reaches of a river. Some of them have been sinking into the sand "sea" since the ancient times, while others still exist as the oases but damaged.

It is true that the oasis ecoenvironment in the desert was changed greatly in the past times. But the reasons for these changes are so complicated that it has never been made clear completely till now. I think that the standpoint is somewhat one-sided of regarding it simply as desertification or of regarding that the desert has been enlarging since the early times, because when the desertification happened in one area, the oasis maybe also apeared in the other areas nearby; conversely, oasis rising through cultivation will cause the desertification of the areas interrelated sooner or later. This is mainly formed by the water's distribution in that areas, which was controlled by either the natural factors or the social actions, directly or indirectly. But the most dominant element in the environmental changes is undoubtedly the social human's activities because the man is the most important and most active factor in the ecosystem.

Namib Desert: Processes and People

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1. Introduction

The Namib Desert of south-western Africa extends 2000 km from north to south between the Carunjamba River in the Mocamedes District of south-western Angola to the Olifants River in the Cape Province of South Africa (Ward et al., 1983). Lying along the entire coast of Namibia, the desert occupies the platform west of the Great Escarpment, is not more than 200 km wide and covers approximately 270000 km^2 (Koch, 1962). This configuration results in an extensive ecotonal area and a desert greatly affected by influences originating in neighbouring environments.

Naibia, where in the majority of the Namib Desert lies, is the most arid country in central and southern Africa (Marsh and Seely, 1992). Although the Namib Desert represents the extremes of aridity with less than 100 mm mean rainfall throughout, less than 5% of the country receives more than 600 mm of rain and can be considered subhumid. The prevailing aridity, when combined with the socio-economic conditions currently found within Namibia, has a major influence on Namibia and on how the population perceives the desert an its potential for sustainable use. The purpose of this paper is to describe some of the dominant processes determining the desert environment of the Namib and how these enhance or limit potential sustainable use of the area by the people of Namibia.

2. Climatic Controls of Desert Processes

Climatic variability, particularly rainfall variability, is the single, most important climatic characteristic of Namibia as a whole, and particularly the Namib, that influences ecological processes and the activities of people. In the desert, variability of over 100% among years (Lancaster et al., 1984) controls the germination, growth, productivity, decomposition and nutrient cycling of vegetation upon which wildlife, domestic animals and people depend (Seely and Louw, 1980). Availability of water is the second major factor. Whereas the availability of water, for drinking, domestic use and irrigation, can be altered by people, the growth of vegetation, particularly grasslands and pastures, can not. Differential levels of human control of the effects of rainfall is a major factor influencing natural and man-induced processes in all deserts including the Namib, and has a major impact on the potential for sustainable use of deserts for the benefit of the human population (Brown, 1992).

The climate of the Namib Desert is influenced, in a manner similar to all coastal deserts, by its position on the west coast of the southern African continent centred on the Tropic of Capricorn (Meigs, 1966; van Zinderen Bakker, 1975). Descending dry air,

as a function of global patterns of atmospheric circulation, produces a stable anti-cyclonic system located just off shore from the Namib Desert and assures arid conditions most of the time (Strahler and Strahler, 1979). When combined with the north-south movement of the Inter Tropical Converence Zone, much of the aridity and variability of the climate of Namibia, and the Namib Desert, can be explained (van Zinderen Bakker, 1975).

Southerly coastal winds flowing along the eastern side of the south Atlantic anti-cyclonic system predominate during most of the year. Over the desert, these winds manifest themselves as southwesterly winds that are strongest in the afternoon (Lancaster et al., 1984). Over the southern Atlantic near the coast, these same winds cause upwelling of the nutrient rich, cold Antarctic bottom waters. As a result, the winds blowing landward are cooled and contribute toward establishing an inversion layer that extends over the desert for varialbe distances inland from the coast (Taljaard, 1979).

During winter, a high pressure system usually establishes itself at a central location over the southern African subcontinent. This results in dry, easterly winds prevailing over the desert. As these winds descend over the western escarpment, they are heated. As a consequence of this adiabatic heating process and its position near the southern Atlantic, the coastal Namib experiences some of its warmest temperatures in winter rather than summer (Lancaster et al., 1984).

During most of the year, however, there is a steep temperature gradient extending inland from the coast (Besler, 1972). Along the coast, under the influence of the cold-water upwelling system of the Benguela, the air is generally cool, warming rapidly immediately inland from the coast and more slowly toward the eastern edge of the Namib. Annual mean temperatures range from 15 ℃ at the coast to 22℃ 100 km inland (Landcaster et al., 1984). Temperature variation throughtout the year is reduced over the coastal portion of the Namib and extremes are moderated because of its coastal position. Consequently, aspects such as growing season of vegetation are influenced less by temperature variations and more by rainfall or lack thereof (Seely and Ward, 1988; Berry and Siegfried, 1991).

Rainfall increases from the coast inland for two main reasons: rain falling over the Namib originates in the east over the Indian Ocean and the cool air inversion layer is better developed over the coast. Rainfall seasons vary from winter, in the southern Namib, to summer in the north. Rainfall can be very localised (Gamble, 1980; Sharon, 1981) causing patchy growth of vegetation where it exceeds a minimal amount of about 20 mm to cause germination and establishment of desert grasslands (Seely, 1978). Topographical variations may increase effective rainfall and alter vegetation growth in localised areas (e.g., Shmida et al., 1986). In the Namib, rainfall occurring outside of the desert may flow through in ephemeral rivers contributing to growth of riverine floodplain vegetation (Seely et al., 1980). All processes and people dependant on rainfall for plant growth and water availability are influenced by its scarcity and the episodic nature of its occurrence in the Namib (Seely and Louw, 1980).

On the other hand, fog is a much more predictable moisture source (Pietruszka and Seely, 1985), albeit present in small quantities at any one time. The amount of fog water precipitation decreases from the coast toward the inland (Lancaster et al., 1984), with the greatest amount of precipitation occurring at elevations between 300 and 600 m. Endemic plants and animals use fog water as a major source of water (Louw and Seely, 1982; Turner and Picker, 1993), and fog is thought to be a major factor in the

relatively high diversity of the Namib biota (Seely and Griffin, 1986).

3. Geomorphic Controls of Processes in the Namib

The surface of the Namib desert is composed of three major geographical units that influence the biota living there (Seely and Griffin, 1986). Sand dunes occupy an area of at least 34000 km^2 in the central to southern Namib (Barnard, 1973) and a much smaller area in the north (Lancaster, 1982). Gravel plains and isolated inselbergs occupy a large proportion of the non-sandy surface. The highest mountain in Namibia, the Brandberg at 2573 m high, lies within the desert reaches. The third major component of the desert is the ephemeral rivers that originate in the highlands, cross the desert to flow into the sea (Stengel, 1964, 1966) or end in the main sand sea of the southern Namib (Seely and Sandelowsky, 1974). Each landscape is primarily controlled by different climate factors, the major processes of each landscape component are different, and each provides a different aspect to people who wish to benefit from the available natural resources. Moreover, from north to south, along the length of this narrow desert, the three main components alternate, providing landscape diversity that supports a diversity of biotic structures, processes and species (Seely and Griffin, 1986).

The Main Sand Sea extends continuously along the Namib coast for about 300 km between the coastal towns of Luderitz in the southern and Walvis Bay in the central Namib (Lancaster, 1989) and supports the richest biota in the extreme desert (Seely, 1991a). At its widest, it extends up to 120 km inland. From the coast inland, three major dune formations are maintained by the prevailing winds. Near the coast, crescentic, barchanoid ridges lie perpendicular to the southerly winds. The crests of these dunes are highly mobile and the dunes support little vegetation (Robinson and seely, 1980). The surface-active invertebrates, lizards and small mammals, numerous but not diverse, that inhabit these dunes are mainly pendent on wind-blown plant detritus for their primary resource base (Crawford and Seely, 1987).

The central dune landscape (Lancaster, 1989) is composed of linear dunes aligned in a notherly-southerly direction, the result of interaction between the southerly coastal winds and the easterly winds of the winter season. The interdunes are either sand covered or consist of exposed Tsondab Sandstone. The bases of these dunes support a sparse perennial vegetation that, in turn, supplies wind-blown plant detritus that accumulates on the mobile slipfaces. The living vegetation and the detritus support a fauna more diverse than that of the coast and also more numerous. Populations of this biota appears to fluctuate more widely than does that of the coast (Seely and Louw, 1980).

On the eastern inland edge of the Main Sand Sea, the variable winds shape star or multi-cyclic dunes that are less mobile that in the west. They support a more extensive perennial vegetation. The biota of the dune slopes is more diverse and numerous than that of the dune crests in the east and even larger mammals such as oryx live permanently in this area.

The substrata of the gravel plains also varies from the coast inland and is determined by climatic factors (Besler, 1972). In the west, gypsum predominates, whereas farther inland, the plains are composed of calcrete. The extensive gypsum plains of the central Namib are thought to be caused by sulphur deposited by the fog (Watson, 1985). The sulphur is derived from decomposition of the organisms produced by the nu-

trient rich Benguela upwelling system that erupts intermittently. The gypsum surface supports very rich lichen fields (Schieferstein and Loris, 1992) and a few woody dwarf shrubs. Easily scarred by vehicle tracks (Daneel, 1992), this area is of growing interest to tourists in the Namib. The annual grasslands that respond to episodic rain develop inland on the calcrete substratum (Seely, 1978). In small depressions where water collects, perennial grasses, shrubs and even small tress may grow.

The rivers also vary as they traverse the desert landscape, often confined in deep canyons in the eastern desert below the escarpment, while spreading out into dunes or shallow water courses, where water flows less frequently, in the west (Stengel, 1964, 1966). The diversity and productivity of the riparian vegetation also varies as the ephemeral river courses cross the desert (Seely et al., 1980).

4. Basis of the Desert's Economy

The Namib Desert itself currently supports a limited economy, although the potential for growth is present. However, land degradation and desertification of the desert's inland margins impinges on this potential (Seely, 1991b).

Tourism presents the greatest possibilities for use of the Namib Desert itself. As the largest single industry in the world, and the third largest income generating industry in Namibia, tourism has a major role to play. The desert, through its dramatic landscapes, vast expanses, stark vistas and sparse population, presents a focal point for tourism in Namibia (e.g. Seely, 1987). The greatest growth potential for tourism in Namibia is located in the northern Namib where spectacular landscape and large animals, such as elephants and lions, coexist. The coastal Namib also represents a potential attraction for tourism, mainly during summer for the beaches, and throughout the year for angling (Penrith and Loutit, 1982).

Initially proclaimed for political reasons, a large portion of the central and northern coastal Namib is proclaimed as park or recreation area (Logan, 1960), while in the south the coastal Namib is encompassed witin the diamond mining areas and off limits to most people. Even these designated diamond areas, currently *de facto* nature reserves, will probably be redirected toward supporting tourism in the future as the resource is depleted.

Communal farming, primarily of goats, but also of cattle, represents the major type of farming on the eastern edge of the northern Namib. Nomadic pastoralism is the dominant mode of the Herero-speaking Himba people of the Kunene region (Jacobsohn, 1990). Farther south the Damara-speaking farmers are predominantly goat farmers settled along ephemeral rivers where water is obtainable or where groundwater is extracted by boreholes. While the Himba people move around the area in response to variable rainfall, the Damara people are predominantly dependent on drought relief for themselves and their livestock when anaturally low rainfall year occurs. One community of communal Nama-speaking farmers (Kinahan, 1991) lives within the Namib-Naukluft Park.

Inland from the communal farming areas in most of the northern regions and bordering the sand dunes in the south-central Namib, are so-called commercial farmers. They have access to large pieces of land but because of the low mean rainfall and high rainfall variability, many are now using their land for game farming or tourism. Water

on commercial farms comes from groundwater or small dams, many of the latter then affecting the runoff from sparse rainfall and flow of ephemeral rivers through communal or tourism areas.

The coastal Namib supports only five towns of any note, two of which have harbours and one of which is exclusively a diamond mining town, along its 2000 km length. Luderitz is a small fishing harbour whose solid rock basin is not suitable for large vessels. Walvis Bay in the central Namib, is an important harbour on the west coast of Africa. It is the base of a major pelagic fishery in the nutrient rich Benguela upwelling system. Walvis Bay is the primary harbour serving the interior of Namibia with rail and road links to the southern African sub-region (Logan, 1960). Oil exploration off-shore is the newest development in the Namib region since the 1990 independence of Namibia and is based primarily at Walvis Bay but also is supported from luderitz.

Although moving sand is a problem for both Walvis Bay and Luderitz, stabilisation of sand dunes has only been attempted at Walvis Bay. The highway leading inland from Luderitz can become covered by moving trains of barchan dune. These dunes are removed by earth moving equipment as required. At Walvis Bay, on the other hand, earth moving equipment is used along the main roads while dunes bordering on the town are stabilised by planting vegetation and using petroleum products on the sand surface. Because of the scarcity of water in the area, only vegetation that will tolerate saline water can be used.

5. Environmental Constraints and Opportunities

As the Namib is a desert it is not surprising that water presents the single biggest constraint for development of any sort. Even tourism is limited by the availability of water in some areas of potential development. The various natural processes providing water to the area, flow of ephemeral rivers with associated recharge of alluvial aquifers, fog and rain are all less than secure water sources. It is only desalination of sea water that holds potential for the future. This option is, however, complicated by the dense particulate matter supported by the nutrient rich waters of the Benguela upwelling system. Farming areas on the inland side of the desert are mainly supported by groundwater extracted by means of boreholes. Recharge is limited, however, and the negative environmental consequences of extending the borehole network are very noticeable.

A second factor impinging on future productivity of the Namib Desert is the rapid population growth rate of Namibia. With a growth rate of more than 3% per annum, upwards of 5% in the urban areas, the more fragile areas are being placed under heavy pressures. As a consequence the number of people living on the borders of the Namib is increasing rapidly and slowly encroaching on the landscapes that are also expected to support the future tourist industry.

Urbanisation is taking place rapidly in Namibia. While not widely recognised as a benefit because of its unplanned nature, it is probabl one of the positive aspects of current development. Alternative development trajectories, that take more of the people off the fragile desert landscape, while not contributing to positive economic growth, are reducing land degradation and desertification in the arid rural areas of the country.

Within the farming areas bordering the Namib desert, the shift from nomadic use of the landscape that was practised up until the current century, to sedentary grazing prac-

tices is almost complete (Kinahan, 1991). This is enhanced by the practice of gender differentiation in farming activities, by absenteeism of male farmers from the land, and the lack of infrastructure and other support of the farming community. Information, awareness and alternatives are allunavailable for a society that is rapidly increasing and having to cope with the natural and variable processes of arid grasslands.

On the other hand, despite certain constraints, tourism as a foreign exchange earning activity continues to increase in the Namib and is perceived by many to be the major use of these desert reaches. The species diversity and unique endemic biota of the desert is a major attraction when combined with the undisturbed landscapes that still remain. The natural processes that led to their development continue to function in the the absence of alternative activities in most of the extreme desert realm. Sustainable use of these landscapes, which both contributes to but can be negatively affected by other human activities, can assure the productivity of the desert and its associated natural processes.

6. Conclusions

Aridity is the overriding factor influencing all processes in the Namib Desert and, consequently, the people that live in and make a living from the desert environment. The basic climatic and geomorphological processes that shape the desert are relatively well studied in Namibia (Seely, 1990) and constitite the main attraction to tourists and a material benefit to the population of Namibia. While the processes themselves, e. g. the wind, fog and sand, will continue despite possible global climate change or human alterations of the environment, their pleasing configuration upon which their usage is based is easily destroyed. While the natural processes, particularly the variability of rainfall and water availability in this arid environment have made it only marginally hospitable to man, these same processes have the potential to provide great benefits if the overriding aridity and its correlates are well taken into consideration.

Acknowledgements

I wish to thank K and P Jacobson for reading drafts of this manuscript, the Desert Research Foundation of Namibia for financial support and the Ministry of Wildife, Conservation and Tourism for permission to work in the Namib-Naukluft Park.

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