*	1:12	3,8/3,2	10,32*	1:12	8/11	2,11	1:12
B_{21} hor.	4,4/4,2	2,76	1:10	3,8/3,8	0,20	1:10	9/4	3,95	1:10
Fynbos A_1 hor.	4,3/3,6	19,65**	1:26	3,6/3,1	10,53**	1:26	7/8	0,26	1:26
B_{21} hor.	4,9/4,4	8,60*	1:21	4,0/4,0	0,22	1:21	6/6	0,01	1:21

Source of variation	Org. matter (%)			Org. Carbon (%)			K (ppm)		
	mean	F	df	mean	F	df	mean	F	df
Forest - fynbos									
Kleineiland A_1 hor.	8,0/6,2	2,52	1:6	4,6/3,6	2,56	1:6			
B_{21} hor.									
Grooteiland A_1 hor.	10,2/7,8	2,69	1:8	5,9/4,5	2,54	1:8			
B_{21} hor.									
Dirk se eiland A_1 hor.	6,4/5,8	0,37	1:11	3,7/3,4	0,39	1:11			
B_{21} hor.									
Forest Creek A_1 hor.	9,5/9,1	0,02	1:4	5,5/5,3	0,03	1:4			
Ratelbos A_1 hor.	7,8/6,9	0,06	1:3	4,6/4,0	0,06	1:3			
B_{21} hor.									
Combined A_1 hor.	8,3/6,9	3,15	1:40	4,8/4,0	3,22	1:40	111/54	8,67*	1:18
B_{21} hor.							45/27	7,63*	1:16
Forest : A_1 - B_{21} hor.							111/45	7,19*	1:14
Fynbos : A_1 - B_{21} hor.							54/27	27,67**	1:20
Between Sites:									
[2]**Kaffirkop/Goudveld:**									
Forest A_1 hor.	8,2/8,6	0,09	1:12	4,7/5,0	0,10	1:12	87/198	11,12*	1:7
B_{21} hor.							46/42	0,07	1:5
Fynbos A_1 hor.	6,1/8,2	5,66*	1:26	3,8/4,7	2,90	1:26	52/64	1,00	1:9
B_{21} hor.							25/36	6,44	1:9

*significant at a 5% level

**significant at a 1% level

df degrees of freedom

[1] E.A. = exchangeable acidity

[2] Kaffirkop includes Kleineiland, Grooteiland and Dirk se Eiland
Goudveld includes Forest Creek Concession Area and Ratelbos Island

Table 6 (continued)

Source of variation	Ca (ppm)			Mg (ppm)			Ca/Mg (ppm/ppm)		
	mean	F	df	mean	F	df	mean	F	df
Forest - fynbos									
Combined A_1 hor.	701/289	16,40**	1:18	166/153	0,74	1:18	4,18/1,93	15,33**	1:18
B_{21} hor.	110/131	1,17	1:17	82/78	0,04	1:17	1,67/1,88	0,45	1:17
Forest : A_1-B_{21} hor.	701/110	28,57**	1:15	166/82	17,29**	1:15	4,18/1,67	15,35**	1:15
Fynbos : A_1-B_{21} hor.	289/131	16,09**	1:20	153/78	24,50**	1:20	1,93/1,88	0,03	1:20
Between Sites:									
^{2}**Kaffirkop/Goudveld:**									
Forest A_1 hor.	731/596	0,27	1:7	179/118	5,38	1:7	3,91/5,16	0,88	1:7
B_{21} hor.	117/91	3,04	1:6	99/32	7,49	1:6	1,28/2,85	33,25**	1:6
Fynbos A_1 hor.	326/126	7,22*	1:9	157/133	1,36	1:9	2,13/1,04	3,08	1:9
B_{21} hor.	140/89	1,86	1:9	88/33	3,42	1:9	1,69/2,77	11,35*	1:9

Source of variation	Na (ppm)			Al (ppm)			E.A.^{1} (m.e.)		
	mean	F	df	mean	F	df	mean	F	df
Forest - fynbos									
Combined A_1 hor.	81/67	1:35	1:17	161/250	6,86*	1:18	2,58/3,24	1,52	1:18
B_{21} hor.	79/54	1:78	1:16	318/192	8,78	1:18	3,68/2,48	2,88	1:17
Forest : A_1-B_{21} hor.	81/79	0,01	1:15	161/318	15,23**	1:15	2,58/3,68	3,09	1:15
Fynbos : A_1-B_{21} hor.	67/54	1,51	1:19	250/192	2,60	1:20	3,24/2,48	1,58	1:20
Between Sites:									
^{2}**Kaffirkop/Goudveld:**									
Forest A_1 hor.	86/63	0,86	1:7	152/192	0,35	1:7	2,46/3,00	0,39	1:7
B_{21} hor.	91/47	1,09	1:5	342/248	2,01	1:6	3,62/3,88	0,04	1:6
Fynbos A_1 hor.	71/53	1:41	1:8	253/237	0,07	1:9	3,12/3,79	0,38	1:9
B_{21} hor.	58/38	0,94	1:9	191/196	0,00	1:9	2,39/2,86	0,14	1:9

Source of variation	Al/E.A. (ppm/m.e.)			S-value m.e./100g clay			Ca/Al (ppm/ppm)		
	mean	F	df	mean	F	df	mean	F	df
Forest - fynbos									
Combined A_1 hor.	60,01/68,45	2,41	1:17	48,87/33,74	3,33	1:16	7,54/1,29	6,04*	1:18
B_{21} hor.	99,41/72,40	2,52	1:17	9,74/9,50	0,01	1:15	0,41/1,21	1,39	1:17
Forest : A_1-B_{21} hor.	60,01/99,41	4,84	1:15	48,87/9,74	16,66**	1:11	7,54/0,41	5,67*	1:15
Fynbos : A_1-B_{21} hor.	68,45/72,40	0,54	1:18	33,74/9,50	22,38**	1:18	1,29/1,21	0,01	1:20
Between Sites:									
^{2}**Kaffirkop/Goudveld:**									
Forest A_1 hor.	58,90/63,88	0,24	1:7				8,78/3,21	0,65	1:7
B_{21} hor.	11,28/63,81	1,28	1:6				0,42/0,39	0,04	1:6
Fynbos A_1 hor.	70,12/61,79	0,80	1:8				1,45/0,57	2,12	1:9
B_{21} hor.	73,36/68,57	0,22	1:8				1,38/0,46	0,36	1:9

***significant at a 5% level**

****significant at a 1% level**

df degrees of freedom

1 **E.A. = exchangeable acidity**

2 **Kaffirkop includes Kleineiland, Grooteiland and Dirk se Eiland**
Goudveld includes Forest Creek Concession Area and Ratelbos Island

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

In the introduction, the following hypothesis was made: The indigenous forest colonises suitable fynbos and disturbed sites adjoining the indigenous forest successfully if the disturbing factor, for example fire, is kept out for sufficient time. A site is suitable for forest regeneration when environmental and edaphic factors, such as aspect and soil type, is comparable with those of the indigenous forest.

On the whole, this hypothesis has been proved incorrect. On the study sites no forest colonisation took place (Chapter 6). A few exceptions to this phenomenon are shown, for example, at the big tree at Woodville State Forest, but only on very limited moist, well-drained sites. Possible reasons are:

(i) The indigenous forests, which grow on nutrient poor soils (Section 4.4), have very shallow spreading roots. Nutrients that become available through decomposition of the organic matter in the surface soil layers, are utilised immediately (Section 3.4.2). Disturbance of the forest disturbs this closed nutrient cycle; no more litter is added to the forest floor, the organic matter present is decomposed and nutrients leached out (see leached horizon in Figure 37) before they can be utilised by regrowth. This conclusion is confirmed by the decrease in the potassium and calcium contents from forest to fynbos (Section 6.7). This gives fynbos, with its superior ability to establish itself on exposed leached sites, a competitive advantage.

(ii) The fynbos, unlike forest, is adapted to fire and can withstand regular burning.

(iii) The microclimate in the fynbos is unfavourable for forest regeneration. In forest the moisture régime is better, as indicated by the increase in aluminium from the A_1 to the B_{21} horizon (Section 6.7).

(iv) The macroclimate might be too dry for the forests. Water deficiencies occur during the summer months (Section 4.2, Figure 8 and Map 3). A rainfall pattern peaking in summer, might be more advantageous than the evenly spread one of the Southern Cape, where much of the effect of the summer rainfall is eliminated by relatively high temperatures. Annual rainfall figures of other forested areas of the Southern Hemisphere, are often much higher than those of the Southern Cape. The maximum of this area, i.e. about 1 200 mm at Diepwalle, is less than

> the minimum of those countries. In Australia evergreen rainforests occur on igneous or calcareous enriched siliceous soils only if the rainfall exceeds 1 300 mm per year. In Victoria (Australia) and Tasmania Nothofagus forests predominates where the annual rainfall exceeds 1 400 mm. In New Zealand beech forests occur along a rainfall gradient from west to east of 1 000 to 5 000 mm per annum, but the western forests are much more species poor than the eastern ones. In the Central Depression of the Valdivian rainforest region in Chile, where evergreen and deciduous Nothofagus forests occur, the annual rainfall exceeds 1 300 mm. On the coastal mountain ranges this forest occurs where the rainfall exceeds 1 500 mm (Geldenhuys, in prep.).

Soil moisture came out in every FA as an important source of variation. At Kleineiland soil moisture, together with drainage, accounted for 51% of the common variance (Section 6.1), at Grooteiland it accounted for 51,8% (Section 6.2) and at Ysternek Nature Reserve for 44,9% of the common variance (Section 6.4). Only at Ysternek, which forms part of the foothill zone (Sections 4.3.1 and 4.4), it caused a grouping of plots between forest and fynbos. Therefore, soil moisture is considered important in controlling the forest-fynbos ecotone in the marginal areas of the foothill zone, where forest only occurs on the moister southern slopes (Section 6.4). Although important in determining the type of forest (Section 2.2) it is not a major controlling factor in the small scale forest distribution on the plateaux.

Generally, soil type as such is not a limiting factor. Forests occur on virtually all the soil types in the Southern Cape (Section 4.5), except those derived from granites or the Enon sediments (Maps 2 and 4). The rock of the Table Mountain and Bokkeveld Groups, which underlie the greater part of the Southern Cape (Section 4.3.2), only influence the forest significantly if it is not far beneath the root systems of the trees (Section 4.5). The limiting of root penetration into the heavy subsoil of the duplex soils (Section 4.4) and the compacted B horizons of the plateau soils (Section 6.7; Figure 37) is more important. The complicated geomorphological history (Section 4.3.3) undoubtedly must have had a major influence on the regional forest distribution and development. Much of this aspect must, however, still be clarified and no conclusions about the present-day influence can be made. Topography and aspect are important in so far they control the soil moisture (Sections 3.2 and 6.4) and the spread of fires (Sections 6.2 and 6.3).

Fynbos is not a seral stage to indigenous forest (see Introduction), and fynbos will not develop into forest within a reasonable time, i.e. 50 (as indicated by Phillips (1931) to 100 or even 200 ? years. The fynbos of the study sites were 10 to 72 years old (Chapter 6), without any indication of forest development. The fynbos and forest of the Southern Cape must be seen as two completely different, competing vegetation types.

Some of the fynbos islands are undoubtedly natural, for example the northern parts of Dirk se Eiland and Groot-eiland, but their sizes are probably increased by fire (Sections 6.2 and 6.3). Others are caused by over-exploitation (for example Forest Creek Area - Section 6.5) and burning (Section 1.6).

With the above in mind these forests must be considered a relict of a much wetter telocratic? (Section 1.1) climatic period. They managed to survive on the protected southern side of the Outeniqua mountains, where the evenly spread orographic mist and rain is higher than of the surrounding country (Section 4.2). On the whole, the present climate seems to be in favour of fynbos. Therefore, the indigenous forests must be managed very carefully, the forest edges must be protected at all costs and small damaged patches must be artificially regenerated by planting indigenous trees if at all possible.

Finally, the following improvements in the measurement and coding of physiographic and soil parameters are proposed, should a similar study be undertaken:

(i) Terrain morphology - use the following classes (Dalrymple _et al_, 1968):

interfluve (0° - 1°) = 1
seepage slope (2° - 4°) = 2
convex creep slope (smaller than 45°) = 3
fall face (greater than 45°) = 4
transportional midslope (26° - 35°) = 5
colluvial footslope = 6
alluvial toeslope = 7

Leave out the position on the different terrain classes. These cause problems when coding.

(ii) Mottles - record only the occurrence and type of mottle. Contrast is very difficult to quantify.

(iii) Estimate consistency always in the moist phase.

(vi) Code structure as follows - this is more in line with the theory of structure development:

single grained = 1
massive = 2
apedal = 3
columnar = 4
prismatic = 5
blocky = 6
spheroidal = 7

(v) Stones - only record the occurrence and use the following six classes (Boaler, 1966):

none = 0
rare = 1

occasional = 2
common = 3
many = 4
little soil = 5

(vi) Soil colour - record the colour of the A and B horizon in the moist phase and code as follows: (Boaler, 1966):

(a) Hue: 10 R = 1
2,5 YR = 2
5 YR = 3
7,5 YR = 4
10 YR = 5
2,5 Y = 6
5 Y = 7

(b) Value: 7 classes (1-7).

(c) Chroma: 9 classes (1-9).

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APPENDIX 1

CHECKLIST OF PLANTS IN STUDY SITES

The species below were found on the plots in the study sites. Families and genera of the Pteridophyta are arranged according to Schelpe (1969) and Spermatophyta according to the genus numbers of De Dalla Torre Et Harms (1958).

Genus no.	Family	Genus and species
	PTERIDOPHYTA	
	Dennstaedtiaceae	Pteridium aquilinum (L) Kuhn
	Aspleniaceae	Asplenium rutifolium (Berg.) Kunze
	Aspidiaceae	Rumohra adiantiformis (G.Forst.) Ching
	Blechnaceae	Blechnum giganteum (Kaulf.) Schlechtd.
	SPERMATOPHYTA	
13	Podocarpaceae	Podocarpus falcatus (Thunb.) R.Br. ex Mirb.
13		P.latifolius (Thunb.) R.Br. ex Mirb.
38	Cupressaceae	Widdringtonia nodiflora (L.) Powrie
169	Gramineae	Oplismenus hirtellus (L.) Beauv.
175		Pennisetum clandestinum Hochst. ex Chiov.
201		Ehrharta rehmannii Stapf
465	Cyperaceae	Ficinia sp.
468		Scirpus prolifer Rottb.
494		Tetraria involucrata C.B. Cl.
500		Chrysithrix capensis L.
522		Schoenoxiphium ecklonii Nees
522		S.lanceum (Thunb.) Kuekenth.

Genus no.	Family	Genus and species
804	Restionaceae	Restio compressus Rottb.
804		R.fourcadei Pillans
804		R.giganteus (Kunth) N.E. Br.
807		Elegia sp.
813		Thamnochortus argenteus Kunth
816		Hypodiscus synchroolepis (Steud.) Mast
816		H.striatus (Kunth) Mast
817		Cannomois virgata (Rottb.) Steud.
1002	Liliaceae	Caesia contorta (L.f.) Dur. & Schinz
1113		Asparagus setaceus (Kunth) Jessop
1113		A.scandens Thunb.
1252	Dioscoreaceae	Dioscorea burchellii Bak.
1265a	Iridaceae	Dietes iridioides (L.) Sweet
1284		Bobartia macrospatha Bak.
1295		Aristea ensifolia Muir
1315		Watsonia fourcadei Mathews & L.Bol.
1866	Piperaceae	Peperomia tetraphylla (G.Forst.) Hook & Arn.
1874	Myricaceae	Myrica humilis Cham. & Schlechtd.
2035	Proteaceae	Protea cynaroides (L.) L.
2035		P.neriifolia R. Br.
2037		Leucadendron eucalyptifolium Buek ex Meisn.
2574	Menispermaceae	Cissampelos torulosa E. Mey. ex Harv.
2788	Lauraceae	Ocotea bullata (Burch.) Baill.
3101	Capparicaceae	Capparis sepiaria L. var. citrifolia (Lam.) Toelk.
3275	Cunoniaceae	Cunonia capensis L.
3294	Bruniaceae	Berzelia intermedia Schlechtd.
3311	Hamamelidaceae	Trichocladus crinitus (Thunb.) Pers.
3353	Rosaceae	Rubus sp.
3388		Cliffortia exilifolia Weim.
3388		C.odorata L.f.
3388		C.stricta Weim.
3446	Mimosaceae	Acacia melanoxylon R. Br.

Genus no.	Family	Genus and species
3608	Fabaceae subfam. Fabaceae	Virgilia oroboides (Berg.)Salter
3620		Cyclopia subternata Vogel
3702		Indigofera flabellata Harv.
3936	Oxalidaceae	Oxalis sp.
4037	Rutaceae	Agathosma ovata (Thunb.) Pillans
4273	Polygalaceae	Polygala fruticosa Berg.
4291	Euphorbiaceae	Lachnostylis hirta (L.f.) Muell. Arg.
4448		Clutia affinis Sond.
4448		C.pulchella L.
4478		Excoecaria simii (Kuntze) Pax
4587	Anacardiaceae	Laurophyllus capensis Thunb.
4594		Rhus lucida L.
4614	Aquifoliaceae	Ilex mitis (L.) Radlk.
4626	Celastraceae	Maytenus heterophylla (Eckl. & Zeyh.) N.K.B. Robson
4630		Pterocelastrus tricuspidatus (Lam.) Sond.
4641		Cassine eucleiformis (Eckl. & Zeyh.) Kuntze
4641		C.papillosa (Hochst.) Kuntze
4641		C.parvifolia Sond.
4645		Hartogia schinoides C.A. Sm.
4686	Icacinaceae	Apodytes dimidiata E. Mey. ex Arn. subsp. dimidiata
4709		Pyrenacantha scandens Planch. ex Harv.
4874	Rhamnaceae	Scutia myrtina (Burm.f.) Kurz
4875		Rhamnus prinoides L'Hérit.
4886		Phylica axillaris Lam.
4917	Vitaceae	Rhoicissus sp.
5112	Ochnaceae	Ochna arborea Burch. ex DC. var arborea
5112		O.serrulata (Hochst.) Walp.
5425	Penaeaceae	Penaea cneorum Meerb.
5425		P.mucronata L.

Genus no.	Family	Genus and species
5425		P.myrtoides L.f.(=P.cneorum Meerb. subsp. gigantea R. Dahlgren)
5428	Oliniaceae	Olinia ventosa (L.) Cufod.
5435	Thymelaeaceae	Gnidia denudata Lindl.
5436		Struthiola sp. cf. macowanii C.H. Wr.
5460		Lachnaea diosmoides Meisn.
5461		Passerina falcifolia C.H. Wr.
5894	Apiaceae	Centella eriantha (Rich.) Drude
6156	Cornaceae	Curtisia dentata (Burm.f.) C.A. Sm.
6237	Ericaceae	Erica canaliculata Andr.
6237		E.curviflora L.
6237		E.densifolia Willd.
6237		E.seriphiifolia Salisb.
6237		E.versicolor Wend.
6237		E.gibbosa Klotzsch ex Benth.
6244		Simocheilus multiflorus Klotzcsh
6314	Myrsinaceae	Rapanea melanophloeos (L.) Mez
6406	Ebenaceae	Diospyros dichrophylla (Gand.) De Wint.
6406		D.glabra (L.) De Wint.
6406		D.whyteana (Hiern) F. White
6428	Oleaceae	Linociera foveolata (E.Mey.) Knobl.
6434		Olea capensis L. subsp. capensis (Harv. ex C.H.Wr.) Verdoorn
6434		O.capensis L. subsp. macrocarpa (C.H. Wr.) Verdoorn
6469	Loganiaceae	Nuxia floribunda Benth.
6559	Apocynaceae	Carissa bispinosa (L.) Desf. ex Brenan
6581		Gonioma kamassi E. Mey.
6860	Asclepiadaceae	Secamone alpinii Schultes
7281	Lamiaceae	Stachys thunbergii Benth.
7350		Plectranthus fruticosus L'Hérit.
7493	Scrophulariaceae	Halleria lucida L.
8281	Rubiaceae	Burchellia bubalina (L.f.) Sims

Genus no.	Family	Genus and species
8352		Canthium mundianum Cham. & Schlechtd.
8352		C.obovatum Klotzsch
8352		C.inerme (L.f.) Kuntze
8435		Galopina circaeoides Thunb.
8438		Anthospermum sp.
8443		Carpacoce spermacocea Sond.
8694	Lobeliaceae	Lobelia neglecta Roem. & Schult.
9006	Asteraceae	Helichrysum cymosum (L.) D.Don subsp. cymosum
9006		H.felinum Less.
9006		H.petiolare Hilliard & Burtt
9043		Metalasia muricata (L.) D.Don
9357		Hippia frutescens L.
9365		Peyrousea umbellata (L.f.) Fourc.
9427b		Chrysanthemoides monilifera (L.) Norl.
9431		Ursinia anethoides (DC.) N.E. Br.

APPENDIX 2

Radiation index figures for 34°S latitude (Frank and Lee, 1966)

Aspect	Slope										
	0% 0°-2°	10% 3°-8°	20% 9°-14°	30% 15°-19°	40% 20°-24°	50% 25°-29°	60% 30°-33°	70% 34°-37°	80% 38°-40°	90% 41°-43°	100% 44°+
(1)N	-	54,45	56,70	58,38	59,53	60,19	60,45	60,39	60,09	59,61	59,02
(2)NE + (8)NW	-	53,64	55,24	56,42	57,21	57,64	57,76	57,64	57,34	56,91	56,38
(3)E + (7)W	-	51,58	51,35	50,99	50,51	49,94	49,30	48,62	47,93	47,23	46,54
(4)SE + (6)SW	-	49,37	46,88	44,30	41,74	39,30	37,04	34,99	33,16	31,55	30,13
(5)S	-	48,40	44,81	41,03	37,20	33,50	30,07	27,15	24,70	22,39	20,73
(0)Even	51,66	-	-	-	-	-	-	-	-	-	-

Radiation index (RI): Proportion of total annual potential insolation to the maximum annual potential insolation of 525600 Langleys (kg. cal/cm^2) as a percentage.

Appendix 3. Data matrices used for the factor analysis

3.1 Kleineiland

Plot No.	Terrain morphology	Total depth	Effective depth	Depth A_1 hor	Contrast of mottles	Texture A_1 hor	Texture B_{21} hor	Clay A_1 hor	Clay B_{21} hor	Consistency A_1 hor	Consistency B_{21} hor
1	1	55	55	35	0	3	3	8	8	7	7
2	1	45	45	25	0	3	4	7	12	7	8
3	1	60	60	30	0	4	5	10	18	2	8
4	1	70	70	45	0	3	4	7	13	7	8
5	1	50	50	30	1	4	4	13	25	7	7
6	1	45	45	30	2	5	5	23	23	7	7
7	1	55	55	30	0	4	5	13	23	8	9
8	1	60	60	40	0	4	5	8	23	8	9
9	1	60	60	35	0	4	6	13	23	8	9
10	1	55	55	30	0	5	5	18	25	7	4
11	1	60	60	45	0	5	5	18	25	7	8
12	1	55	55	40	0	5	6	18	28	7	8
13	1	60	60	30	1	5	6	18	30	7	9
14	3	85	85	35	0	4	4	12	14	3	4
15	3	85	85	35	0	4	7	13	38	3	5
16	1	80	80	50	0	4	5	8	23	7	4
17	1	75	75	35	2	4	5	15	25	2	7
18	1	70	70	35	2	4	6	10	25	2	7
19	1	55	55	35	1	6	6	20	28	2	7
20	1	60	60	35	0	6	6	20	25	2	7
21	3	60	60	30	1	3	3	8	13	2	7
22	3	70	70	25	0	1	1	3	3	1	4
23	3	80	30	30	2	3	4	7	9	7	3
24	3	90	65	35	1	6	6	20	33	2	7
25	3	90	60	30	0	6	6	15	25	2	7
26	3	70	70	35	0	6	6	20	25	7	8
27	3	70	70	35	1	6	6	15	28	2	8
28	3	65	65	30	1	6	6	15	20	2	8
Mean	1,71429	65,53571	61,78571	34,10714	0,53571	4,39286	5,00000	13,39286	21,78571	4,82143	6,92857
Std. deviation	0,97590	12,79027	12,03500	5,78208	0,74447	1,25725	1,27657	5,21635	7,92724	2,63949	1,71979

Plot No.	Structure B_{21} hor	Concretions	Abundance of roots A_1 hor	Size of roots A_1 hor	Abundance of roots B_{21} hor	Size of roots B_{21} hor	pH A_1 hor	Org. matter A_{11} hor (%)	Radiation index
1	6	0	3	2	2	2	6,0	9,31	49,37
2	6	0	3	2	2	1	4,2	15,51	49,37
3	6	0	3	2	2	1	4,6	8,81	51,66
4	6	0	3	2	2	1	4,1	12,64	51,58
5	6	0	3	2	2	2	4,1	10,66	51,58
6	6	0	3	2	2	1	4,3	7,15	51,58
7	6	0	3	2	2	2	4,5	10,70	46,88
8	6	0	3	2	1	3	4,6	10,44	46,88
9	6	0	3	2	1	3	4,6	7,77	49,37
10	5	0	2	2	1	1	4,3	7,80	49,37
11	6	0	2	2	1	1	4,2	12,04	49,37
12	6	0	2	2	1	1	3,9	11,50	51,58
13	5	0	2	1	1	1	4,5	8,89	57,64
14	5	0	3	2	1	1	4,5	11,45	41,03
15	5	0	3	2	1	1	4,5	10,72	49,37
16	5	0	3	2	1	1	5,2	18,06	54,45
17	6	0	2	2	1	1	4,3	10,13	46,88
18	6	2	2	2	1	1	4,1	10,56	46,88
19	6	0	2	2	1	1	4,2	7,76	49,37
20	6	0	2	2	1	1	4,3	7,78	51,58
21	6	0	3	2	1	1	4,0	6,15	44,81
22	6	0	3	2	1	1	4,5	5,68	46,88
23	6	0	3	2	0	0	5,4	6,85	51,58
24	6	2	3	2	2	1	3,6	10,21	46,88
25	6	0	3	2	1	1	4,2	9,70	44,81
26	6	0	3	2	1	1	4,3	10,55	44,81
27	6	0	3	2	1	1	4,2	11,33	44,81
28	6	0	3	2	1	1	4,3	8,62	46,88
Mean	5,82143	0,14286	2,71429	1,96429	1,25000	1,21429	4,41071	9,95607	48,83036
Std. deviation	0,39002	0,52453	0,46004	0,18898	0,51819	0,62994	0,46931	2,66141	3,42499

3.2 Grooteiland

Plot No.	Terrain morphology	Total depth	Effective depth	Depth A_1 hor	Contrast of mottles	Texture A_1 hor	Texture B_{21} hor	Clay A_1 hor	Clay B_{21} hor	Consistency A_1 hor	Consistency B_{21} hor	Structure A_1 hor
1	3	50	25	25	0	1	1	3	3	7	7	6
2	3	60	30	30	0	3	3	7	7	7	7	6
3	1	70	45	45	0	4	4	13	13	2	2	6
4	1	70	45	45	0	4	4	14	14	8	8	6
5	1	80	65	40	0	3	4	13	25	2	8	6
6	3	30	30	30	0	4	0	10	0	9	0	5
7	3	40	40	40	0	4	0	15	0	4	0	5
8	3	40	40	40	0	4	0	13	0	7	0	6
9	3	75	55	35	1	4	6	15	23	7	8	6
10	3	90	60	35	0	6	6	15	28	7	8	6
11	3	65	25	25	0	4	6	13	28	8	9	6
12	3	55	30	30	0	3	3	7	7	1	1	6
13	3	55	30	30	0	3	3	7	7	1	1	6
14	3	65	40	40	0	3	3	7	7	1	1	6
15	3	50	50	35	2	6	6	18	23	7	8	6
16	3	65	65	40	0	4	7	18	40	8	9	6
17	3	60	60	40	0	6	7	20	30	7	8	6
18	3	55	55	30	0	2	3	3	5	1	1	6
19	3	45	45	25	0	2	2	2	4	1	1	6
20	1	50	50	30	0	2	2	2	3	1	1	6
21	1	45	45	25	0	3	3	5	6	1	1	6
22	1	45	45	25	0	4	4	13	13	2	2	6
23	1	95	50	50	2	3	3	9	9	2	2	6
24	1	80	80	30	0	4	3	13	11	8	7	5
25	3	70	50	30	1	4	4	15	15	8	8	6
26	3	60	35	35	0	3	3	9	9	7	7	6
27	3	70	45	45	0	3	3	8	8	2	2	6
28	3	70	45	45	0	4	4	8	8	7	7	6
29	1	45	45	25	0	3	3	7	7	8	8	6
30	1	45	45	25	0	3	3	7	7	7	8	6
31	1	40	40	20	0	3	3	7	7	7	7	6
32	1	40	40	20	0	4	4	15	15	7	7	6
33	1	40	40	40	0	6	0	25	0	7	0	6
34*	1	90	30	30	0	3	4	10	20	7	7	6
Mean	2,17647	58,97059	44,70588	33,38235	0,17647	3,61765	3,35294	10,76471	11,82353	5,17647	4,73529	5,91176
Std. deviation	0,99911	16,50434	12,24381	7,95066	0,52052	1,12855	1,85672	5,37141	9,89481	2,92814	3,44048	0,28790

*Plot 34 was not part of the grid system and was not taken into account when drawing the factor diagram.

Plot No.	Structure B_{21} hor	Concretions (horizon)	Abundance of stones A_1 hor	Size of stones A_1 hor	Abundance of stones B_{21} hor	Size of stones B_{21} hor	Form of stones B_{21} hor	Abundance of roots B_{21} hor	Size of roots B_{21} hor	pH A_1 hor	Org. matter A_{11} hor (%)	Radiation index
1	6	0	3	3	3	5	1	1	1	4,6	18,45	27,15
2	6	0	2	3	3	5	1	0	0	3,1	21,24	41,74
3	6	0	0	0	3	5	1	0	0	3,3	14,42	47,81
4	6	0	0	0	0	0	0	0	0	3,7	9,88	44,81
5	6	0	0	0	0	0	0	2	1	3,9	11,77	44,81
6	0	0	0	0	0	0	0	0	0	3,5	8,37	30,07
7	0	0	0	0	0	0	0	0	0	3,7	21,26	41,03
8	6	0	0	0	0	0	0	0	0	3,4	17,34	41,03
9	6	0	0	0	0	0	0	2	1	3,9	11,69	41,03
10	6	0	0	0	0	0	0	2	1	4,1	8,77	44,81
11	5	2	0	0	0	0	0	0	0	3,8	9,14	44,81
12	6	0	2	3	3	3	1	0	0	4,3	29,54	44,81
13	6	0	2	3	3	3	1	0	0	4,1	14,14	44,81
14	6	0	2	3	3	3	1	0	0	4,1	14,88	44,81
15	6	0	0	0	0	0	0	2	1	4,1	14,17	44,81
16	3	0	0	0	0	0	0	2	1	4,4	10,32	44,81
17	3	2	0	0	0	0	0	2	1	4,5	9,53	44,81
18	6	0	3	2	3	4	1	2	1	3,9	11,52	46,88
19	6	0	3	2	3	4	1	2	1	5,3	38,63	46,88
20	6	0	3	2	3	4	1	2	1	3,6	10,62	44,81
21	6	0	3	3	3	4	1	2	1	3,9	18,18	46,88
22	6	0	0	0	3	5	1	2	1	4,5	13,36	44,81
23	5	2	3	3	0	0	0	0	0	4,3	12,93	49,37
24	6	0	0	0	3	3	1	1	1	4,4	9,09	49,37
25	5	2	0	0	0	0	0	1	1	4,4	12,64	46,88
26	6	0	0	0	3	5	1	0	0	4,0	18,93	44,30
27	6	0	3	3	3	5	1	0	0	4,1	13,62	46,88
28	6	0	0	0	3	5	1	0	0	3,8	11,27	44,81
29	6	0	2	2	3	5	1	2	1	4,0	13,98	46,88
30	6	0	0	0	3	5	1	2	1	4,0	14,52	46,88
31	6	0	0	0	3	5	1	2	1	4,1	12,78	46,88
32	6	0	0	0	3	5	1	2	1	4,8	7,53	49,37
33	0	0	0	0	0	0	0	0	0	4,4	6,16	53,64
34*	5	2	2	3	0	0	0	1	1	4,5	6,08	51,66
Mean	5,00000	0,29412	0,97059	1,67647	1,02941	2,44118	0,55882	1,00000	0,55882	4,07353	14,02206	44,76882
Std. deviation	2,00000	0,71898	1,29065	1,51198	1,35926	2,28554	0,50399	0,95346	0,50399	0,44402	6,49229	4,93346

*Plot 34 was not part of the grid system and was not taken into account when drawing the factor diagram.

3.3 Dirk se Eiland

3.3.1 Sampling area on western boundary

Plot No.	Terrain morphology	Total depth	Effective depth	Depth A_1 hor	Contrast of mottles	Texture A_1 hor	Texture B_{21} hor	Clay A_1 hor	Clay B_{21} hor	Consistency A_1 hor	Consistency B_{21} hor
1	3	25	25	25	0	2	0	5	0	1	0
2	3	50	50	50	0	3	0	5	0	1	0
3	3	45	45	45	0	3	0	10	0	2	0
4	3	25	25	25	0	2	0	4	0	1	0
5	3	35	35	35	0	2	0	4	0	1	0
6	3	40	40	40	0	3	0	7	0	1	0
7	3	40	40	40	0	3	0	7	0	1	0
8	3	40	40	40	0	3	0	7	0	1	0
9	3	35	35	35	0	4	0	14	0	2	0
10	3	25	25	25	0	3	0	9	0	2	0
11	3	90	70	30	0	2	3	7	10	1	2
12	3	55	35	25	0	2	3	5	7	1	1
13	3	75	55	25	0	3	3	5	5	1	2
14	1	55	55	25	0	1	3	3	8	1	1
15	1	105	60	45	2	3	3	5	5	6	7
16	1	85	50	30	2	3	3	5	6	6	7
17	1	105	75	30	0	1	3	4	8	1	2
18	1	75	50	30	0	1	3	5	7	1	2
19	1	100	75	30	0	3	3	7	7	1	2
20	3	65	65	40	0	3	4	7	16	1	6
21	3	55	55	40	0	3	3	8	8	1	2
22	3	50	50	50	0	3	0	5	0	1	0
23	3	75	75	45	0	3	4	4	8	1	2
24	3	85	60	35	0	3	3	7	7	7	7
25	3	85	75	45	0	3	6	7	20	8	9
26	3	55	55	45	0	3	3	9	9	1	2
27	3	45	45	45	0	3	0	5	0	1	0
28	3	35	35	35	0	3	0	9	0	1	0
29	5	65	65	45	2	3	4	9	14	6	7
30	4	65	65	40	2	3	4	5	13	2	7
31	3	60	60	40	1	2	3	3	7	1	7
32	3	45	45	45	0	3	0	7	0	7	0
33	3	50	50	45	2	5	6	18	25	7	8
Mean	2,72727	58,78788	51,06061	37,12121	0,33333	2,72727	2,03030	6,69697	5,75758	2,33333	2,51515
Std. deviation	0,91079	23,01597	14,88275	8,10385	0,73598	0,80128	1,91188	3,06681	6,42276	2,35407	3,06310

Plot No.	Structure A_1 hor	Structure B_{21} hor	Concretions (horizon)	Abundance of stones A_1 hor	Size of stones A_1 hor	Form of stones A_1 hor	Abundance of stones B_{21} hor	Size of stones B_{21} hor	Form of stones B_{21} hor	Abundance of roots A_1 hor	Abundance of roots B_{21} hor	Size of roots B_{21} hor	pH A_1 hor	Org.matter A_{11} hor	Radiation index
1	4	0	0	0	0	0	0	0	0	3	0	0	6,1	12,65	53,38
2	6	0	0	0	0	0	0	0	0	3	0	0	4,8	8,90	56,42
3	6	0	0	0	0	0	0	0	0	3	0	0	3,9	10,38	56,42
4	4	0	0	0	0	0	0	0	0	3	0	0	4,2	19,43	55,38
5	4	0	0	0	0	0	0	0	0	3	0	0	4,2	9,41	53,38
6	6	0	0	0	0	0	0	0	0	3	0	0	4,1	8,49	53,64
7	6	0	0	0	0	0	0	0	0	3	0	0	4,7	12,57	55,24
8	6	0	0	0	0	0	0	0	0	3	0	0	5,0	9,38	56,70
9	6	0	0	0	0	0	0	0	0	3	0	0	3,4	14,36	56,70
10	6	0	0	0	0	0	0	0	0	2	0	0	4,0	9,95	56,70
11	6	6	0	0	0	0	0	0	0	2	2	1	4,6	5,50	54,45
12	4	6	0	0	0	0	0	0	0	2	2	1	4,1	6,19	54,45
13	4	6	0	0	0	0	0	0	0	2	2	1	4,2	5,15	53,64
14	4	6	0	0	0	0	0	0	0	3	2	1	3,8	18,39	51,66
15	6	6	0	0	0	0	0	0	0	3	2	1	3,5	14,12	51,66
16	6	6	0	0	0	0	2	1	1	3	2	1	4,0	7,35	51,66
17	4	6	0	0	0	0	0	0	0	2	2	1	3,9	6,48	51,66
18	4	6	0	0	0	0	0	0	0	2	1	1	3,1	5,65	51,66
19	4	6	0	0	0	0	0	0	0	2	2	1	4,0	6,48	51,66
20	5	6	2	0	0	0	0	0	0	3	2	1	4,2	7,45	46,88
21	6	6	2	0	0	0	0	0	0	3	2	1	5,0	7,89	49,37
22	4	0	0	0	0	0	0	0	0	3	0	0	5,1	9,34	46,88
23	6	6	0	0	0	0	0	0	0	3	2	1	4,4	14,05	44,51
24	6	6	0	0	0	0	0	0	0	3	2	1	3,8	9,22	44,51
25	6	6	0	0	0	0	0	0	0	3	2	1	3,9	9,30	46,88
26	6	6	2	0	0	0	0	0	0	3	2	1	4,1	6,89	46,88
27	4	0	0	0	0	0	0	0	0	3	0	0	4,0	12,32	49,37
28	6	0	0	0	0	0	0	0	0	3	0	0	4,5	6,70	51,35
29	6	6	0	0	0	0	0	0	0	3	2	1	5,0	8,28	51,35
30	6	6	0	0	0	0	0	0	0	3	2	1	4,1	19.07	44,51
31	6	6	2	0	0	0	0	0	0	3	2	1	3,7	12,10	46,88
32	6	0	0	0	0	0	0	0	0	3	0	0	3,8	13,04	49,37
33	5	6	0	0	0	0	0	0	0	3	2	1	4,2	9,58	46,88
Mean	5,30303	3,45455	0,24242	0,00000	0,00000	0,00000	0,06061	0,03030	0,03030	2,78788	1,09091	5,57576	4,26667	10,03182	51,69636
Std. deviation	0,95147	3,01134	0,66287	0,00000	0,00000	0,00000	0,34816	0,17408	0,17408	0,41515	0,97991	0,50189	0,54524	3,56501	4,28281

3.3.2 Dirk se Eiland - sampling area on south-eastern boundary*

Plot No.	Terrain morphology	Total depth	Effective depth	Depth A_1 hor	Contrast of mottles	Texture A_1 hor	Texture B_{21} hor	Clay A_1 hor	Clay B_{21} hor	Consistency A_1 hor	Consistency B_{21} hor	Structure A_1 hor	Structure B_{21} hor
1	3	60	60	30	0	2	2	3	3	1	1	6	6
2	3	55	55	30	0	2	2	3	3	1	1	6	6
3	3	45	54	20	0	2	2	3	3	2	2	6	6
4	3	65	65	35	0	3	3	3	7	2	2	6	6
5	3	65	65	35	0	2	2	5	5	1	1	6	6
6	1	70	70	40	0	3	3	7	7	2	2	6	6
7	1	35	35	20	0	2	5	4	20	7	9	6	3
8	3	60	60	30	0	2	3	3	7	1	1	6	6
9	1	75	75	45	0	2	2	4	4	1	1	6	6
10	3	50	50	25	0	1	1	3	3	1	1	4	4
Mean	2,40000	58,00000	58,00000	31,00000	0,00000	2,10000	2,50000	3,80000	6,20000	1,90000	2,10000	5,80000	5,50000
Std. deviation	0,96609	12,06464	12,06464	8,09664	0,00000	0,56765	1,08012	1,31656	5,15967	1,85293	2,46982	0,63246	1,08012

*This data matrix was combined with the one for the western boundary for the analysis.

Plot No.	Concretions	Abundance of stones A_1 hor	Size of stones A_1 hor	Form of stones A_1 hor	Abundance of stones B_{21} hor	Size of stones B_{21} hor	Form of stones B_{21} hor	Abundance of roots A_1 hor	Abundance of roots B_{21} hor	Size of roots B_{21} hor	pH A_1 hor	Org. matter A_{11} hor	Radiation index
1	0	2	3	1	3	5	1	3	1	1	4,9	36,72	30,07
2	0	3	4	1	3	5	1	3	1	1	4,5	47,37	22,39
3	0	3	4	1	3	5	1	3	1	1	3,4	18,50	24,70
4	2	0	0	0	0	0	0	3	2	1	4,6	9,59	27,15
5	0	0	0	0	3	5	1	3	1	1	3,9	11,21	41,03
6	0	0	0	0	3	5	1	3	1	1	4,5	7,76	49,37
7	0	0	0	0	0	0	0	3	2	1	5,2	41,73	37,20
8	0	1	4	1	0	0	0	3	2	1	4,0	27,33	41,74
9	0	1	1	1	0	0	0	3	1	1	3,7	18,63	49,37
10	0	1	2	1	0	0	0	3	1	1	4,6	10,45	55,24
Mean	0,20000	1,10000	1,80000	0,60000	1,50000	2,50000	0,50000	3,00000	1,30000	1,00000	4,33000	22,92900	37,82600
Std. deviation	0,63246	1,19722	1,81353	0,51640	1,58114	2,63523	0,52705	0,00000	0,48305	0,00000	0,56184	14,52808	11,45254

3.4 Ysternek Fynbos Reserve

Plot No.	Terrain morphology	Total depth	Effective depth	Depth A_1 hor	Texture A_1 hor	Texture B_{21} hor	Clay A_1 hor	Clay B_{21} hor	Consistency A_1 hor	Consistency B_{21} hor	Structure A_1 hor	Abundance of stones A_1 hor
1	3	55	55	30	3	3	5	5	1	1	6	2
2	3	75	75	45	6	6	23	23	2	2	6	2
3	3	90	90	55	5	7	18	30	2	2	6	0
4	1	50	50	30	3	3	5	5	2	2	6	0
5	3	45	45	25	3	3	4	4	1	1	6	3
6	3	45	45	25	1	1	4	4	1	1	6	3
7	3	45	45	25	4	4	10	10	2	2	6	3
8	3	60	60	40	3	3	7	7	2	2	6	2
9	1	80	80	65	4	4	20	25	2	2	6	0
10	1	45	45	25	2	2	5	5	1	1	6	2
11	3	45	45	25	1	1	3	3	1	1	4	3
12	3	45	45	25	4	4	11	11	2	2	6	1
13	3	65	65	40	4	4	14	14	2	2	6	1
14	3	40	40	40	3	0	7	0	2	0	6	0
15	1	60	60	35	1	3	7	7	2	2	6	0
16	3	45	45	25	3	3	7	7	2	2	6	0
17	3	45	45	25	2	2	4	4	1	1	6	2
Mean	2,52941	55,00000	55,00000	34,11765	3,17647	3,11765	9,05882	9,64706	1,64706	1,52941	5,88235	1,41176
Std. deviation	0,87447	14,68417	14,68417	12,02020	1,28624	1,72780	6,13871	8,54337	0.49259	0,62426	0,48507	1,22774

Plot No.	Size of stones A_1 hor	Abundance of stones B_{21} hor	Size of stones B_{21} hor	Abundance of roots B_{21} hor	pH A_1 hor	Org. Matter A_1 hor	Radiation index
1	4	3	5	2	5,6	31,93	33,50
2	3	3	4	2	3,7	25,49	37,20
3	0	0	0	1	3,7	22,16	37,20
4	0	3	3	1	3,5	28,70	51,58
5	3	3	4	1	3,8	16,73	60,39
6	3	3	4	1	4,1	17,39	60,39
7	2	3	4	2	4,3	19,34	30,07
8	3	3	5	2	3,5	23,11	27,15
9	0	0	0	1	3,2	16,73	44,81
10	3	3	4	1	3,3	37,39	51,58
11	3	3	4	1	3,3	11,04	57,21
12	3	3	4	2	3,5	15,81	33,50
13	2	3	4	2	3,5	21,04	33,50
14	0	0	0	0	4,0	30,56	33,50
15	0	3	4	1	3,3	29,53	46,88
16	0	3	4	1	3,5	19,05	57,64
17	3	3	4	1	3,8	21,22	57,76
Mean	1,88235	2,47059	3,35294	1,29412	3,74118	22,77765	44,34471
Std. deviation	1,49509	1,17886	1,65609	0,58787	0,56685	6,91928	11,78040

Appendix 4

Rotated factor matrices from factor analysis

4.1 Kleineiland

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality
Terrain morphology	-.04310	.12931	.89669	-.24976	-.15401	-.00509	-.22725	.96040
Total depth	.02320	.07863	.71364	.40152	-.24708	-.12421	-.23204	.80754
Effective depth	.10355	-.25030	.49222	.48669	-.20523	-.28581	.11224	.68893
Depth of A_1 horizon	.14406	-.15513	-.11410	.80051	.07657	.05047	-.16906	.73565
Contrast of mottles	.05677	.86752	-.07881	-.09191	-.19711	.09558	-.08964	.82650
Texture A_1 horizon	.89323	.09037	.03990	.00208	-.03370	.06717	-.07560	.81899
Texture B_{21} horizon	.85819	.07606	.02796	.22580	.13535	-.13107	-.09205	.83801
Clay A_1 horizon	.86980	.07291	-.16631	-.14716	-.09500	.01251	-.01899	.82072
Clay B_{21} horizon	.86935	.10922	.00798	.24676	.07921	-.23696	.08431	.89819
Consistency A_1 horizon	.03432	-.20547	-.25776	.17923	.80877	-.11437	-.10212	.81958
Consistency B_{21} horizon	.05049	-.42883	.07119	.05461	.50586	-.53012	.01758	.73172
Structure B_{21} horizon	-.04493	.17285	-.08036	-.24879	.02577	.68511	.19772	.60938
Concretions (horizon)	.18391	.35750	.16166	.23572	-.22719	.11085	.28554	.38877
Abundance of roots in A_1 horizon	-.42084	-.00852	.51763	-.05807	.44988	.13267	.18040	.70102
Size of roots in A_1 hor.	-.10650	-.19739	.25782	.15722	.00165	.76192	.03448	.72321
Abundance of roots in B_{21} horizon	-.09429	-.06220	-.20322	.01565	.19080	.14621	.77456	.71203
Size of roots in B_{21} hor.	-.01528	-.22528	-.11459	.01401	.61330	.08589	.22541	.49864
pH A_1 horizon	-.50302	-.08664	-.12341	.07108	.25466	-.08256	-.38061	.49735
Organic matter in A_{11} hor.	.00103	-.19001	-.02391	.65589	.13718	-.09358	.16391	.52130
Radiation index	-.03179	.10868	-.66627	.10036	.06293	-.37345	-.07967	.61658
Common variance accounted for	27,9%	23,1%	17,5%	11,0%	8,1%	7,1%	5,3%	

4.2 Grooteiland

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Communality
Terrain morphology	.03374	.06026	.07067	-.14806	-.17009	-.71407	-.03201	-.05458	.57451
Total depth	.15922	.23779	.59973	-.19359	-.24065	.24807	.01552	.29105	.58345
Effective depth	-.23313	.11938	.21961	-.07452	.28042	.23231	.01438	.63497	.65839
Depth of A_1 horizon	-.07264	.15674	.06719	-.30597	-.59176	.02814	.08988	.42863	.67075
Contrast of mottles	-.00840	.91993	.08949	-.16983	.00527	-.01113	.09193	.06888	.89654
Texture A_1 horizon	-.71260	.07340	.08543	-.41358	-.08359	.09200	.32941	.13541	.82621
Texture B_{21} horizon	-.16095	.12916	.83621	-.12851	.28253	-.09240	.20863	.08343	.89753
Clay A_1 horizon	-.71755	.08855	.08657	-.52298	-.06475	.12081	.26335	.08324	.89879
Clay B_{21} horizon	-.29113	.02652	.80454	-.32043	.20277	-.03967	.11742	.16490	.91909
Consistency A_1 horizon	-.57819	.01625	.09394	-.34019	-.02612	.02982	-.45789	-.23264	.72448
Consistency B_{21} horizon	-.29078	.13122	.83490	.01070	.21525	.08193	-.14028	-.07152	.87679
Structure A_1 horizon	.22048	.09579	.40894	.19043	.05772	.02485	.42386	-.09472	.45386
Structure B_{21} horizon	.31372	.12295	.50418	.58860	.16859	.11882	.08630	.06529	.76844
Concretions (hor.)	.10044	.28324	.34021	-.46755	-.02993	.20032	.07972	-.28183	.55147
Abundance of stones in hor.	.95607	.02484	-.10935	.13769	.05601	-.02532	.09066	.00291	.95761
Size of stones in A_1 horizon	.93993	-.00339	-.02477	.10191	-.09840	-.03325	.13517	-.12349	.93880
Abundance of stones in B_{21} hor.	.31104	-.24044	-.12741	.89394	.06175	.03798	.08226	-.04687	.98414
Size of stones in B_{21} horizon	.21416	-.22267	-.08626	.90688	.06784	.06721	.02000	-.13264	.95244
Form of stones in B_{21} horizon	.31104	-.24044	-.12741	.89394	.06175	.03798	.08226	-.04687	.98414
Abundance of roots in B_{21} hor.	-.06106	.02688	.19659	.10449	.92035	.06943	.05051	.23574	.96401
Size of roots in B_{21} horizon	-.00039	.06895	.22458	.04743	.93654	.15592	-.06807	.14165	.98356
pH A_1 horizon	.11466	.06521	.08986	-.04875	.48793	.05052	.35065	-.10650	.40278
Organic matter in A_{11} hor.	.34529	.01750	-.26529	.28392	.03359	-.45062	.13780	-.04604	.49127
Radiation index	-.01105	.04893	.14711	.00306	.05733	.54387	.50239	.12199	.59052
Common variance accounted for	36,4%	20,2%	14,4%	8,0%	6,4%	6,1%	3,8%	3,5%	

4.3 Dirk se Eiland

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality
Terrain morphology	.68200	-.21680	.25733	.04413	-.29059	.23197	.12837	.73502
Total depth	.96324	.11966	-.04831	.03613	.03613	-.12368	.02718	.96340
Effective depth	.98890	.00733	.03313	-.00580	.01818	-.06105	.08698	.99074
Depth of A_1 horizon	.29915	-.22687	-.20771	.24939	-.10392	.47411	.41899	.65743
Contrast of mottles	-.00663	.23910	-.07560	.91726	.01261	.20270	-.09408	.95440
Texture A_1 horizon	-.07622	-.11583	-.23568	.19443	-.02237	.81969	.15864	.81014
Texture B_{21} horizon	-.06439	.95466	-.00047	.15049	-.02132	.17031	-.01147	.96777
Clay A_1 horizon	-.25043	-.05709	-.31329	.07517	-.08984	.70288	-.03549	.67314
Clay B_{21} horizon	.73105	.55573	.01370	.08741	-.13890	.23225	-.01128	.92447
Consistency A_1 horizon	-.21615	.33259	-.00246	.10818	-.02276	.65069	-.34354	.71098
Consistency B_{21} horizon	.05480	.87836	-.00715	.26610	-.03014	.24273	-.10999	.91731
Structure A_1 horizon	-.66506	.13801	.13913	.13415	.16588	.44861	.17442	.75789
Structure B_{21} horizon	-.11686	.87948	.09587	.11535	.25023	-.21779	.16617	.94731
Concretions (horizon)	-.06963	.26288	-.10518	-.00948	-.11387	.00187	.78854	.71988
Abundance of stones in A_1 hor.	-.07491	.01595	.84998	-.07329	.39578	-.13384	-.01041	.90837
Size of stones in A_1 horizon	-.08267	.03637	.89247	-.07629	.27359	-.16881	-.00584	.91386
Form of stones in A_1 horizon	-.09538	.02545	.87096	-.07476	.19733	-.22933	.01571	.86569
Abundance of stones in B_{21} hor.	-.05740	.05661	.31706	-.00991	.93679	-.03254	-.05284	.98855
Size of stones in B_{21} hor.	-.05536	.04957	.34551	-.05698	.91944	-.02497	-.03678	.97550
Form of stones in B_{21} hor.	-.05872	.06376	.27809	.04510	.93976	-.04077	-.07057	.97668
Abundance of root in A_1 hor.	-.78213	-.04609	.19069	.15789	.08073	.29076	.18285	.79964
Abundance of roots in B_{21} hor.	.07344	.93718	-.01858	.17561	-.06972	-.10500	.13203	.94820
Size of roots in B_{21} horizon	-.12549	.91641	.14434	.10490	.19319	-.19462	.09531	.97168
pH of A_1 horizon	-.75616	-.01667	.01179	-.03646	-.08276	.02799	.00274	.58116
Organic matter in A_{11} horizon	.10076	.06669	.75618	-.01746	.13932	-.00203	-.14898	.62832
Radiation index	.96709	-.18037	-.07434	.00126	-.08728	-.06279	-.00556	.98493
Common variance accounted for	28,5%	22,7%	22,4%	10,3%	6,0%	5,8%	4,4%	

4.4 Ysternek Fynbos Reserve

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Terrain morphology	-.04997	-.14198	.63605	.26268	-.29819	58513
Total depth	.94868	.04926	-.15097	.05245	.06195	.93180
Effective depth	.94868	.04926	-.15097	.05245	.06195	.93180
Depth of A_1 horizon	.83192	-.31570	-.26924	.09473	.06057	.87689
Texture A_1 horizon	.69648	.03369	-.02362	.58580	.17523	.86065
Texture B_{21} horizon	.79891	.34726	-.02239	.33463	.05024	.87385
Clay A_1 horizon	.85528	-.03342	-.07606	.35736	-.03813	.86757
Clay B_{21} horizon	.96137	.07011	-.12215	.16261	-.09591	.97971
Consistency A_1 horizon	.32662	-.06823	-.47985	.79982	.01734	.99921
Consistency B_{21} horizon	.46552	.65452	-.34992	.46165	-.12468	.99621
Structure A_1 horizon	.18925	.06688	-.11409	.24533	.54977	.41574
Abundance of stones in A_1 horizon	-.24973	.24862	.76375	-.25457	-.25466	.83714
Size of stones in A_1 horizon	-.17873	.31630	.88017	-.17222	-.02962	.93723
Abundance of stones in B_{21} horizon	-.53036	.76374	.30264	.03815	-.01159	.95776
Size of stones in B_{21} horizon	-.47431	.71422	.44532	.05331	.04077	.93789
Abundance of roots in B_{21} horizon	.24375	.61319	.52689	.47973	.05353	.94603
pH of A_1 horizon	-.09503	-.11486	.55025	.03398	.35448	.45181
Organic matter in A_{11} horizon	-.09972	-.09538	-.10299	-.02463	.84607	.74608
Radiation index	-.34158	.16790	-.26042	-.67929	-.29718	.76243
Coomon variance accounted for	44,9%	27,8%	12,0%	9,3%	6,0%	

Appendix 5

Chemical and physical soil analyses. (All results are expressed in terms of the air-dried sample passed through a 2 mm sieve).

Plot No & horizon	Vegetation	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	S-Value m.e./100g clay	Al (ppm)	E.A.* (m.e.)	Ca/Mg	Al/EA	Ca/Al	pH		Organic		Texture		
													(H_2O)	($CaCl_2$)	matter (%)	carbon (%)	% sand	% silt	% clay
Kleineiland																			
1 A1	forest	5	58	686	189	134	74,55	208	3,70	4,69	56,22	4,26	4,2	3,7	10,4	6,0	63	28	9
B21		11	47	130	107	493	18,05	364	2,05	1,21	177,56	0,36	4,5	3,8			57	22	21
6 A1	fynbos	5	52	391	171	68	63,17	260	2,64	2,29	98,48	1,50	4,4	3,8	6,0	3,5	64	30	6
E		13	36	151	95	55	14,31	230	1,36	1,59	169,12	0,66	4,9	4,0			61	26	13
B21		5	35	202	139	103	12,81	169	1,61	1,45	104,97	1,22	4,9	4,0			58	21	21
7 A1	forest	9											3,9	3,5	8,9	5,2			
B21		5											4,5	3,7					
B22													4,4	3,9					
13 A1	fynbos	10											4,4	3,5	6,3	3,7			
B21		21											4,8	3,9					
14 A1	forest	13	103	861	210	89	74,22	115	1,81	4,10	63,54	7,49	4,6	4,0	7,3	4,2	62	29	9
B21		16	63	133	122	76	9,35	370	1,95	1,09	189,74	0,36	4,4	3,7			50	27	23
19 A1	fynbos	8	36	250	149	59	35,38	333	0,31	1,68	1074,19	0,75	4,5	3,7	5,7	3,3	61	31	8
B21		9	18	126	75	48	10,07	169	0,21	1,68	804,76	0,75	4,9	4,1			57	28	15
22 A1	forest	7											4,7	4,2	5,3	3,1			
E		6											4,5	3,6					
B21		10											4,3	3,6					
27 A1	fynbos	15											4,4	3,5	6,8	3,9			
B21		8											4,8	3,8					
Grooteiland																			
1 A1	forest	8	129	1135	228	103	138,67	64	1,10	4,98	58,18	17,73	4,4	4,0	10,4	6,0	74	20	6
B21		11	30	98	57	49	9,62	236	2,97	1,72	79,46	0,42	4,4	3,5			76	11	13
5 A1	fynbos	12	41	394	167	104	29,92	285	4,05	2,36	70,37	1,38	3,8	3,2	8,9	5,2	58	29	13
B21		6	22	111	47	49	7,56	292	3,76	2,36	77,66	0,38	4,5	3,7			56	28	15
10 A1	fynbos	7											4,2	3,2	8,6	5,0			
B21		5											4,5	3,8					
12 A1	forest	10	44	252	126	50	20,23	227	3,07	2,00	73,94	1,11	4,1	3,5	8,6	5,0	61	26	13
B21		14	21	98	59	63	5,91	249	3,27	1,66	76,15	0,39	4,6	3,9			53	25	22
17 A1	fynbos	6	43	257	179	96	18,22	333	4,50	1,44	74,00	0,77	4,4	3,7	5,9	3,4	53	29	18
B21		7	25	159	154	67	6,51	398	5,48	1,03	72,63	0,40	4,7	3,9			46	17	37
19 A1	forest	5	101	995	190	112	364,00	39	1,23	5,24	31,71	25,51	3,7	3,3	11,6	6,7	72	26	2
E		6	302	101	133	190	15,19	419	5,77	0,76	72,62	0,24	3,8	3,3					
B21		5						42	1,17		35,90		4,3	3,9			57	22	21
21 A1	fynbos	4											3,9	3,6	12,0	7,0			
23 A1	fynbos	7											4,1	3,7	7,4	4,3	52	31	17
B21		4											4,5	3,8			52	20	28
C			23	171	198	112	5,41	436	6,19	0,86	70,44	0,39	4,5	3,8			41	3	56
24 A1	fynbos	9											4,2	3,5	5,2	3,0			
B21		4											4,6	3,8					
31 A1	fynbos	9											3,9	3,2	6,6	3,8			
B21		5											4,6	3,7					

*E.A. = exchangeable acidity

The values encircled were regarded as outliers and not used in the analyses of variance (Table 6).

Plot No & horizon	Vegetation	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	S-value m.e./100g clay	Al (ppm)	E.A.* (m.e.)	Ca/Mg	Al/E.A.	Ca/Al	pH		Organic		Texture		
													(H_2O)	($CaCl_2$)	matter (%)	carbon (%)	% sand	% silt	% clay
Dirk se Eiland																			
13 A_1	fynbos	16	46	277	137	357	46,44	183	2,90	2,02	63,10	1,51	4,0	3,4	5,8	3,4	63	29	9
B_{21}		5	31	88	52	106	9,40	130	1,83	1,69	71,04	0,68	5,0	4,2			62	23	15
B_{22}		10											5,3	4,5					
15 A_1	forest	5	91	475	144	58	50,50	135	2,31	3,30	58,44	3,52	4,0	3,7	7,7	4,5	70	23	8
E		7	47	99	66	70	12,08	320	4,48	1,50	71,43	0,31	4,2	3,5			67	21	12
16 A_1	fynbos	4											4,9	4,2	5,7	3,3			
B_{21}		4											4,8	4,1					
19 A_1	fynbos	5											4,5	3,2	7,0	4,1			
B_{21}		7											4,9	4,2					
22 A_1	forest	7											4,7	4,3	6,3	3,7			
B_{21}		5											4,3	3,8					
26 A_1	fynbos	3											3,8	3,4	7,1	4,1			
B_{21}		4											4,9	4,0					
28 A_1	forest	8	80	513	169	53	18,25	279	3,97	3,04	70,28	1,84	4,5	3,9	5,2	3,0	59	17	24
B_{21}		5	71	141	114	79	6,00	412	5,71	1,24	72,15	0,34	4,3	3,9			53	11	36
32 A_1	fynbos	5	49	191	157	61	16,50	279	4,20	1,22	66,43	0,68	4,1	3,4	6,6	3,8	57	27	16
B_{21}		7	24	99	52	34	3,65	237	3,77	1,90	62,86	0,42	4,8	3,9			51	18	31
44 A_1	fynbos	9											5,0	4,4	3,4	2,0			
B_{21}		3											5,4	4,7					
45 A_1	fynbos	7	71	251	177	77	32,20	160	2,43	1,42	65,84	1,57	3,8	3,2	7,0	4,1	66	25	10
B_{21}		3	24	97	66	36	7,75	157	2,26	1,47	69,47	0,62	5,1	4,1			63	22	16
46 A_1	fynbos	2											4,4	3,6	6,8	3,9			
E		3											5,1	4,1					
47 A_1	fynbos	7	87	460	123	58	42,00	306	4,78	3,74	64,02	1,50	4,1	3,3	6,0	3,5	69	22	9
B_{21}		3	25	142	86	44	11,93	132	2,10	1,65	62,86	1,08	5,1	4,1			64	22	14
48 A_1	fynbos	4	41	461	152	43	42,67	135	2,30	3,03	58,70	3,41	5,0	4,1	2,4	1,4	73	18	9
B_{21}		4	24	235	120	36	15,87	34	0,52	1,96	65,38	6,91	5,4	4,6			67	18	15
B_{22}		3											5,3	4,6			65	19	16
Forest Creek Concession Area																			
1 A_1	forest	10	138	343	122	62		204	3,12	2,81	65,38	1,68	4,0	3,3	7,2	4,2			
B_{21}		5	24	91	33	38		185	2,91	2,76	63,57	0,49	4,5	4,0					
2 A_1	forest	15											3,5	2,9	11,7	6,8			
3 A_1	fynbos	8											3,6	2,8	7,4	4,3			
4 A_1	fynbos	15											3,4	2,8	11,6	6,7			
5 A_1	fynbos	7	64	126	174	58		177	3,09	0,72	57,28	0,71	3,6	3,1	7,1	4,1			
B_{21}		4	31	88	38	39		216	3,11	2,32	69,45	0,41	4,4	4,0					
6 A_1	fynbos	16											3,3	2,8	10,4	6,0			
Rateltbos Island																			
1 A_1	forest	13	257	848	113	64	55,45	179	2,87	7,50	62,37	4,74	3,9	3,5	11,3	6,6	66	23	11
B_{21}		3	59	91	31	56	4,07	310	4,84	2,94	64,05	0,29	4,0	3,7			57	16	27
2 A_1	forest	4											3,7	3,2	4,3	2,5			
B_{21}		4											4,2	3,7					
3 A_1	fynbos	3											3,4	3,1	4,0	2,3			
B_{21}		2											4,1	3,6					
4 A_1	fynbos	3											3,9	3,6	10,9	6,3			
B_{21}		3											4,5	3,9					
5 A_1	fynbos	2	64	125	92	47	10,88	297	4,48	1,36	66,29	0,42	4,0	3,4	5,8	3,4	59	25	16
E_{21}		13	40	90	28	37	9,4	176	2,60	3,21	67,69	0,51	4,7	4,3			62	28	10

*E.A. = exchangeable acidity
The values encircled were regarded as outliers and not used in the analyses of variance (Table 6).