The Butterflies of the Gemsbok National Park in Botswana (Lepidoptera - Rhopalocera)

Introduction

The purpose of this paper is to give an up-dated list of the butterflies known to occur in the Gemsbok National Park in the Republic of Botswana, including the Mabuasehube Game Reserve and the Nosop Valley between Gemsbok and Bokspits. All records from the Kalahari Gemsbok National Park in the Republic of South Africa have also been included. The ecology of the two areas is similar, and have for long been managed as one unit, the border is not fenced, and migratory access for ungulates is maintained. Very little has been published on any insect groups in Botswana and the paper is meant to be a contribution towards the gradual building up of an inventory of all organisms found in the Botswana National Parks.

The Gemsbok National Park lies in the extreme southwest of Botswana and is adjoined by the Kalahari Gemsbok National Park in the Republic of South Africa. The South African park was established as far back as 1931, and in 1936 the government of the then Bechuanaland Protectorate agreed to gazette a 40km wide belt along the Nosop River and to place this under joint administration by the South African Parks authorities. In 1966 the area covered in Botswana was increased fourfold, to link up with the Mabuasehube Game Reserve, and was formally designated as a national park. At the moment this vast area is accessible to the public only along the Nosop River where a road winds its way along the unfenced border, occasionally on the Botswana and occasionally on the South African side. Eventually a road connection through the area between Mabuasehube and the Nosop will be opened.

The setting

The whole of the area consists of the type of Kalahari sands which stretch from the Orange River in South Africa north to Angola and southern Zaire, and east to the rock formations of eastern Botswana. There is a considerable variation as one moves from the southwest of the park towards the east and northeast. The vegetation consists of low savannah formations, classified as arid shrub savannah by Weare & Yalala (1971), though more open grasslands and large pans also occur. Typically the vegetation cover is too dense for new dunes to form. In the south west average rainfall is 250 mm, varying from virtually nothing to more than 500 mm in exceptional years. Trees are mainly found in the fossil river beds, the dune country consisting mainly of low shrubs and grasses.

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The Kalahari is often referred to as a desert, but though surface water is absent it cannot be classified as such since rainfall is too high and plant cover too dense to meet the normal criteria for a desert.

As might be expected in such an arid area, which is relatively far south, temperature variations both seasonally and daily are extreme. The fauna and the flora are certainly considerably influenced by the fact that winter frost of some severity (as low as -15 Centigrade) is not unusual at night. At Tsabong, just to the east of the area, there are 22 days of ground frost and 10 days of air frost in each of the months of June and July.

In the south west the dominant trees and shrubs are the Grey Camel Thorn (*Acacia haematoxylon*), the large shade-giving Camel Thorn *Acacia erioloba* (=giraffae), the Shepherd's Tree (*Boscia albitrunca*), and the characteristic shrub *Rhigozum trichotomum*. Most of the plants of the south west are also found further north, but plant diversity in general is much lower towards the south and is especially low in sandy dune country. Along the Nosop River on calcrete ridges and scarps a special, low-growing, flora which includes succulents such as *Aloe hereroensis* and *Ruschia* (unidentified, new to Botswana) is found. This flora begins to show affinities to the South African Karoo, allowing also a few Karoo butterflies to maintain a foothold.

Towards the northeastern part of the area, trees become more plentiful and the plant cover in general more luxuriant, falling within the southern Kalahari bush savannah of Weare and Yalala (1971). Rainfall is somewhat higher and considerably more predictable than in the south west. *Acacia mellifera*, *A. hebeclada*, *Dichrostachys cinerea*, *Zizyphus mucronata*, and various *Grewia* are much in evidence.

**The butterfly fauna**

The butterfly fauna of an area with such an extreme climate cannot be expected to be very large. Of a total of 250 species in Botswana, only 41 are found. Most butterflies are poorly equipped to cope with low and erratic rainfall. Many of the tropical species which are drought resistant cannot cope with frosts. The composition of the total butterfly fauna, and some discussion of its determinants will be dealt with towards the end of this paper.

The butterflies of the area have been very poorly studied. The only previous paper, dealing with the lower part of the Nosop valley, was based on a brief visit (February, 11-20, 1958) (van Son 1959). Other occasional data are included in a book on the butterflies of southern Africa (Pennington 1978). As part of research for a book on the butterflies of Botswana I briefly visited both the lower Nosop River and Mabuasehube in February 1991, which gave the impetus to consolidate all data on the butterflies of the area.

In addition to species which have been recorded with certainty, I have added (with an asterisk) a limited number of species which seem almost certain to occur given their
distribution in the northern Cape Province of South Africa, Namibia and Botswana. That some surprising discoveries still lie in wait cannot be entirely discounted, but they are not likely to be many. Further discoveries, if any, will probably be associated with calcrete ridges and scarps.

Systematic list

PAPILIONOIDEA
PAPILIONIDAE
Papilioninae

Papilio demodocus demodocus  Esper, 1798

The Citrus Swallowtail (Christmas Butterfly or Orange Dog) is very common at times in the lower part of the Nosop Valley and possibly elsewhere if the larval food plant is present. As the name indicates the larvae usually feed on cultivated Citrus (Rutaceae) in southern Africa, and may reach pest proportions. I have found it as far into the Kalahari as Kang. In the Nosop Valley the food plant is Pituranthos (Deveria) aphyllus; larvae feeding on this Apiaceae plant, and on Foeniculum vulgare in South Africa, have a variegated colour pattern in brown and yellow, instead of the usual green (see Clarke et al. 1963). This form is only found from the Cape to Gemsbok, though a similar one occurs in the Dhofar province of Oman in Arabia. The stability of the larval colour pattern indicates genetic isolation from the migratory population further east. The species is found in all of tropical Africa, Madagascar and Mauritius, as well as southwestern Arabia.

PIERIDAE
Coliadinae

Catopsilia florella  Fabricius, 1793

The African Emigrant is a well known migrant butterfly which sometimes breeds in large numbers in the park, but it is not always present. A large-scale migratory movement began at Mabuasehube on 1st March 1991, and was eventually found to cover most of Botswana, and to involve at least 1.5 billion individuals (Larsen 1992a). Males often gather in large numbers at the boreholes along the Nosop and Molopo Rivers. The larval food plants are normally wild and cultivated species of Cassia (Leguminosae). Pointing out that no Cassia is available in the Nosop Valley, van Son (1959) thought the likely larval food plant was Rhigozum (Bignoniaceae), but this cannot be so. Though I have seen no previous references, I have determined that in the Kalahari, and the Nosop Valley, as well as elsewhere in Botswana, the most common food plant is the ground creeper Cassia italica (Leguminosae), which in years of good rain grows in profusion. I am quite certain they do not feed on Rhigozum, but they often climb up on this plant to pupate. This is a common butterfly throughout Africa and the Indian subcontinent, extending to the Canary Islands, the
eastern Mediterranean, and Arabia.

**Colias electo electo** Linne, 1763

The African Clouded Yellow is a migrant butterfly of temperate origin which occurs irregularly and sporadically in southern Botswana. I saw a single specimen in the Nosop Valley, where van Son (1959) also noted a few. The larval food plants are mainly Leguminosae, especially lucerne, vetches, and clovers. *C. electo* is found in the mountains of southwestern Arabia, the highlands of eastern Africa, the highlands of Cameroun, and isolated mountains of south-central Africa. In southern Africa it descends to low levels.

**Eurema brigitta brigitta** Stoll, 1870

The Small Grass Yellow is a very widespread species, probably with some migratory potential, therefore being somewhat erratic in frequency. It was found to be very common in the Nosop Valley by van Son (1959) in February, while I did not see it at all. I also found it at Mabuasehube and it probably occurs all over the area. The larval food plants are *Hypericum aethiopicum* (Hypericaceae), species of *Cassia*, and many other genera of Leguminosae. The range covers all of tropical Africa as well as most of the Oriental region.

**Pierinae**

**Pierini**

**Pinacopteryx eriphia eriphia** Godart, 1819

The Zebra White is a common dry-zone butterfly which is widespread. I saw it both on the Nosop and at Mabuasehube, though it was not common. The larvae will feed on most genera of Capparaceae, probably mostly *Boscia albitrunca* in the area in question. The range covers most of the drier parts of the Afrotropical Region, as well as southern Arabia. A distinct subspecies flies on Madagascar.

**Colotis regina** Trimen, 1863

The Queen or Regal Purple Tip, a large member of the genus, has not yet been recorded from the area, but I have seen it in Tsabong and 50km south of Tshane, so it should occur in the eastern parts of Gemsbok and at Mabuasehube. The larval food plants are mainly *Boscia albitrunca* (Capparaceae), at least in the Kalahari. The range is from southern Africa to southern Kenya.

**Colotis evenina evenina** Wallengren 1857

The Orange Tip is a very light member of the genus which has been recorded from both the Nosop area and from Mabuasehube. The very light form *lericheri* van Son, 1959 was named after the le Riche family, so closely associated with the Gemsbok Park; it is not characteristic of the population, since males which I saw at Nosop were
typical. Probably the species occurs all over the park, where the larval food plant is probably mainly *Boscia albitrunca* (Capparaceae). The range stretches from Ethiopia to Kenya, Uganda, south eastern Zaire, and southern Africa (excluding Natal and Zululand).

**Colotis euippe omphale** Godart, 1819

I was extremely surprised to find a single male specimen of the Round-Winged Orange Tip 10km north of Bokspits where the area seems much too dry for it. I have found it nowhere else in the inner Kalahari, though it is common where rainfall exceeds 500 mm a year. Larvae have been recorded on *Capparis, Maerua* and *Boscia* (Capparaceae). *C. Euippe* is found in most of Africa, as well as in south western Arabia, tending to avoid the driest tracts.

**Colotis lais** Butler, 1876

I saw a few specimens of the Kalahari Orange Tip at water in Mabuasehube, but it is probably widespread in the area, though there are no records from the Nosop Valley. There are no records of the early stages either but I have often found the species in places where the only potential food plant is *Boscia albitrunca*. The range is effectively limited to the southern half of the Kalahari, with weak extensions into neighbouring areas. A single female of *Colotis pallene* Hopffer (1855) was recorded from Gemsbok, but this is probably a misidentification for the present species.

**Colotis evagore antigone** Boisduval, 1836

There are no records of the Tiny Orange Tip from the area, but it seems certain to occur in the eastern parts of Gemsbok and at Mabuasehube, since it is common in Kang and Hukuntsi. The recorded larval food plants are *Capparis, Cadaba*, and *Maerua* (Capparaceae), but *Boscia albitrunca* is almost certainly used as well. The range covers practically all the drier parts of tropical Africa, northern Africa, and parts of Spain, as well as south western Arabia. It is the only member of the genus to reach the Palaearctic area in North Africa and southern Spain.

**Colotis agoye bowkeri** Trimen, 1883

The Kalahari Sulphur Tip is common all over the area, and in the Nosop Valley I saw many of both sexes at water. Ssp. *bowkeri* is so distinctive that I considered raising it to specific rank until I found intermediates between this and the nominate subspecies near Letlhakeng (Larsen, 1992b). The larval host plant is invariably *Boscia albitrunca* (Capparaceae) on which the green larva, with a yellow dorsal line and yellow lateral lines just below the spiracles, is very well camouflaged. The larva is taller than it is wide and somewhat keel-shaped, aiding camouflage by resembling the *Boscia* leaves. Ssp *agoye* is found in northern Transvaal, and in eastern and northern Botswana. In the central Kalahari, Namibia, Namaqualand, and northern Cape Province all populations are of ssp. *bowkeri*. Ssp. *zephyrus* Marshall, 1897 occurs in a very disjunct
population in Somalia and south eastern Ethiopia.

**Colotis subfasciatus subfasciatus** Swainson, 1823

I saw small numbers of the handsome Lemon Traveller at Mabuasehube; it is an occasional migrant, so I would expect it to occur also further south. The larval food plants are *Boscia albitrunca* (Capparaceae). The range covers most of southern Africa, but the species is particularly common in Botswana.

**Colotis eris eris** Klug, 1832

The only records of the Banded Gold Tip from the area are a few which I saw at Mabuasehube, but it is probably widespread at the right time of the year, though it may not extend to the Nosop. It is occasionally drawn into large migratory movements of other species. In Botswana the usual larval food plant is *Boscia albitrunca* (Capparaceae). The range covers most of the dry zone of tropical Africa and southern Arabia.

**Belenois aurora** Fabricius, 1793

The Caper White is a strongly migratory butterfly, with an ability to build up large populations, and it may be very common in the park. It is strongly attracted to mud puddles together with *Catopsilia florella*. It breeds on *Boscia albitrunca* (Capparaceae) and may occasionally entirely strip the trees of foliage. The range covers most of dry, tropical Africa, Madagascar, Arabia and the Indian subcontinent. Invasions of the eastern Mediterranean occur at irregular intervals.

**Pontia helice helice** Linne, 1764

The Meadow White is widespread in southern Africa and is shown from the Gemsbok area by Migdoll (1988), but I have not seen definite records. However, the species is migratory and I have met with it elsewhere in the Kalahari, where it is certainly not resident. The larval food plants are many species of Cruciferae and Resedaceae. The nominate subspecies is from southern Africa, with a distinct subspecies in the mountains of eastern Africa. The genus is Palaearctic.

**LYCAENIDAE**

**Theclinae**

*Spindasis natalensis* Westwood, 1851

The Natal Silverline occurs commonly at Kang and Tsabong and should occur at least in the eastern part of the area. The larvae have been found on *Mundulea* and *Vigna* (Leguminosae), *Canthium* (Rubiaceae) and *Clerodendrum* (Verbenaceae); they are usually associated with *Crematogaster* ants. The range covers the area from the Cape to Tanzania, but its exact limits and relationship with *S. nyassae* Butler, 1884, are not wholly clear.
Spindasis phanes Trimen, 1873

The Silvery Silverline was seen at water in Gemsbok, from where it was also recorded by Pennington (1978), as well as in the valley between Bokspits and the park gate. It probably occurs sporadically throughout the area. The larva has been found on Ximenia (Olacaceae), attended by crematogaster ants (Henning 1983). The species is found in a band across southern Africa, not penetrating far into the Cape Province, nor much north of Botswana.

Argyraspodes argyraspis Trimen, 1873

The Warrior Copper has been collected at Gemsbok and I found it also in the Molopo Valley, but it is scarce and local. It is sometimes attracted to water. Material from Gemsbok was named as form labuchagnet van Son, 1959; it is lighter than the nominate form. My Molopo specimens match this form as well and it may deserve subspecific status. The early stages appear to be unknown. The species is limited to the Cape Province, Namaqualand, parts of Orange Free State, Namibia and south western Botswana, a karoo type distribution.

Phasis sardonyx Trimen, 1868

The King Copper has been recorded from Gemsbok, but it seems to be local and scarce, and I did not see it. It will probably be associated with calccrete scarps. The early stages are apparently unknown, but the first instar larva is illustrated by Clark & Dickson (1971). The range is limited to the Cape Province, parts of the Orange Free State, Namaqualand, southern Namibia and south western Botswana - a karoo type distribution.

Aloeides simplex Trimen, 1893

The Kalahari Copper is found throughout the area, but it is much more local than A. damarensis, though not necessarily uncommon. The early stages are unknown. The species is limited to the northern Cape Province, parts of Namibia and the Kalahari.

Aloeides damarensis damarensis Trimen, 1891

The Damara Copper occurs throughout the area, often in considerable numbers. It sometimes visits water. Like other members of the genus it spends much of its time sitting on the bare ground. The larval food plants are Aspalathus (Leguminosae) as is usual in the genus. This is a widely distributed butterfly, stretching from Namaqualand and the Cape provinces through most of southern Africa to southern Angola, southern Zambia, Zimbabwe, and southern Mozambique. The smaller A. molomo krooni Tite & Dickson, 1973 may also occur. I have taken it near Tsabong.
Iolaus bowkeri subinfuscata Grunberg, 1910

Bowker's Marbled Sapphire occurs in both the Nosop Valley and ten kilometres north of Bokspits. Ssp. subinfuscata is sometimes treated as a valid species. Single specimens are usually seen flying about inside thorn trees, often settling on bare twigs. The larvae feed on parasitic mistletoes (Loranthaceae) and the range covers all of Africa.

Polyommatinae

Anthene talboti Stempffer, 1936

Talbot's Ciliate Blue has been recorded from the junction of the Aoub and the Nosop by Pennington (1978). I failed to find it in the area and it is generally uncommon in Botswana. The larvae feed on Acacia (Leguminosae). The range covers most arid parts of eastern and southern Africa.

Lampides boeticus Linne, 1767

The Pea Blue is a migratory pest species which occurs sporadically in the area. It is not common in Botswana. The larval food plants comprise a large number of Leguminosae; cultivated peas and beans are particularly attractive and the Pea Blue can reach pest proportions, especially as it normally feeds inside the pods. The species is found throughout the Old World tropics, penetrating temperate Asia and the Mediterranean, migrating north to Germany and the United Kingdom.

Leptotes pirithous Linne, 1767

The Common Zebra Blue is shown from the Nosop River on the map in Migdoll (1988) though I did not see it. However, though avoiding extremely arid areas it is likely that it does occur, especially in the east, not least since it is migratory. I have found it common in Kang. The generic names Syntarucus and Cyclyrius should not be used for the genus (Larsen 1991b).

Zizeeria knysna Trimen, 1862

I found a few specimens of the African Grass Blue 20 kilometres N of Bokspits and at the Mabuasehube Pan, but it is not usually common in such arid habitats. It is often associated with harder ground than the Kalahari sands, such as the edges of pans and calcrete formations. The larval food plants are extremely varied, including several Leguminosae, but in the Kalahari the main host seems to be Tribulus terrestris (Zygophyllaceae). It occurs throughout tropical Africa, in south western Arabia, as well as in Morocco and Algeria.
Zizula hylax Fabricius, 1775

The Tiny Grass Blue is generally scarce in the inner Kalahari and I was very surprised to see a single female in the Nosop Valley. The food plants are very varied, and in Africa include especially Acanthaceae (Phaulopsis, Ruellia, Justicia, Chaetacantha, Dyschoriste) and Tribulus (Zygophyllaceae), as well as Oxalis (Oxalidaceae). The species is common throughout Africa, southern Arabia, the Oriental Region and Australasia.

*Azanus* ubaldus Cramer, 1872

There are no records of the Desert Babul Blue from the area, but it is certain to occur in Mabuasehube, and should be found also in the south west. The larval food plants are species of Acacia (Leguminosae); I have found it on Acacia nilotica in Gaborone. The range covers all of Africa, Arabia, and the Indian sub-continent.

Azanus jesous Guerin-Meneville, 1847

I saw the African Babul Blue in small numbers at Mabuasehube, but there are no records from the extreme south-west. The larvae feed on many genera of the Leguminosae, especially Acacia (sometimes Entada, Dischrostachys and even Medicago). The range covers all of Africa, Arabia, and the Indian sub-continent, as well as the eastern Mediterranean. On Madagascar it is replaced by A. sitalces, Mabille, 1899.

Freyeria trochylus trochylus Freyer, 1845

The tiny Grass Jewel is very common throughout the Kalahari and occurs everywhere in the area, often coming to water. The normal food plants are Indigofera (Leguminosae) and Heliotropium (Boraginaceae), but others may be used on occasion. The species is found in most of Africa and Arabia, as well as in India, scattered parts of Asia, and northern Australia. In addition to the tropical range, the species occurs in most of the Middle East and in Greece, thus being one of the very few butterflies to be at home in both the tropics and the Palaearctic.

Brephidium metophis Wallengren, 1860

The Dwarf, or Tingtinkie, Blue was recorded by van Son (1959) from the junction of the Aoub and the Nosop; I failed to find it in the area. It is usually local, but may be very common where it occurs. It is one of the smallest butterflies in the world. It is found in most of southern Africa.
NYMPHALIDAE
Danainae

_Danaus chrysippus chrysippus_ Linne, 1758

Common Tiger, or African Monarch, is common in the area and found everywhere. I saw large numbers coming to water in the Nosop area and counted up to 50 specimens on piles of gemsbok excrement. The larvae feed on practically all genera of the Asclepiadaceae and Periplocaceae, with some questionable records from other plant families (e.g. _Ipomoea_ (Convolvulaceae)). I found them on _Gomphocarpus rostratus_ in the Nosop Valley. The distribution is vast, covering most of Asia, parts of Australia, Arabia, and parts of the Middle East, as well as all of Africa. During the 1980s the species established itself in Spain, but I suspect that a cool winter might one day eradicate the species as a resident of the Mediterranean, except for Egypt, Sinai and the Dead Sea area (Larsen 1986).

_Nymphalinae_

_Hyposimnas misippus_ Linne, 1764

The Diadem, or Danaid Eggfly, is a migrant whose presence in the area is probably not permanent. 1991 was an exceptionally good year for the species in Botswana and I found it between Bokspits and the Park gate as well as at Mabuasehube. The female is a splendid mimic of _Danaus chrysippus_. Many families of host plants have been recorded, with _Portulaca oleracea_ (Portulacaceae) and several genera of Acanthaceae (_Asystasia, Justicia, Blepharis, Ruellia, Pseuderantheum_) as favourites. The species is found all over Asia and Africa, and was possibly introduced to the Caribbean area with the slave trade.

_Junonia hierta cebren_ Trimen, 1870

The Yellow Pansy is one of the most common butterflies all over Botswana and occurs everywhere in the park. The larval food plants are many different Acanthaceae (_Asystasia, Isoglossa, Justicia, Paulownilhelmia, Ruellia_); I have found it on _Justicia flava_ and _Ruellia patula_ in Gaborone. The species is common in most of the drier parts of Africa and in Arabia; its migratory habits on occasion brings it to Egypt, the Sinai and Lebanon, but it is not able to survive winter so far north. Nominate ssp. _hierta_ Fabricius 1798 occurs in the Indian sub-continent.

_Vanessa cardui cardui_ Linne, 1758

The Painted Lady is a notorious migrant and its numbers in Botswana vary considerably. It is sometimes common in the area. The larval food plants are exceptionally varied, with thistles (Asteraceae), nettles (Urticaceae) and mallows (Malvaceae) as favourites. Occasionally even Leguminosae are used. The illustrated life history is given by van Son (1979), who lists the following food plants: _Arctotis_,
Artemisia, Argyrolobium, Berkheva, Carduus, Dimorphotheca, Gazania, Gnaphalium, Filago, Cirsium, Lappa, Madia, Venidium (Asteraceae, Anchusa, Echium (Boraginaceae), Urtica, Boehmeria (Urticaceae); Malva (Malvaceae); Lupinus and Phaseolus (Leguminoseae). Many more are known from other parts of the world. The species is cosmopolitan, though scarce or absent from most of South America.

Acraeinae
The Acraeas

Acraea axina Westwood, 1881

The Little Acraea was recorded from the Gemsbok Park by Pinhey (1968-1974) but I failed to find it in the area. It is found sporadically throughout the Kalahari, but never seems to be very numerous. I have seen no records of the early stages. The species is found in most of South Africa, Zimbabwe, Botswana and Namibia.

Acraea stenoea Wallengren, 1860

The Suffused Acraea is a dry zone species that is not usually all that common. It should occur in most parts of the area; I saw it 25 kilometres north of Bokspits and at Mabuasehube. The early stages appear to be unknown. The range covers most of Namibia, Botswana and parts of southern Africa, usually not east of the Transvaal.

Acraea neobule neobule Doubleday, 1847

The Wandering Donkey probably occurs throughout the area. It found it both in the Nosop Valley and at Mabuasehube, though van Son (1959) does not mention it. It was very common in the Molopo Valley. The larval food plants are mainly Passifloraceae (especially Adenia and Passiflora), but also Hybanthus (Violaceae). This is one of the most common and widespread African butterflies, absent only from virgin forest. It is found in southern Arabia as well.

HESPERIOIDEA
HESPERIIDAE
Pyrginae

Leucochitonea levubu Wallengren, 1857

The distinctive White Cloaked Skipper was seen by me at Mabuasehube and is widely distributed in the central Kalahari. How far it extends into the area I do not know. Usually only two or three specimens are met within any one spot. The larval food plants are Grewia (Tiliaceae). The range covers most of southern Africa.

Spialia diomus ferax Wallengren, 1863

The Diomus Grizzled Skipper is found throughout the area. In the Nosop Valley I
saw large numbers on a pile of leopard or cheetah dung. Water is avidly visited. The host plants are *Hibiscus, Sida, Pavonia* (Malvaceae), Waltheria and *Hermannia* (Sterculiaceae). The range covers most of tropical Africa and south-western Arabia.

**Spialia mafa mafa** Triman, 1870

I saw a single Mafa Grizzled Skipper, attracted to human excrement, in the Nosop Valley. Since the species is tolerant of arid conditions it is probably found throughout the area. The host plants are *Hibiscus, Pavonia* and probably other Malvaceae, as well as *Hermannia* (Sterculiaceae). The range is from southern Africa to Sudan and southern Arabia.

**Discussion**

It has already been mentioned that the climatic conditions of the area are such that they pose severe problems for butterfly survival. Drought, unpredictability of rainfall, and frost combine to limit the numbers. Several larval food plants which are present in the Central Kalahari are absent. This list covers 41 species and relatively few additional records remain to be made, except perhaps in Mabuasehube. This compares with a Botswana total of about 250, many of which only occur in the extreme north-east, the Okavango and south to the Tswapong Hills.

The butterflies of the area show a diversity of biogeographical distribution patterns, but as shown in Table 1 there is a predominance of very wide ranging species, found throughout Africa and even beyond. These tend to be either very adaptable species and/or migratory. About a quarter of the species are limited to southern Africa, or stretch from southern Africa to Somalia, Ethiopia and Arabia.

Six species are essentially centred on the Kalahari, not being found far from the sands. Two are species of the karoo, reaching their norther distribution limits in the area. Finally two species are derived from a contact with the temperate Palaeartic Region; in Africa they are only found in southern Africa and in the East African highlands.
TABLE 1

Biogeographical categories of the butterflies in Gemsbok National Park

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<thead>
<tr>
<th>Biographical Category</th>
<th>Number of species</th>
<th>Percent</th>
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<tbody>
<tr>
<td>1 Cosmopolitan</td>
<td>1</td>
<td>2</td>
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<tr>
<td>2 Palaeotropical</td>
<td>11</td>
<td>27</td>
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<tr>
<td>3 Pan-African</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>4 South/East African</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>5 South African</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>6 Kalahari centred</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>7 Karoo centred</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>8 Temperate</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>41</strong></td>
<td><strong>100</strong></td>
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</tbody>
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Source: Appendix to this paper

Migration plays an important part in defining the constitution of the butterfly fauna. Five species probably only occur because of migration. A further ten are regular migrants; they probably survive in good years, but frequently become extinct. A further eight are occasional migrants. Thus, 56% of the species are well documented migrants, and only 44% non-migratory. This pattern matches that of other arid zones, such as the arid parts of Arabia and lower Egypt, where about half the butterflies are migratory (Larsen 1976).
TABLE 2

The extent to which the butterflies of Gemsbok National Park are migratory

<table>
<thead>
<tr>
<th>Category</th>
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<tbody>
<tr>
<td>*** Strong migrants</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>** Regular migrants</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>* Occasional migrants</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>- Non-migrants</td>
<td>18</td>
<td>44</td>
</tr>
<tr>
<td>TOTAL</td>
<td>41</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Appendix to this paper

Essentially butterflies can survive in arid zones either through feeding on plants which retain leaves and moisture during dry seasons, through carefully tuned diapause mechanisms, through making themselves independent of moisture, or through migration, that is being only transient members of the fauna. Combination of these strategies are also possible. Details are given in table 3, which calls for a few additional comments. The main water conserving host plant for butterflies in the area is Boscia albitrunca, but possibly some of the Lycaenidae could feed on Acacia erioloba. Some of the Lycaenidae live (or can live) in a commensal or predatory relationship with ants. In some cases larvae and pupae can spend very long periods in the ants' nests, awaiting suitable climatic conditions for further breeding. Finally, many resident species probably become extinct from all or parts of the area from time to time, which is where the migratory capacity becomes important. However, at least six of the species are regular visitors which cannot survive permanently.
TABLE 3

Survival strategies of the butterflies in Gemsbok National Park

<table>
<thead>
<tr>
<th>Survival Strategy</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Water conserving larval host plants</td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td>b Precise diapause mechanisms</td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>c Diapause and relationship with ants</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>d Combination of host plants and migration</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>e Migration, not permanent residents</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>41</td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Source: Appendix to this paper

Conclusion

The butterfly fauna of the Gemsbok National Park are strongly influenced by aridity, the unpredictability of rainfall, and the high incidence of winter frosts. The same factors also combine to ensure that potential larval host plants present in the Central Kalahari are not found in the area. Compared to the fauna of the Central Kalahari (e.g. Kang) there is a gradual falling off in species numbers, with the gain of only two species that are centred on the Karoo.

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Acknowledgements

My personal visit to the Gemsbok Park and to Mabuasehube were financed by a grant from the Danish Carlsberg Foundation for which I am most grateful. These visits were part of a project directed towards publishing a book on the Butterflies of Botswana and their Natural History under a research permit kindly issued by the Office of the President, Gaborone. The collaboration of the National Museum, Monuments and Art Gallery, Botswana has greatly aided the project. I am indebted to Dr. Bruce Hargreaves of the Natural History Section of the Museum for botanical advice. My wife, Nancy Fee, provided support and company in the field, as on so many other occasions.

Appendix

Some characteristics of the butterflies of the Gemsbok National Park (for symbols see the relevant tables in the text).

<table>
<thead>
<tr>
<th>Species</th>
<th>Migratory Capacity</th>
<th>Biogeogr. category</th>
<th>Survival strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. demodocus</td>
<td>**</td>
<td>3</td>
<td>b</td>
</tr>
<tr>
<td>C. florella</td>
<td>***</td>
<td>2</td>
<td>e</td>
</tr>
<tr>
<td>C. electo</td>
<td>**</td>
<td>8</td>
<td>e</td>
</tr>
<tr>
<td>E. brigitta</td>
<td>**</td>
<td>2</td>
<td>b</td>
</tr>
<tr>
<td>P. eriphia</td>
<td>*</td>
<td>3</td>
<td>a</td>
</tr>
<tr>
<td>C. regina</td>
<td>*</td>
<td>4</td>
<td>a</td>
</tr>
<tr>
<td>C. evenina</td>
<td>*</td>
<td>3</td>
<td>a</td>
</tr>
<tr>
<td>C. equippe</td>
<td>*</td>
<td>3</td>
<td>a</td>
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197
<table>
<thead>
<tr>
<th>Species</th>
<th>Count</th>
<th>Code</th>
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<tbody>
<tr>
<td>C. lais</td>
<td>-</td>
<td>6 a</td>
</tr>
<tr>
<td>C. evagore</td>
<td>**</td>
<td>3 a</td>
</tr>
<tr>
<td>C. agoye</td>
<td>*</td>
<td>6 a</td>
</tr>
<tr>
<td>C. subfasciatus</td>
<td>*</td>
<td>6 a</td>
</tr>
<tr>
<td>C. eris</td>
<td>*</td>
<td>3 a</td>
</tr>
<tr>
<td>B. aurota</td>
<td>***</td>
<td>2 d</td>
</tr>
<tr>
<td>P. helice</td>
<td>**</td>
<td>8 e</td>
</tr>
<tr>
<td>S. natalensis</td>
<td>-</td>
<td>4 c</td>
</tr>
<tr>
<td>S. phanes</td>
<td>-</td>
<td>6 c</td>
</tr>
<tr>
<td>A. argyraspis</td>
<td>-</td>
<td>7 c</td>
</tr>
<tr>
<td>P. sardonyx</td>
<td>-</td>
<td>7 c</td>
</tr>
<tr>
<td>A. simplex</td>
<td>-</td>
<td>6 c</td>
</tr>
<tr>
<td>A. damarensis</td>
<td>-</td>
<td>5 c</td>
</tr>
<tr>
<td>I. bowkeri</td>
<td>-</td>
<td>4 b</td>
</tr>
<tr>
<td>A. talboti</td>
<td>-</td>
<td>4 b</td>
</tr>
<tr>
<td>L. boeticus</td>
<td>***</td>
<td>2 e</td>
</tr>
<tr>
<td>L. pirithous</td>
<td>**</td>
<td>3 d</td>
</tr>
<tr>
<td>Z. knysna</td>
<td>-</td>
<td>3 b</td>
</tr>
<tr>
<td>Z. hylax</td>
<td>-</td>
<td>2 b</td>
</tr>
<tr>
<td>A. ubaldus</td>
<td>**</td>
<td>2 d</td>
</tr>
<tr>
<td>A. jesous</td>
<td>**</td>
<td>2 d</td>
</tr>
<tr>
<td>F. trochylus</td>
<td>-</td>
<td>2 b</td>
</tr>
<tr>
<td>B. metophis</td>
<td>-</td>
<td>5 b</td>
</tr>
<tr>
<td>D. chrysippus</td>
<td>**</td>
<td>2 d</td>
</tr>
<tr>
<td>H. misippus</td>
<td>***</td>
<td>2 e</td>
</tr>
<tr>
<td>J. cebrene</td>
<td>**</td>
<td>2 d</td>
</tr>
<tr>
<td>V. cardui</td>
<td>***</td>
<td>1 e</td>
</tr>
<tr>
<td>A. axina</td>
<td>-</td>
<td>5 b</td>
</tr>
<tr>
<td>A. stenobea</td>
<td>-</td>
<td>6 b</td>
</tr>
</tbody>
</table>

198
### PLATE 1

<table>
<thead>
<tr>
<th></th>
<th>Common Name</th>
<th>Gender</th>
<th>Cat No.</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Papilio demodocus</em>, male</td>
<td></td>
<td>3</td>
<td>UPS</td>
</tr>
<tr>
<td>2</td>
<td><em>Catopsilia florella</em>, male</td>
<td></td>
<td>5</td>
<td>UPS</td>
</tr>
<tr>
<td>3</td>
<td><em>Catopsilia florella</em>, female</td>
<td></td>
<td>3</td>
<td>UPS</td>
</tr>
<tr>
<td>4</td>
<td><em>Colias electo</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>5</td>
<td><em>Eurema brigitta</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>6</td>
<td><em>Acraea axina</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>7</td>
<td><em>Acraea stenohea</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>8</td>
<td><em>Acraea neobule</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>9</td>
<td><em>Junonia hierta</em>, male</td>
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<td>UPS</td>
</tr>
<tr>
<td>10</td>
<td><em>Danaus chrysippus</em>, male</td>
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<td></td>
<td>UPS</td>
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<td>11</td>
<td><em>Hypolimnas misippus</em>, male</td>
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<tr>
<td>12</td>
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### PLATE 2

<table>
<thead>
<tr>
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<th>Description</th>
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</thead>
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<td>14</td>
<td><em>Pinacopteryx eriphia</em>, male</td>
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<td></td>
<td>UPS</td>
</tr>
<tr>
<td>15</td>
<td><em>Colotis regina</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>16</td>
<td><em>Colotis regina</em>, female</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>17</td>
<td><em>Colotis euippe</em>, male</td>
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</tr>
<tr>
<td>18</td>
<td><em>Colotis euippe</em>, female</td>
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<td>19</td>
<td><em>Colotis evenina</em>, male</td>
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<tr>
<td>20</td>
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<td>21</td>
<td><em>Colotis lais</em>, male</td>
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<td>22</td>
<td><em>Colotis lais</em>, female</td>
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<td>UPS</td>
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<tr>
<td>23</td>
<td><em>Colotis evagore</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>24</td>
<td><em>Colotis evagore</em>, female</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>25</td>
<td><em>Colotis agoye bowkeri</em>, male</td>
<td></td>
<td></td>
<td>UPS</td>
</tr>
<tr>
<td>26</td>
<td><em>Colotis agoye bowkeri</em>, female</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>27</td>
<td><em>Colotis subfasciatus</em>, male</td>
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<td></td>
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<td>28</td>
<td><em>Colotis subfasciatus</em>, female</td>
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<tr>
<td>29</td>
<td><em>Colotis eris</em>, male</td>
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<td>32</td>
<td><em>Belenois aurota</em>, male</td>
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<td>UNS</td>
</tr>
</tbody>
</table>
33  *Pontia helice*, male UNS
34  *Leuchochitonea levubu*, male UPS
35  *Spialia diomus*, male UPS
36  *Spialia mafa*, male UPS

**PLATE 3**

37  *Spindasis natalaensis*, male UPS
38  *Spindasis phanes*, male UPS
39  *Spindasis phanes*, male UNS
40  *Argyraspodes argyraspis*, male UNS
41  *Tylopaedia sardonyx*, male UPS
42  *Aloeides simplex*, male UPS
43  *Aloeides damarensis*, male UPS
44  *Iolaus bowkeri*, male UPS
45  *Anthene talboti*, male UPS
46  *Anthene talboti*, male UNS
47  *Lampides boeticus*, male UNS
48  *Lampides boeticus*, male UNS
49  *Leptotes piritous*, male UPS
50  *Leptotes piritous*, male UNS
51  *Zizeeria knysna*, male UPS
52  *Zizeeria knysna*, female UPS
53  *Zizeeria knysna*, male UNS
54  *Zizula hylax*, male UPS
55  *Zizula hylax*, male UNS
56  *Azanus ubaldus*, male UPS
57  *Azanus ubaldus*, male UNS
58  *Azanus jesous*, male UPS
59  *Azanus jesous*, male UNS
60  *Freyeria trochylus*, male UPS
61  *Freyeria trochylus*, male UNS
62  *Brephidium metophis*, female UNS
Introduction

Five years' work considering range change in Botswana culminated in the analysis of Landsat MSS imagery to assess how these changes varied between drought and post-drought conditions. Much of this work was promoted by Prof H J Cooke and developed as an extension of both his work and that of other colleagues (e.g. Cooke, 1983, 1985 and Arntzen and Veenendaal, 1986).

The period 1983 to 1988 coincided with the culmination of the last extensive drought (1981-89). During this time a number of factors were said to be exacerbating declines in rangeland conditions. These included:

- Cattle stocking rates above carrying capacity in the hardveld and sandveld;
- Borehole development into Kalahari ecosystems;
- Increased human pressure along routeways and roads throughout the country.

The present work considered methods to relate environmental changes observed on Landsat MSS imagery with statistical data collected from various Government Ministries to determine whether any feasible relationships might be established.

Background

Studies analysing the effects of rangeland degradation can only describe 'trends' if these took place over extended periods. A minimum of ten years has been recommended by the United Nations but longer terms are advisable, particularly in areas where little is known about the causes or consequences of change (Barry and Ford, 1977; Reining, 1978). A number of authors have assessed change over time using integrated image processing and Geographic Information Systems (e.g. Wood, 1990 and Falconer et al, 1990). Most published work emphasises the results rather than the problems encountered while undertaking such a project. Here, the problems are highlighted in an attempt to avoid the repetition of 'pitfalls' already encountered in the semi-arid environment of Botswana.

1 Faculty of Science, Northern Territory University, Australia, formerly a member of staff at the University of Botswana.
2 Dumfries, Scotland.
3 Vimar, New Delhi, India.
Study Area and Imagery Used

The study area occupied 11 000 km² of south-east Botswana as shown in Figure 1. This area is divided into the relatively productive hardveld and the eastern fringes of the Kalahari, referred to as the sandveld. The imagery used for this study is shown on Table 1, and is seen to span the period 1972-87, mostly in the wet season (December-March) with a final check made in September 1987. A number of problems are inherent in obtaining imagery over such a protracted period.

(a) The earlier dates shown covered the initial orbit of ERTS-1 (1972) and Landsat 3 (1982), whereas the later imagery involved an orbit change for Landsat 4 and 6. This meant that in the case of 1982, two images had to be bought to cover the area on the ground considered as the base year (1984).

(b) The sensors on board the four satellites were each calibrated differently so that pre-flight calibration values were necessary to include into the percent reflectance calculations required to make the data as comparable as possible (details of the relationships used in the calculations are available in Ringrose et al, 1990a and 1990b).

(c) The development of radiometrically comparable data was completed by geometric correction to the UTM grid, obtained using map coordinates with a final root mean square (RMS) error of 2.2.

(d) The data were:

(i) separated into hardveld and sandveld subscenes because the reflectance characteristics of the two areas were notably different;

(ii) gridded out into 10 x 10 km squares so that locations on the imagery could be lined up with ancillary statistical data from different Government Ministries.

The study considered changes in range conditions from 1972 to 1987. The earlier imagery (1972-82) represented a period of relatively good rainfall followed by a drought period, 1982-87.
Fig. 2  Ecoregions

Source:  Ringrose and Matheson (1987)
Fieldwork

Obviously the period when fieldwork data could be collected was logistically limited to the time when the authors were in Botswana, so no field data were available for 1972-82. Conditions during this time had to be inferred:

(a) From appropriate MSS imagery interpretations during later times (e.g. around water sources, etc.).

(b) By discussions with cattle owners and long-term University of Botswana personnel. A literature review was also conducted.

Fieldwork began in 1984 and was undertaken using the following techniques:

(a) The area was stratified, using a MSS colour composite print into zones (ecoregions) of homogeneous reflectance. A copy of the ecoregions was produced and their significance can be found in Ringrose and Matheson (1987), and is shown here as Figure 2.

(b) As many field sites as possible were located within the zones. Field site information obtained from 100 sites included the following data from within 80 x 80 transects:

(i) the continuous recording of tree and shrub cover (diameter);
(ii) nine estimates of dead and live herbaceous cover;
(iii) soil Munsell colour and erosion status;
(iv) presence of cattle or small stock.

The same field sites were checked in 1985, 1986 and finally in 1987 and characteristics such as species change and the development of erosion features were noted.

Classification and the Development of Indicators

Orbital changes and changes to the calibration of the sensor systems, although modified rigorously and tested in terms of four dimensional feature space similarity, still leave the user guessing the absolute meaning of pixel reflectance values over times when this is impossible to validate. One approach is to check the results of classification based on the year when field checks were undertaken (in this case 1984) against the nearest available air-photo data. Limited aerial photography was available for the years in question and was available for only part of the area during the dry season. Nonetheless photographs were used as a basis for comparison of the classified data to provide a basis for accuracy assessment.

Classification procedures were regarded as the most effective method of characterising the spectral response of the 1984 image using EASI-PACE software at SAC, Pretoria.
(a) The location of field sites (recorded on 1:50 000 map sheets) were found on the image and values within 3 x 3 pixel square were recorded and saved.

(b) Univariate statistical data were generated:
   (i) for the field site data base files - separated into hardveld and sandveld components; and
   (ii) a graphical representation of the data was generated in 2-dimensional features space (NIR/Red). Data clusters were allocated similar attributes to the results obtained from fieldwork.

(c) The above procedures were used for the establishment of training sites which had a known physical basis.

When the statistical nature of the training sites was considered reliable, the entire image (in hardveld and sandveld sub-areas) was classified using a maximum likelihood classifier with minimum distance resolution of ties in the case of pixels which could not otherwise be ascribed to a specific class.

These separate procedures resulted in sixteen classes being obtained for the hardveld data and eleven from the sandveld, as shown in simplified form on Tables 2 and 3. The expanded version of these Tables is available in Ringrose et al (1990a and b). Once established for 1984 the same training areas were applied to the other remaining dates comprising the data sets. The classification results were considered acceptable while the number of pixels that was not allocated to the nil category was less than 10%. This number was exceeded in the case of the sandveld 1986 and 1987 data, so these data sets were re-classified using the same procedures but later field data, i.e. new training class boundaries were generated.

**Change Analysis**

Classification analysis was conducted over the entire study area. A list of classes and the size of area for 260 hardveld grid squares and 70 sandveld grid squares over the five yearly data sets was printed out at SAC Johannesburg and transferred manually onto IBM-PCs at the University of Botswana for statistical analyses. Each class in each square was plotted over time to determine whether recognisable 'trends' could be discerned in known areas. For instance, it was known from the field data where areas of bush encroachment had increased or decreased or where areas of soil erosion were prevalent or where species depletion had taken place.

As a result of visual analysis of several hundred graphs a serious of classes were used individually or in groups and referred to as "Severity of Degradation Indicators" or SDIs. Two specific changes in SDIs were noted: firstly, those changes corresponding to the wet years (1972-1982); and secondly, those corresponding to the dry years.
Chosen SDIs for the hardveld comprising the following:

SDI 1 = changes in the amount of dense, green, actively growing vegetation (classes 2 and 15)

SDI 2 = changes in area of bush encroachment and vegetation and an increase in the area of dead trees and erosional phenomenon (classes 3 and 10)

SDIs

3 & 4 changes in area of moderate to sparse vegetation cover on red/brown soil (class 4) and red/yellow soil (classes 8 and 9)

SDI 5 = changes in area of sparse green herbaceous vegetation (class 12).

These changes in area were offset by increases in such characteristics as bare soil, exposed rock and to a lesser extent, urban growth. However, definitive trends for these specific characteristics could not be discerned (presumably because of class mixing over the years) by the classification techniques used.

Chosen SDIs for the sandveld comprised the following:

SDI 6 = changes in area of broadleaf and *Acacia* species on pinkish/grey soil on the edge of pans and in fossil valleys (class 5)

SDI 7 = changes in area of broadleaf dominant species on pale brown soil on interfluves between fossil valleys (class 7)

SDI 8 = changes in area of exposed soil, including cultivation in the fossil valleys and areas of wind erosion and deposition. Areas of dead trees were also included (class 11).

**Ancillary Data Collection and Multiple Regression Analysis**

A number of ancillary data bases were collected using the same grid format as that superimposed over the results of the classification analysis. This required drawing the grid onto the available 1:50 000 topographic maps to the same design as that superimposed over the data during the image analysis phase. Data were collected for the same years as the imagery (where possible) and included:

(a) Census data for human population trends (1971 and 1981 census data), gridded out using maps available from the Department of Town and Regional Planning).

(b) Cattle and smallstock data from the Ministry of Agriculture, Statistical Records Department, gridded out by assuming uniform distributions in agricultural districts.
Rainfall data from the Department of Meteorological Services. Data from a total of six stations were available throughout the area. Equidistant lines were drawn from these to the nearest grid squares and proportional estimates of rainfall made on the basis of relative proximity.

These data sets were chosen because increases or decreases in human population pressures, cattle and smallstock and/or climatic factors are often cited as reasons or causes for range degradation. It was believed that some light might be shed if changes in trends in SDIs (verified as being aspects of range degradation the field) could be related to the supposed reasons. Extensive discussions with statisticians at the University of Botswana suggested multiple regression analysis would be applicable for such data sets comprising, for instance, (for the hardveld) SDIs in 260 squares over years by human, cattle, smallstock and rainfall data. The statistical package SPSS was used to determine what the degree of correlation was between discrete data sets (independent variables) and the SDIs which were held as dependent variables. The nature of the relationships and significance of the results in terms of probabilities using the F-test are shown on Tables 3, 4 and 5.

Increases in dense, green vegetation were positively related to population distribution in 1971, to rainfall in 1986 and to cattle in 1987 in the northern hardveld. For the hardveld, SDIs 1 through 5 were run against the independent variables. The localised increases in rainfall in 1986 were followed in 1987 by increases in cattle, probably because of the renewed availability of browse and grass in 1986. SDI 2 was correlated with the highest number of variables. SDI 2 was negatively correlated with rainfall in 1972 suggesting that as rainfall increases, the areas of dead trees, bush encroachment and/or erosional features decreased. In the early stages of drought these areas were positively correlated with rainfall. A second negative correlation with rainfall took place in 1986 which was a slightly wetter year. Throughout most of the drought years, SDI 2 was positively related to the distribution of smallstock and negatively related to cattle data. Therefore, during the drought years, increases in the number of smallstock were accompanied by increases in dead trees, bush encroachment and/or erosional phenomena. Simultaneously, the number of cattle decreased as a result of the drought.

SDIs 3 and 4 represented changes in area of moderate to sparse vegetation cover. In the earlier stages of the drought SDI 4 was negatively related to smallstock distributions. As the drought progressed negative relationships developed with livestock distributions suggesting that cattle were contributing to the decrease in available browse. SDI 5 (the area of sparse green herbaceous cover) was most positively correlated with smallstock data, and less positively correlated with cattle and rainfall data. It appeared that in the areas of remaining herbaceous cover the distribution of cattle and smallstock was concentrated.

Similar trends were noted in the southern portion of the hardveld, Table 8b. SDI 1 was positively correlated with rainfall in 1982. Positive correlations existed throughout the drought years between SDI 2 and cattle distribution data. This suggested some relationship between larger number of cattle and, in this case, areas of dead trees, bush
encroachment and/or erosional phenomena. SDIs 3 and 4 were positively related to smallstock distributions in the pre-drought (rainy) period. During the drought, negative relationships developed with livestock distributions especially in the case of SDI 4. This again suggested that as livestock numbers increased, the area of moderate to sparse vegetation cover decreased, thereby decreasing the amount of available browse. SDI 5 throughout the drought was negatively correlated with the distribution of smallstock. This suggested that as smallstock numbers increased, the areas of remaining herbaceous cover decreased. Also as rainfall increased slightly in 1986, SDI 5 (changes in areas of green herbaceous cover) decreased. Although additional herbaceous cover was available, it seemed that livestock consumption at this time was in excess of herbaceous cover production.

Multiple regression analyses on the same controlling variables were run against SDIs 6, 7 and 8 for the sandveld portion of the study area. In 1982 decreases in rain were accompanied by increases in SDI 7 (sparse vegetation in interfluve areas) which suggested that the vegetation was either adapting to drought or was maybe partially overgrazed, as areas of sparse vegetation were becoming more apparent. For the same reason increases in rainfall in 1986 were accompanied by decreases in sparse vegetation in the interfluves. Peripheral to pans and fossil valleys (SDI 6) where the bush was initially less dense, increases in rainfall were accompanied by increases in moderate to sparse vegetation. This may have been facilitated by the out-migration of people from these areas as the drought intensified. The 1982, 1986 and 1987 results showed that smallstock numbers increased during the drought, as did areas of sparse vegetation. This increase was accompanied by a decrease in the number of cattle. It therefore appeared that smallstock thrived relatively on the available drought adapted vegetation, while cattle numbers declined.

The decreases in rainfall in 1983 and 1984 were accompanied by an increase in SDI 8, which combined areas of cultivation, dead trees and wind erosion and deposition features. As noted in the fieldwork, more areas were cleared for cultivation as the drought progressed. Results of 1987 showed that increases in smallstock contributed to the increase of SDI 8, suggesting that smallstock caused trampling and the development of erosional features.

With respect to the geographical location of SDIs and the relative severity of degradation in the hardveld and sandveld, the following are considered significant relative to Figure 2. In the hardveld post-drought regeneration is relatively slow, especially on eroded soils. Species depletion and bush encroachment pose extensive range problems.

(a) Degraded areas occurred patchily in between 30-50% of hardveld ecosystem 1, with an emphasis on soil erosion and bush encroachment.

(b) Ecosystems 2 and 3 were more densely vegetated and comprised elements of bush encroachment.

(c) Degraded areas occurred in scanty locations in ecosystem 4. These areas are
mainly controlled by watering source and settlement location over 10-20% of the area.

(d) Ecosystem 5 was less degraded but vulnerable as the rocky soils have a decreased regenerative capability. Mostly the area was subject to woody cover thinning particularly adjacent to access roads.

In the sandveld apparent post-drought regeneration was comparatively rapid as the sandy soils were less eroded and contained a high proportion of seeds (or rhizomes). Relative species depletion requires further work throughout, but especially in the sandveld.

(a) Degraded areas occurred patchily in 20-30% of sandveld ecosystems VI and VII. Particularly degraded areas were located peripheral to fossil valleys (Ecosystem VIII) and pans.

(b) In ecosystem VIII large areas have been cleared for cultivation. Range degradation is apparent in the vicinity of water sources.

Conclusions

Whereas it can rightly be regarded as problematic to draw definite conclusions from the above work, in the absence of alternative studies to date the following is proposed:

1. Obviously, increased rainfall leads to increased areas of green, healthy vegetation while, conversely, decreased rainfall (drought) has the reverse effect.

2. As smallstock numbers increased (and to a lesser extent, cattle) the areas of bush encroachment and/or erosional phenomena also increased, whilst moderate to sparse vegetation cover decreased. Hence it appears reasonable to suggest that both livestock types contributed to browse consumption in drought years.

3. The absence of rain led to increases in the area of dead trees, bush encroachment and/or erosional phenomena. These increases were accompanied by a decrease in cattle. Being less adaptive feeders, cattle were more affected by lack of rainfall than smallstock.

Correlation for the sandveld SDIs resulted in the following:

(a) During good rains, increased cattle numbers paralleled increases in moderate to sparse vegetation, thereby contributing to range degradation;

(b) Increased numbers of smallstock in 1982, 1986 and 1987 led to an increased area of sparse vegetation in the interfluve areas. This suggests that cattle numbers contributed to vegetation reduction, even in good years. These increases were also accompanied by increases in areas subject to trampling, wind erosion and deposition.
From the above conclusions, two management recommendations are made pertaining to Botswana rangelands. Firstly, it appears necessary to reduce the number of cattle during wet periods to allow the range to regenerate fully, and secondly, reductions in the number of smallstock are advised, especially during drought periods, to avoid irreparable damage to the range.

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