Establishing indicators of biological integrity in western Namibian rangelands

Submitted by
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Declaration

I declare that this thesis is my own original work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination iin any other University.

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Juliane Zeidler

Johannesburg, December 1999

To DRFN -

in appreciation for all the support & the phantastic opportunities!

Juliane

Abstract

An Index of Biological Integrity (IBI) has been developed for rangeland condition assessment in arid northwestern Namibia. The usefulness of termites as bio-indicators has been tested and reliable sampling protocol for termite diversity in an arid environment has been developed. The study was conducted mainly at a high- and low-intensity site on each of three farms. Two of the farms were communally owned; the other was commercially owned.

No single reliable method for rapid termite diversity assessment seems to detect all termite taxa present. Three different methods for sampling termites generated different results. A standard belt-transect, a defined search protocol and a baiting experiment using three different types of bait, were compared. The search protocol required the lowest sampling effort, however produced the poorest results by detecting the lowest number of taxa. The standard belt-transect and baiting methods, both, produced similar results in numbers of taxa found, but often-sampled different termite taxa. *Trinervitermes sp.* were found mainly by applying the transect method, representatives of *Macrotermes*, however, through the baiting experiment. *Microtermes* and *Psammotermes* were detected with any of the used methods. They were the most frequently found termite taxa in the study area. From the results it becomes apparent that (1) several termite taxa are highly seasonal and (2) certain sampling methods are appropriate for certain termite taxa. Compared to other arid regions in Africa and elsewhere, the number of termite taxa collected from the study area (11 genera, 18 identified taxa) is close to numbers sampled from similar environments.

The IBI includes measures of vegetation (forage quality, herbaceous, woody and litter biomass), soil parameters (nitrogen (N), organic carbon (OC), phosphorus (P), C:N ratio, light fraction (LF) and LF:C ratio), as well as termite diversity measures such as the community composition of functional groups. Application of the combined IBI at six study sites of varying land tenure and land use intensity reveals that the ecological resource base on the communally owned farms was more constrained than on the commercially owned farm.

Organic Carbon (OC) levels were extremely low, ranging between 0.12 and 0.27 %. The OC level could be the factor limiting soil resilience in systems as arid as the study area. The OC levels were especially low under high land use intensity on the communal farms. The C:LF ratio was used as an indicator of soil resilience. The turnover of light fraction, the "active" OC pool, into soil organic matter, the "slow" and more stable OC pool, is indicative of transformation processes that are crucial to the maintenance of soil fertility. The C:LF ratio ranged between 5 and 9% in March 1998 and 6 and 17% in October 1998 at the six study sites. The higher levels measured in October, towards the end of the dry season, are explained by the work of termites and other soil related flora and fauna, which contribute to the replenishment of soil nutrients after the growing season (October-March). It was conspicuous that at one of the communal farms the C:LF ratio remained low over the seasons. Soil fertility was overall lowest at this site. The number and composition of termite taxa found at the various study sites differed, as did the composition of functional groups. This could affect the soil – soil biotic interface and interaction, since not all termite species will contribute to underlying ecosystem processes in a similar fashion.

The term "land use intensity" was defined and explored in detail in this study. Livestock numbers obtained annually by the Ministry of Agriculture indicated that stocking numbers were highest at the commercial farm. This farm, however, obtained the best IBI scores in the habitat assessments. Stocking numbers at the commercial farm averaged 441 LSU over a 10-year period, whereas the two communally owned farms recorded averages of 372 and 356 LSU respectively. All farms were of similar size. It was therefore concluded that stocking numbers, *per se,* are a poor indicator of land use intensity. In-depth investigations at one of the communal farms aimed to establish, in close collaboration with the farmers, (1) reliable stocking numbers at their farms and (2) causes of land degradation. It is recommended that stocking numbers on communal farms ought to be established at a household level and not on a farm level. Tracking of animal numbers should be done in a participatory fashion and on a monthly basis to gain useful insights into de-stocking and restocking dynamics on communal farms. The farmers identified various causes of land degradation on their farm, naming especially lack of access to secure emergency grazing areas under prolonged drought conditions, and lack of decision-making powers on their own farms.

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FOREWORD

Namibia signed the "International Convention to Combat Desertification". As a result Namibia's National Programme to Combat Desertification (Napcod), a collaborative effort between the Ministry of Agriculture, Water and Rural Development (MAWRD), the Ministry of Environment and Tourism (MET) and the Desert Research Foundation of Namibia (DRFN), was launched. The programme addresses the political, socio-economic as well as biophysical aspects related to desertification and land degradation. The focus of its first phase was a National Workshop to Combat Desertification, which produced a draft policy and framework for a National Programme. It supported the overall objective of combating desertification by promoting the sustainable and equitable use of natural resources suited to Namibia's variable environment.

Phase II of Napcod ran from 1995 to 1999. One of the programme's objectives addressed the need to establish and implement an appropriate inter-disciplinary research programme to derive a reliable knowledge base on the characteristics of desertification in the Namibian context. It became apparent that the lack of understanding of natural variation versus environmental degradation in Namibia is of major concern. The elaboration of an ecological information base for monitoring and evaluation purposes was also considered important. To date, habitat condition assessment is largely based on subjective measures and perceptions of individuals, and land-use planning is only rarely derived from data collected in the field. It was stated that all research activities should be linked to training and capacity building of Namibians at all levels.

The "Desert Research Foundation of Namibia" (DRFN), a private Namibian organisation, co-ordinated the research and training objectives of the Napcod II programme. This PhD study was conducted under the auspices of DRFN and the activities were incorporated into the overall research framework of Napcod. The research questions of this PhD project were formulated keeping the needs expressed by the National programme in mind. The results will hopefully contribute to a better understanding of habitat condition and natural resource use in western Namibian rangelands and ultimately provide some useful tools for their assessment. The results of this PhD form the foundation of parts of phase three of Napcod (1999-2003) implemented by DRFN and Namibia's Economic and Policy Research Unit (Nepru), and in that sense will be developed on a national scale.

INTRODUCTION

Namibia, the most arid country in sub-Saharan Africa (Figure 1), depends on earnings from agriculture, particularly livestock and game production, as well as indirect benefits deriving *inter alia* from wildlife and tourism (Tapscott, 1994). Large areas of Namibia are rangelands which are primarily used for livestock/wildlife production. Management systems include conservation areas, nomadic pastoralism, mixed subsistence farming, and commercial livestock farming (Tapscott, 1994).

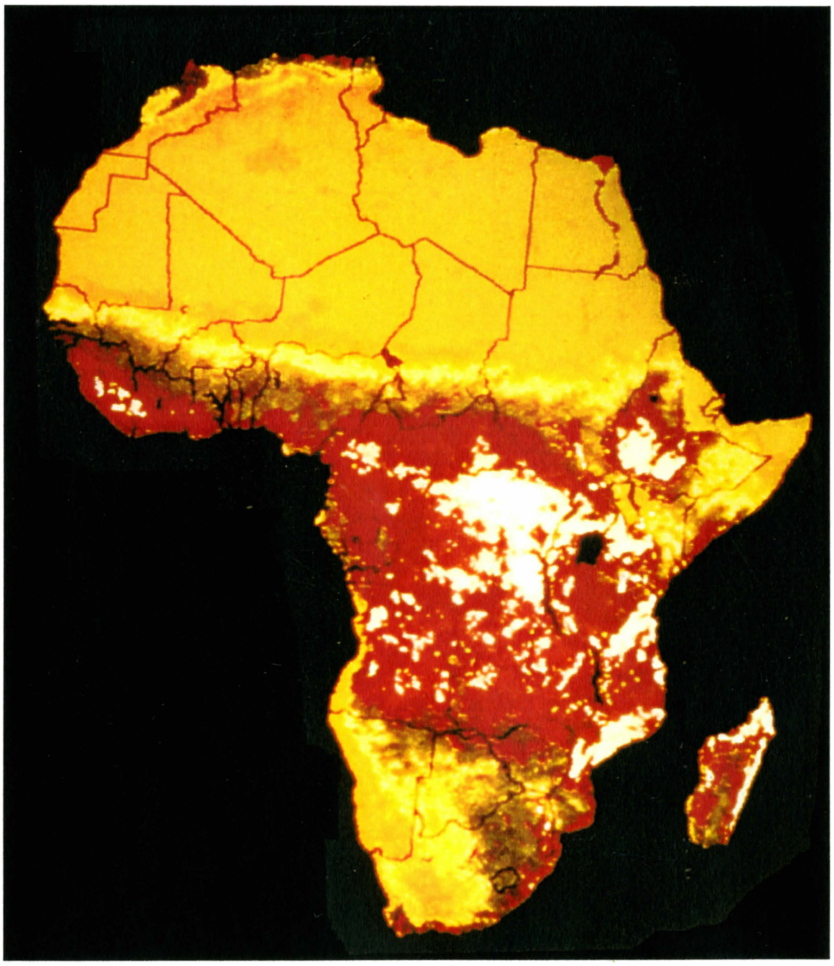

Figure 1: *Satellite image of Africa. The yellow colour code depicts areas with low biomass and of high aridity. The south-western tip of Africa, including most parts of Namibia, is the most arid part in sub-saharan Africa.*

Given the harsh natural conditions of Namibia's' environment, i.e. the extremely low (Figure 2) and variable rainfall conditions (Hutchinson, 1995), it becomes clear that careful and appropriate land-use management has to be practised in order to make best use of the natural resources and maintain a healthy environment (e.g. Seely *et al.*, 1994; Tapscott, 1994; Behnke *et al.,* 1993).

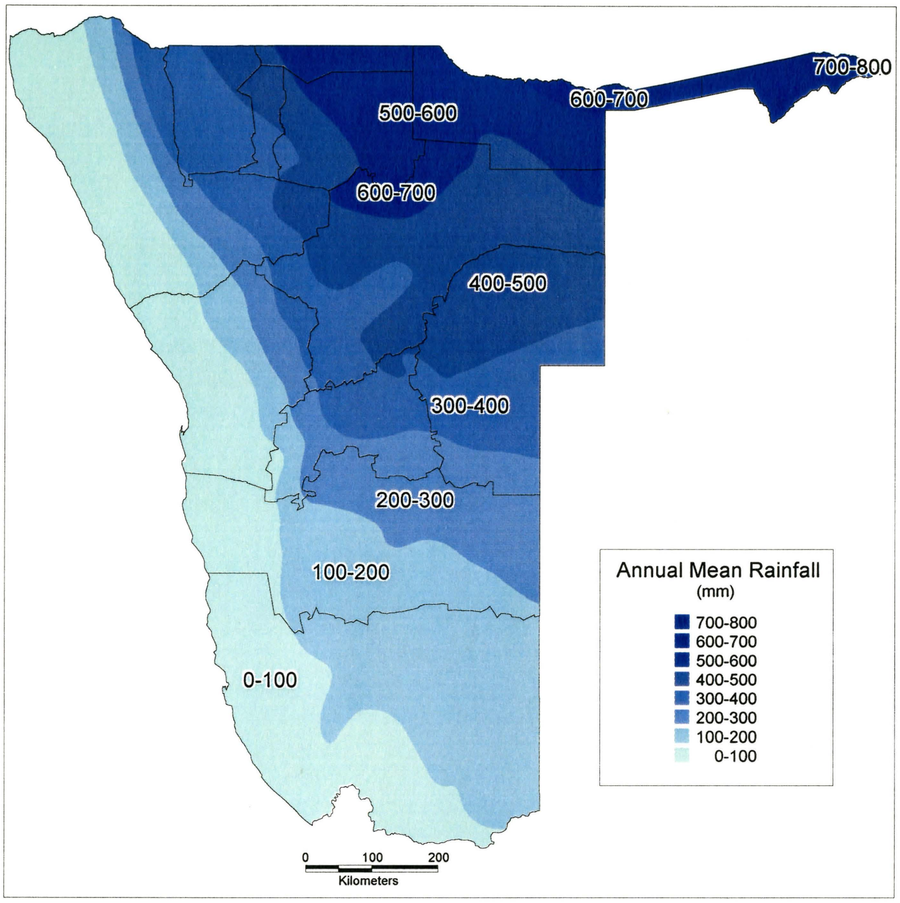

Figure 2: *Rainfall range map of Namibia*

Although there is discussion on whether Namibia's environment is particularly prone to desertification and land degradation (e.g. Sullivan, 1998), Seely & Jacobson (1994) maintain that as a result of normal but difficult ecological conditions, past and current land-use and land management, as well as political and socio-economic pressures and constraints, the environment is put under severe pressure. The question is how to manage Namibia's rangelands and their natural resources in a responsible and sustainable manner, guaranteeing their long-term productivity and maximum outputs. This not only places the responsibility on rangeland scientists to investigate and recommend suitable management strategies, but also requires the input from resource users, extension personnel, and politicians alike, who will have to learn about the issues at stake and may have to commit themselves to changes in attitudes and habits.

Globally, desertification and/or land degradation manifests itself in a reduction of secondary productivity, induced by changes in rangeland conditions (e.g. Milton *et al.*, 1994; Walker, 1993; Stafford-Smith & Pickup, 1993). It is not clear whether or not overall secondary productivity is declining in Namibia and this needs to be carefully investigated. However, verbal communications by farmers indicates that livestock were doing much better in the past, compared to today. Poor rainfall conditions and lack of management authority are mentioned as the main causes of the problems of communal farmers (Chapter 3). Reference is also made to the possibility that rangelands are becoming less productive e.g. due to overgrazing, leading to deteriorating soil condition and changes in forage species composition. This notion needs to be carefully examined, especially with the background of current thinking in range science. It is now accepted that many dryland ecosystems do not follow equilibrium dynamics. Based on the variability of rainfall which exceeds a Coefficient of Variation of 30%, Namibia would be characterised as a non-equilibrium system, where the risk of environmental degradation due to overgrazing is thought to be unlikely. It is believed that livestock populations rarely reach levels likely to cause irreversible damage, and that it is mainly rainfall determining the availability of grass in the rangeland (Behnke *et al.*, 1993; Scoones, 1995). However, to date we have very little understanding of how well Namibia's rangelands are.

Although most farmers claim to assess the condition of their farmland on a more or less regular basis, such an assessment seldom seems to be based on habitat measurements that would allow for unbiased comparative analyses. It is not clear which habitat parameters would provide the most meaningful description of habitat condition in Namibian rangelands, particularly considering that the vegetation base is of an extremely ephemeral nature. Furthermore, if productivity and sustainability of the range and farm are to be gauged, indicators have to be considered, which include the assessment of the socio-economic situation of the farmers, the families' and the individuals' livelihoods. Whereas this PhD study mainly focuses on the development of indicators of range condition based on the concept of biological integrity, an parallel study was conducted, exploring such socio-economic and livelihood oriented indicators. The results of this latter study are produced elsewhere, but are considered in this PhD.

Structure of the thesis

This thesis is presented in four parts, which are organised in individual chapters. The structure is visualised in Figure 3.

Structure of the thesis

PART I

Literature review & conceptual framework
- Rangeland ecology in arid systems
- Range condition assessment
- Biological integrity & ecosystem function
- Soil resilience and soil fauna
- Disturbances

PART II

Background to the study area
- Huab catchment in north-western Namibia
- Commercial and communal farms
- Land use intensity and range management at the three study farms

PART III

Index of Biological Integrity (IBI)
- Termites as potential indicators
- Other bio-physical indicators
- Index development and site assessment

PART IV

Final discussion & conclusions
- Range assessment tools - the usefulness of the IBI
- Non-equilibrium systems and land degradation
- Pastoral developments in Namibia - recommendations

Figure 3: *Structure of this thesis.*

PART I

CHAPTER 1 - LITERATURE REVIEW

1.1. Rangelands at non-equilibrium

Range science - change of paradigms

Recent biological research in African rangelands implies that the standard views of range ecology are flawed by wrong assumptions, leading to inappropriate management of livestock and range (Behnke & Scoones, 1993). Today, a large body of literature exists on plant-herbivore interactions, rangeland ecology and rangeland management. Behnke *et al.* (1993) summarise new directions in range science. This collection of papers brilliantly illustrates the shift in paradigm in modern rangeland science from a single, fixed approach to a more adaptive one, accounting for variable environmental conditions and given management necessities.

Previously it was believed that all rangelands functioned as equilibrium systems and it was assumed that the number of livestock affects forage production (Behnke & Scoones, 1993; Ellis *et al.*, 1993; Ellis 1995). The interaction of herbivores and plant productivity was believed to be strictly density dependent, thus plant production would directly determine livestock production and vice versa. Consequently, overstocking would deplete forage production and limitation of livestock numbers would keep forage production at equilibrium. Based on this notion the concept of carrying capacity and optimal stocking numbers was developed, using vegetative measures, such as succession and decreaser/increaser concepts, as indicators of range condition and a baseline for the assessment of stocking rates (for a review see below). For mesic systems these concepts have provided invaluable insights into the relationships between animal numbers and production and may have provided good information for management directions (Clements, 1916; Dyksterhuis, 1949). However, in more arid ecosystems as well as under non-commercial management systems the equilibrium paradigm seems not to apply unconditionally. Environmental conditions determine how herbivore plant interactions are characterised (Behnke *et* *al.*, 1993; Ellis & Swift, 1988; Mentis *et al.*, 1993, Scoones, 1995; Walker, 1993; Westoby *et al.*, 1989) and for example, rainfall and soil conditions may be the primary drivers for plant production. Based on this appreciation, two complementing concepts have been formulated, the quasi-equilibrium and non-equilibrium paradigms. The quasi-equilibrium paradigm states that stocking numbers do affect plant production, but only to a certain extent (Coppock, 1993; Ellis, 1995; Galvin & Ellis, 1996). In a non-equilibrium system, stocking numbers do not determine plant production (Behnke & Scoones, 1993; Ellis, 1995; Ellis *et al.*, 1993), thus plant production is a density-independent variable. While total amount of plant production controls herbivore numbers, herbivore numbers will not significantly affect total plant production. However, plant species composition and structure, e.g. represented by tree:grass ratios, can be altered through herbivory (Walker, 1993).

The non-equilibrium paradigm applies to arid systems, characterised by low and variable rainfall conditions, where the annual rainfall is below 400mm and the coefficient of variation above 33% (Ellis & Swift, 1988; Ellis, 1995; Galvin & Ellis, 1996; Walker, 1993). Most of Namibia's rangelands are situated in regions where such climatic conditions prevail. A number of authors of recent publications drawing from work conducted in arid to semi-arid Namibia pay tribute to the non-equilibrium concept, which negates the immediate effects of density-dependent overgrazing on the natural resource base. According to the research, stochastic environmental variation (e.g. rainfall) overrides or masks the impacts of pastoralism on the vegetation (e.g. Sullivan, 1996; Sullivan, 1998; Ward *et al.*, 1998; Ward *et al.*, *in press*).

However, a few voices of criticism on the newly developed paradigm have become loud over the past years and words of caution have been voiced, indicating that issues are possibly more complex. In a recent paper, for example, Illius & O'Connor (1999) challenge the non- and disequilibrium concept in the sense that they argue that (a) such concepts do not justify the view that herbivory has little impact in climatically variable systems, (b) animal numbers are regulated in a density-dependent manner by the limited forage available in "key resource" areas which are utilised in the dry season, (c) uncoupling animal populations from vegetation carries an increased risk of degradation. They underpin their arguments with relevant data.

Other authors indicate that degradation of the natural resource base in non-equilibrium systems would only occur under exceptional conditions such as prolonged drought (e.g. Toulmin, 1995). In the Namibian context drought should be considered as natural and expected, therefore effects on the natural resource base can be expected to occur.

In the book "Living with Uncertainty" (Scoones, 1995), the various contributors give directives for how to manage variable non-equilibrium systems. In the forefront stands the call for more adaptive and opportunistic range exploitation. It is generally described that traditional nomadic and pastoral strategies as applied e.g. by the Turkana people in Kenya (Ellis & Swift, 1988, Galvin & Ellis, 1996; McCabe, 1987) or the Namibian Himba people (e.g. Bollig, 1997), are indeed adequate for managing rangelands in arid systems (Scoones, 1995). These are people who track the natural resource base and move their animals according to resource availability, exploiting key resources in "tight" times, and applying mixed livestock-crop farming strategies. The main management directives given, call for flexible and responsive planning processes that are in tune with the pastoralists' needs (Perrier, 1995). They suggest various effective tracking strategies, including alternative feed supplies for livestock (Bayer & Waters-Bayer, 1995), effective livestock marketing (Holzmann & Kulibaba, 1995), and discuss social welfare interventions (Holzman & Kulibaba, 1995; Toulmin, 1995), for instance supporting effective de- and restocking (Toulmin, 1995). Appropriate resource tenure systems are discussed (Lane & Moorehead, 1995), facilitating flexible, mobile and adaptive resource management and the need for community-based and service-providing institutions are outlined as well (Sylla, 1995). In Namibia, existing land-tenure and policy arrangements, lack of access to land, high expectations on the ranges' productivity and the economic setting are difficult and may not favour adaptive management.

Although most interventions that deal with managing variable systems are related to the improvement of land-use practices and institutional capacities, it is still important to reliably determine rangeland condition. To manage rangelands effectively it is necessary to track and monitor the natural resource base on a continuous basis.

1.2. Assessing and managing range quality: a review of concepts

Under the assumption that rangelands would function according to the equilibrium paradigm, the concepts of Succession (Clements, 1916) and Range Condition (Dyksterhuis, 1949) evolved. The belief was that setting a certain stocking rate would allow ranges to progress to a specific point along a continuum of botanical composition. Progress was towards the single permitted climax, whereby productivity obtained was maximal and sustainable. This would be coupled to the range being maintained in good condition, assessed from the Range Condition concept (Abel 1993; Bartels *et al.*, 1993; Behnke & Scoones, 1993; Bester, 1993; Ellis & Swift, 1988; Joyce, 1993; de Leeuw & Tothill, 1993; Mentis *et al.*, 1989; Reed *et al.*, 1997; Scoones, 1993; Tainton, 1981; Walker, 1993; Westoby *et al.*, 1989). Assessment of condition was done by comparing ratios of decreasers to increasers. Decreasers were plants that were desirable (palatable & digestible) from the context of stock productivity (maximum production per head) and the increasers (unpalatable & indigestible to a greater or lesser degree) were those that increased with increasing stocking rate. Rising numbers of increaser grasses led to increased grazing pressure and reduced stock productivity. Determination of the ratio of decreasers to increasers was therefore crucial to determination of range quality. Quality of forage in rangelands (the suggested ratio of decreasers to increasers) was achieved by adhering to stocking rate, calculated from carrying capacity, derived from the observed ratio of decreasers to increasers. Bad management lead to undesirable changes in vegetation composition (Behnke & Scoones 1990) in a way that productivity per unit area declined (Behnke & Scoones 1993). As a result, destocking was seen to be the optimal strategy to help reverse and restore the degraded veld's productive capacity.

The thinking of much of the sixties to eighties was tainted by the “Tragedy of the Commons” concept that would blame farmers in communal and open access areas in Africa of mismanagement of the range due to overstocking (Hardin, 1968).

However, since then Hardin's viewpoint has been revised and heavily criticised (e.g. Scoones *et al.*, 1993; Scoones, 1995).

Today it is clear that destocking is not the only way to reverse land degradation (e.g. Hary *et al.*, 1996) and it is apparent that restoration of rangelands and the natural resource base should not be seen simplistically (Bakker & Berendse, 1999). The suite of arguments presented above does not hold for systems that are not at equilibrium, and thus where herbivory does not affect plant production in a predictable fashion. In such systems it may be the prevailing environmental conditions, e.g. attributable to Global Climate Change (GCC), that lead to vegetation changes, not 'overgrazing' *per se*. This may lead to a misunderstanding of the problem of land degradation, with false implications for land management. However, as Illius & O'Connor (1999) point out, a combination of environmental and herbivore interactions can be expected.

In essence it can be said that it is not only stocking numbers *per se* that are important to management in arid to semi-arid systems, but that the concept of land-use intensity and resulting impacts on the vegetative and soil systems need to be defined in a broader sense. It is not only the stocking numbers, grazing systems and the type of livestock farmed that affect the farmers and the range. The existing management opportunities, often determined by the set policy framework, and the operational support systems to deal with drought, thus the socio-economic and political environment, are also extremely important.

1.3. Biological Integrity and ecosystem functioning

Changes in rangeland condition are probably most conspicuously portrayed by changes in vegetation such as the larger scale conversion of grasslands[1] to shrublands (e.g. Schlesinger *et al.*, 1990), of perennial to annual grasslands (e.g.

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[1]The term grassland is used in this text to describe rangelands with a predominantly grassy vegetation component, falling into the classical Namibian vegetation zones (e.g. Namib Desert, Nama Karoo).

Seely & Jacobson, 1994), or of palatable to unpalatable vegetation systems (e.g. Milton, 1994). Vegetation parameters are often used in the delineation of environmental as well as land-use gradients and of change (e.g. Milchunas & Lauenroth, 1993; Ward & Olsvig-Whittaker, 1993; Nash & Whitford, 1997). However, it is important to look at the less conspicuous system parameters driving such alterations as well as ecosystem functioning *per se*. These are, to a large extent, the underlying biogeochemical processes which ultimately supply water and nutrients to the plants, and hence determine soil fertility and finally primary and secondary productivity. Such processes are dependent on abiotic components and are largely mediated by soil biota.

Soil biota are recognised key actors in maintaining and improving soil characteristics such as nutrient status, organic matter stabilisation and water balance, and protecting against processes such as leaching and erosion (Lee & Wood, 1971a; Lee & Wood, 1971b; Anderson, 1988a). Generally, soil micro, meso- and macrofauna modulate the chemical and physical attributes of soil through mechanical and physiological processes, ultimately contributing to soil fertility and ecosystem productivity. Some soil organisms impact such biogeochemical processes more than others do (Anderson, 1994). The diversity and composition of soil biotic communities and the functions associated with them vary within and between ecosystems and may shift under changing land-use regimes (Swift & Anderson, 1993; Anderson, 1994). Similarly, environmental fluctuations, induced for example by global climate change or pollution, may alter naturally established soil biotic structures (e.g. Whitford, 1992). Even today very little is known about the full implications of biological diversity for ecosystem performance *per se*, although numerous attempts have been made by researchers to elucidate the issue (e.g. Huston, 1994). However, one of the main discussions that also relates to the problem of desertification, revolves around the question of whether the loss of particular species and/or communities may disturb or even interrupt crucial biogeochemical processes and ultimately lead to an impoverishment of ecosystem functioning and performance (e.g. Naeem *et al.*, 1994; Whitford, 1996). This needs to be critically examined, and possible causes that lead to changes in biodiversity clearly identified, in order to allow for appropriate resource management.

As pointed out in the ecological literature, there is no such thing as a single most sensitive species that can reflect habitat condition over a broad scale (Crains, 1986; Noss, 1990). Multi-scale and multi-factor approaches are recommended. It was suggested that an Index of Biological Integrity (IBI) (e.g. Karr *et al.*, 1986; Karr, 1987) adapted to Namibian rangelands be developed as part of the Napcod programme. Aside from the general discussion about what needs to be measured, biological diversity or biological integrity (Angermeier & Karr, 1994), the concept embodies an approach that aims to provide practicable management tools for habitat condition controls. Indices based on biotic parameters such as species richness and composition, abundance and condition of selected target taxa, as well as trophic composition of the system are being developed, and are thought to indicate different levels of ecosystem disturbance or, vice versa, ecosystem functioning (e.g. Karr, 1981; Karr, 1991). The appeal in applying such a concept to terrestrial ecosystems seems to be the broadly based and functional approach to indicator studies as well as the practicability of its application. However, a good understanding of the ecosystem under investigation is required. Although not much was known specifically about the ecosystem under investigation, basic concepts elaborated for arid rangelands e.g. in Behnke *et al.* (see above) provided good guidelines as to what type of indicators might be useful in the research context. These could be incorporated into an IBI for Namibian rangelands.

1.3. Disturbance ecology

There has been considerable debate on the definition of disturbance and its implications for biodiversity and ecosystem functioning. White & Pickett (1985) describe disturbance to be "any relatively discrete event in time and space that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment". Disturbance has long been recognised as an important factor influencing community structure and dynamics and today it is widely acknowledged that disturbance is a natural process occurring at different temporal and spatial scales (e.g. White & Pickett, 1985; Wiens, 1985; Remmert, 1991; Sousa, 1984; Sprugel, 1991). Ecologists and conservationists recognise that many forms of disturbance are important components of the natural systems, including phenomena such as fire, storms, floods, frost etc. Many plant and animal communities even depend on such disturbances, especially for regeneration (e.g. Pickett & White, 1985). However, disturbance may also lead to degradation of natural communities by e.g. promoting establishment of invasive plants (Hobbs, 1993), loss of key stone species (Walker, 1992; 1995) and habitat fragmentation.

Ecological disturbance theory has developed over the past years and several models were suggested. The diversity-stability hypothesis was first formalised by McArthur (1955), who suggested that complex natural systems are more stable than simple systems. However, the diversity-stability concept did not persist in scientific discussion in its original form and was further developed by Pimm (1979), who suggested that it is not the change in the model's complexity that affects the system the most, but that such a model reacts particularly sensitively to the removal of specific species from the system. Thus, he indicated the importance of functional relationships within systems, an idea which was elaborated later e.g. in the resilience concept of Walker (1992; 1995). The Intermediate disturbance hypothesis suggested that species diversity should be highest at moderate levels of disturbance (e.g. Connell, 1978; Petraitis *et al.*, 1989). The ecosystem resilience approach (e.g. Walker, 1992; 1995) contrasts the ordinary species (biodiversity) approach through its functional dimension. He acknowledges that ecosystem condition depends not only on single species but also on complex multi-species interactions that mediate a number of ecosystem processes. The representation of species in functional groups is thought to be important. Promoting and maintaining diversity of functionally congruent species - particularly of so-called keystone species - enhances the resilience of an ecosystem. Walker (1995) links redundancy and ecosystem resilience in variable and extreme environments: redundancy, characterised by the adaptation of an organism to a wide range of environmental conditions, acts as a buffer during severe periods of drought and allows for effective recovery from disturbance.

1.4. Termites as so-called "ecosystem engineers"

Termites are usually regarded as pests and farmers actively eliminate termites from their fields and pastures (e.g. Wood *et al* 1980; Logan *et al.*, 1990; Logan 1991). Occasionally termites' contribution to other trophic levels i.e. as food source for organisms such as aardvark, birds, monkeys, and even humans, is acknowledged (e.g. Kok & Hewitt, 1990; Logan, 1992; Willis *et al.*, 1992). Termites play a major role in the structuring of soils (e.g. Anderson, 1988a; Lee & Woods, 1971a; Lobry de Bruyn & Conacher, 1990) and even of entire landscapes (Anderson, 1994). They contribute to the nutrient turnover and decomposition processes, particularly in arid environments (e.g. Crawford, 1981; Crawford & Seely, 1994; Whitford, 1991; Holt & Coventry, 1990). Drawing from studies that were conducted in dry ecosystems all over the world, it can be anticipated that the biological, chemical and physical processes associated with termites are of significance to the functioning of these systems.

Only a few studies conducted in this region, however, fully appreciate the termites' potential as keystone species (e.g. Bond, 1993), or as, more adequately termed, so-called "ecosystem engineers" that contribute actively to ecosystem functioning. Jones *et al.* (1994) define "ecosystem engineers" as "organisms that directly or indirectly modulate the availability of resources (other than themselves) to other species, by causing physical state changes in biotic or abiotic materials". As outlined in more detail in Part III, termites may well fall under this definition (e.g. Whitford *et al.*, 1992; Didham *et al.*, 1996).

In the Namibian context, it is relevant to study aspects of termite biodiversity, since termites are thought to form the major part of soil macrofauna in the more arid areas, contributing to various ecosystem processes (Crawford & Seely, 1994). Measured by biomass, termites are the most numerous and predominant herbivores in savanna ecosystems (Wood & Sands, 1978). Termites have various attributes that possibly make them good indicators for ecological analyses. These are, for example: their taxonomic and ecological diversity, their relatively sedentary habits, their taxonomic tractability, the fact that individuals are present throughout the year and their functional importance in ecosystems (Bond, 1993; Soule & Kohm, 1989). However, there are also problems that make termite studies difficult to undertake and the resulting data difficult to interpret (Eggleton & Bignell, 1995). Sampling for termite diversity, for example, remains difficult and time-consuming. Whereas species richness can probably be determined fairly reliably, population parameters and abundance measures are extremely hard to obtain. This is particularly true for arid systems, where many species are subterranean, and populations may spread out over large areas. Also there is little information available on the biology and the role that individual termite species play in ecosystem processes.

1.6. Soil resilience

Soil fertility is probably the single most important factor aside from water availability that affects agricultural productivity (e.g. Greenland & Szabolcs, 1994). Primary productivity is dependent on soil nutrient status, nitrogen (N) and phosphorus (P) are often limiting factors in African savannas (e.g. Bell, 1982; Scholes, 1990). Organic carbon (OC) and light fraction (LF) content of the soil are important to soil chemical and soil physical characteristics of the soil. It is through the breakdown of the organic material that the soil nutrients are replenished. However, there are a number of other important nutrients, often referred to as micro-nutrients. Soil fertility is considered to be an important indicator of rangeland condition (e.g. Behnke *et al.*, 1993) and the effect of land use practices on soil condition have to be monitored and consequently to be managed (e.g Greenland & Szabolcs, 1994). In the context of this research, the impact of grazing and other rangeland uses on the soil system was investigated. Historically, most rangeland studies have focused on forage production and animal response, however recently more research efforts have attempted to link these to soil systems i.e. to the cycling of nutrients e.g. N between biosphere, lithosphere and atmosphere (e.g. Custers, 1997; van de Koppel, 1997; de Mazancourt, 1999; Schuman *et al.*, 1999). The concept of soil resilience has been reviewed in Greenland & Szabolcs (1994) and is broadly characterised as including all the processes that enable soils to counteract stress and alterations. Soil resilience includes such important properties as the buffering capacity of a soil to chemical, physical and biological impacts. The potential for renewal after soil loss is very important, as is the functioning of important soil processes such as decomposition and nutrient transformation (e.g. Szabolcs, 1994). The role of soil biota and, in the context of this research, termites, has already been mentioned.

1.7. Objectives & key questions

The conceptual model underlying the research questions suggested for this PhD study is depicted in Figure 1.1. The aim of the research was to develop appropriate methods for rangeland assessment and to determine the biological integrity of the system. Three themes have been identified as being important for such assessments: firstly, land practices and secondly, farmer livelihoods. A third category of issues revolves around the status of biological integrity of the system. Rangeland integrity can only be assessed if we have a good understanding of the dependencies and socio-economic relations between the farmers and their farms.

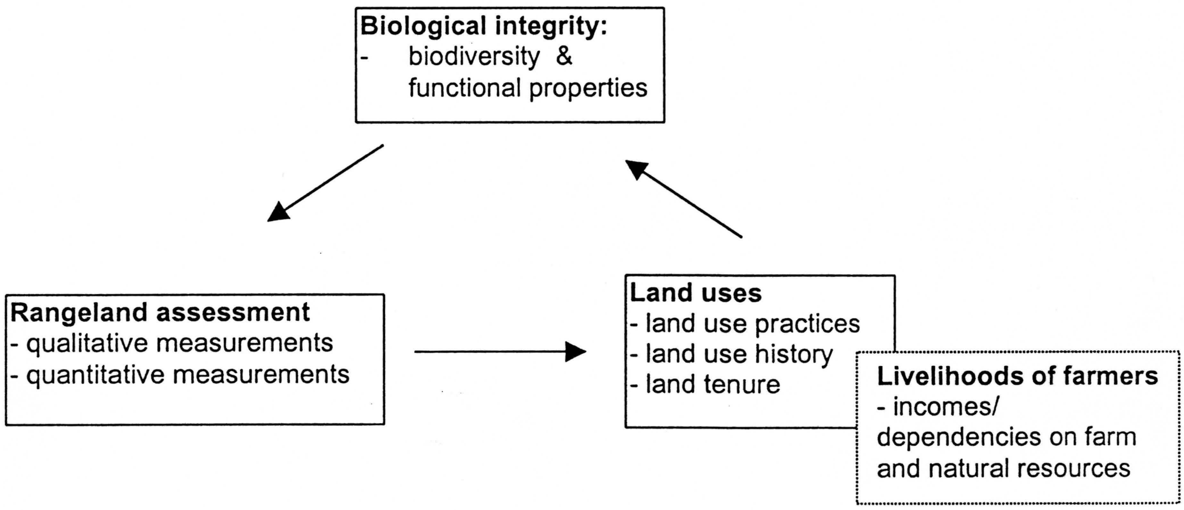

Figure 1.1: *Conceptual framework of the thesis.*

To be able to practice adaptive rangeland management, information on the current state of the habitat and various aspects of the use of the land must be considered. To achieve this, it is important to delineate the most effective and practical ways of assessing rangeland condition as well as land uses. In the context of this study, measures of biological integrity and geophysical surrogates, aspects of biodiversity, its functional properties and effects on the environment, are used for habitat assessment. The results of the scientific investigation are compared with common local and indigenous practices, which are usually qualitative in their nature. The most suitable set of indicators is derived from these different approaches. Land uses at the farms are investigated in some detail, firstly to define land use intensity at the sites more accurately and secondly to identify causes that may lead to habitat deterioration.

A flow chart, visualising the functional linkages between vegetation, livestock, soils and soil fauna i.e. termites, conceptualised for arid Namibian rangelands, is presented in Figure 1.2. Key aspects of this system are included in the measure of biological integrity of the study sites. This concept forms the basis for the ecological measure of habitat condition presented in part III of this PhD thesis.

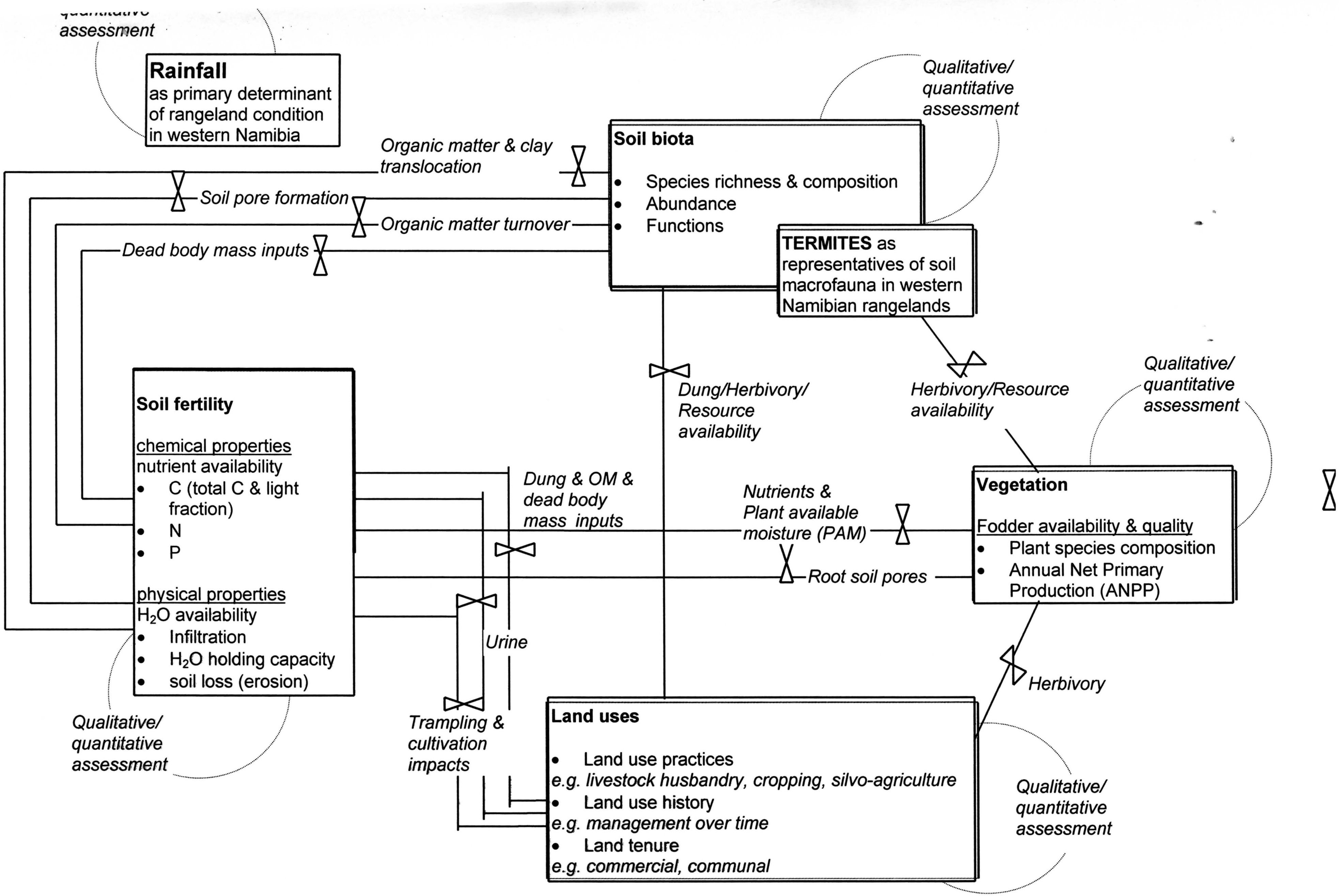

Figure 1. 2: *Linkages that determine biological integrity in western Namibian rangelands – conceptual framework.*

Objective 1

To review the environmental and socio-economic situation in relation to rangeland management and desertification in the Huab catchment area in western Namibia and to establish profiles of the three selected study farms.

Key questions:

(1) What are the environmental and socio-economic factors underlying land use practices and rangeland management on communal and commercial farms in western Namibia?

a) How does the political history of Namibia and the environmental setting in the study area affect current land uses and management?

b) How can the long-term patterns of rainfall in the study area be described and how do these affect farming and land use practices in the study area?

(2) How do the three selected study farms differ in land use intensity as defined by land use, land use history and management?

(3) Which factors determine rangeland integrity at the communal farm Olifantputs?

Objective 2

To determine whether termites are suitable indicators of biological integrity in western Namibian rangelands.

Key questions

(1) What are the minimum sets of termite parameters that need to be measured and type of approaches that need to be carried out in order to use termites as indicators of biological integrity?

a) How can termite species richness, composition and relative abundance be reliably and efficiently determined?

b) Using data from a broad survey in western Namibia, are termite species richness, composition and relative abundance correlated with land use practice and land tenure. If so, how?

(2) Do measures of termite species richness, composition and relative abundance derived from in-depth investigations at Olifantputs prove to be suitable indicators of biological integrity?

a) Are termite species richness, composition and relative abundance correlated with environmental factors such as above and below ground vegetative biomass, total soil carbon and light fraction?

Objective 3

To assess the biological integrity of three selected farms in western Namibian rangelands and to determine the effect of land use practices and land tenure on their biological integrity.

Key questions

(1) What minimum set of indicators, including termite, soil and vegetation parameters, provide a reliable reflection of biological integrity in western Namibian rangelands?

a) Which set of factors, including termite, soil and vegetation parameters, is to be measured in order to obtain a robust model for the assessment of biological integrity?

b) Do total soil C, N and P decrease with increased land use intensity and with a move from commercial to communal land tenure?

c) Will fodder availability and quality decrease with increased land use intensity and with a change from commercial to communal land tenure?

d) How do termite species richness, composition and relative abundance vary with land use practices and land tenure?

(2) How do the farmers perceptions of rangeland integrity compare with scientific measures?

a) Do communal and commercial farmers assess the status of their land for grazing potential, livestock production, biological integrity? If so, what methods do they apply?

b) How do the farmers categorise the status of six selected study sites?

c) Are the indicators used by farmers for the assessment of grazing potential, livestock production and biological integrity different from the ones used in the scientific approach?

d) If the farmers assess the land based on their own, traditional qualitative measures, are the results similar to the results obtained by quantitative measurement?

PART II

CHAPTER 2

BACKGROUND TO THE STUDY AREA AND SITE SELECTION

2.1 Damaraland: the historical and socio-political background

In the context of this study it is important to realise that the Namibian environment and also the study area in Damaraland have been under human influence and land use for thousands of years. Life forms and land uses have differed between societies in the past and still do so today.

Early inhabitants and land uses

Western Namibia, despite its arid and highly variable climatic conditions and the hostility of the desert environment, was inhabited by prehistoric societies. Evidence of hunter-gatherer and early nomadic pastoralists have been found throughout the western part of Namibia (e.g. Sullivan, 1998; Kinahan, 1991). Khoe San speaking people, for example, have lived along the Kuiseb river as well as in the mountainous escarpment for centuries and relics of human presence in the form of rock paintings are found across the central Namib and what is known as Damaraland (Sandelowsky *et al.*, 1979).

Nomadic Khoe speaking pastoralists and herders in the central Namib and adjacent areas are thought to have been present for at least the past 2 000 – 4 000 years (Sullivan, 1998; Sandelowsky, 1977; Kinahan, 1983, 1990, 1991). They exploited the opportunities presented by a variable environment through extensive mobility, aggregation at focal settlements during rain periods followed by dispersal in response to resource scarcity in dry periods. Stock posts were linked to larger settlements situated several kilometres away (Kinahan, 1983, 1991, 1993). The Bergdamara, a Khoe San speaking people, who inhabited the Namib transition zone in western Namibia, reportedly inhabited the plains in western Namibia keeping many cattle as well as collecting veld fruits for subsistence (Lau, 1987; Sullivan, 1998). In about 1550, OviHereros are reported to have moved to Kaokoland from their eastern grazing areas. They also moved further south with their cattle, migrating into areas in which Khoe-San speaking people such as the Bergdamara were living.

The homelands

In the 19th century, when European settlers and farmers invaded native southern Africa, the Rhenische Mission established what later constituted the apartheid homelands. What was initially created as a support system and retreat for the local pastoralists, was later defined as exclusive reserves. Rules against the collection of veld fruits, hunting of game and keeping of livestock were implemented and zones were declared for use by European settlers only. The areas provided by the Rhenische Mission in which the African population retained their land use rights were the only subsistence strongholds of the people. Work opportunities were only on the white farms and enterprises. Fransfontein was one of the first reserves to be established in 1898 (Adams & Werner, 1990).

During the German colonial rule, the police zone, which effectively separated the northern and southern part of Namibia was implemented. Within the police zone in the south, direct administrative control allowed for the settlement of Europeans and the confinement of the non-labouring indigenous population to reserves. The German-Herero (1904-1907) war was a brutal result of years of confiscation of property and alienation of the rights of Africans by the German colonialists. A great majority of Herero and Nama people were killed during this war and the Damara people were also dramatically decimated.

After the first world war Germany lost her colonial "rights" to the South African UN Mandate after which South Africa's Native Land Act of 1913 guided segregation politics in Namibia. After 1922 the proclamation of additional small reserves (less than 5% of the land for 90% of the population) was instituted during a "first schedule" of resettlement. Fransfontein, Okombahe and Sesfontein were set aside for Damara-Nama people and the Otjihorongo reserve was created in the same area for Herero people. Later, under the "second schedule" of 1925, Otjihorongo was incorporated in so-called Damaraland with the existing Nama-Damara reserves (Adams & Werner, 1990). Black people were only allowed to settle and farm in the areas set aside for them. White farmers were encouraged to move into the "vacated" areas and to establish commercial farms either on lease or freehold titles. The success of the ensuing national Land Settlement Programme in terms of increases in the white farming population is astonishing: between 1913 and 1962 the number of surveyed and settled farms increased from 1 138 to 5 500. The white population rose from 14 830 to 72 000 and the total area occupied grew from 11 490 000 to 39 812 000 hectares (First, 1963; Sullivan, 1998; Rhode, 1994). The establishment of commercial farms was supported by the Administration and subsidies of various kinds were granted to the white farmers.

The reserves were governed under the overall control of a white commissioner, but the day to day running of affairs fell to a "reserve board" comprising the "paramount head", two headmen and councillors from each area of the reserve (Koehler, 1959). The traditional leaders often acted as puppets of the SWA Administration.

Most of the active labour population, young and middle aged man, left the reserves to seek employment in the urban areas, the mines or as labourers on adjacent farms and enterprises. Mainly women, elders and children remained in the homelands, dependent on monies sent from their spouses and on subsistence farming from a small area of land.

After the Odendaal commission

In 1962 the Commission of inquiry into South West African Affairs, better known as the Odendaal commission investigated the land requirements of the main ethnic groups residing in the protectorate. Based on the recommendations made by the commission in the early 1970s, separate development laws for the various homelands under segregation politics were put into place. (Adams & Werner, 1990).

In western SWA Damaraland, extended boundaries were created to include the Fransfontein, Okombahe and Otjihorongo reserves together with Sesfontein to the north of the red line, a relic of the early police zone (Eirola, 1987). Adjacent commercial farms, which were mainly deserted by their former white owners due to difficult farming conditions, were incorporated into Damaraland. Altogether an additional 4 million hectares of surveyed and fenced commercial farms, unsurveyed state owned land and game reserves (Odendaal Report, 1964), were added. A total of 223 previously white owned farms, settled only since the 1930's and covering an area of 1,872,794 ha were included (Odendaal Report, 1964; Rhode, 1994; Sullivan, 1998). These farms varied in size from 4,000 to 25,000 ha, averaging about 8,500 ha (Odendaal Report, 1964). Typically these had been extensive cattle and small stock enterprises dependent almost entirely on black labour. The arid environment and the sparse grazing meant that stock had continually to be distributed and moved over considerable distances between camps and water points. By the time of the implementation of the Odendaal plan many of these farms were already abandoned by their white owners and tenants or used as grazing reserves for farming enterprises based closer to the central commercial areas. Compensation payments were made by the State, often to the benefit of white farmers, who had left the area anyway due to unfavourable economic dependencies on South Africa, (Kambatuku, 1996; Rhode, 1994). After allocation of these "redundant" farms to the black population, an average farm allocation per family amounted to approximately 250 ha per family compared to approximately 8,500 per white farm previously (Rhode, 1994).

During the time when the Odendaal Plan was implemented there was no traditional land allocation system in place. In the seventies and eighties a form of "traditional" leadership was created through the establishment of twelve wards, each with ward heads and councillors, however all were under strong surveillance from the South African Administration. These homeland politics which were instigated, created dependency especially because of the flow of economic resources through the South African government.

Although the increase in total land area especially of the Damaraland homeland may look impressive, its agricultural potential is limited. An acute lack of surface and underground water renders large portions of land useless for stock and arable production. Poisonous plants and deficiencies in base elements, both in the water and soil, have been additional problems in the areas opened up for settlement. No less than 87% of Damaraland, for example, falls within the desert or semi-desert agro-ecological zone, while 40% of Damaraland lies in the Namib Desert.

In the past, fixed carrying capacities were also calculated for the communal areas (Adams & Werner, 1990). The Five Year Plan for the Development of the Native Areas (Windhoek, 1966) recommended a total carrying capacity of 182 454 LSU for the entire Damaraland (Adams & Werner, 1990). In the late 70s a carrying capacity of 84 000 LSU was recommended. The SWA Administration publicised that land degradation was happening in the communal farming areas due to mismanagement by the local farmers. This notion is often still maintained. There is evidence that, for political reasons, the initial carrying capacity suggested for Damaraland was exaggerated and natural climatic variability, suggesting a much lower carrying capacity in dry than in wet years, was not taken into account.

Post independence

After the independence of Namibia in 1990, regional boundaries were re-drawn in 1992 in an effort to neutralize the apartheid past. Damaraland was then divided between the Erongo and Kunene regions. Now that central government and state ownership rule, the tribal leadership is becoming increasingly more symbolic, particularly since no customary or traditional laws are in place. However, overall, Damaraland retains its social, economic and administrative identity and recent decentralisation, development and land policies are aimed at re-strengthening the regions.

Current development plans for the regions also affect the farming and agricultural sectors. After independence there was the notion that the land question did not primarily refer to an absolute shortage of land in the region but more to a lack of infrastructure to utilise land efficiently (Adams & Werner, 1990). Subsequently, a number of boreholes were drilled to make optimum use of the available grazing in the area, which led to controversial views on grazing and land management practices. Increasing pressure on the land and increasing competition for available pastures were observed. Indications were that poorer communal farmers were becoming marginalised, and that richer stock owners were ‘encroaching’ on the land available to poor pastoralists (Adams & Werner, 1990). Mention has also been made that formerly “saved” emergency grazing areas are used earlier in the season.

It can be concluded that pastoralists have used the study area for centuries. However, it becomes also clear that the intensified land-uses today may put great pressure onto the natural resources available in this arid environment.

2.2 The Huab catchment – environmental background

The catchment of the Huab river (Figure 2.1.), one of the major westward flowing ephemeral rivers in Namibia, was selected as study area for this project. Within catchments, environmental interactions and connections can have profound effects both on water and rangeland resources. Vegetation clearance in the upper reaches of a catchment may, for example, lead to rapid run-off of surface water after rainfall. Soil erosion may be a result, reducing the potential for regeneration of vegetation. Rapid water run-off may also impair the ground water recharge of aquifers, leading to the lowering of the ground water table. Jacobson *et al.* (1995) point to the importance of catchments for sustainable development in western Namibia.

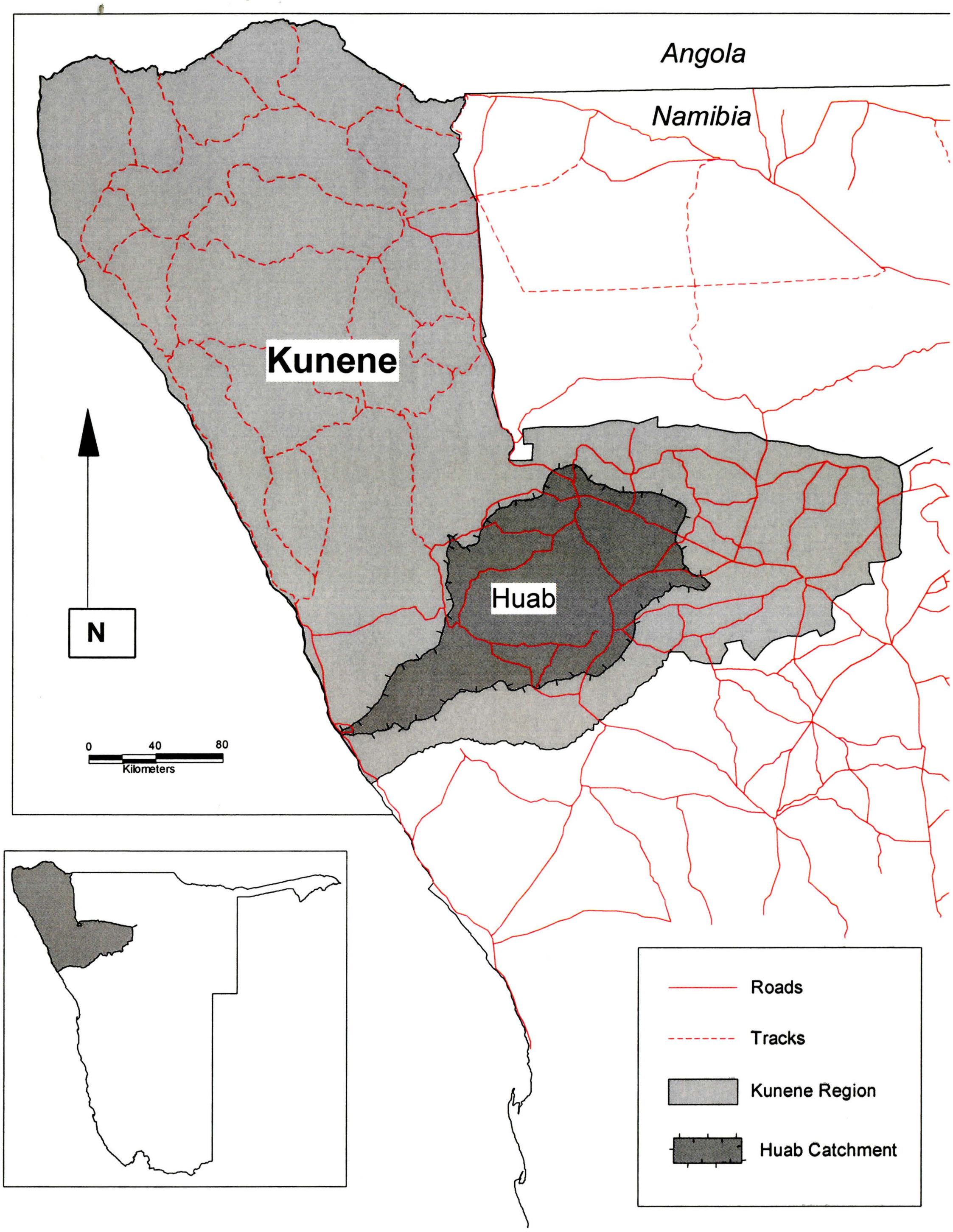

***Figure 2.1**: Huab Catchment: geographical situation in Namibia*

The location of communal and commercial farms in the catchment is shown in Figure 2.2. It is apparent that the communal farms are situated more to the west, towards the coast, where the rainfall gradient is declining (see Figure 2.5.)

In all maps the three farms Weerlig, Olifantputs and Halt, indicate the main study sites. The additional farms, Grootberg, Olifantwater, Waterval and de Riet were the Napcod pilot sites and the research described in chapter 5, a termite survey, was conducted at these sites.

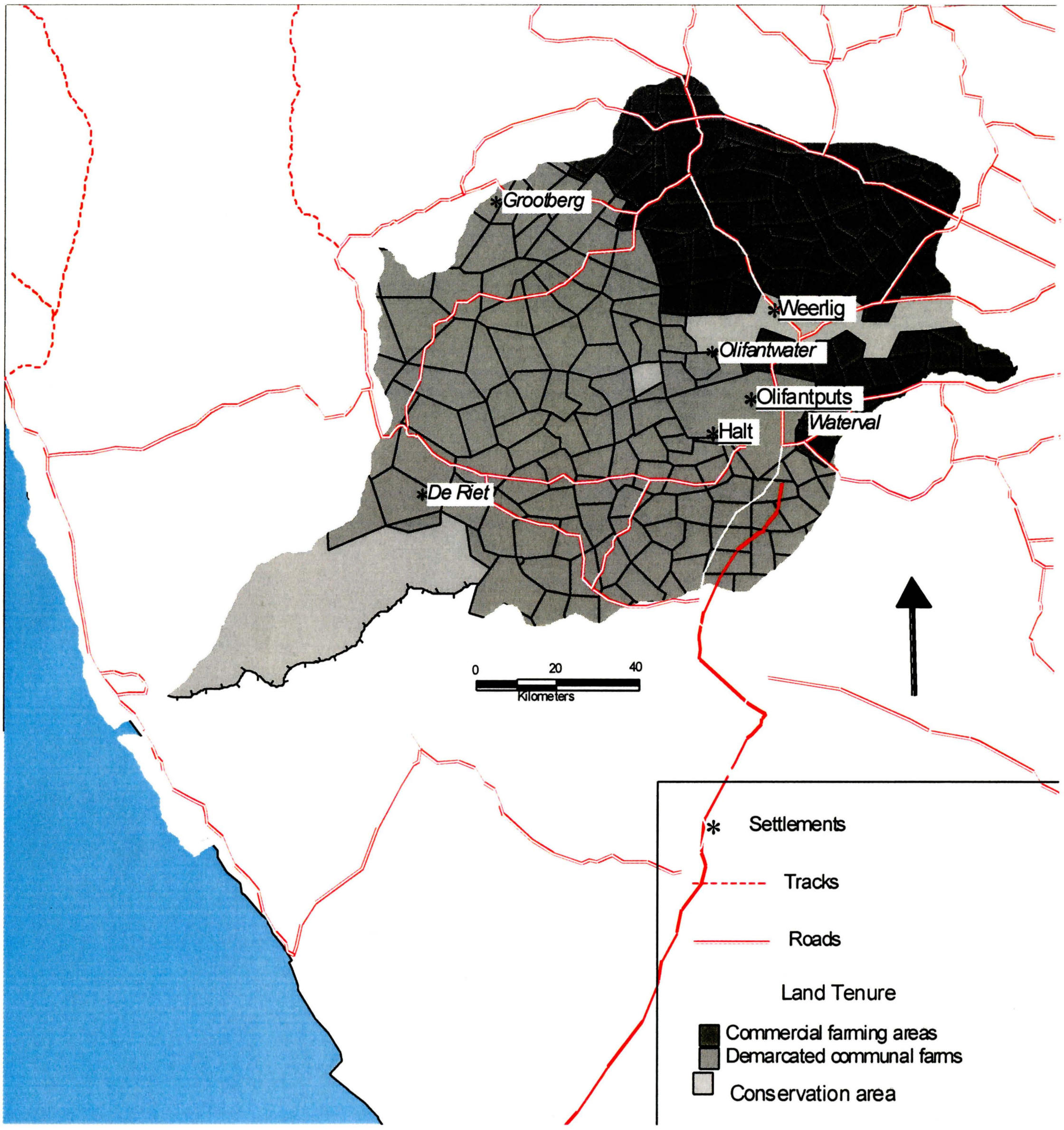

Figure 2.2: *Huab Catchment: communal and commercial farming areas*

Environmental background data for the catchment are best illustrated in the form of maps. In the following, vegetation biomass distribution (Figure 2.3) (after Mouton, 1997), underlying geology (Figure 2.4), as well as coarse-grained rainfall distribution patterns (Figure 2.5), are presented.

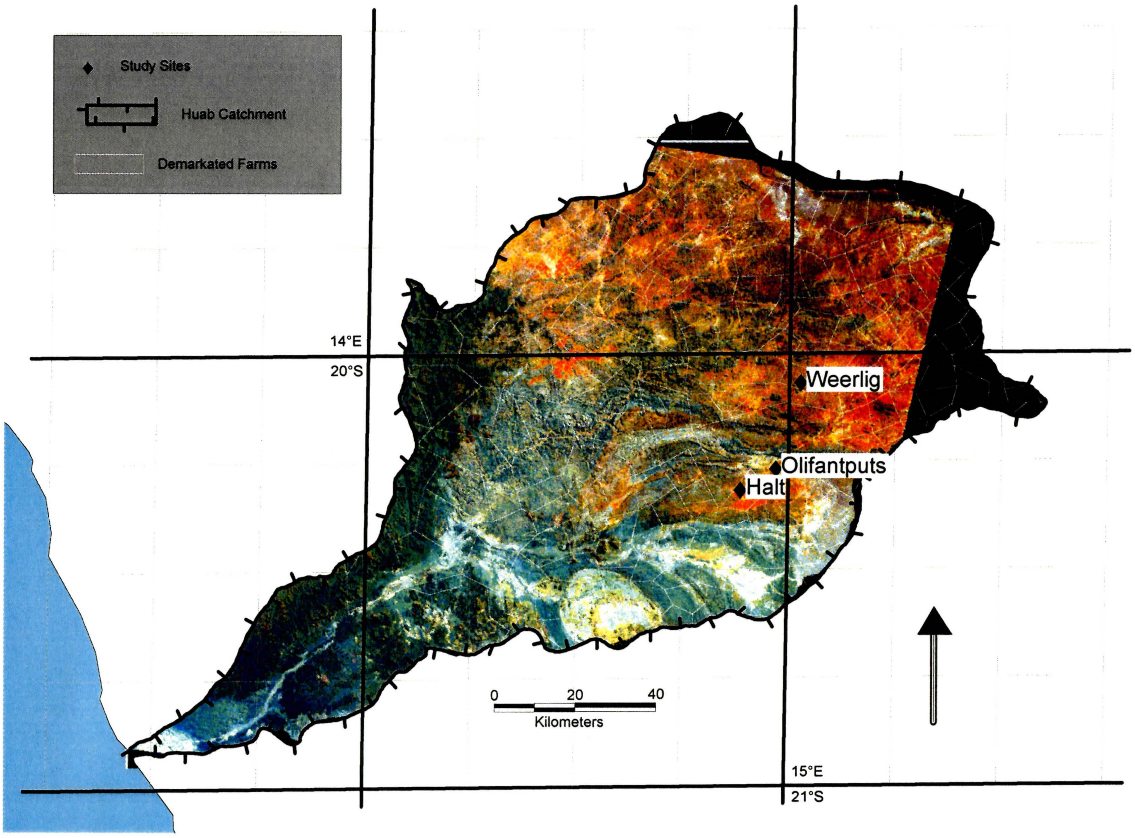

Figure 2.3: *Huab catchment: Landsat TM (1996). Green color codes represent low vegetative biomass, red and yellow represent a higher reflectance of vegetation, thus a higher biomass.*

Vegetative biomass distribution in the catchment (Figure 2.3) strongly follows the rainfall gradient within the catchment (Figure 2.5.). The three study farms are situated relatively close to one another and vegetative biomass production can be expected to be relatively similar, although dependent on local rainfall distribution patterns. The farm, Weerlig, might be slightly wetter, being situated further inland.

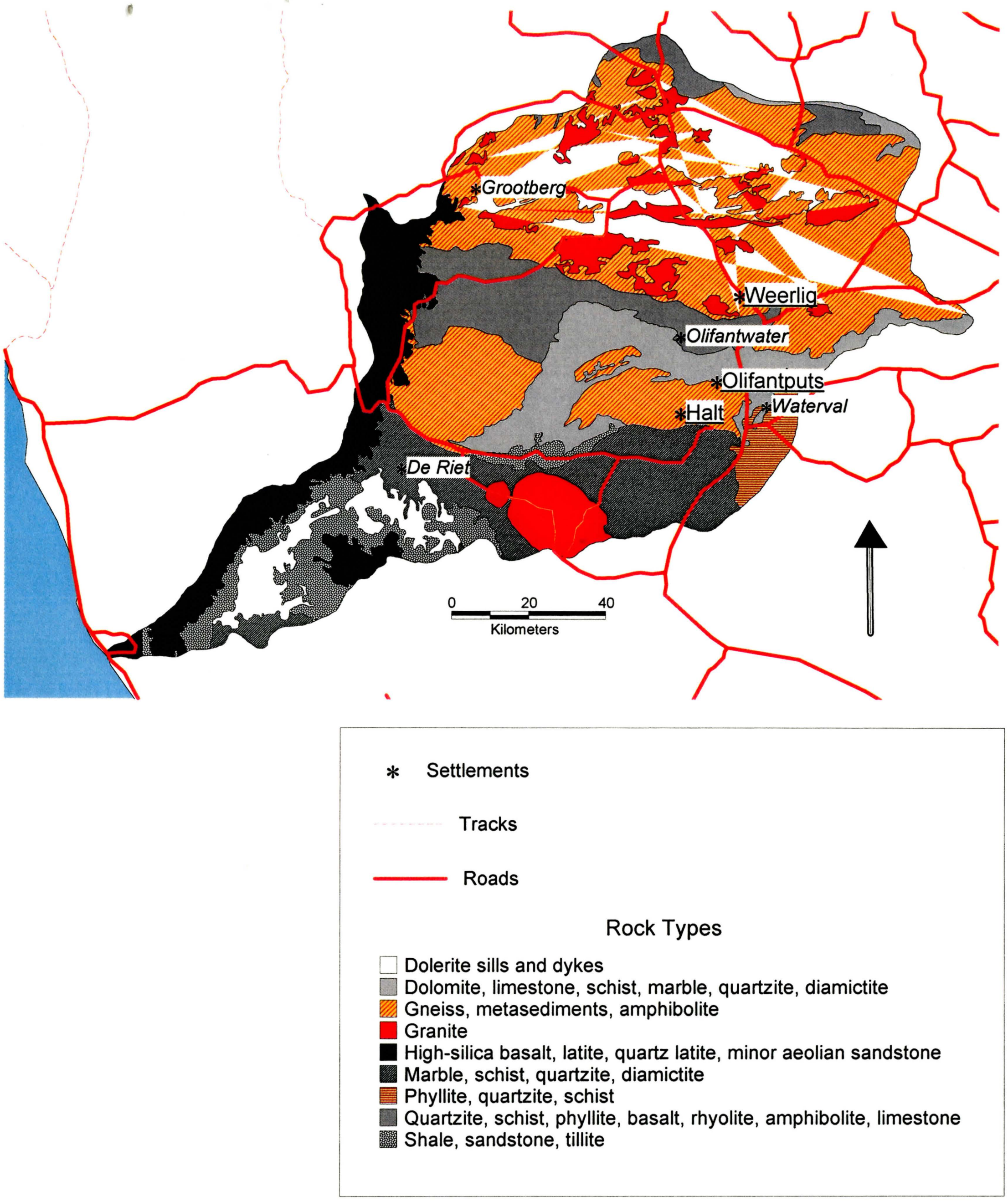

***Figure 2.4**: Huab Catchment : Geology*

The three study sites are situated on similar parent material, which is predominately made of gneiss. In arid environments the parent material is the dominating factor determining soil formation and soil fertility. Consequently soil properties at the three study sites could be expected to be similar. (Chapter 8).

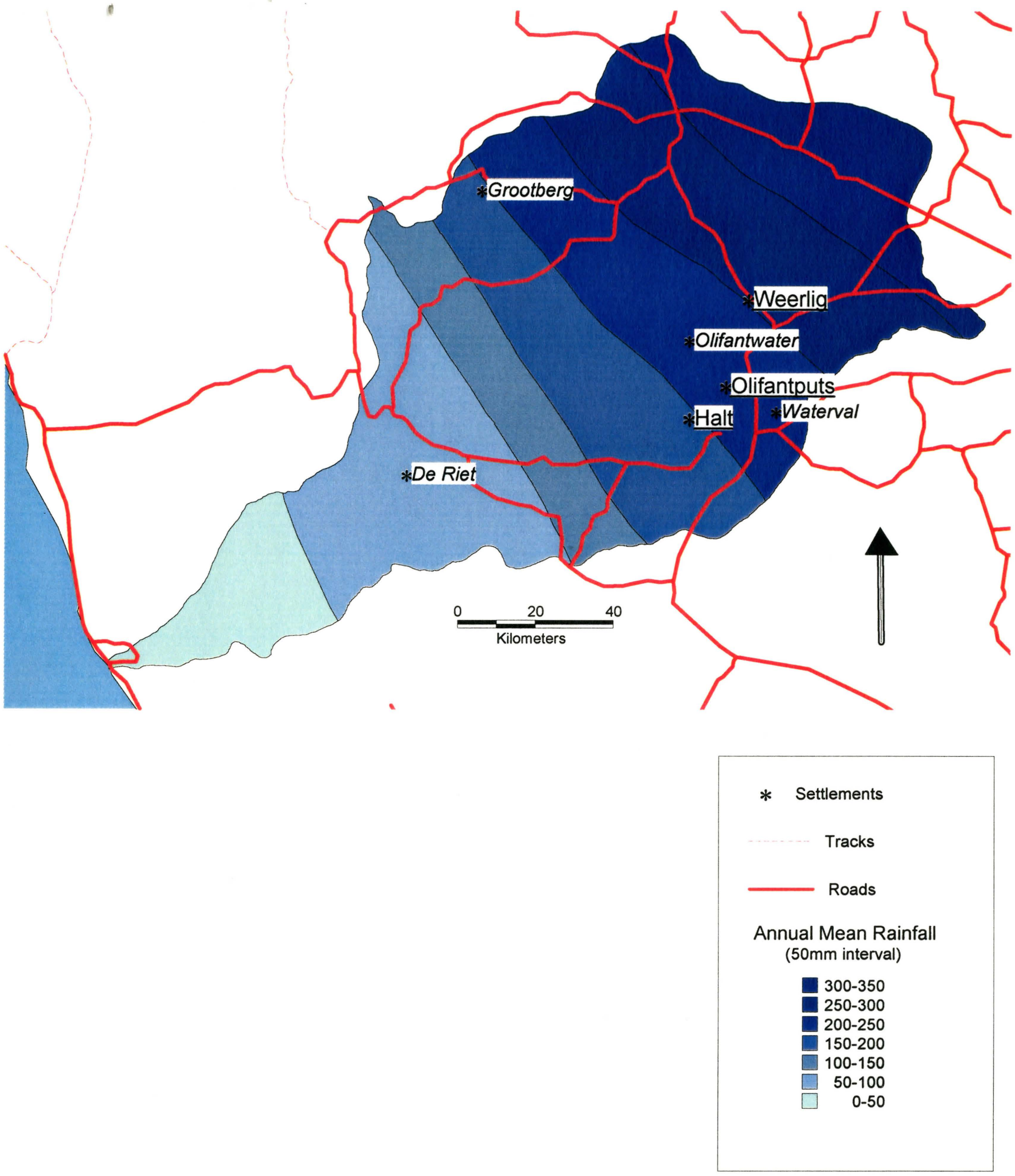

Figure 2.5: *Huab Catchment - annual mean rainfall, interval 50mm*

The three main study sites are situated in an area of a relatively similar range of 150-250mm mean annual rainfall. Although mean annual rainfall is not a particularly descriptive way of expressing the extreme variability and patchiness of its distribution, it gives a feel for the magnitude of rainfall expected. In-depth investigations of the nature of rainfall in the Huab catchment based on the analysis of data from nine rainfall stations were done by Zeidler & Olszewski (unpubl.) and will be published separately. However, a few main points on the rainfall situation in the study area will be drawn from the data:

The climatic conditions in the study area seem to suggest that agricultural practices other than small stock farming are generally not suitable. However, even Small Stock Drought (SSD), periods without rainfall that would allow for grass production for more than 80 days after an initial productive rain, is a common occurrence. The spatial and temporal distribution of rainfall suggests the need for adaptive management practices such as nomadism and migration to allow for optimal resource exploitation and conservation. These are "normal" practices among most farmers (see chapter 4) and have been observed by various authors working in adjacent areas (e.g. Bollig, 1997; Sullivan, 1998; Rhode, 1994).

As far as Namibia is concerned, several variations of the effects of El Niño can be identified (Olszewski, 1996). Beginning with the very dry El Niños of 1924, 1964 and 1983, wetter varieties, 1931, 1940 and 1958, for example, have occurred. However, a problem with El Niño years is that rainfall precedes the agricultural season and therefore harvests are sometimes poor. Extremely high temperatures and high evaporation often accompany these early rainfall events.

The 1934 rainfall year was an exceptionally good one for Namibia, which is sometimes referred to as a "replenishment" year, allowing for recharge of underground aquifers. Such years of good rainfall are more of an exception than the norm and should be regarded as such. It should also be noted that the major influx of white settlers to the area took place after this fantastic rainfall event. By the sixties, many of these farmers had moved from the area due to "relatively" deteriorating rainfall conditions.

2.3 Partner selection & study sites in the Huab catchment

The main assumption underlying the study site selection is that all sites are similar in their geological characteristics and therefore in the parent material that determines soil formation. Therefore, originally, soil conditions have been similar at the sites. Differences in measured soil characteristics today, can be interpreted as changes, which occurred during the shorter-term biological time horizon. This assumption is crucial to the study and differs from other studies, which have attempted to compare results from today with baselines established earlier. The problem with such comparisons over time is that especially for communal areas no comparative data are available and often the methodologies applied do not allow for comparison of the data.

Farms and farmers with different backgrounds, including representatives from the communal as well as commercial farmers in the area, were part of this study. They were chosen firstly because they farm under different land tenure conditions that place specific land-management opportunities and constraints on them. Secondly it is likely that the way the farmers perceive the habitat as well as land-use intensity might differ.

Three farms were selected for this research: Weerlig, Halt and Olifantputs.

Olifantputs is one of five partner villages of Napcod II, situated in the communal farming area of the former Fransfontein reserve. A good and interactive relationship has been established between the Napcod programme staff and the villagers and the interactive involvement of outside researchers could be integrated into the programme's envisaged process of information and knowledge sharing. The Napcod programme has initiated the establishment of research activities based on Participatory Rural Appraisal (PRA) methodology and baseline data on social issues as well as on the use of natural resources.

A number of people from each farm were involved in the research process because in the communal areas the decision-making process with respect to land-use management does not reside with only one designated farmer. Also farm/livestock owners sometimes live in an urban setting and only visit the farm occasionally. The herdsmen, hired personnel or family members, carry out day to day management such as selecting the grazing area. However, it is ultimately the farm/livestock owner who takes decisions about matters such as stocking numbers.

The three farms were chosen for their relative similarity of prevailing soil and vegetation types. The soils can generally be described as sandy, red Arenosols, in some areas bordering on Lithosol types (von Harmse, 1978). The dominant vegetation type is characterised as Mopane savanna (Giess, 1971; Scholes, 1994). Vegetation biomass production across the Huab catchment (Figure 2.3), one of the major ephemeral riverine systems situated in western Namibia (Jacobson *et al.*, 1995) in which the study sites are situated, is linked to an increasing rainfall gradient from the west to the east (Mouton, 1997) and is extremely variable from year to year, depending on local rainfall events. The study sites fall into a similar rainfall bracket with mean annual rainfall between 150-250mm (Figure 2.5) and according to other sources that take the variability of rainfall into consideration, a rainfall range of 179 - 587mm per year (Dealie *et al.*, 1993). Local variability is significant and should be monitored on site. Overall the three farming areas are characterised by similar ecological background data, but different land-management systems and stocking rates (chapter3). Farm Weerlig is under commercial land-tenure, whereas Olifantputs and Halt are communal farms. The later farm is a so-called Odendaal farm, which was under commercial ownership until the early sixties before being made available for communal farmers. Olifantputs is the largest community with 13 households. Stocking numbers and management practices varied between sites. This selection of study sites allows for comparison of habitat condition between sites of different land-use history and land-use intensity.

At each of the farms two study sites were chosen - one site with low and one with high land-use intensity. The site selection was based on the resident farmers' subjective perception of land-use intensity. All study sites were situated in the bottom of the valley. At Olifantputs for example, the sites were chosen on the recommendations of two of the older men, Festus Hamukwea and Frederick !Nanuseb, who pointed out one area close to the village which was heavily grazed and was a main pathway for the livestock on the way to the waterhole situated within the village. The low intensity site, situated approximately five kilometres from the village and close to the border of the neighbouring farm, is, according to the two informants, too far away from the borehole to be suitable for more permanent grazing by the cattle. This grazing ground is apparently only used in extreme periods at the end of the dry season.

At the farm Halt the resident herder selected the two sites in a similar way.

Danie van Vuuren, the owner of Weerlig, maintained that on his farm all sites were managed under similar intensity because he practised rotational grazing. However, based on personal assessment, one camp near the farmhouse was chosen as the higher impact site, and a low impact site was situated within a camp a few kilometres away. For the final assessment of range condition, all sites were treated in a similar way and the ranking of each site was on an individual basis. The low and high impact classifications were only tools in selecting sites with the help of the local farmers.

PART II

CHAPTER 3

LAND USE HISTORY AND LAND USE INTENSITY ON THE THREE SELECTED STUDY FARMS

3. The Farms

In the following sections, farm histories, current and past land uses and indications of land use intensity manifested in longer-term records of stocking numbers are described for the three study farms. The information and data were derived from records available from the archival files (Windhoek) (Manuel, 1997) and from the State Veterinarian in Outjo, as well as from interviews with the farmers, PRA activities and a questionnaire. The data from the questionnaire are included in a database (Appendix 1) and references in the text are made to the database entries. In-depth investigations conducted at the farm Olifantputs on management practices and constraints are provided in Chapter 4. Some baseline information was obtained from the National Archives in Windhoek.

3.1 Weerlig

Farm background

Weerlig is a commercially owned farm, situated approximately 40km north of Fransfontein the former district town of Damaraland South. The area of the farm is 5,032 ha.

Mr. S.P. van Vuuren applied for the farm Weerlig in 1920, and a temporary lease agreement for five years was formulated. The van Vuurens purchased the farm in 1944. Since this time the farm has been family property. Today D.P.J. van Vuuren, S.P. van Vuuren's grandson, owns the farm.

The records in the Archival files indicate that already in the early '40s the van Vuurens realised that the farm Weerlig was not appropriate for large scale cattle farming but that sheep farming was more appropriate. A first farm dam was constructed at the time, and others were to follow. In the early stages two dwellings were established.

Today 14 water points are maintained at Weerlig, drawing on a ground water aquifer. The farm is divided into 30 paddocks and rotational grazing management is practised. Four families are living on the grounds of the farm, including the van Vuuren family and the households of his labourers. Up to 17 people stay permanently at Weerlig. Mr. Van Vuuren owns a second farm elsewhere. However, in dry years such as 1998 Mr. Van Vuuren had to move his livestock to other emergency grazing areas.

Land use intensity

In June 1998, a questionnaire was used to establish current stocking rates (Table 3.1) as well as to track sales and purchases of stock (Appendix 1). In June1998, four times as many small stock were held at Weerlig than large stock. Table 3.1 indicates how the ownership of livestock is distributed on the farm. Most cattle and all sheep and horses belong to Mr. Van Vuuren and his family, all goats, two cattle and all donkeys belong to others living on the farm, mainly the foreman. No animals were owned by absentee farmers or "emergency grazers".

Table 3.1: Livestock ownership at Weerlig (June 1998)

	Weerlig			
	Total	Decision maker	Others in household	Others elsewhere
Cattle	152	150	2	0
Goats	100	0	100	0
Sheep	503	503	0	0
Donkeys	10	0	10	0
Horses	10	10	0	0
Pigs	0	0	0	0

During 1997/1998 Mr. Van Vuuren bought only 10 sheep. According to the questionnaire (Appendix 1) no sales were made at all. However, off-takes were relatively high, due to slaughtering, predators and stock theft.

Mr. Van Vuuren practises rotational grazing, putting equal grazing pressure on all his paddocks.

Stocking numbers for the years 1990-1998 from annual livestock censuses were provided by the Ministry of Agriculture, Water & Rural Development (MAWRD) and are displayed in Figure 3.1.

The recommended stocking rate[1] for Weerlig and adjacent farms is 1 LSU[2] per 25ha. Hence for a farm the size of Weerlig (5,100 ha) a stocking rate of 204 LSU or 1,224 SSU is recommended. From the stocking rate data available from MAWRD it seems that the farmer at Weerlig continuously overstocks.

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1 There is information on how the recommended stocking rates were derived. However these are the values MAWRD uses as a guiding value.

2 According to the Agricultural Extension Services 1 LSU (Large Stock Unit) is calculated at 400kg live weight and 6 SSU (Small Stock Units) are calculated as 1 LSU.

Stocking numbers versus CC

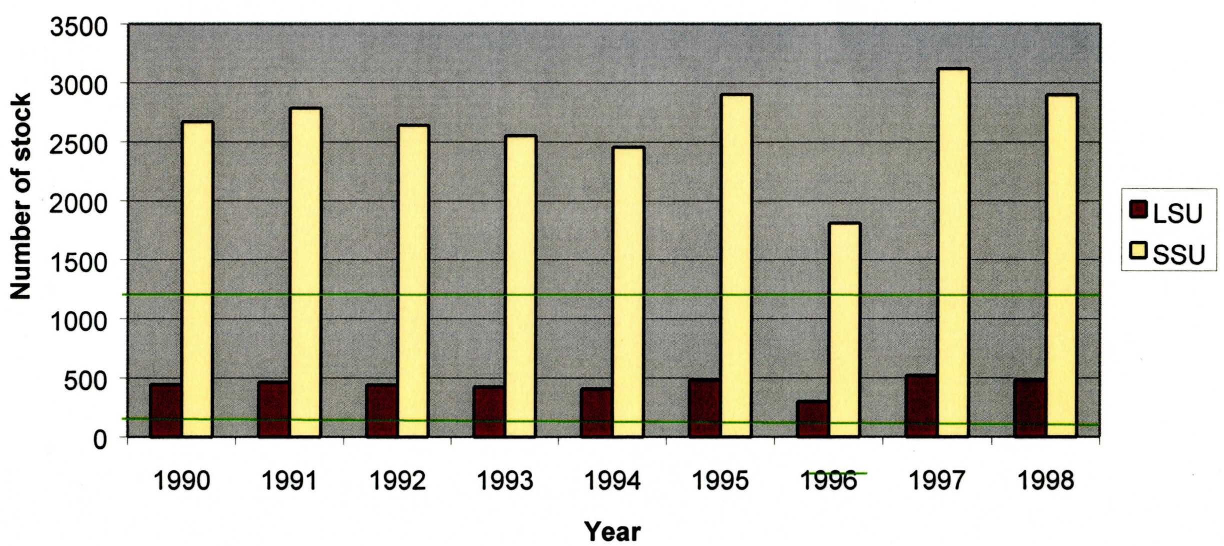


***Figure 3.1**: Weerlig stock vs Carrying Capacity (CC) 1990 – 1998; the line (-------) indicates the carrying capacity for the farm (determined by MAWRD). The upper limit is calculated for SSU and lower limit for LSU. In practice large and small stock are mixed.*

Decision making process

Mr. Van Vuuren is the only real decision maker on the farm. His farm workers do report observations they make on the farm, however they do not often take final decisions.

3. 2 Halt

Farm background

Halt is situated at the western fringe of the communal area of Fransfontein. In 1950 farming rights were granted to Mr. Pearson, who established Halt No. 379 as a commercial farm. The farm covered an area of 5,634 ha.

In the Archival files it is recorded that in his early days Mr. Pearson made several attempts at drilling boreholes for ground water. Of 13 placed boreholes only two had good flow. Mr. Pearson fenced five camps. Halt was already used as an emergency grazing area under the early management of Mr. Pearson who had applied to the land boards for an emergency grazing license. It should be mentioned that in the Archival files mention is made at various occasions that no additional stock (e.g. for emergency grazing) were allowed on the farm due to low rainfall and comparatively high stocking numbers.

Today Halt is inhabited and used by three households. Mrs. Dina Giel is the senior farmer who “inherited” the farm from her father. Mr. Simon Awaseb and Phillipus Ganeb head the two other households on the farm.

Three waterholes of which two are mainly used for human consumption and one for the livestock support the farming area. The farm is divided into three paddocks, which were all in use in June 1998.

The three individual households are composed of six, six and five members respectively, which were all living on the farm for most of the time.

Land use intensity

The data obtained from our investigations show that cattle numbers were low at the time of the census in June ’98, 34 cattle were recorded (Table 3.2), however, numbers increased dramatically after June, when emergency grazers were moved onto the farm (Giel, pers.com).

From the numbers collected, it becomes apparent that the stocking rate is generally low, however, it shoots up when other farmers in the area need emergency grazing. Farmers at Halt reported that compensation might be paid by outside farmers who bring their stock in for grazing.

The three camps at Halt are used for some rotational grazing. However, the reports on how the different camps are put to use were not consistent amongst the farmers. Some said that the camps are changed every three months and others maintained that the animals are only rotated after six months (QHA1, QHA2, QHA3).

The data of the June 1998 survey, revealing current stocking rates as well as livestock sales and purchases of stock are presented in the Appendix 1 and summarised in Table 3.5. Most animals on the farms belonged to the decision makers and household heads, however almost 30% of all goats were owned by absentee farmers (Table 3.2). It should be mentioned that later in the season large numbers of cattle were moved onto the farm for emergency grazing (Dina Giel, pers. com.).

Table 3.2: Livestock ownership at Halt (June 1998)

	Halt			
	Total	**Decision maker**	**Others in household**	**Others elsewhere**
Cattle	34	31	3	0
Goats	242	151	28	63
Sheep	9	9	0	0
Donkey	17	8	3	6
Horse	7	4	3	0
Pigs	6	6	0	0

Stocking rates at Halt No. 379 are displayed in Figure 3.2. Cattle numbers maintained at the farm are relatively low, small stock numbers are reported to be more than 10 times as high in average. Horses and donkeys numbers, ranging between 31 and 61, seem to be fairly high considering that only three households are situated on the farm.

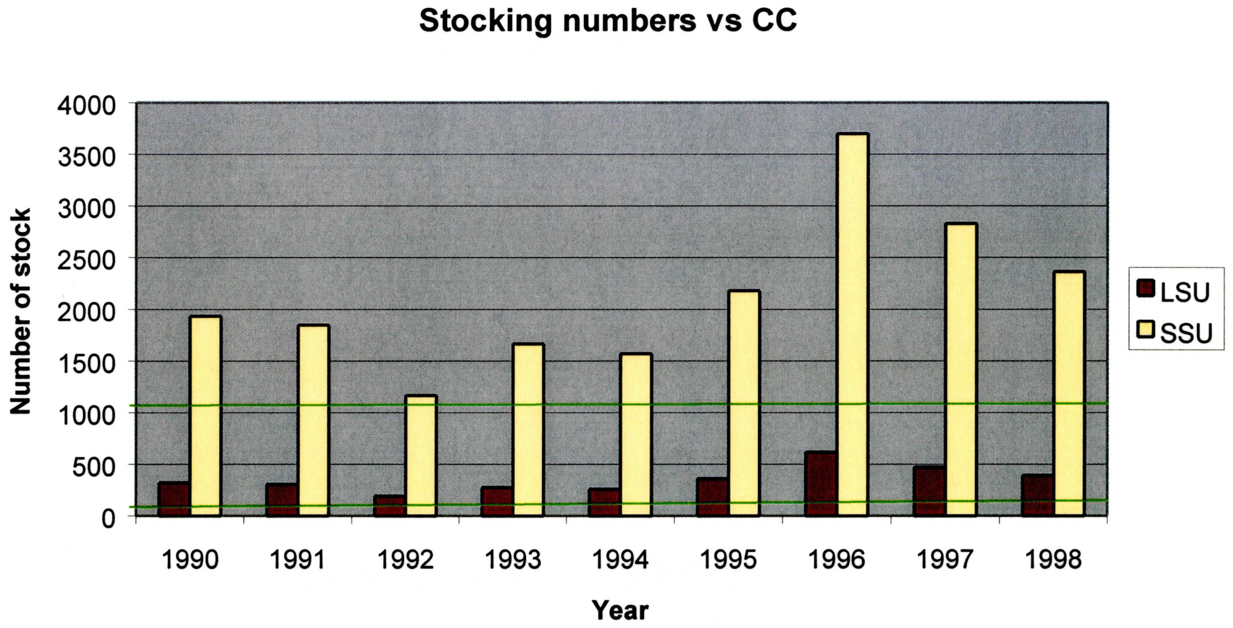


Figure 3.2: *Stocking rates and Carrying capacity at Halt; the line (-------) indicates the recommended carrying capacity for the farm (by MAWRD). The upper limit is calculated for SSU and lower limit for LSU. In practice large and small stock are mixed.*

According to MAWRD the recommended stocking rate for this region is 1 LSU to 30 ha. At a size of approximately 5,500 ha the recommended stocking rate for this farm is 183 LSU or 1,100 SSU. Stocking rates on Halt are above the recommended stocking rates for most years (Figure 3.2), however less so compared to the other two farms under investigation.

Decision making process

Mrs. Dina Giel seems to be the most senior decision maker at Halt. In the Awaseb household, the mother, a pensioner, is considered to be the decision maker. Phillip Ganeb is an absentee farmer working in Windhoek. His son looks after his animals and farm.

3.3 Olifantputs

See also chapter 4.

Farm background

Olifantputs is situated in the Fransfontein communal area, which was established as part of Damaraland in 1898. Mainly Damara-speaking people, but also some Hereros, settled in this area. Fanuel Amporo who chose the area for the good available grazing established the farm Olifantputs itself in 1953. There was no water accessible at that time. The first borehole was drilled in 1954 and a windmill was established in 1957. Since that time more farmers moved into the area and permanent settlements were formed (Chapter 4; Napcod, *unpubl.*). Today the village comprises 13 households with approximately 66 household members staying on the farm permanently.

Land use intensity

In order to develop a good understanding of how livestock management and decision-making works at Olifantputs, livestock numbers and other baseline data were collected at a household level, not only at farm level (Chapter 4). These data were produced by using a questionnaire and through facilitated interviews carried out with students communicating in the local languages.

The stock numbers derived from the questionnaires which were completed in June 1998 are displayed in Table 3.3) These data were collected after two years (1996 and 1997) of particularly good rainfall thus stock numbers were extremely high at that time.

Examining the livestock purchases, sales and losses in some detail (Appendix 1) shows that off-takes during the year 1997/98 were comparatively high. Altogether 132 small stock and 83 cattle were sold during the year, only few animals were purchased. Almost 10% of all goats were slaughtered during the year for own consumption. Many cattle and small stock were stolen, died of starvation or fell victim to predators. 61 donkeys were kept at the village.

Farmers resident at Olifantputs owned the largest number of livestock. Approximately 7% of cattle and small stock are owned by absentee farmers. (Table 3.3). However, on the household level some more detailed insights were obtained (Chapter 4).

Table 3.3: Livestock ownership at Olifantputs (June 1998)

Olifantputs				
	Total	**Decision maker**	**Others in household**	**Others elsewhere**
Cattle	457	406	4	47
Goats	1046	955	24	67
Sheep	205	196	0	9
Donkeys	58	44	10	4
Horses	8	6	0	2
Pigs	0	0	0	0

MAWRD staff determined stocking numbers at Olifantputs over the past years (Figure 3.3). Cattle numbers have increased since the 1992 drought and were highest in 1995. Small stock numbers vary a lot and were highest in 1994 following the drought of 1992/93 and lowest in 1996.

According to the MAWRD, the recommended stocking rate for this region is 1 LSU to 30ha. At a size of approximately 5,000 ha, the recommended stocking rate for this farm is 167 LSU or 1,000 SSU. According to the livestock census data of MAWRD, for the time period of 1990-98 farmers at Olifantputs continuously overstocked (Figure 3.3).

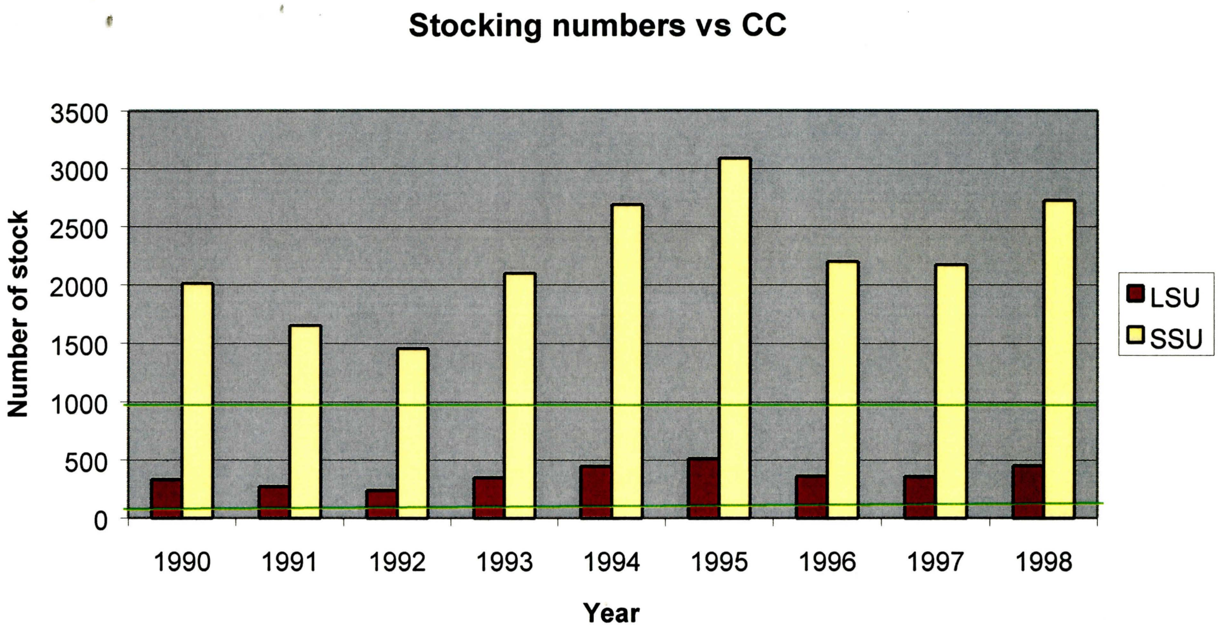


Figure 3.3: *Olifantputs stock numbers vs. carrying capacity (CC); the line (--------) indicates the recommended carrying capacity for the farm (by MAWRD). The upper limit is calculated for SSU and lower limit for LSU. In practice large and small stock are mixed.*

Decision making process

On a communal farm with 13 households, decision making processes are extremely complex (see Chapter 4).

3.4. Conclusions

All three farms are continuously stocked above the recommended limits. The fact that the recommended limit was higher per hectare at Weerlig than at the two communally owned farms, indicates an average stocking rate of 216% of the recommended limit at Weerlig (at 1 LSU per 30 ha) and 223% at Olifantputs and 194% at Halt (both farms at 1 LSU per 25 ha). Donkeys and horses have been excluded from these calculations, however their impact on the natural resource base could be severe through trampling as well as foraging and should be evaluated in future.

The carrying capacity concept has been thought to be useless in highly variable environments (e.g. Behnke et al., 1993; Scoones, 1995), where stocking numbers should rather be adapted according to the status of the natural resource base, depending mainly on the amount and nature of rainfall during the season (Hocking & Mattwick, 1993). In order to assess land use intensity and impact, annual stocking numbers should be viewed in relation to rainfall and grazing condition, and in a management and policy framework (various authors in Scoones, 1995). However, no unifying "formulae" are available at this stage which would allow for easy "calculation" of the expected impacts.

Table 3.4 shows substantial differences in numbers in our two data sources.

Table 3.4 LSU recorded at the farms by MAWRD (12/98) and a questionnaire based census (06/98)

	MAWRD (12/98)	Census (06/98)	% difference
Weerlig	483	251	52
Halt	393	76	19
Olifantp.	454	666	147

Comparing the LSU values provided by MAWRD for December 1998 and the questionnaire data from June 1998, it is apparent that at Weerlig and Halt the census recorded much lower animal numbers. The LSU numbers at Weerlig were in June only 52% of the numbers recorded by MAWRD in December. At Halt the numbers in June were only 20% of what was reported for December by MAWRD. This relationship was reversed at Olifantputs, were animal numbers (LSU) in June were 147% of the numbers counted by MAWRD in December. Emphasis needs to be placed on collecting reliable stocking numbers over time.

Livestock owners should do tracking of animal numbers on a regular basis to gain a better picture of the actual land use intensities. Dynamics of stocking numbers are extremely variable. Migration, presence of emergency grazers, purchases, sales, losses through predation, and theft, are all factors that influence the actual stocking rates (Table 3.5) with large fluctuations.

Table 3.5: Livestock add-on and take-off dynamics over a year (1997/98) at the three farms in relation to total stocking numbers in June 1998 – a summary of data from Appendix 1

				% of animal off-takes and add-ons (based on June total)						
		Total # in June 1998	*% absentee owned*	*bought*	*Sold*	*starved*	*slaughter*	*predated*	*stolen*	*TOTAL % off-take*
Weerlig	Cattle	150	0	0	0	5	0	0	8	13
	Goats & Sheep	603	0	2	0	0	8	7	18	33
Halt	Cattle	34	0	0	27	30	12	0	41	110
	Goats & Sheep	253	25	10	6	9	13	8	12	48
Olifantputs	Cattle	457	10(54)*	0	18	6	1	0	5	30
	Goats & Sheep	1251	5	2	11	3	9	5	7	35

* number in brackets would count cattle in households Hamukwea/Gertze as 200 owned by absentee farmer Gertze

On the communal farm, ownership of livestock as well the dynamics surrounding management decisions of which type of stock and how many stock to keep and whether to sell or purchase animals are made on a household level, not on a community basis. It therefore seems necessary to assess livestock numbers on a household level rather than on a farm basis to really understand the dynamics around the counted number of stock present.

Chapter 4 of this thesis is an in-depth study undertaken at the farm Olifantputs. It addresses some of the aforementioned issues because it seems important to understand such household level interactions and decisions to understand how management in communal areas works. It is equally important to identify where management problems lay, to be able to finally make recommendations for interventions. Also it will be the household level, which holds promising information for useful and practical indicators as well as monitoring systems of land uses and possibly desertification.

PART II

CHAPTER 4

LAND USES AT THE COMMUNAL FARM OLIFANTPUTS

It seems impossible to make statements on communally owned farms where, as in the case of Olifantputs, 13 different households use and manage the area. In the scope of this study it was decided it is necessary to look at mechanisms on the household level rather than seeking an universal "communal " explanation to understand the rationale behind decision making and management of the natural resources on communal farms.

As already pointed out in the literature review, the book "Living with Uncertainty" edited by I. Scoones addresses some of the organisational and institutional frame conditions that enable or hamper sustainable management of the range in arid environments. Such issues also need to be examined in the context of Olifantputs. An in-depth study focusing on socio-economic structures and dynamics at the village has been conducted (Napcod, *unpubl.*). This study will be used as reference material for the following section.

4.1. Introduction & methodologies

The methodological approaches varied a great deal and the type of information generated were in the form of notes from interviews, drawings, diagrams and matrixes derived with community members through PRA methods, quantitative data from physical counts and information provided through answers to the questionnaires. The different tools of, and approaches to, information gathering generated results which complemented each other and also allowed for triangulation of the information. Reference to the statements and information provided are given in parenthesis. The reference number given corresponds to the database which contains the computerised information from the questionnaires (Q reference), PRA activities (OP reference) and interviews (dated) (Appendix 1).

4.2. Olifantputs historic and demographic background

History of establishment

According to the oral history of Olifantputs (OP 43 & 44), the village was established in 1953 by Fanuel Amporo when the first permanent water source, a donkey-driven borehole, was established. In the following years a number of families settled in Olifantputs. Fanuel Amporo was the headman of the village, deciding on grazing and settling rights of those newly arrived. Today still, Amporo's family and descendants play a prominent part in local politics and decision making in the region. Many of the families staying at Olifantputs today share a long association with the village. Olifantputs presently comprises 13 households. These are (1) Amporo, (2) Bamm, (3) & (4) Gertze/Hamukwea, (5) Goagoseb, (6) Haraes, (7) J. Howoseb, (8) S. Howoseb, (9) Nanuseb, (10) Shiwana, (11) Tsawaro/Rutjindo, (12) Veverako and (13) Katjimune/Nerongo. According to an estimate by the villagers (OP80) 136 people inhabit Olifantputs and 66 people stay at the village most of the time i.e. 50% of the inhabitants stay on the farm only temporarily. This is largely due to a number of children attending boarding schools, and family members, mainly those of an economically productive age, seeking employment in the urban centres. Olifantputs, however remains "home" especially to the elders, and the village is the place for retirement.

Boundaries

Olifantputs is situated in the south of the former Fransfontein reserve. No physical village boundaries are in place, because fencing is prohibited in communal areas. However, the old fences demarcating the reserve, the remainders of a village fence (OP81 & OP82 & OP83) and the existing calf camp can be found. The area of Olifantputs is estimated to consist of 5 000ha (Murorua, pers.com). Olifantputs is surrounded by a number of neighbouring villages. The neighbouring villages are

Petrusfontein, Middelpos, Karates towards the north and Bampos in a southerly direction. Fransfontein lies to the east of the farm. (OP 93).

Community-based decision making structures

Jonas Howoseb, as village elder, was elected headman after the late Salomon Amporo passed away in the mid-eighties. Today other official village representatives and decision makers are Charlie Bamm, who is a councillor (Murorua, pers. com.) and Frederik Nanuseb, the secretary and Festus Hamukwea. In addition to the traditional community leadership, a Water Point Committee was elected to strengthen community structures and support community-based decision making, planning and resource management.

Household level decision making structures

Six households at Olifantputs are led by females, the remaining six by men (Appendix 1). The household heads and their spouses make most household decisions. Explicit decisions about livestock farming seem to be taken by individuals in the household who are not necessarily regarded as the household heads. For instance, in the Bamm household it is the sons that really seem to be steering household decisions. Similarly, in the Veverako household, the mother, Sarafina, is stated as a household head but it is in fact her children who own and make decisions regarding the livestock (QOP7).

4.3 Livestock and range management

Livestock farming has traditionally been the main activity at Olifantputs, in fact the village was initially founded as a cattle post. Livestock farming is the prime agricultural activity in the entire area, which from a climatic point of view, is not suitable for crop farming and plant cultivation (Chapter 2). However, a few rain-fed gardens are maintained, and the Headman, Jonas Howoseb, irrigates his garden. Livestock numbers at Olifantputs were monitored on various occasions during October 1997 to October 1998, however, the questionnaire based survey conducted in June 1998 provided the most detailed data (Figure 4.2; Appendix 1).

Livestock numbers presented here are the total number of animals present per household. They include livestock owned by the household as well as livestock that belongs to absentee farmers or were given to the household to care for. Numbers range from 0 - 205 head of cattle per household (Figure 4.1; Appendix 1). For goats the range is 0 - 240 head, and for sheep 0 - 76. It should be mentioned that the Hamukwea/Gertze household represents the same family and should, strictly speaking, be interpreted in this way. Ownership structures within one household are more complicated, and several family members have their own shares in the household herds.

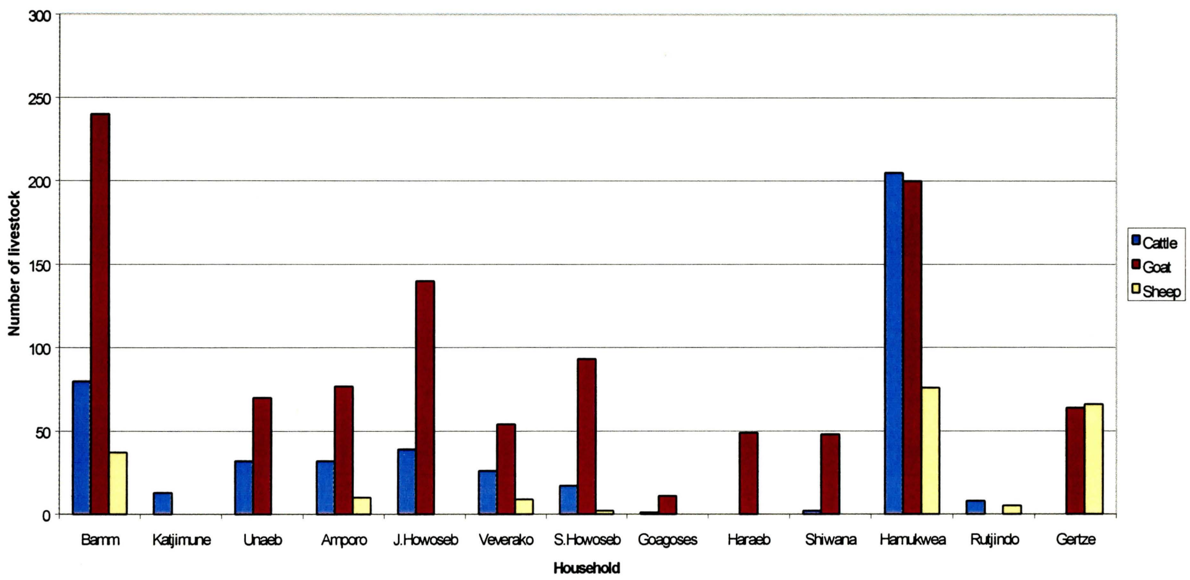


Figure 4.1: *Stock numbers per household*

The Hamukwea and Gertze households have almost 55% of all cattle and sheep on the farm. These two households also own 25% of all goats counted at Olifantputs in June 1998. The Bamm household also owns a large number of animals and with almost 250 goats has the largest herd in the village. Most of the other households keep below 40 head of cattle and some have fairly large goatherds with numbers ranging between 50 and 150 head. About five households keep very low numbers of animals, amounting to fewer than fifty altogether.

Absentee owned livestock

When inspecting the ownership of livestock at the village (Figure 4.1, Appendix 1), it becomes apparent that there is relatively little absentee stock. Forty-seven cattle and 23 goats and sheep are hosted, which amounts to about 7%, if Thomas Gertze is excluded.

Dynamics over the past 12 months

Overall it seems that the households at Olifantputs reacted to the prevailing dry conditions by selling some of their livestock during the 6/97-6/98 time period.

For some households the off-take numbers were relatively high in relation to animals owned, although total numbers were mostly below 20 head of cattle sold in the same period. Farmers Bamm and Hamukwea sold most livestock. However, in relation to their overall herd sizes these numbers are not particularly high. C. Bamm sold approximately 30% of his cattle, and a much lower percentage of his goats. F. Hamukwea sold approximately 15% of both his cattle and his goats. In relation to this the Rutjindo household sold a much higher proportion of their animals, that is, 100% of their goats by selling the 20 they had (Figure 4.2).

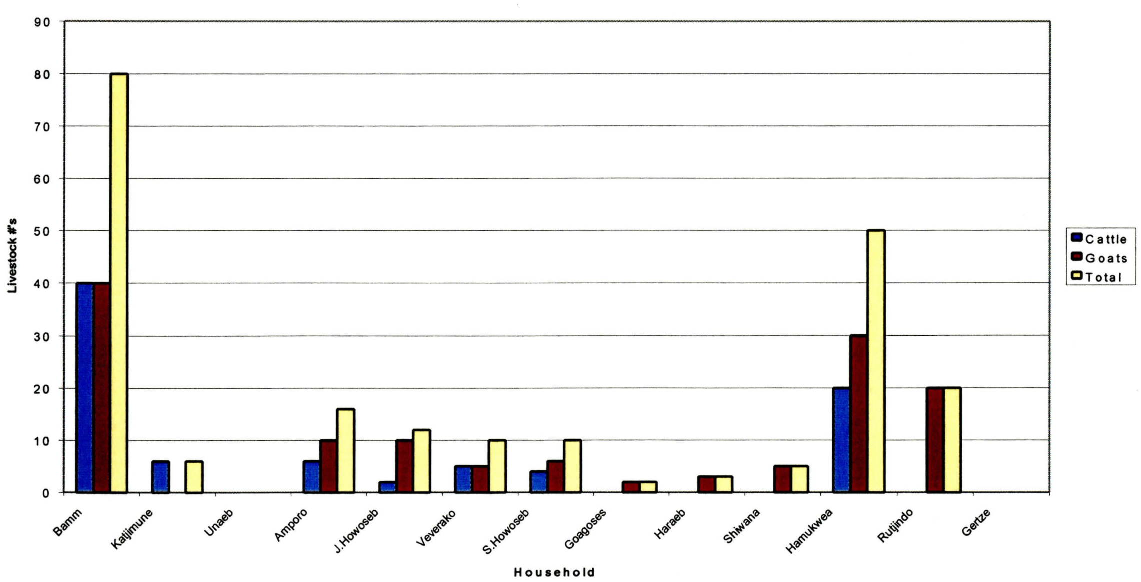
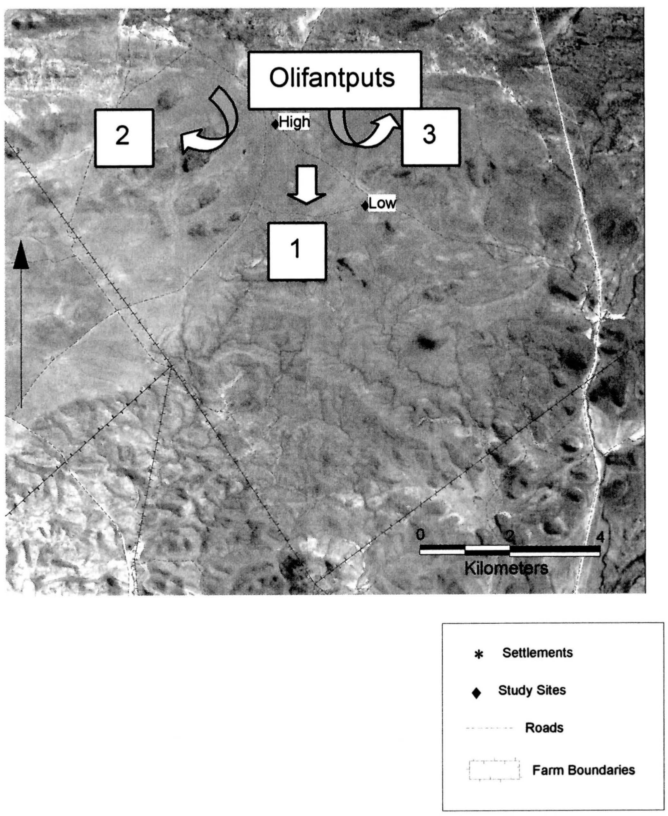


Figure 423 : *Total sales of livestock at Olifantputs 6/97 – 6/98*

Livestock management

Herding and grazing rights

95% of the 5 000ha-land area of Olifantputs is used for grazing (3/98 Festus Hamukwea). Although the land is communal, only people resident at Olifantputs seem to have grazing rights here. Residence and grazing rights are decided on by the local community structure with the headman as the leader. Animals from neighbouring villages may come into the Olifantputs "boundaries" for grazing. However, this is frowned upon by the Olifantputs villagers (e.g. 3/98 Festus Hamukwea). The grazing area is not fenced. Within the community there are non-legislated "rules" as to who grazes their animals where. For cattle this is difficult since they are not herded, but only "pushed out" into the bush (e.g. 3/98 Frederik Nanuseb). Goats and sheep are herded because of fear of livestock thieves. These herds will depart into various pre-allocated directions in the field, according to which area is "reserved" for their owners. This could be portrayed as follows in a drawing of the grazing areas (Figure 4.3):



Grazing areas of families:

1. Utjindo, Haraes, Hangula, Veverago

2. Amporo, Langman, Bamm

3. J Howoseb & S Howoseb

Figure 4.3: *Grazing Patterns at Olifantputs*

A number of goat owners have not been mentioned and there are no clues provided as to where these owners would take their animals. This will have implications for land use intensity at the various sites.

Whereas it is the household heads that take decisions such as which direction the herds of particular owners are supposed to move, it is the herders who take the day-to-day decision of where to let the animals graze. The herders have a good knowledge of where the browse and grazing are suitable at the time. The four herders, Joseph Ayonga, France Nangedha, Daniel Nghuwete and William Numbinga present at Olifantputs in October 1998, mentioned that they sought out food the goats liked to eat (10/98, herders). The animals seemed to browse most trees growing on the farm, however, they preferred young *Mopane* leaves and *Acacia* pods, and also feed on *Catophractes* leaves and flowers and parts of *Boscia* spp.

Goats and sheep are usually kept in the same herd, accompanied by dogs and the herder for protection against thieves and predators. It should be noted that about 43% percent of small stock loss per annum (6/97-6/98) were attributed to these factors (Appendix 1). Small stock is kept in protected kraals overnight and only goes out to browse and graze for a couple of hours. During the rainy season they move approximately 4-5km into the veld, while in the dry season, when most resources are depleted or scarce, they have to walk an average of 5-7km to find enough browse (OP64). Although goats are mainly browsers they also feed on the remaining grass stumps in the rainy season (10/98, herders). The goats have the advantage that browse is more perennial than grazing. The goats drink once a day.

Cattle are not herded at Olifantputs but remain out in the grazing area throughout the night and move back to drink at the waterhole in the early morning hours. Then they are kept in the vicinity and the cows are milked, if milk is available (mainly in the rainy season). Apparently they drink for a second time in the afternoons before departing for further grazing. The calves are separated from their mothers overnight. They stay in the only camp available on the farm; the calf camp.

No rotational grazing is practised at Olifantputs, thus the area is continuously exploited where and whenever good food is available. The farmers identify this and overgrazing as two of their main problems on the farm.

Coping with drought

Damaraland normally has very low rainfall. During "disaster drought" (Anon, 1997) conditions are so bad that livestock die of starvation and the farmers have to apply drought coping strategies. In this variable environment farms should be managed in a way that enough grazing is available for livestock over a number of years of expected poor rainfall. However, where this is not the case, other strategies need to be applied. At Olifantputs these are foremost (1) to move the livestock, particularly the cattle, for emergency grazing to other areas, (2) sell animals to reduce stock numbers, and (3) feed supplementary fodder. All three strategies will be described with data from Olifantputs for the year 1998.

Emergency grazing

1995 -1997 were relatively good rainfall years in western Namibia. Vegetation growth was good after 96/97 rainy season (Zeidler, pers. com.) and grazing was available. In March 1998 grass biomass per ha was already as low as 20kg/ha and deteriorated to 12kg/ha in October 1998. Thus available grazing declined rapidly. By June 1998, the farmers at Olifantputs had already moved most of their cattle as well some goats to other farms. Usually this is done with permission from the Ministry of Agriculture, but always with the consent of the owner of the selected grazing area. In the case of Olifantputs the following movements were tracked (10/98, Shimali):

Mainly the four households of Hamukwea, J. Howoseb, Rutjindo and Amporo had moved some of their livestock. The animals of the Hamukwea family were moved to a farm some 30km from Olifantputs, a former Odendaal farm called Nortal-Lofdal, situated west of the Fransfontein area. A. Rutjindo and T. Amporo both negotiated for emergency grazing on Naute farm, which is an Odendaal farm even further to the west. J. Howoseb, the headman, received permission from the farm owner, Mrs. Poppy !Hauses, to bring his 53 cattle to the farm Losshoof.

Although most of these farms were also stroke by drought the owners permitted emergency grazers access. When the owner of farm Nortal-Lofdal was asked why he had allowed other farmers to bring their cattle he simply said: "we felt sympathy for the Olifantputs farmers and we decided to help them."

Supplementary fodder

Only few of the farmers at Olifantputs mentioned feeding supplementary food as one of their actions against drought (QOP1-13). However, when asked whether they did supply extra food at times, a number of them came up with supplements given. All farmers provided salt licks for their livestock. Lucerne was another common extra. In former times, lucerne was grown in the local gardens but when the gardens are dry this is not an option and lucerne needs to be brought in from elsewhere. Other extras were bone meal, maize stalks, mealie meal and cabbage. Two farmers mentioned the use of a mix of natural supplements, including *Acacia erioloba* pods, sunflower seeds, maize stalks and grass. Another natural food used was mopane leaves, which had been stored. It was observed that individual farmers were raking grass stalks in a manner similar to making hay.

In the 1992/93 drought as well as in 1994 the Government provided livestock subsidies in the form of cash allocations for supplementary fodder. A number of households at Olifantputs were recipients of such subsidies (Napcod, *unpubl.*), but this has been criticized as supporting unsustainable land use, especially under drought conditions.

Other (economic buffers)

Drought preparedness is a key word in Namibia's National Drought Policy. Besides agriculturally based activities, communities and individual farmers could and should investigate other opportunities to be less vulnerable to such emergency situations. Mobilization of savings, diversification of incomes etc. are just a few of the concepts that could be considered. It is clear that at Olifantputs several households have very slim buffers for coping with extreme situations. It could not be established how far individual households were safely bound to urban family connections, which could provide a social backstop system in times of great need. Data looking into existing structures and mechanisms are provided in the Napcod study (*unpubl.*), which was carried out simultaneously to this study.

4.4 Livestock related environmental problems

The discussion on whether environmental degradation is taking place in north-western Namibia or not has been going on for a long time and there have been some outspoken voices (e.g. Sullivan, 1998, Rhode, 1994). However, it cannot be denied that there are problems, and as one farmer expressed these include:

> *"(We have) no choice to improve our land since the main income is only farming with livestock. Since the land is short and has a great number of people, it is difficult to manage it. For example I can decide to concentrate grazing my animals on one side of the camp while the other side (is) recovering but while doing that someone else will use the other side. If I was alone, I could have tried a lot of ways of management such as selling some of my animals or preventing over-utilising of the field. But now, whether you try to minimise your number of livestock, you only risk yourself because the other people are not doing the same". Everyone is trying to have more animals. The more animals you have the more money you can receive". (3/98 S. Howoseb).*

Foreign cattle

One of the main concerns of the Olifantputs community is that "foreign" cattle, owned by villagers from neighbouring settlements, access their grazing area and even more disturbing to them, their water point (3/98 Festus Hamukwea). All households (QOP1-13) have mentioned foreign cattle as the main reason for "overuse of natural resources". In communal areas no community has the right to exclude "outsiders" from using resources, even if they are situated in "their" area. Now, especially with the new water costing system coming into place, this will mean that local farmers may have to "pay" for the "foreigners". At Olifantputs this causes great concern. During various problem analyses (M&E 5/98), this issue has come up as the main "environmental" problem facing the village.

During a one-day survey conducted in October 1997, animals were counted at the water point and their household affiliation was determined by individual brand marks. Cattle of eight owners from Olifantputs could be identified unambiguously. A number of cattle had "foreign" brand marks and one type of mark could not be associated unequivocally. Altogether 638 cattle were counted at the water point during that day.

Cattle observed at the waterhole per day

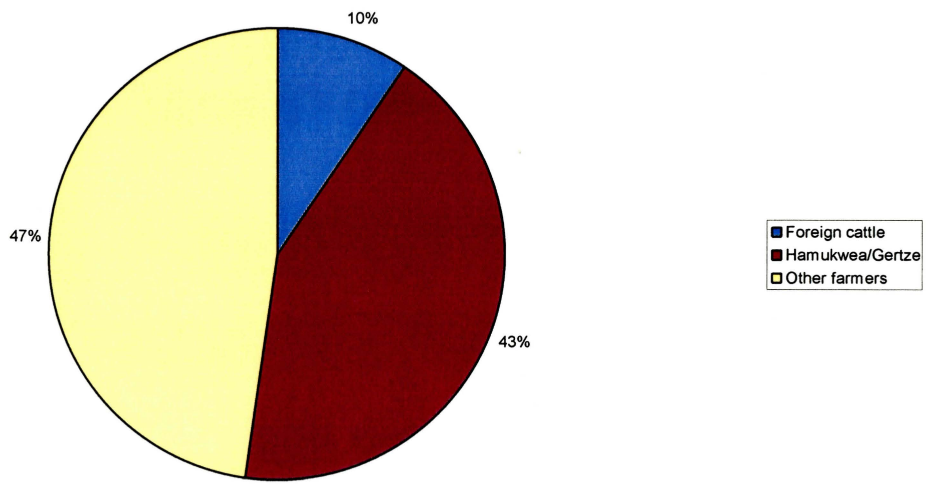


Figure 4.4: *Percentage of foreign cattle drinking at Olifantputs*

Cattle numbers per household were very different from the numbers obtained during the June 1998 survey. This could be due to many reasons: the observation was carried out at a different time; a number of cattle came to the borehole to drink twice; not all cattle came to drink during the time of observation. However, this should not be of concern to the research question posed, to determine the percentage of foreign cattle drinking at the Olifantputs water hole. From the data obtained (Figure 4.4) in the worst case scenario, 9.6% of the animals visiting the borehole were "foreigners". If the animals with the "unequivocal" mark did, after all belong to an Olifantputs resident, the number would drop to 4.7% "foreign" invaders at the water point. In contrast to this it is one "family" that makes up for 43% of all cattle watered at Olifantputs water point alone!

4.5. Conclusions

The information presented in this chapter adds an additional dimension to the establishment of desertification indicators and monitoring, which complements the ecological one presented in the following chapters. Whereas it is important to reveal whether land degradation does indeed occur, possibly under specific management regimes, it is as important to link issues such as land degradation to the livelihoods of individual people and local communities. We have to understand how communal farming systems work and how they support the livelihoods of rural people. We also have to work out the true causes that may lead to land degradation, especially in communal areas. These connections of sociological and ecological research have to be made to address issues of desertification in Namibia. This is especially important if practical recommendations for interventions should be made.

It is not good enough to say that communal land tenure systems *per se* are constraining sustainable land management (e.g. Scoones, 1995). Often it is "outside" issues that are constraining management e.g. practices such as de-stocking because of limited opportunities (e.g. Toulmin, 1995), i.e. markets and poor policy frameworks (e.g. Holtzmann & Kulibaba, 1995; Lane & Moorehead, 1995; Sylla, 1995). Individual farmers have indeed a good understanding of the issues at stake, and dealing with everybody as "the culprits" has never been very successful. If we consider land use intensity as mainly imposed through high stocking numbers and poor grazing practices, according to the study at Olifantputs the main issues that cause overstocking are:

- A few farmers who keep extremely high numbers of livestock at the farm, ranging up to 200 cattle and 240 goats. These are residents and absentee farmers. The majority of people living at Olifantputs own only relatively low numbers of cattle, usually below 40 head or no cattle at all. Goat herds range between 50 and 150 heads for an average family, however several families only keep individual animals and make a modest living off their livestock (Figure 4.1).

- "Foreign" cattle that use the limited grazing as well as water resources. These animals come from neighbouring villages and cannot be controlled. The residents of Olifantputs call for a fence to allow them to manage their own grazing and water. However, considering that only 10% of all cattle observed at the waterhole seem to be "foreign" it seems to be the ownership structures at the village itself that are really confounding the problem of overstocking and need to be addressed at that level. The Hamukwea/Gertze household alone makes up 43% of all cattle drinking at the borehole (Figure 4.4).

- Lack of incentive to de-stock in poor rainfall years. This is a result of, for example, poor prices fetched on the market for livestock from communal areas, which value an average goat of an communal farmer 30% lower than goats from commercial farms (AGRA auction at Outjo, October 1998; Murorua, *pers. comm.*). This situation is confounded during prolonged times of drought, when many of the animals are in poor condition. The high risk of loss of animals to predation especially by jackals, theft and disease, threatens the income base of the farmers. At Olifantputs 6% of cattle were lost in the year 1997/98 to these factors and almost 20% of small stock (Figure 4.2).

- Lack of communal decision making and support systems, as well as competitive farm management.

- Lack of safe and reliable places to move animals to for emergency grazing. The farmers seem to be reluctant to leave their livestock in emergency grazing areas because they have little control of their animals if these are far from home and often the areas made available have limited water available and as well as payment of herders might be expensive. Although most of the farms used for emergency grazing in 1998 were at average distance of only 30 – 50 km from Olifantputs, these areas were often considered unsafe. It seems that the farmers at Olifantputs have become more settled and are not keen to move with their animals themselves. They rather employ herders or caretakers; however, there is little overseeing authority that can be practised if these are far away.

- The grazing areas are utilised to the extreme. Emergency grazing areas are made available privately or through the government often only at a very late stage when the resources at the farm are already heavily used. (At Olifantputs less than 12 kg per ha of vegetative biomass was available in October 1998, however, there were still animals grazing on the farm, see Chapter 8). Similarly animals seem to be moved back to the farm early, either because of the abovementioned concerns connected to emergency grazing areas or in hopeful anticipation of the onset of the rainy season. Little is known of the condition of the emergency farms themselves. However, the farm Halt is often used as a emergency area. According to the research presented in Part III of this study, especially chapter 8 and 9, this farm is characterised by poor soil condition and is possibly not in a good condition if considering the biological integrity concept.

- Grazing areas cannot be managed, e.g. rested. This is for example because there is no consensus amongst the farmers to set grazing areas aside and free grazing by cattle is practised. Also there are no camps and fences in place, which would direct the movement of the animals. Water points distributed across the farm could reduce the land use intensity at the "peak sites" at the village and would possibly reduce movement costs of animals (Bayer & Waters-Bayer, 1995). However, such an intervention would possibly also reduce management options and lead to an even more pronounced over-utilisation at more water points, if not managed carefully. It may help to train herders to recognise habitat condition and become involved in planning where to move herds.

These issues that have been mainly raised by the farming community at Olifantputs seem to be much in line with issues addressed in the book "Living with Uncertainty" (Scoones, 1995). Many management aspects, which are seen to be crucial to facilitate adaptive range management in arid environments, are not in place at Olifantputs. There are also a number of additional issues relating to desertification at Olifantputs, which have not been raised in this chapter. One of the most pressing issues would be the amount of groundwater available at the study farm, and the fact that the Department of Rural Water Supply (DRWS) budgets for only two-thirds of the actual consumption at Olifantputs. The village is assumed to consume 13,100 l per day, whereas cross-validated data derived by Napcod calculates a daily consumption of up to 20,278 l per day (Napcod, *unpubl.*).

It is necessary to assess whether the level of income that can be generated through farming activities at a farm situated in the study area as marginal as Olifantputs will be sufficient to fulfil the expectations people have for development and their own livelihood security. It seems that farming alone does not provide enough income to support families to a level that would be desirable for rural communities in Namibia. Therefore other sources of income need to be tapped and developed. Sandford (1995) reckons that, instead of spending much government money on rangeland development which might only bring meagre rewards, it might be more economically to spent the resources on re-equipping the expanding pastoral population for non-pastoral occupations.

If we look for indicators of desertification we possibly have to look for indicators of sustainable development and livelihood security, which need to include socio-economic aspects such as income and expenditure from agricultural activity and other, time inputs on farming activities, and life quality indicators. The list is long and what seems to be important is to acknowledge that social and ecological indicators have to be considered together to monitor whether rangelands are fit to support sustainable livelihoods in Namibia.

Whether the natural resources and rangeland are over-utilised and possibly even degraded will be investigated from a biophysical ecological point of view as part of this research project and is presented in Parts III and IV of this thesis. Insights into local as well as scientific indicators of habitat condition using a set of biophysical measures will be described. The effect of land management practices on the natural resource base will also be investigated.

PART III

Deteriorating rainfall conditions, overuse of natural resources such as water and grazing, problems arising from decision making structures, as well as indications of a permanent loss of productivity of the range were mentioned by farmers as serious constraints to farming in the Huab catchment in western Namibia. Most of these concerns were purely anecdotal. Part III of this thesis (1) establishes whether termites could be good indicators of range condition and what methods for sampling termites are useful, (2) investigates whether the natural resource base in the form of the rangeland/grazing area is impaired, by studying ecological functions and processes, and (3) investigates possible causes of degradation if such processes are detected. (4) An Index of Biological Integrity (IBI) based on termites as representatives of the soil macro fauna, as well as on other bio-physical indicators such as soil and vegetation parameters is developed.

Because the emphasis of this study is placed on termite related research an in-depth literature background is presented at the beginning of Part III.

LITERATURE BACKGROUND ON TERMITE STUDIES

Termite research in southern Africa - a historical overview

Termites are abundant in the tropics (MacKay, 1991) and there have been studies of their biology and ecology over the past two centuries. The historical period of isopteran taxonomy extends from the early description of the genus *Termes* by Linneaus in 1758 to Holmgren's publication of a first classification of this order in 1911/1912. During this period of about 150 years, termite taxa from southern Africa were described by De Geer (1778), Latreille (1804), Rambur (1842), Hagen (1853-58), Gerstäcker (1891), Sjöstedt (1897-1911), Haviland (1898), Wasmann (1902-1908) and Silvestry (1908) (after Coaton, 1974). During the following decade it was particularly Sjöstedt (1914, 1924, 1926) and Fuller

(1921, 1922) who contributed greatly to the collection and identification of the Isoptera in Namibia (former South West Africa), at that stage counting nine genera and 18 species (Coaton & Sheasby, 1972). In the 1960's the National Survey of Isoptera of South Africa, which was initiated in 1958, was expanded to include adjoining countries such as Mozambique, Zimbabwe, Botswana and Namibia. During the years of 1964 and 1967 six survey expeditions were conducted throughout Namibia, sampling the termite fauna on 16km intervals across the country (Coaton & Sheaby, 1972). The full collection represents one of the most intensive efforts of its kind in the world and a number of publications derived from these surveys, including manuscripts on new species and genera descriptions, some related to natural history and biological information, as well as amazingly comprehensive distribution maps were produced. For Namibia all samples were identified to the genus level and some to the species level. Specimens belong to 4 families, 10 sub-families and 33 genera. The full reference collection is archived at the National Insect Collection, Agricultural Research Council (ARC), Plant Protection Research Institute, Pretoria, South Africa. Zeidler (1997) computerised the data from the Namibian collection and distribution maps are now available in a GIS.

Boullion (1970) provides a comprehensive review on the termite fauna of the Ethiopian region, including information on its evolution, biology, physiology, and ecology. Brian (1978) provides an overview of global termite ecology.

Termite studies conducted in arid to semi-arid Africa

It has been suggested that termites play a major role as soil organisms in arid Namibian ecosystems, contributing to processes such as decomposition, particularly during dry periods when most other soil organisms are inactive (Crawford, 1981; Crawford *et al.*, 1993; Crawford & Seely, 1994). Drawing from studies that were conducted in semi-arid savannahs in Nigeria, Kenya, Zimbabwe and South Africa, it can be said that the biological, chemical and physical processes mediated by termites are also significant in these relatively dry African ecosystems (Wood & Sands, 1978; Deshmukh, 1989).

Termites affect physical soil parameters and process rates through, for example, the distribution and breakdown of soil organic matter, the alteration of soil nutrient composition and changes in soil texture. Studies on the composition of mound and gallery systems of various representatives of *Macrotermitinae* in semi-arid regions in Kenya (Arshad, 1981; Arshad, 1982; Bagine, 1984; Darlington, 1982), South Africa (Griffioen & O'Connor, 1990) and Zimbabwe (Watson, 1976) and *Trinervitermes* from South Africa (Laker *et al.*, 1982), show that fine grained soil particles as well as exchangeable cations, nitrogen and occasionally organic carbon are accumulated in termite mounds. This suggests that important constituents contributing to soil fertility are amassed in termite structures. Griffioen and O'Connor (1990) also show that a distinct herbaceous flora is associated with the soils of termitaria. However, based on her studies carried out on the *Macrotermitinae* in Tanzania, Jones (1990) hypothesises that these termites contribute little to carbon, nitrogen and phosphorus accumulations in the soil. On the contrary, she suggests that soil organic matter is removed from soil and accumulated in termitaria, thereby reducing the organic matter content of dry tropical soils. A lack of organic matter dispersion through the soil would lead to high erodability and poor nutrient- and water-holding capacities of soils, and thus to their impoverishment.

When trying to assess the impact of termites on ecosystems it is important to consider their role as primary consumers, secondary producers and as agents of transformation within the system. In African savannahs total termite biomass can outnumber large mammal herbivore biomass (Wood & Sands, 1978; Gandar, 1982). For Nylsvlei, a South African savannah system, it was calculated that large mammal biomass was 6kg/ha, while termite biomass constituted 10kg/ha.

The annual consumption per unit of biomass by termites was 50% greater than that of large mammals (Gandar, 1982; Deshmukh, 1989). Other studies do not provide such pronounced results but certainly underline the notion that termites are important consumers in various African ecosystems (e.g. Wood & Sands, 1978). Biomass and consumption rates do not necessarily reflect the relative significance of different species of termites in production ecology. The efficiency, with which individual termite taxa fix and return energy and nutrients to the ecosystem, is of great interest.

More functionally oriented termite research was the focus of various studies conducted in other parts of Africa. Work done for example in the more arid savannah systems in Nigeria and Kenya investigated, amongst other, the role of termites in the decomposition of grass, wood and litter (Ohiagu & Woods, 1979; Collins, 1981; Buxton, 1981), and their effects on soil systems (Wood et al., 1983). From this type of research a great number of termite process-oriented synthesis were published by e.g. Woods (1976, 1978), Woods & Sands (1978); and Anderson (1988a,b, 1995). Anderson focused on invertebrate mediated transport processes in soils, such as the translocation of organic matter.

Ferrar (1982a, 1982b, 1982c, 1982d) investigated termite communities in two sub-habitats, the broad-leafed and fine-leafed savannah, as part of the South African Ecosystem Project at Nylsvlei. He studied population parameters, such as termite species richness, community composition, population size, biomass and activity patterns. Scholes & Walker (1993) used his data and they grouped termite species according to their feeding habits. Two classes, the litter and soil feeders were distinguished. In order to obtain some quantitative estimates on the contribution of termites to biomass cycling, litter and soil mass consumption were calculated, and the combined organic matter consumption for the broad-leafed savannah was then compared with consumption rates in other savannah ecosystems in Africa. The fine-leafed savannah only had low termite numbers. The results suggested that in fact termites consumed only 1.5% of the litter in the broad-leafed savannah, and it has been speculated that decomposition through microbial activity predominates in this habitat. This result differs greatly from findings in other regions in Africa, where termites seem to play a more significant role in soil organic matter turnover (e.g. Wood & Sands, 1978; Gandar, 1982).

However, in southern Africa, and particularly South Africa, termite research has traditionally been conducted in the context of pest control. The work done by Coaton, Sheasby, Ruelle and colleagues at the National Insect Collection laid the cornerstone of termite research in the region. Other termite research in southern Africa focused on the harvester termite *Hodotermes mossambicus.* This species is regarded as a severe pest organism on pastures throughout its distribution area in sub-Saharan Africa (e.g. Coaton, 1958; Nel 1968; Nel & van Aswegen, 1971), and is said to compete with larger herbivores for food resources under drought conditions (Braak, 1995). A multitude of literature on *H. mossambicus* is available, covering topics such as food consumption, preference and acceptance (e.g. Nel & Hewitt, 1969a; Botha & Hewitt, 1978; Duncan *et al.*, 1990; Van Biljon & Hewitt, 1990), foraging and aggressive behaviour (Duncan, & Hewitt, 1989; van der Linde *et al.*, 1989), energy and nitrogen budgets (Hewitt *et al.*, 1990), *H. mossambicus'* contribution to other trophic levels (Kok & Hewitt, 1990), connections to abiotic conditions (Nel & Hewitt, 1969b; Mitchell *et al.*, 1993) as well as on other miscellaneous aspects of its physiology, biology, particularly population biology and social structure (e.g. Coaton, 1981; Darlington *et al.*, 1977; Hewitt *et al.* 1969; Hewitt *et al.*, 1972; Nel *et al.*, 1969; Nel & Hewitt, 1978; Watson, 1976; Watson *et al.*, 1971). However, some literature on other taxa, e.g. *Cubitermes, Trinervitermes, Macrotermes*, in the region is also available (e.g. Griffioen & O'Connor, 1990; Laker *et al.*, 1982; Dangerfield *et al.*, Dangerfield 1990; Dangerfield, 1991).

Currently a number of new termite projects are being established in southern Africa, most of them taking a functional approach to the study of these insects.

Drawing from studies conducted around the globe: termite impacts on soil properties and primary productivity

Although the conspicuous physical structures such as above-ground termite mounds and elaborate subterranean gallery systems built by termites has attracted the attention of various early termite biologists and pedobiologists, it was only Lee & Wood (1971a,b) who provided a first comprehensive overview of the role termites play in supporting soil chemical and soil physical processes, which they describe primarily for Australian environments. Lobry de Bruyn & Conacher (1990) published a thorough literature review incorporating more recent studies conducted on soil macrofauna, specifically termites and ants in Australia (see also Lobry de Bruyn & Conacher, 1994a,b). The review provides some good background information as a context in which to base soil related aspects of termite research, which could be complemented with research conducted in the United States and elsewhere over the past 20 years.

Authors like Harverty, Nutting (1975a,b, c), LaFage et al. (1973) respectively, and Bodine & Ueckert (1975) and Ueckert, Bodine & Spears (1976) were some of the pioneers who addressed more functionally oriented questions related to termite research in the United States. They present some early work on subterranean termites in Arizona, introducing new baiting methods for effective population assessment and developing models for studying biomass consumption and decomposition rates. In 1977, a long-term study was initiated at the Jornada Experimental range, southern New Mexico, and a suite of studies and experiments was performed over many years by a number of scientists, which probably represents the most comprehensive investigation on termite ecology and termites' interaction with and impacts on their environments. Numerous publications have derived from this remarkable research effort. MacKay, Zak & Whitford (1990) give an overview of the natural history and role of subterranean termites in the Chihuahuan desert, synthesising 15 years of intensive termite research.

Two termite species, *Gnathamitermes tubiformans* (Bukley) and *Amitermes wheeleri* (Desneux), predominate/occur in the northern Chihuahuan desert, the latter being the less common species (e.g. Whitford et al., 1992); MacKay et al., 1987). Both species are subterranean, and only surface to resume foraging activities when climatic conditions are favorable (e.g. Johnson & Whitford, 1975). Studies on population parameters such as activity patterns and population size were supplemented with detailed investigations delineating the termites' involvement in processes such as organic matter and nutrient cycling (e.g. Schaefer & Whitford, 1981; Whitford et al., 1982; Whitford et al., 1983; Parker et al., 1982; MacKay et al., 1985; Silva et al., 1985; MacKay et al. 1987; MacKay et al., 1992; MacKay et al., 1994; Nash & Whitford, 1995; Moorhead & Reynolds, 1991), alteration of soil physical aspects (e.g. Elkins et al., 1986), and impacts on plant communities (MacKay et al., 1990). These extensive studies revealed that termites do indeed contribute greatly to important ecosystem processes. Summarising the results from the different publications, it can be stated that the most emphasised and measurable impact of the abundant termites was clearly observed to be organic matter translocation and fragmentation. It has been suggested that in fact termites may play the most significant role in litter decomposition in arid environments (MacKay et al., 1994). Whether termites take on a pivotal role in active nutrient cycling still seems unclear. Termites have been described as acting e.g. as nitrogen sources and sinks, respectively. Schaefer & Whitford (1981) and Parker et al. (1982) conclude from data from experimental plots at the Jornada Experimental Range that nitrogen increases in plots from which termites were excluded, thus suggesting that termites deplete soil nitrogen reserves. Alternatively soil fauna, including termites, contribute to nitrogen and phosphorus levels through the high turnover rate of dead bodies of termite individuals as well as nitrogen and phosphorus enriched faeces (e.g. Hewitt et al., 1990). More recent laboratory research supports the notion that termites are capable of actively fixing atmospheric nitrogen if supply from food sources is deficient (Slaytor & Chappell, 1994; Curtis & Waller, 1995). Clear results were obtained assessing the influence of termites on soil physical structures. Water infiltration and retention capacities were found to be improved through organic matter enrichment in the soil, and accumulation of smaller grained soil particles such as clay. Extensive subterranean gallery systems enable better water drainage into the soils (Elkins et al., 1986). The complex interaction of termites, nutrients and water properties could not be readily separated, but exclusion of termites definitely leads to changes in plant species composition and differences in vegetation performance over a three to four year period. Annual fluff grass (*Erioneuron pulchellum*) for example, disappeared from treatment plots without termites, as phenology was negatively affected (MacKay et al., 1990). Recent termite research at the Jornada Experimental Range have focused on the effect of termites on soil hydraulic properties as well as on studies of food and bait preferences and the detection of such sources (e.g. Taylor, 1996). Results of a study that was pursued in semi-arid Australia suggested that subterranean termites may be even more important detritovores and soil modifiers in Australian ecosystems than has been documented for the Chihuahuan desert (Whitford et al., 1992).

A clear picture emerges that defines the possible role subterranean termites play as ecosystem engineers in arid to semi-arid areas.

Classification into functional groups – a useful approach?

Classification of termite into "functional groups" based on trophic characteristics, hence into categories such as soil, wood, litter- and mixed-feeders (e.g. Scholes & Walker, 1993; De Souza & Brown, 1994; Eggleton et al., 1995; Zeidler, 1997), is helpful for describing community composition. However, there are reservations about the category's usefulness in understanding termites' significance in sustaining ecosystem processes. Not much information is provided for example on the termite's' impacts on bio-geochemical processes. It could be argued that these are primarily determined by the feeding habits displayed; soil-feeders for example might contribute less to organic matter cycling but are probably more important in the alteration of soil physical properties than wood-feeding termites and those living in wood. Subterranean, organic matter feeding species on the other hand may have the most pronounced consequences on soil physical as well as soil chemical aspects.

However, it should be mentioned that Bouche introduced a classification of soil macrofaunal units into so-called ecological categories as early as 1959. This concept has been applied widely for earthworms, distinguishing epigeic, anecic and endogenic taxa (e.g. Menaut et al., 1985; Lavelle, 1983). Attempts have thus been made to incorporate some more functional information by adding soil-related attributes such as soil mixing, burrowing, organic matter translocation to the classification. A similar approach for termites has been suggested (Lavelle pers. comm.), but the above reservations about the usefulness of broad groupings apply.

Loss of biodiversity

Land-use

Changing land use is most likely to have the greatest impact on biodiversity and ecosystem functioning at present. Effects on termites have been under study for years, but have recently been intensified. Some early work in West Africa (Sands, 1965; Bodot, 1967) indicated that termite abundance and biomass is reduced by forest clearing. The researchers attributed the observed decrease in termites primarily to limitations in food availability, as well as to changes in habitat condition such as e.g. microclimate. However, at that stage no conclusions were drawn pointing to the fact that a loss of termites may significantly impair ecosystem performance. Even contemporary termite research addressing impacts of land-use and disturbance on termite communities and/or trophic groups (often referred to as functional groups) explicitly (e.g. De Souza &

Brown, 1994), often seems to lack such a functional approach and restricts itself to measuring changes of faunal aspects without considering the extent to which ecosystem function may be damaged by e.g. termite taxa losses. It should be noted that most of this research was conducted in more humid environments.

De Souza & Brown (1994) as well as Eggleton et al. (1995) observed changes in "functional groups" across land-use gradients. Both studies revealed that soil-feeding termites seem to be particularly sensitive to forest clearance, whereas wood-feeding termites seemed to be more resilient to disturbance, as are litter feeders, which often rely on a mixed diet, including dry wood. The sensitivity of soil-feeding termites was attributed primarily to the fact that these are often soft-bodied termites, which may react strongly to changes in microclimate. It should be noted that no significant immigration of savannah termite species into the disturbed areas was observed.

A study that explicitly tested the impact of sheep-grazing on subterranean termites in Australia revealed that neither termite abundance nor diversity were inversely affected on grazed treatment plots compared to ungrazed controls (Abensberg-Traun, 1992). These findings were firstly attributed to the fact that food apparently was not limiting to the species under study. Secondly it was speculated that the mound colonies might benefit from a reduction in grass cover, which would allow for easier harvesting trips. However, it is also possible that impacts were not detected because the treatment area was too small to really affect termite colonies, which may forage over extremely large territories.

Climate change

Generally it can be stated that soil inhabiting organisms are not particularly prone to climatic changes since soil is a relatively buffered environment, showing little differences in temperatures and humidity (e.g. Whitford et al., 1992). However, as we have already seen in the examples above, some termite species seem to be affected by changes in microclimate (De Souza & Brown, 1994; Eggleton et al., 1995).

Climate also seems to restrict termites in their bio-geographic distribution e.g. through factors such as rainfall and temperature (e.g. Buxton, 1981; Coaton & Sheasby, 1972; Haverty & Nutting, 1976; Zeidler, 1997). For Namibian termites Zeidler (1997) established that genera richness increased throughout the country with increasing rainfall. Four genera showed negative associations with rainfall, while 22 genera were positively related with rainfall in their spatial distribution. Consequently some response to larger scale climatic alterations can be expected.

However due to their social organisation as well as to their protective nesting constructions, social insects in general and termites in particular are said to be relatively resilient to disturbance (Brian, 1983). In times of limited food resources e.g. during prolonged periods of drought, termite colonies may live off their stored food resources. As long as the royal pair, the only colony members that contribute directly to the reproductive potential of the colony, survive, the colony may remain, although the total number of colony members will possibly be reduced (Oster & Wilson, 1978). The architecture of nesting and gallery systems allows for thermal regulation as well as for maintenance of relatively constant humidity within the constructions (e.g. Turner, 1993), thus making the termites less dependent on outside climatic conditions.

PART III

CHAPTER 5

TERMITE SPECIES RICHNESS, COMPOSITION AND DIVERSITY UNDER DIFFERING LAND-USES IN SOUTHERN KUNENE REGION, NAMIBIA

5.1. Introduction

This chapter presents the results of a broad survey conducted at five farms in former Damaraland, which were selected as the Napcod pilot sites in the north western part of Namibia (Chapter2). A preliminary study was conducted to establish the nature and occurrence of termites in the study area. A standard termite sampling method was tested and refined for application in arid environments using a standard belt-transect method, which was initially developed for tropical areas (Davies, 1997; Eggleton *et al.*, 1997). The aims of the survey were to establish termite inventories for each site and to investigate whether aspects of termite diversity are determined by land-use practice and land-use intensity in the study area.

5.2. Methods

Study sites

An inventory of termite species richness and composition was conducted at the five Napcod study sites, namely De Riet, Waterval, Olifantswater, Olifantputs and Grootberg (Figure 1.2, Chapter 2). The sites have differing land-use histories and are situated along a rainfall gradient (Table 5.1).

At each place, two sites of different land-use intensity were sampled. The high land-use intensity sites were at villages where most agricultural activities occur. Here, livestock impacts are usually high, particularly at waterholes and kraals. The low land-use impact sites were placed approximately 3.5km into the open rangelands, where livestock and human induced land-use intensity were lower. Overall, 10 study sites at five farms were sampled for termites in Damaraland.

Sampling method

Sampling in the southern Kunene region took place in March/April 1997, after the rainy season.

A standard belt transect method as suggested by Davies (1997) and Eggleton *et al.* (1997) was used. A 100m long line transect is laid out and distinguished into 20 sampling sections of 2m x 5m. Every second section is further divided into two, and two searchers examine one of the two sections respectively for termite presence. The search of each 1m x 5m sub-plot takes 1 hour. All termite specimens detected are collected for later identification. All possible habitats are searched, even the top 5 – 10cm of the soil. The method is described in more detail in Chapter 6, which reviews termite sampling methodologies tested as part of this research. However, in this study, the ten sampling sections were spaced along a 200m belt transect, instead of using a 300m transect across a 1ha area as described for chapter 6. The sampling effort was consequently more intensive in this study.

Analyses

Termite species richness (i.e. number of species) was compiled for each site. Functional properties of termites were summarised as trophic groups, taxonomic groups and nesting groups, which refer to above or below ground dwelling termites as well as tree living species. These records were derived from literature accounts summarised in Zeidler (1997) and reproduced in Appendix 9. Diversity indices were also calculated for each site, using the Shannon-Weaver Index to determine richness and evenness and the

Table 5.1: *Land-use histories and land-use intensities at the 5 Napcod study sites in southern Kunene region, Namibia.*

Study site	Ecological description	Land-use history[4]
DE RIET (S20°28'074 E14°11'155)	**Rainfall range[1]**: 59-339mm **Soils[2]**: Acid igneous rocks, metamorphic rocks, alluvial sands **Vegetation[3]**: Medium dense mixed riparian woodland, grassland on pains and pediplains *Faidherbia albida, Acacia erioloba, Colophospherum mopane, Salvadora persica a.o.*	Commercial, communal since 1968
WATERVAL (S20°20'888 E14°15'559)	**Rainfall range[1]:** 179-587mm **Soils[2]:** Acid igneous rocks, calcrete & calcareous rocks, dark alluvial sand & loams **Vegetation[3]:** Open mixed bushland plains *Colphospherum mopane, Acacia reficiens, Catophractes alexandri a.o.*	Commercial, communal since 1968
OLIFANTWATER (S20°09'418 E14°52'874)	**Rainfall range[1]:** 179-587mm **Soils[2]:** Adic igneous rocks, calcrete & calcareous rocks, arenosols (mainly red), dark alluvial sands & loams **Vegetation[3]**: Open Commiphora dominated bushland on hilly terrain *Commiphora spp., Colophospherum mopane, Terminalia prunioides, a.o.*	Communal since 1898
OLIFANTSPUTS (S20°16'799 E14°58'181)	**Rainfall range[1]:** 179-587mm **Soils[2]:** Acidic igneous rocks, metamorphic rocks, arenosols (mainly red) **Vegetation[3]:** Open Mopane dominated bushland with wooded grasslands on plains *Colophospherum mopane, Commiphora spp., Terminalia prunoides a.o.*	Communal since 1898 (village founded 1952)
GROOTBERG (S19°48'530 E14°22'212)	**Rainfall range[1]:** 179-587mm **Soils[2]:** Acidic igneous rocks, calcrete and calcareous rocks, arenosols (mainly red), dark alluvial sand and loams **Vegetation[3]:** Open Mopane dominated bushland with wooded grasslands on plains *Colophospherum mopane, Commiphora spp., Terminalia prunoides a.o.*	Commercial, communal since 1992 (before governmental, agricultural research station)

[1]After Dealie et al., 1993
[2]After von Harmse, 1978
[3]After Mouton et al., 1997
[4]National Archives Windhoek, Namibia

Simpson Index as a measure of dominance (Magurran, 1991). The use of the Shannon and Simpson indices as diversity measures was based on a number of assumptions, which are described and discussed in more detail in Chapter 6. A two-sample t-test was used to test whether diversity was significantly different at the high or low intensity sites. Results obtained from samples collected from the transects were calculated separately from results that included off-transect (search) samples. A qualitative comparison of the regionally obtained termite inventory from the National Survey of the Isoptera 1963-68 (NSI) (Coaton & Sheasby, 1972) was made with the data obtained in this study. During the NSI, Coaton and collaborators searched for termites using a standardised search protocol, spending 4.5 search hours in a single location. The sampling locations across all Namibia were selected along major roads where sampling took place at 16km intervals. The computerised data of the NSI were used for comparative purposes.

5.3 Results and Discussion

The sampling results from the broad survey are summarised in Table 5.2.

Termite diversity

Termite diversity in western Namibia is generally low. The Shannon index ranged between no specimen (0) found and 1.46 at the richest site, Olifantputs. The Simpson index calculated a dominance ranging between no specimen (1) found and 0.26, again at Olifantputs (Table 5.2). Termite generic richness and spatial distribution throughout Namibia (Zeidler, 1997) suggests that termite generic richness is positively correlated with rainfall. Rainfall at the study sites is generally low and extremely variable (Chapter 4), indicating that a relatively low number of termite genera may be expected. Termite generic richness has been found to be proportionally linked to termite species richness world-wide (Eggleton *et al.*, 1994). Due to the small sample numbers, few clear differences in diversity are discernible between the plots.

However, diversity is generally higher at the low impact sites in the rangelands compared to the high impact sites at the settlements (Olifantputs, Waterval, Grootberg & Olifantwater), although statistically no significant difference at the 95% confidence limit could be established (two sample t-test, two tailed, $p=0.07$ for the results obtained through the transect method).

Table 5.2. - List of termite species collected at each sampling site, and diversity indices calculated. Pilot sites used by Namibia's National Programme to Combat Desertification II (Napcod II).

Taxonomic and functional groups abbreviated as follows.
Taxonomic groups: H = Hodotermitidae, R = Rhinotermitidae, T = Termitinae, M = Macrotermitinae, N = Nasutermitinae
Nesting groups: h = hypogeal, e = epigeal
Trophic groups: G = grass feeding, WLSD = wood, litter, soil & dung feeding, HLSD = humus, litter, soil, dung, FW = fungus grower, wood, W = wood
In brackets [ ] are species that were collected off the transects, during the additional search

Taxon	**Groupings**	**Olifantswater**		**Olifantputs**		**Waterval**		**Grootberg**		**De Riet**	
		Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Transect											
Hodotermes mossambicus	H,h,G					1		[1]			1
Psammotermes allocerus	R,h,WLSD	1		3						1	4
Amitermes hastatus	T,h,WLSD	1	5	1							
Cubitermes	T,h,HLSD		1								
Macrotermes michaelseni	M,e,FW				[1]			2	1		
Macrotermes sp.	M,e,FW			1							
Odontotermes	M,e,FW							1			
Microtermes	M,h,FW		[1]	1							
Trinervitermes rapulum	N,h,W			1	1		[1]				
Other						3*					
transect (excl. unidentifiable)											
Shannon W. Index (Diversity; Hs)		0.69	0.45	1.46	0	0 (0.56)*		0.64	0	0	0.5
Simpson Index (Dominance; D)		0.5	0.71	0.26	1	1(0.63)*		0.54	1	1	0.68
off transect											
Shannon W. Index (Diversity; Hs)			0.76		0.69		0	1.04			
Simpson Index (Dominance; D)			0.54		0.5		1	0.38			

*incl. 3 individuals from a sample with same morphological specimens, not identified.

This, however, is not true for the sites of de Riet, where this relationship is reversed (Table 5.2). This could be attributed to the fact that these are situated in an area of rainfall ranging between 59-339mm, which is more arid than the other sites (179-587mm). In such arid systems, resource availability as well as microclimatic conditions may be restricting termite invasion., particularly at the low impact sites. Dung inputs as well as artificial wood sources (e.g. kraal fencing) might provide additional resources at the high impact sites.

Species assemblages

Termite species assemblages differ between farms as well as across the land-use gradients (Table 5.2). Whether this is attributable to differing environmental parameters or land-use histories is not clearly discernible.

However, a few patterns can be described. De Riet is situated in an area, which is more arid than the others (Dealie *et al.*, 1993). At this site *Hodotermes mossambicus* as well as *Psammotermes allocerus* are found. These are the classic arid land species, routinely found in extremely dry environments (Zeidler, 1997).

Although Waterval is situated in a more mesic area, only two species were identified, *H. mossambicus*, a grass feeder, and *Trinervitermes rapulum*, a wood eating species. It should be noted that the soil surface at this farm is particularly rocky and calcareous, probably not suitable for termite invasion. At Grootberg, two fungus-growing species, *Macrotermes michaelseni* and *Odontotermes sp.* were found. Additionally, a specimen of *H. mossambicus* was collected. At Waterval as well as Grootberg none of the usually abundant smaller generalist feeders such as *Psammotermes allocerus* or *Amitermes hastatus* were found. However, these two species are present both at Olifantswater and Olifantputs. This may be of relevance considering that these species are extremely active in the breakdown of dung, and the relatively high livestock numbers at the two farms. In high intensity areas where resources other than dung might be scarce, they might play, together with dung beetles, a notable role in the translocation of organic matter. Olifantputs has the highest species richness, with at least five different species.

Comparison: National Survey of the Isoptera (NSI) 1963-68 - Southern Kunene Survey 1997

Termite taxa found in southern Kunene region in the NSI study were compared to the present study. Seven termite taxa that were recorded at the time of the NSI were not found during this survey, namely *Anguilitermes*, *Epicalotermes*, *Microcerotermes*, *Macrotermes subhyalinus*, *Trinervitermes dispar. T. trinervoides* and *T. rhodensiensis* were recorded from the region before and are now absent. Why these taxa were not detected during this recent study needs to be carefully examined to draw reliable conclusions. The strength and value of a data set such as the NSI is that it formed an inventory of a snapshot nature of biodiversity 30 years ago against which changes can be gauged, setting a baseline for long-term monitoring. However, the reliability of the historic as well as recently obtained data sets needs to be evaluated (see also chapter 6).

Arboreal species, such as *Angulitermes* and *Epicalotermes*, for example, were not found during the recent survey. It is possible that because of the wide spacing of trees in the area, arboreal living species were not detected using the transect sampling technique. Furthermore Coaton & Sheasby (1972) only recorded limited distribution of *Macrotermes subhyalinus* in the region. It seems extremely probable that this species was simply not detected in the later study. During the NSI, several *Trinervitermes* species were represented in this region. The only species that was found in southern Kunene during the 1997 survey was *T. rapulum* (Table 5.2). However, subsequent sampling, which was done after the 1997 survey, suggests that other *Trinervitermes* may be active during different seasons in the year. *Microcerotermes*, a genus that was spatially abundant during the NSI, was not found during recent investigations at all.

Possible sources of error and suggestions for improvements

A number of samples could not be identified because they were damaged or only workers were collected. Although a worker key is now available (Sands, 1998) it is still difficult for laymen to use such a key. Expert identification of samples is extremely costly. Termite samples collected with the transect method are sometimes damaged because specimens are detected when turning over the soil. Great care has to be taken when searching the soil, as samples need to be protected from desiccation under field conditions.

This broad survey highlights difficulties of sampling termites in a semi arid environment where populations are limited and possibly wide spread.

The calculated diversity indices need to be interpreted with caution, because sample numbers are extremely low. It is difficult to draw unequivocal conclusions on whether differences in termite taxa and assemblages derive from environmental variability or land-use impacts.

The beauty of applying the standardised transect method is that it provides results that can be quantitatively analysed and compared between sites worldwide. However, for application in arid to semi-arid environments there is a need for modification. Chapter 6 explores three different termite-sampling methods and compares their results for reliability and efficiency. Chapters 7 and 8 follow on with more in-depth investigations bringing together the termite diversity data and ecological background data.

PART III

CHAPTER 6

TERMITE SAMPLING METHODS

6.1. Introduction

Termite diversity is difficult to determine reliably. Abundance is an even harder aspect to measure in these social insects. A number of methodologies have been used in the past to sample for termite diversity and abundance in various ecosystems and habitat types. The aim of this study was to test three different methods and to develop a reliable sampling protocol for termite diversity in arid lands. Three commonly used methods, including the use of a belt transect method (Davies, 1997; Eggelton *et al.*, 1997), a standardised search protocol (Coaton & Sheasby, 1972), and baiting experiments (e.g. La Fage, 1973, Ferrar, 1982c), were tested. The effectiveness and efficiency of the methods are compared and recommendations for a sampling protocol are made.

6.2. Methods

Study areas

The experiments were conducted at the three farms Olifantputs, Halt and Weerlig. The full termite sampling protocol was first developed at Olifantputs. It was then tested at the farm Weerlig. At Halt no baiting experiment was carried out. Sampling took place at the high and low intensity sites established for all project investigations (Chapter 2).

Termite parameters were measured between October 1997 and October 1998, including both a rainy season (March 1998) and two dry-season samples (October 1997 & October 1998). The samples are defined as wet (January-May) and dry (June-December) season samples.

Transect method

A standard belt-transect method (Davies, 1997; Eggleton *et al.*; 1997) was modified. Ten 2mx5m sections were sampled for termites. The sections were subdivided into two sub-sections and searched by one investigator each. They were spaced evenly along a 300m line transect, which was separated into three 100m sections placed at regular distances across a 1ha plot (Figure 6.1.). Each sub-section was searched for termites for 30 minutes. All wood, dung and other debris were examined and the entire soil-surface was loosened and searched to a depth of 5-10cm in order to locate sub-terranean termites (Figure 6.2.). All termites collected from each of the sub-sections were kept in vials of alcohol and preserved for later identification.

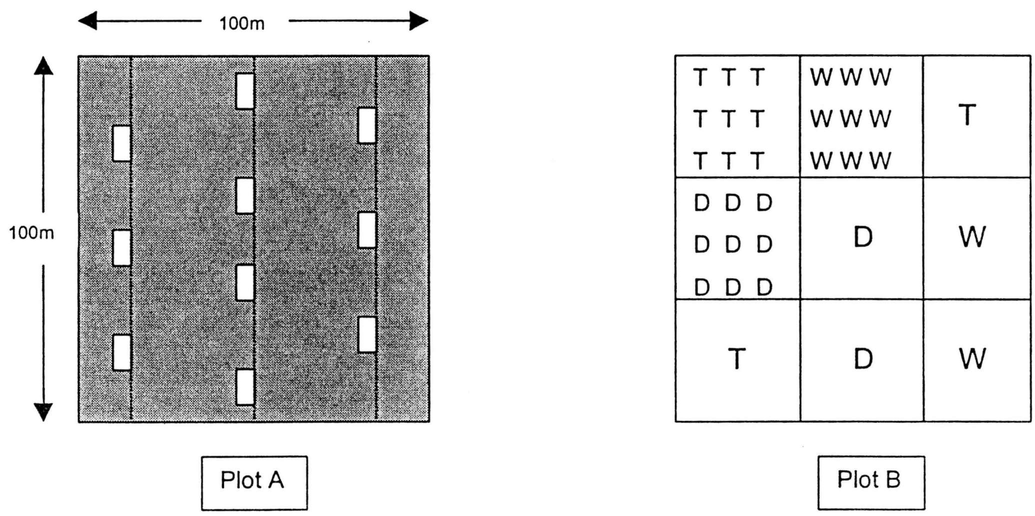


Figure 6.1 *Sampling design. Two 1 ha plots are sampled for termite diversity. In plot A the transect as well as search methods are applied. In plot B the baiting experiment is established. The various bait types are marked T = Toilet paper, D = Dung and W = Wood. All nine blocks have the same sampling design using nine baits in a sub-section as indicated in the left corner.*

Figure 6.2: *The transect method of sampling used*

Standardised search protocol

Each 1ha plot was searched for termites. One hour was spent searching in each plot. All possible termite microhabitats were searched, including the bark of trees, visible termite mound structures, fallen logs and others. All specimens collected were put into vials of alcohol for later identification.

Baiting experiment

The baiting experiment was started at Olifantputs first in October 1997 and ran for one year until October 1998. Additional baiting experiments were established on the farm Weerlig in December 1997. These plots were also active until October 1998.

A 1ha permanent plot was established adjacent to the 1ha plot that was searched for termites applying the transect and searching methods (Figure 6.1). The plots were situated in areas that were similar in their environmental parameters and types of microhabitats. Three types of baits were placed in a regular spacing in each of the 1 ha study plots: (1) toilet paper rolls, (2) dung samples and (3) soft wood tongue depressors. The 1ha plot was divided into nine blocks. Three blocks were used for the placement of a specific type of bait. The location was allocated randomly and followed the same pattern at each study site. Nine replicates of one bait type were placed in each of the respective blocks. This design resulted in 3x9 baits of each bait type being laid out at each study site. Altogether 81 bait samples were provided in each 1ha-study plot (Figure 6.1).

The baiting experiment was conducted over a one-year period for the toilet paper baits and wood baits. Fresh dung baits were offered during the October 1997 and April 1998 field visits.

Toilet paper

The baits were seen as an addition to the existing, natural forage. The spacing of the baits at 10m intervals was theoretically derived from the experimental set-up of Ferrar (1982c) who recommended 5m spacing for his study sites in a savanna ecosystem at Nylsvley, South Africa. In a more arid system resource inputs are considered to be lower, thus spacing of the baits should be larger (Ferrar, 1982c).

The toilet roll baits, which were prevented from unrolling by a clear tape strip, were half buried in the soil. A stone was placed on top of each of them as protection against passing cattle and rainfall (Figure 6.3.). The rolls were examined on each sampling date and any termite specimens present were collected and placed into a vial. The percentage of toilet paper eaten was visually estimated and noted. The bait was then placed back into the ground or was replaced if more than 80% - 100% had been removed. Consumption was calculated in a cumulative manner upon inspection of the baits.

Figure 6.3: *The bait method of sampling*

Wood

Three soft wooden sticks (14 cm long, 1.5 cm wide) were bundled and stuck into the soil so that half of the stem was placed under ground (Anderson & Ingram, 1993). The wooden baits were checked during all sampling occasions and the proportion eaten was noted.

Dung

The dung baits were prepared in the laboratory. A 6cm diameter and 6cm deep tin was filled with fresh cattle dung and placed with the open side down. The tin was buried approximate 50mm into the ground to protect the bait from rapid desiccation and disintegration as a result of climatic conditions. At the onset of two major field excursions conducted in October 1997 and March 1998 dung baits were laid and checked for termite infestation on several occasions, however not in defined time intervals. After checking, the bait was returned to its original position on the ground. The fresh dung baits were only examined over the period of each field trip, which lasted no longer than four weeks. No long-term consumption of dung baits was monitored.

6.3. Results

Taxon richness & composition at sites

Table 6.1 indicates which termite taxa were found using the different sampling methods at the various study sites. Both, the baiting and the transect method detect 78% of each taxa, whereas the search method only sampled 64% of all taxa.

Termite taxon numbers found at the six study sites range between eight and 13 for specimens that could be identified to at least the genus level. The highest number of termite taxa were found at the farm Weerlig where 13 termite taxa were found at the high land-use intensity site and eleven at the low intensity site. At the farm Olifantputs, eight (high intensity site) and nine (low intensity site) taxa were found respectively, at both sites at the farm Halt nine termite taxa were present.

Some termite taxa were detected using all the applied sampling methods, however others were only found by using a specific method. This is especially true of representatives of taxa that were less abundant. Whether this is a matter of chance needs discussion, however, it seems that certain taxa would prefer certain types of bait, while others do not consider baits at all.

Rhadinotermes was found using only the transect method, and *Baucaliotermes* was detected using only the baiting experiment. Specimens of the genus *Macrotermes* were found mainly at the baits and during searches, and were seldom detected using the transect method. In contrast to this four different species of *Trinervitermes* were found using the transect method. All *T. rapulum* and *rhodesiensis* samples, and most *T. dispar* specimens were collected only on transects and with no other sampling method. *Cubitermes* were mostly found through the searches. *Microtermes* and *Psammotermes* were found in all sampling procedures.

Table 6.1*:* Termite taxa found at six study sites in southern Kunene region, Namibia.

1. Farm codes: Olifantputs: low intensity (OPL), high intensity (OPH); Weerlig: low intensity (WLL), high intensity (WLH); Halt: low intensity (HAL), high intensity (HAH)
2. Sampling methods: B=Baiting, T=Transect, S=Search
3. Bait type: ❖=dung, ◆=toilet paper, ✧=wood
4. Season: O=dry, ●=wet

Termite taxa	OPL			OPH			WLL			WLH			HAL			HAH		
	Method	*Bait*	*Season*	*Method*	*Bait*	*Season*	*Method*	*Bait*	*Season*	*Method*	*Bait*	*Season*	*Method*	*Bait*	*Season*	*Method*	*Bait*	*Season*
RHINOTERMITIDAE																		
Psammotermitinae																		
Psammotermes																		
P. allocerus	B,T,S	◆,❖,✧	O,●	B,T,S	◆,❖	O,●	B,T	◆,❖,✧	O,●	B,T,S	◆,❖,✧	O,●	T,S		O,●	T,S		●
TERMITIDAE																		
Termitinae	S		O				B,T		O,●				T,S		O,●			
Amitermes	B,T	❖,✧	O,●				B,S	◆	O,●	S		●	T,S		●	T		●
Microcerotermes							B	◆,❖	●	T		●						
Cubitermes	S		●	T,S		●	B,S	◆	●	S		●	S		●			
Angulitermes							B	❖	●	T		●	S		●			
Macrotermitinae																		
Macrotermes	B,T	◆	●	B,S	❖	O,●	B	◆,❖	●	B,S	◆	●	T,S		O,●	S		●
M. michaelseni										B	◆	●				S		●
M. subhyalinus	B	◆	●	B	◆	●												
M. vitrilatus													S		●			
Odontotermes	T,S		O,●	B	✧	O	T		O,●	B,S	◆,❖	O,●	T,S		●	T,S		O,●
Microtermes	B,T	◆,❖	●	B,S	◆	O,●	B,T,S	◆,❖,✧	●	B,T,S	◆,❖,✧	●	T,S		●	T,S		●
Nasutermitinae																		
Baucaliotermes										B	❖	●						
Trinervitermes	B,T,S	◆	O,●	B,T,S	◆	O,●	B,T,S	◆,❖	O,●	S		●	T,S		O,●	T,S		O,●
T. dispar	T		●	T		●	B,T	◆	●	T		●				T		●
T. rapulum							T		O	T		O				T		O
T. rhodensiensis	T		O	T			O						T		O	T		O
T. trinervoides	B	◆	O	B,T	◆	O,●	B,T,S	◆	O,●	B,T	◆	O,●	T,S		O	S		O
Rhadinotermes										T		●						

Different types of baits

The results (Table 6.1) revealed that termite taxa do indeed have preferences for specific types of bait. Toilet paper bait was the type most frequently attacked, perhaps because the cellulose in the paper is easily digestible. *Trinervitermes* and *Macrotermes* were most commonly collected from this bait type. *Angulitermes* and *Baucaliotermes*, two rarely detected genera, were found in the dung baits only. The wood baits were attacked only occasionally, namely by the genera *Amitermes*, *Microtermes*, *Psammotermes* and *Odontotermes*. *Microtermes* and *Psammotermes* were found with all three types of baits used.

Seasonality of termite activity

Table 6.1 also reflects the season during which the various termite taxa were found at the study sites. Overall, it is apparent that termite activity and species numbers are highest during the wet season (Table 6.1). Genera samples such as those of *Angulitermes*, *Baucaliotermes*, *Cubitermes*, *Microcerotermes*, *Rhadinotermes*, as well as most of the *Macrotermes*, *Microtermes* and *Trinervitermes dispar* were collected in the wet season. *Trinervitermes trinervoides* were found both during the dry and wet season, as were *Psammotermes* and *Odontotermes. Trinervitermes rhodesiensis* and *T. rapulum* were found exclusively during the dry season.

Bait consumption

The mean consumption of the toilet roll baits at each of the four study sites was calculated. The mean consumption was highest at OPH, with 138%[1] (n=20). At WLH 101% (n=23) were consumed, at OPL 62% (n=24) and at WLH only 38% (n=18). The consumption rate was significantly different (ANOVA, $p<0.001$). No correlations were made with termite species occurrence, diversity or other data.

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[1] Because baits were replaced after they were consumed to >80%, consumption rates above 100% are calculated.

6.4. Discussion

A reliable sampling protocol for termite diversity has been tested however no single reliable method for rapid termite diversity assessment seems to detect all termite taxa present. In this research, three different methods for sampling for termite diversity generated different results. From the results it becomes apparent that (1) several termite species are highly seasonal and (2) certain sampling methods are appropriate for sampling certain termite species.

A baseline inventory for most termite species can be established by using either a baiting experiment or the standard belt-transect. The baiting method generated the highest numbers of termite taxa. A variety of baits offered is desirable, but the use of only toilet paper seems to be a good option, since this bait type yielded the highest number of taxa and involved a relatively low sampling effort and error.

Since the sampling periods of this study were preceded by two years of good rainfall (Chapter 2) it can be speculated that the number of termites found in the region, altogether 11 genera and 18 species/taxa (Table 6.1, Table 6.2), gives a fairly complete picture of the termites present in the area.

Compared to other arid regions in Africa and elsewhere, the number of termite taxa collected from the study area (11 genera, 18 identified taxa) is close to numbers sampled from similar environments. Eggleton *et al.*, 1994 derived a correlation between generic and species richness. According to the established relationship, for an arid environment approximately 15 genera comprising 20 species can be expected to occur. Lepage (1972) recorded 19 termite species from a study area of 100ha in the Sahelian savannah in Senegal, as did Sands (1965) for 4ha in the Northern Guinea savannah, Nigeria. The number of termite species found in the Ethiopian bio-geographical region is generally much higher compared to the Neotropical

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Consumption of one toilet roll would be enumerated with 100%, consumption of two with 200% etc.

and Indo-Malayan regions (Eggleton *et al.*, 1994). This also seems to be true for arid areas, e.g. Namibia.

Termites were sampled from three different farms and at each farm from two study sites of differing land use intensity. This was done to compare whether land use intensity and management affect termite community composition (chapters 7 & 8). Differences in species numbers present were indeed detected, with the highest number of taxa being recorded from Weerlig, the commercial farm. Taxa numbers were lowest at Olifantputs, the farm situated in former Damaraland reserve, thus in the communal area.

From the literature, provisional functional or feeding groups for termite taxa occurring in Namibia were established (Appendix 2). Placing the various taxa in "functional groups" reveals differences in the six study sites. Whereas at both sites at Olifantputs the majority of taxa are either fungus growers or grass feeding, at Weerlig this balance is shifted to a dominance of wood and litter feeding taxa. At Halt high intensity site (HAH) wood/litter and fungus growers are in equal in numbers but are outnumbered by grass feeders. At Halt low intensity site (HAL) wood/litter and grass feeders are equal in numbers but are outnumbered by fungus growers. This shift in dominance of functional groupings is based only on taxon presence data, not on abundance data. It can also not be established whether these differences are related to differences for example in woody biomass *per se*, which was the highest at Weerlig (chapter 8). However, this would not explain the difference between HAL and the low intensity site at Olifantputs (OPL). It is conspicuous that grass feeding termites are a lot more dominant at Olifantputs high intensity site (OPH), OPL and HAH than anywhere else, and possible functional relations to soil processes are explored in more detail in chapter 8.

Termite richness has not changed substantially over 30 years. Comparing Coaton and collaborators termite diversity data of the Namibian Survey of the Isoptera (NSI 1962/63; Table 6.2) for the broader study region in the sixties (11 genera, 14 identified taxa, Table 6.2) shows similar results to those derived from this study. It is therefore suggested that a search protocol can derive a robust reflection of the overall termite diversity. Experience of the collectors, however, seems to be a significant factor.

The main differences between the termite data from the two sampling events are that the genus *Epicalotermes* and the species *Hodotermes mossambicus* were not found in the recent investigation. *Epicalotermes* is a tree living species, which was probably not identified by the applied sampling methodologies, however it should have been detected through at least the search protocol. It is unexpected that no *Hodotermes* were found during the investigation, as it is so common.

Table 6.2: Species lists from termite diversity surveys conducted in southern Kunene region over the past 30 years: a comparison of taxa found during the respective surveys.

NSI (1963-68)	March 1997 Napcod sites	1997/98 study
Amitermes	*Amitermes (prob. hastatus)*	*Amitermes*
Anguilitermes	*Cubitermes*	*Anguilitermes*
Cubitermes	*Hodotermes mossambicus*	*Baucaliotermes*
Epicalotermes	*Macrotermes*	*Cubitermes*
Hodotermes mossambicus	*Macrotermes michaelseni*	*Macrotermes*
Macrotermes	*Microtermes*	*Macrotermes subhyalinus*
Macrotermes subhyalinus	*Odontotermes*	*Macrotermes michaelseni*
Macrotermes michaelseni	*Trinervitermes*	*Macrotermes vitrilatus*
Microcerotermes	*Trinervitermes rapulum*	*Microcerotermes*
Microtermes		*Microtermes*
Odontotermes		*Odontotermes*
Psammotermes allocerus		*Psammotermes allocerus*
Trinervitermes		*Rhadinotermes*
Trinervitermes dispar		*Trinervitermes*
		Trinervitermes dispar
		Trinervitermes rapulum
		Trinervitermes rhodesiensis
		Trinervitermes trinervoides
TOTAL:	***TOTAL:***	***TOTAL:***
• ***11 genera***	• ***7 genera***	• ***11 genera***
• ***14 identified taxa***	• ***9 identified taxa***	• ***18 identified taxa***

However, this could be due to the fact that sampling took place in a period with relatively good rainfall. *H. mossambicus* is known to forage primarily on dry grass stalks (Botha & Hewitt, 1978). It could be speculated that this termite species would become active under prevailing drought conditions.

Other species that had not been recorded from the area before were found during this study. These are *Baucaliotermes*, *Rhadinotermes* and *Macrotermes vitrilatus*. The latter two can be expected to occur in the area, since the genus/species' general spatial distribution throughout Namibia includes parts of the southern Kunene region. The single record of *Baucaliotermes* is surprising. A single species, *Baucaliotermes hainesi* Fuller has been recorded from Namibia (Coaton & Sheasby, 1972), with its spatial distribution restricted to the south east of Namibia. *Baucaliotermes* show a very strong correlation with low rainfall, with an increasing probability of occurrence with decreasing rainfall (Zeidler, 1997). Whether the presence of this species in north western Namibia is a sign of changing environmental conditions, especially climatic conditions, should be carefully examined.

The baiting method using toilet rolls provides additional information. Two observations can be made (1) bait "consumption" was higher in the wet compared to the dry season and (2) at high land use intensity sites (Olifantputs vs Weerlig and Olifantputs high vs. low) more baits showed termite activity. The higher rate of bait consumption at the high intensity sites could be a reflection of higher termite activity or alternatively of severe resource limitation.

While the search protocol generated low species numbers, it also detected species that were not detected using the other methods. The search required small inputs in time (1 hour for a 1ha area compared to 10 hours spent on the transect) and few materials and should therefore be considered as a useful backup methodology. The search produced the least quantifiable outputs.

With any of the methods used it remains a problem to collect soldiers for easy identification. Although today an identification key to the worker class of termites exists (Sands, 1998), identification of soldiers is easier and more reliable. It is especially difficult to detect soldiers with the transect method. This is probably particularly true in arid ecosystems, where surface temperatures are high and termites generally retreat below the soil surface. It should be mentioned that the sampling effort for the transect study is very high. The sampling of ten sections demands approximately two or more man-days. It is possible that an increasing number of sampling sections would also lead to an increase in termite species detected.

All specimens found on baits should be collected because occasionally more than one species attacks the same bait. Toilet roll baits are the "simplest" and most efficient in their application as they attract large numbers of species and individuals and a relative consumption rate can be noted. Dung, however, attracted a few species that were not detected by any other method. It should be noted that fresh dung in particular seemed to be attractive, probably because of the high moisture content. A drawback of the baits is that they are easily disturbed by humans as well as by passing animals.

Eggleton (*pers. com.*) suggested that the transect method would possibly detect a number of soil feeding termite species, which were not detected through the search sampling protocol applied by Coaton & Sheasby (1972). The results of this current investigation do not corroborate this. However, it is clear that particularly *Trinervitermes* species are only detected with the transect methodology. These species are thought to be grass feeding in Namibia, however, not enough biological data are available to reliably determine the feeding group to which they belong. Generally, it is clear that few or no exclusively soil feeding termite species occur in the study area, which is generally low in soil organic matter.

While this chapter focuses on testing termite sampling methodologies and establishing termite taxa inventories from the six study sites, the following chapters explore the suitability of using termites as potential indicators of biological integrity in conjunction with other environmental data.

PART III

CHAPTER 7

PRELIMINARY INVESTIGATIONS OF INDICATORS OF HABITAT CONDITION ASSESSMENT AT THE COMMUNAL FARM, OLIFANTPUTS

7.1. Introduction

After testing various methods of sampling termites, the data can now be used to test whether termite diversity measures are indeed suitable indicators of habitat quality. The following chapter presents research that was carried out at the farm Olifantputs in October 1997. An experimental design for selecting suitable indicators of habitat condition was implemented. Biological indicators such as diversity measures of termites were used, along with other selected bio- and geophysical indicators to describe two study sites on the farm, one under high and one under lower land use intensity (Chapter 2).

Defining and measuring rangeland degradation is extremely difficult. The problem of having to differentiate between changes in the environment attributable to natural variation versus true land degradation needs to be addressed in particular. Several papers question the use of simplified vegetation models as suitable indicators of degradation (e.g. Behnke & Scoones, 1993; Ellis *et al*, 1993; Coppock, 1993; Tapson, 1993; Stafford-Smith & Pickup, 1993) and a set of biophysical indicators of land degradation is defined. It incorporates measures of soil change, indicated by a decrease in fertility, water holding capacity, infiltration and soil loss in excess of soil formation. Vegetation changes are characterised by a loss of: productivity over time unrelated to rainfall patterns, cover, species composition and shifts between vegetation transition states that result in decreased fodder. Indicators of livestock production are condition-scoring of animals, calving and death rates, and milking yields (Behnke & Scoones, 1993). These indicators have been considered in the preparation of this study.

From the above it seems justifiable to place an emphasis on soil related research. Whereas inherent soil fertility is mainly determined by the underlying base rock and long term weathering processes, the so-called resilience of soils or the ability to regenerate to an equilibrium after disturbance (Swift, 1994) arises from a range of recovery or regenerative processes, including the activity of the biota (e.g. root development & soil fauna) (Elliott & Lynch, 1994). Soil biota are classified as micro-, meso- and macro-fauna and flora. Their involvement in soil related processes such as the nitrification and mineralisation of components and soil organic matter (SOM) cycling, affect soil chemical and physical properties. The role of soil biota in maintaining soil processes has been demonstrated extensively and has been reviewed in the literature (Anderson, 1988; Swift & Anderson, 1993). Termites are particularly prominent representatives of the soil fauna in Namibia (Crawford & Seely, 1994; Zeidler *et al.*, 1999) and are therefore considered in particular in this study.

In the following a few main concepts and properties around soil fertility that are relevant to the research presented in this PhD are described.

Decomposition

Despite new inputs from the atmosphere and from rock weathering and plant adaptations to minimise the loss of nutrients, most of the annual nutrient requirements by land vegetation are supplied from the decomposition of dead materials in the soils (Swift *et al.*, 1979). Decomposition of organic matter completes the cycle by releasing nutrient elements for plant uptake. Decomposition is a general term to refer to the breakdown of organic matter. Mineralisation is a more specific term that refers to the processes that release carbon and nutrients such as phosphorus and nitrogen. A variety of soil animals including termites translocate, fragment and mix fresh organic matter, however it is mainly fungi and bacteria which perform the bio-geochemical transformations in the soils (Schlesinger, 1991; Anderson, 1995).

Soil carbon

Soil carbon in the form of Soil Organic Matter (SOM) is the largest biospheric pool of carbon with a turnover rate of decades to centuries (Schlesinger, 1991). Soil contains inorganic carbon, which is not very reactive in short time-scales, and organic carbon (OC), which occurs in three different pools of differing turn over rates. The "active" pool consists of small litter particles, which are easily transformed, and with turnover rates of hours to months. These form the Light Fraction (LF). The light fraction is thought to build up, in particular, in the soils through the activity of macro fauna. In arid Namibia the soil fauna is dominated i.e. by termites. 2-5% of SOM is in the bodies of living microbial biomass, which also contribute to the active pool. The "slow" pool has a turnover rate of decades to centuries and consists of hard to decompose particles of humic substances and clay-associated organic matter. The "passive" pool contains essentially inert organic substances (Schimmel, 1995; Scholes & Walker, 1993; Scholes & Scholes, 1996). The "active" pool, especially containing the light fraction, is extremely important for the sustainability of soil systems. Changes in the light fraction will ultimately result in changes of the "slow" SOM pool, because of the quantity and quality of the inputs. This pool is the key to medium and long-term sustainability acting in the range of decades and centuries.

Nitrogen

Nitrogen is the element most frequently limiting primary production in terrestrial systems, and often, secondary productivity as well. It is an important component for building structural and metabolic proteins in living organisms. Soil nitrogen forms the largest terrestrial pool of nitrogen. Nitrogen occurs as organic nitrogen, which is mainly bound to carbon compounds, and inorganic nitrogen, which is particularly important to primary productivity. Inorganic nitrogen is released through the mineralisation of SOM. The C:N ratio provides a measure of N availability per C.

Phosphorus

Phosphorus is the element second most likely to be limiting in terrestrial ecosystems. It is an essential part of cell nuclei and genetic material. The soil phosphorus forms the largest terrestrial pool of phosphorous. Phosphorus is the least mobile of nutrients. It is bound by Aluminium (Al) and Iron (Fe) ions in acid soils, which "lock the nutrient" and lead to infertile soils.

Soil water
Water is the medium that transports soluble nutrients in the landscape and makes these available to plants. It plays a dominant role in controlling the rate of many chemical and biological processes and most nutrient cycles follow the water cycle. Water penetration into the soil is important and soil pores, e.g. created by animal burrows such as termite galleries, are important to prevent run-off. SOM as well as clay particles retain water and increase the water holding capacity of soils. SOM and clay both are translocated and accumulated in the soil by termites.

This pilot study formed the background for the study presented in Chapter 8, which aims to test the suggested indicators on the three farms Olifantputs, Halt and Weerlig, respectively.

7.2. Methods

Study site selection

The same study sites, OPL and OPH, already introduced in Chapter 6 were used for these investigations. A more detailed background to the sites is also given in Chapters 2 and 3.

Data acquisition & sampling method

(a) Termite data

Various termite parameters, i.e. taxa presence, diversity and resource consumption were investigated (Chapter 6). These data are used in this chapter to establish possible relationships between termite diversity and habitat condition.

Termite diversity was calculated in two different ways, using the Shannon Weaver index of diversity and the Simpson index of dominance. Both these indices use relative abundance as the parameter in their calculations. Relative abundance of termites was computed on the basis of census data from the baits, following Davidson (1977) for calculating ant diversity data. Davidson established that the value p_i in the Shannon Weaver Index ($H' = -\Sigma\, p_i \ln p_i$) corresponds to the proportion of the total baits attacked by the *i* th species. Hence, this index measures diversity on the basis of resource exploitation rather than the relative abundance of colonies or workers of each species. The same relationship was assumed for calculating the Simpson index ($D = \Sigma\, p_i^2$). A similar rationale has been assumed for termites (Johnson & Whitford, 1975).

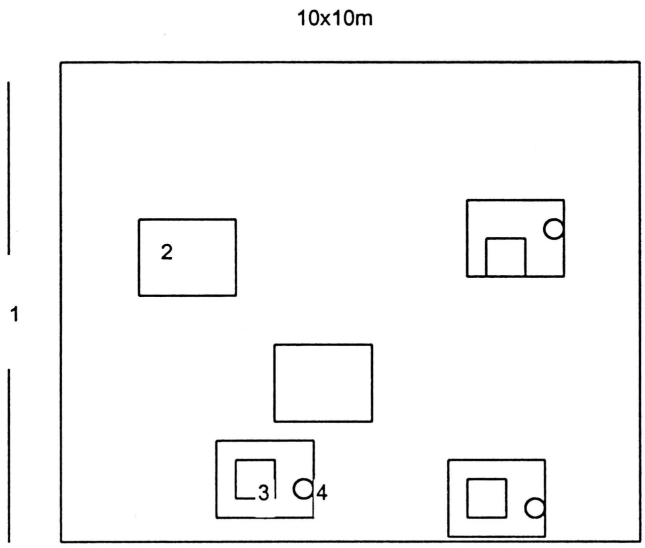
The data are provided and calculated for each of six bait sampling events, including samples from the wet and dry seasons. As shown in Chapter 6 some termite taxa show strongly seasonal activity patterns. It is assumed that sampling during the dry and wet seasons detects maximum termite taxa richness and related measures. These maximum numbers ought to be used for the termite parameters assessed in this study.

The termite data collected from both, the (1) low intensity site (OPL) and (2) high intensity site (OPH), were compared using two-sample t-tests and the equivalent non-parametric statistics when data were not normally distributed.

(b) Sampling design

Sampling for vegetation and soil parameters took place only during the dry season in October 1997. The previous rainy season yielded good rainfall and biomass production was at a maximum during the wet season around March 1997 (see Appendix 7). Since then biomass, however it was still better in October 1997 compared to the following seasons. Although the vegetation and soil data were only collected during one season, the termite data related to this study covers a longer time period, including the wet season sample of March 1998. The termite sampling took place on the same plot.

A 1ha study area was selected at OPH and OPL respectively. Within each 1ha, three sub-plots measuring 10mx10m were selected randomly for sampling. Sampling for all parameters took place in each of these sub-plots, using a random design. The applied sampling procedure is depicted in Figure 7.1.



(1)Tree and shrub species composition and biomass were assessed recording all woody vegetation by species in each of the three 10x10m sections.

(2) Within each 10x10m section five 0.5x0.5m sub-sections were selected
Each was sampled for:
(a) Herbaceous biomass
(b) Litter & dung

(3) Within the 0.5x0.5m sub-section a 0.25x0.25x0.25 soil block was sampled for root biomass & soil fauna.

(4) One soil sample was taken at three sites per sub-plot, using a 30cm soil corer. The samples were analysed for
(a)Light fraction carbon
(b)Total organic carbon
(c)Total nitrogen
(d)Total phosphorus

Termites were sampled at the same plots using the baiting method (Chapter 6).

Figure 7.1: *Sampling design. Three 10m^2 sections of this kind were allocated randomly across a 1ha study area for investigations. All these sections were sampled in a similar fashion.*

(c) Vegetation data

Tree and shrub species composition and biomass were determined following Rutherford (1982). All woody vegetation occurring in a 10mx10m sub-plot was identified and the circumferences of the stems were measured. From these data the biomass of woody vegetation in the sub-plot was calculated using the general species regression equation developed by Rutherford (1982) for combined tree species. This equation was used because species composition was diverse and did not necessarily incorporate species for which individual formulae were defined. Herbaceous biomass was determined through clipping and weighing. Five 0.5mx0.5m sub-sections within each 10mx10m sub-plot were sampled for standing herbaceous biomass. These sub-sections were also used for litter and dung collected from the ground and weighed in the laboratory. Root biomass was assessed by sieving the soil volume of $0.25m^3$ taken from the designated sampling quadrates (Figure 7.1) and weighing the oven-dried roots. All data were calculated to the hectare. The soil volume was calculated using a bulk density value of 1.6 derived from the literature (Miller & Donahue, 1990), a value, which could be expected for the prevailing soil types at the study sites.

(d) Soil data

Soil cores were taken to a depth of 0-30cm. From these, total soil carbon using the modified Walkley Black method (Nelson & Sommers, 1982; Appendix 4), total nitrogen applying the Kjeldahl oxidation method (McGill & Figueiredo, 1993; Appendix 4) and plant available phosphorus following the Olsen method (Shoenau & Karamanos, 1993; Appendix 4) were determined. Light fraction analyses were done using a standardised wet sieving method (Anderson & Ingram, 1993; Appendix 4).

(e) Data analyses

All parameters were compared between the two study sites OPL and OPH by two-sample t-tests ($p<0.05$, unless stated otherwise). ANOVA was run to establish within-site variability. All data were tested for normality and relevant non-parametric statistical procedures were applied (Mann-Whitney U-test and Kruskal-Wallis).

7.3. Results

The data obtained from the termite baiting experiment are presented in Chapter 6 and are summarised in table 7.1. Numbers of baits attacked by an individual termite taxon (here genus level) are given per sampling event. The calculated diversity indices are also included.

Table 7.1: Termite genera collected at Olifantputs (Oct.97 – Oct.98) during baiting experiment and diversity indices (Shannon Weaver Index = H'; Simpson Index = D) calculated

Site	Sample event	Psammo-termes	Ami-termes	Macro-termes	Odonto-termes	Micro-termes	Trinervi-termes	Total # sampled	H'	D
OPL	10/97	3	1					4	0.57	0.63
	12/97	2						2	0	1
	03/98(1)	10		1				11	0.32	0.84
	03/98(2)	28	2			3		33	0.5	0.73
	04/98	24	1	1		2		28	0.45	0.75
	10/98	7					2	9	0.52	0.66
OPH	10/97				1			1	0	1
	12/97							0	0	1
	03/98(1)	5				1		6	0.46	0.72
	03/98(2)	19		4		2	1	24	0.72	0.64
	04/98	15				3	4	22	0.85	0.51
	10/98	1					1	2	0.69	0.5

Six different termite genera, namely *Psammotermes*, *Amitermes*, *Macrotermes*, *Odontotermes*, *Microtermes* and *Trinervitermes* were found at Olifantputs, using a baiting experiment. Specimens of the genus *Amitermes* were only found at OPL and a single specimen of the genus *Odontotermes* was found at OPH. All other genera were found at both sites, but only one genus, *Psammotermes*, seemed to be relatively abundant. Sample numbers were generally higher during the wet season in March/April compared to the dry season (September/October), as were numbers of different genera found. Several genera were only found during the wet season sampling.

T-tests on all the termite parameters obtained during the various sampling events showed no significant difference for either diversity or dominance between the two study sites.

Table 7.2 summarises the various environmental data collected. The mean value scored for each sub-plot is displayed as well as the significance tests for the comparison between values of OPL and OPH. Species composition of woody vegetation is recorded as a "taxa present" list.

It is apparent from the data that the mean values for all of the parameters measured, except the herbaceous biomass, are higher at OPL compared to OPH. However, these values are mainly significantly different only for the soil parameters. The mean for total nitrogen in the soil is significantly higher at OPL with 0.054% ($p<0.001$, two-sample t-test, two- tailed) than at OPH,

Table 7.2: Environmental data for the high and low intensity study sites at Olifantputs collected in October 1997.

VEGETATION/ORGANIC MATTER BIOMASS					
	Tree/shrub biomass kg/ha	**Tree/shrub species**	**Litter/ Dung kg/ha**	**Herbs kg/ha**	**Roots kg/ha**
Low intensity site	104.4	*Colophospermum mopane, Acacia senegalensis, Catophractes alexandri, Maytenus senegalensis, Commiphora spp.*	1024	43.6	478
Stdv	*112.5*		*556*	*32*	*421*
High Intensity site	100.6	*Acacia tortilis, Boscia foetida, Catophractes alexandri*	648	102.4	208
Stdv	*162.3*		*512*	*118*	*200*

SOILS						
	P (plant avail.) ppm	**Total N %**	**Total C (OC%)**	**C:N**	**Light fraction %**	**C:LF**
Low intensity site	10.42	0.054	0.47	8.18	0.056	12.59
Stdv	*6.37*	*0.025*	*0.27*	*2.14*	*0.048*	*7.47*
High Intensity site	7.53	0.027	0.14	5.25	0.042	3.46
Stdv	*4.06*	*0.008*	*0.04*	*1.38*	*0.013*	*0.94*

where only 0.027% were measured. Within-plot variability is significant at both study sites (ANOVA, $p<0.001$, $n=15$) and two sites at OPL had particularly high N-contents compared to all other sites. Total carbon (OC%) was found at significantly higher levels at OPL compared to OPH ($p<0.001$, two-sample t-test, two-tailed). For the OC samples, a similar pattern in within-site variability can be detected as for nitrogen, singling out two plots with high values. Calculating the C:N ratio reveals that this is significantly higher at OPL ($p<0.001$, Mann Whitney U-test), scoring 8.2 and only 5.3 at OPH. There was no significant difference in the light fraction (LF) content at either site. However, the C:LF ratio, which could be used as an index of organic matter mineralisation, is higher for OPL, although not significantly so. It should be noted that the data set of OPL contains outliers. Removal of the outliers leads to a much highr C:LF ratio ranging at 16:8. This would also mean that the C:LF ratio was significantly different between OPL and OPH ($p=0.003$, two-sample t-test, two tailed).

The data from the vegetation-related sampling do not show significant differences between the two plots, although tree, litter and dung as well as root biomass were higher at OPL. This relationship was not found for herbaceous biomass, which scored higher at OPH. Looking at the data from the ANOVA it is apparent that herbaceous biomass was indeed very similar at all plots at OPH as well as OPL, however, there was one major outlier recorded for OPH, with a high value. In this plot, biomass inputs were exceptionally high.

7.4. Discussion

Comparing vegetation, soil and soil biotic, i.e. termite measures between two sites of differing grazing intensity, reveals some first indications of which parameters might be useful in discriminating between sites of varying habitat integrity/condition.

The vegetation parameters measured generally did not discriminate between the two sites, although trends such as higher vegetative biomass and below and above ground inputs were found at the low land use intensity site. This was not true for herbaceous biomass, which was higher at the high intensity site. The fact that there are no significant differences in herbaceous biomass could possibly indicate that by October, grazing resources were similarly used at all sites, particularly considering that Olifantputs is a communal farm where cattle can move freely, using grazing wherever available. The extremely low figures for herbaceous biomass, 102.4 kg/ha at OPH and only 43.6 kg/ha at OPL, suggest that the grazing resource was extensively used by October, which is shortly before the rainy season and not much grazing was left to feed the cattle which were still on the farm. There is no unequivocal explanation why herbaceous biomass was higher at OPH, a site situated nearby the village and the watering point. No records were made on the species composition and therefore it can not be qualified whether the standing biomass was perhaps made up of unpalatable species. As also in all other parameters measured variability in the collected data biomass is extremely high, which illustrates the patchy resource distribution in this area.

Litter and dung are subject to such patchiness. Windblown litter accumulates at the base of perennial grass tussocks or trees or in soil depressions. Dung is distributed unevenly and the chance of collecting dung at a selected study plot is low. Dung mass also varies a lot, depending on what animals dung has been sampled and how "decomposed" it is. Dung and litter were not separated in the collection procedure and it cannot be determined which of the two parameters is contributing most to the high biomass inputs recorded. With 1024 kg/ha at OPL and 648 kg/ha at OPH litter and dung inputs were much larger compared to the herbaceous resource. It was conspicuous that most of the litter was made of broken off grass stalks. This could explain the high amount of litter recorded from the sites, which exceeds the amounts of standing herbaceous biomass. At OPH litter biomass is 25 times higher than standing herbaceous biomass. However, strictly speaking this resource is also available as grazing to livestock.

Excluding tree biomass, above ground biomass was 2.2 times greater than below ground biomass at OPL and 3.6 times so at OPH. Considering that tree biomass was similar at both sites and herbaceous biomass was even higher at OPH, this is surprising. Considering only herbaceous biomass as above ground input the above to below ground biomass ratio shows that at OPL below ground reserves are 11 times larger than above ground, whereas at OPH below ground vegetation biomass is almost 50% less than the remaining above ground herbaceous biomass. It could be expected that below ground reserves would be quite high because roots often remain in the soils even if the aboveground part of a plant is grazed. The herbivore pressure on below ground resources is also much less. Although this study also did spot checks for soil related fauna other than termites, only few organisms were found, including several spiders. A more in-depth study conducted near the study farms (Nghitila, 1995) used Berlese extraction methods to detect soil meso- and microfauna. However, few soil organisms were found, and the study concluded that termites indeed were the most abundant organisms. This would indicate that below ground herbivory could be very low in the area. However, the fact that root biomass is lower at OPH could be attributed to the lower tree biomass or different vegetation types found at the site, which could possibly have different root systems, e.g. more annual herbaceous vegetation with less developed roots compared to more perennial vegetation with strongly developed root systems.

Woody biomass was similar at both sites, however, slightly higher at OPL. Most of the tree biomass at OPH was constituted by one large tree (*Boscia foetida*). Tree species composition is a bit different. Whereas at OPL a number of mopane trees were found, none were reported from OPH. It is likely that this can be attributed to exploitation of this species close to the village – mopane wood is used for fires and as a building material. Mopane leaves are the main forage for goats and even for cattle when grazing is depleted. Considering this, it is possible that the herbaceous biomass at the perceived low intensity site was lower because in this area animals would also be able to find browse (i.e. mopane tree leaves).

When the biomass of all the vegetation parameters are summed up, resource availability is higher at OPL compared to OPH.

The measured vegetation parameters provided some useful insights into the nature of the two study sites. However, for future studies it can be recommended that more qualitative data be collected, especially on the grazing potential of the vegetation, i.e. by determining the palatability of the species occurring there. Litter and dung inputs should possibly be considered separately to get a better feeling for the magnitude of contribution from each resource. Some of the applied field sampling methods, especially the assessment of below ground vegetative biomass and herbaceous cover, were extremely time consuming and other standard procedures should be explored. Sampling design could possibly be improved so as to take the extremely patchy distribution of the resources into account. An increase in sample number of the various parameters could be a first improvement.

Soil fertility is considered a major contributor to habitat condition, although rainfall is the primary trigger of primary production in areas as arid as Damaraland (Scholes, 1990). A variety of the measured soil parameters seems to supply extremely useful information, pointing at differences in "habitat integrity/condition" between the two study sites, as well as providing insights into the general "fertility/quality" of the area.

Generally, the southern African savannahs, including the part of Namibia where this study took place, are characterised as arid and eutrophic savannahs, growing on relatively nutrient rich substrates (Scholes, 1990). In arid areas soil formation is predominantly determined by the underlying parent material and time (Singer & Munns, 1992). The parent material determines for example the rate of soil formation, type and content of nutrients, the amount of clay as well as the soil colour (Miller & Donahue, 1990).

Olifantputs is situated on parent material made predominantly of gneiss (see geological map, Fig. 1.3, Chapter 1). Gneiss is a metamorphic rock formed mainly from granites, rhyelites and andesites, which are igneous rocks mainly containing feldspar, quartz and dark minerals. Gneiss is considered to form medium fertile soils (Miller & Donahue, 1990). The soil carbon, nitrogen and phosphorus pools are in a constant flux with natural inputs mainly coming from animals and plants living above and below the ground. The organic matter is translocated into the soils where it is transformed and relocated. Losses to the atmosphere as well as e.g. through leaching into the ground and sometimes ground water occur. However, in an environment as arid as the study area, it is unlikely that soil nutrients are lost through leaching.

For the interpretation of the data of this study it is assumed that in geological time the fertility of the soil was similar at both study sites, which are situated on the same parent material. Any significant difference in soil parameters are therefore interpreted as the result of shorter-term impacts, e.g. land use intensity, which may affect the biota. Biota, including vegetation and animals, are main contributors to the cycling of nutrients on a shorter time horizon, primarily contributing to the dynamics of the "active" and shorter-term pools of soil nutrients, which ultimately effect the longer-term pools (see literature review).

Most of southern Africa's savannahs are particularly N limited although P also plays a significant role as a limiting factor for plant growth (Scholes, 1993). Comparing the plant-available P concentrations obtained from the soil samples at Olifantputs, these range between 10.42 ppm at OPL and 7.53 ppm at OPH. These are relatively high values, considering that application of phosphorus fertilisers are usually recommended from values around 2 ppm in southern African savannahs. In a broad-leafed savannah system in South Africa P levels were measured as 5.1 ppm. P is not a limiting factor in soil fertility at Olifantputs, particularly also when considering the results for N and C, indicated below.

At Olifantputs mean nitrogen contents were 0.054 % at OPL and 0.027 % at OPH. Comparing these values with N values from a southern African savannah system at Nylsvlei, South Africa (Scholes & Walker, 1993), the N content at OPH seems extremely low. Considering that both study sites at Olifantputs were situated on similar substrates and habitats, it can be speculated that the low nitrogen content at OPH is caused by more recent impacts. However, it could be expected that N inputs are high at the high intensity site, due to defecation. Nevertheless it seems that N limitation is more critical under high land-use and grazing pressure, possibly because the N content in soils is closely linked to carbon and its cycling (see below). Studies e.g. by Frank *et al.* (1995) and Schuman *et al.* (1999) point to the effect of grazing pressure on C and N distribution in the soil profile. These studies indicate that net N and C remain similar under long-term grazing regimes, however, the distribution within the soil profile as well as between the soil-plant interface shifts. This was not addressed in detail in this study, where soil samples were taken from the top 15 cm of the soil, which are considered to be the volume from which plants extract their nutrients (e.g. Miller & Donahue, 1990).

The organic carbon levels recorded from Olifantputs lay between 0.47 % at OPL and 0.14 % at OPH. These values are very low, even compared to a nutrient poor savanna system - OC levels at Nylsvlei range between 0.32 % and 0.92% (Scholes & Walker, 1993). Although arid soils are known to contain low soil organic matter and to yield low organic carbon levels (Scholes *et al.*, 1994), the values obtained from Olifantputs seem crucially low and seem to be even more impoverished under high land use intensities or grazing pressures. A difference of 70% in total OC content between soils at the low and high intensity site seems dramatic.

The imbalance of the OC content in the soils at Olifantputs is also illustrated by the extremely low C:N ratios, recorded as 8:1 at OPL and 5:1at OPH, both below the "rule of the thumb" for these types of environments which would be expected to be in the area of 10:1 (e.g. Miller & Donahue, 1990). Generally there is more N associated with C at Olifantputs. This leads to a conclusion that at Olifantputs, nutrients such as N and P are conserved and C losses are high and inputs low. The C:N ratio is significantly different at OPH compared to OPL. The extremely low C:N ratio at OPH underlines that it is the OC that is the crucial soil component being affected by land use impacts at the study sites.

The ratio of total OC and the light fraction, C:LF, is calculated as 13:1 at OPL and 4:1 at OPH. Although the results are not statistically significantly different, removing an outlier data point from the OPL data set pushes the ratio for this site to 17:1, now indicating a significant difference between the two sites ($p=0.003$; two-sample t-test, two-tailed). In any case it is apparent that at OPH the associated C is extremely low compared to LF. This seems to indicate that at OPH, where the total OC level is already extremely low, the fraction that is made of LF, thus non-humified organic material, is disproportionatly high. This would indicate that it is the conversion of the "active" OC pool to the "slow" OC pool that is not taking place, or at a very low rate. Again, it is in the end the "slow" pool that guarantees longer-term sustainability of the soil system.

The modification of LF to SOM is mediated by soil microbes. However, Zeidler *et al.* (1999) hypothesised that the conversion of LF into humified C could possibly also be linked to termite activity in north western Namibian rangelands. As predominant representative of the soil macro fauna at the study sites at Olifantputs, termites are thought to not only function as translocators of organic matter from the soil surface into the soil, but also to directly affect nutrient mineralisation through mutualistic associations with micro-organisms e.g. in their digestive systems (e.g. Lavelle *et al.*, 1994). No in-depth studies of the soil microbial system at the study sites have been conducted so far however, Crawford & Seely (1994) point to the activity of soil microbes after rainfall events in the Namib. It should be investigated in future, if it is the lack of microbial activity that inhibits the transformation of LF into more stable fractions of SOM with a slower turnover rate that leads to a low C:LF ratio at the high land use intensity site. Also it would be interesting to understand whether termites could indeed play a significant role in LF to SOM transformation themselves in arid environments.

It would be interesting to establish whether termite abundance differs between the study sites and if termite activity might affect the soil carbon pool. A study by Jones (1990) indicates that termites of the family Macroterminae deplete the soil carbon content, although other studies point to soil carbon concentrations in relation to termite activity.

In this study, species assemblages of termites as well as diversity indices calculated from the termite data did not reveal significant differences between termite communities at either OPL or OPH. Although two species were present at only one of the two sites, this could be attributed to a sampling "error", not detecting all species present by the applied sampling protocol.

It should briefly be discussed that the termite data used in this study reflected termite diversity measurements taken over a one year period (October 1997-October 1998), while the soil and vegetation data were measured only once, in October 1997. This was done primarily because the termite data from October 1997 did not seem to provide a good reflection of termite diversity at the sites. Only a few specimens of the genera *Psammotermes allocerus*, *Amitermes* sp. and *Trinervitermes rhodensiensis* were collected from OPL, and *Odontotermes* and Nasutermitinae, prob. *Trinervitermes* from OPH. As pointed out in Chapter 6, a termite sampling protocol combining various methods and taking place over the two peak seasons (dry & wet), are necessary to establish a more complete picture of species presence.

It can be concluded that OPL, a site that was identified by the farmers as being grazed and used only lightly compared to OPH, has a higher soil fertility status today, although both sites were assumed to be historically similar and to have undergone similar pedogenic processes resulting in soils of similar fertility (Chapter 2). It should be noted that both sites are low in soil organic carbon, but that they seem to differ greatly in the way the "active" and "slow" pool dynamics work. It would be interesting to further establish how the dynamics of these pools work under the differing land use impacts. It would be important to establish, whether the low levels of carbon maintain, perhaps even deteriorate, or whether they fluctuate naturally and possibly improve again over time.

To prevent lasting soil degradation, management interventions to restore the soil organic carbon pool should be applied. In agricultural systems it is common practice to improve soil carbon levels through application of organic matter such as plant residues and manure (e.g. Miller & Donahue, 1990), however such interventions would not re-establish the soil biotic systems if these are disturbed. In the Namibian context it seems that such remedies would be impractical and a long-term reduction of land use intensity, i.e. grazing is possibly the only way to prevent soil degradation. However, it is important to study and monitor if the crucial links in the nutrient transformation cycle including a great number of key players such as soil biota are indeed constrained. If so targeted interventions may have to be planned.

Although this pilot study could not establish whether termites are indeed suitable indicators of habitat condition, important functional links could be drawn. A number of potential vegetation and soil related indicators were tested and especially soil carbon levels were identified as an important factor discriminating between range condition at two land use intensity sites at Olifanstputs. The following chapter will establish whether land tenure and associated with it, land use practice and land use intensity affect range condition differently.

PART III

CHAPTER 8

TOWARDS AN INDEX OF BIOLOGICAL INTEGRITY FOR HABITAT ASSESSMENT IN NAMIBIA – DEVELOPING INDICATORS AND MONITORING TOOLS: RESULTS FROM THREE FARMS OF DIFFERING LAND USE AND LAND TENURE IN NORTH-WESTERN NAMIBIA

8.1. Introduction

The preceding chapter pointed out potential indicators to be measured for habitat assessment. These were primarily soil nutrient based indicators, measuring e.g. soil nitrogen (N), organic carbon (OC), light fraction (LF) and the C:N to C:LF ratios. Several vegetation parameters were suggested, including herbaceous biomass. Sampling procedures were to be improved and particularly measures of palatability and records species composition were suggested. These suggested indicators were to be tested. This was done at the study sites Weerlig, Halt and Olifantputs. Weerlig and Halt, although situated in a similar environmental setting as Olifantputs (Chapter 2), differ in their land tenure, land management and land-use intensity histories and current practices (Chapters 2 & 3). This is a good setting to test whether the selected set of indicators indeed provided a good tool for distinguishing natural variability in the ecosystem from degradation processes. It also may provide clues as to whether different forms of land tenure, land management and land-use intensity affect the natural resource base to varying degrees.

The aim of this research is to develop reliable and practical methods for range condition assessment and monitoring by using two complimentary approaches: (a) using locally existing farmers' knowledge (Chapter 10), and (b) applying scientific methods to determine range/habitat condition (Zeidler *et al.*, 1998). This research explicitly investigates whether and how existing land tenure systems in Namibia affect range condition by combining detailed data derived from the community-based research and information exchange presented in Part II of this thesis, with ecological techniques.

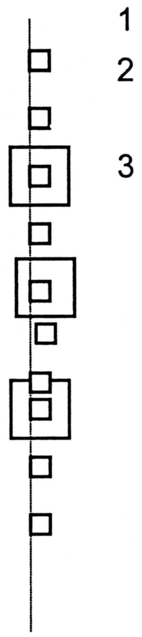
It is unlikely that there is a single most sensitive species that can reflect habitat condition over a broad scale (e.g. Crains, 1986; Noss, 1990). This study takes a multi-factor approach, attempting to establish process-oriented linkages between land-use, rainfall, vegetation, soil and particularly soil biota.

8.2. Methods

Vegetation, soil and soil faunal parameters, namely plant species composition, abundance of dominant species, above ground annual net primary production (ANPP), total soil carbon, light fraction, total soil nitrogen and phosphorus, termite species richness, composition and relative abundance were chosen as indicators of biological integrity of western Namibian rangelands. Additionally, dung and litter biomass at each site was measured to get an idea of resource availability for termites. The indicators were chosen based on a literature survey, existing knowledge of the study area and the results from Olifantputs presented in Chapter 7. The synthesised conceptual framework is presented in Figure 1.4 (Part I).

(a) Sampling design and number of samples

All samples were taken during March and October 1998 from a 1ha plot at each of the six study sites. A combination of line intercept and quadrate methods was used to measure the various vegetation, soil and termite parameters. Three 100m line transects were run across the 1ha sampling area along which the sampling quadrates were located.



(1) Every 2m a 0.25x0.25m quadrate was placed where plant species composition and biomass were assessed using the estimation method by T'Mannetje & Haydock (1963). Tree density was defined using the nearest tree neighbour method (Müller-Dombois, 1974). Along the three 100m long transects 150 vegetation data points were measured.

(2) In every fifth quadrate (every 10m) litter and dung were collected. Their dry weights were determined in the lab. Altogether 30 samples were taken.

(3) Every 30m a 2x5m rectangle was overlaid within which the vegetation, litter and dung parameters were measured, and termites as well as soil samples were collected. Altogether 10 termite and composite soil samples were collected along the three line transects.

Figure 8.1*: Field sampling design: one of three 100m transects is depicted. The drawing is idealised.*

(b) Vegetation

Herbaceous vegetation: species composition, biomass and forage quality

Species composition and biomass estimates were measured applying the "Dry weight rank" method after T'Mannetje & Haydock (1963), reviewed in Barnes *et al.*, 1982. The species composition of the three most dominant herbaceous species within each 0.25mx0.25m quadrate was estimated. This was done by recording them according to rank from one to three, with one being the most dominant species. Additionally biomass estimates for the samples were made, ranging from one to five, from lowest to highest. Bare ground was recorded as a zero value. The biomass estimate was done in a purely subjective manner - ranking by eye. To determine the actual biomass of the various ranks assigned, random samples for each ranking class were clipped, dried and weighed. The average biomass scored for each rank could thus be determined and a dry-rank-weight curve established. This was used for analysis in a computer model developed for this dry-weight-rank methodology (Carter & Scholes, 1999). The model calculates the herbaceous biomass per ha, as well as determining the species composition across the one-hectare study site. Van Oudtshooven (1992) provides palatability values for southern African grass species, which are included in digestibility calculations in the model. The highest palatability value, five, indicates that the forage value of the species is excellent. Herbs and forbs for which no palatability values are available were categorised as "very bad", thus as one. This was done rather than assigning random values because they looked rather unpalatable from their appearance (either spiky or woody).

Along the three 100m line transects across a hectare, 150 quadrates were sampled. Plant samples were collected and later identified in the lab. A reference collection has been established which is currently housed at Gobabeb Training & Research Center (GTRC), Namibia.

Woody vegetation

Tree density estimates per hectare were generated by applying the "Nearest tree neighbour" method described in Müller-Dombois (1974) and Greig-Smith (1983). Sampling points derived from the line transect in 2m escapements. The nearest tree from the sampling point was selected and the distance to the nearest tree neighbour measured. The distances were calculated and inserted into the type 1 and type 2 formulae (Mueller-Dombois, 1974), which were compared. One hundred and fifty (150) sampling points were included in the inventory.

In a pilot survey conducted in October 1997 tree and grass species present at the study sites were established. The most common species are listed in this chapter (Table 8.2).

(c) Litter & dung mass

The amount of dung present at each site was estimated because it was believed that such a feature might provide an indication of land-use intensity. Dung and litter biomass inputs may also reflect resource availability for termites. Dung and litter were collected from 30 0.25m^2 quadrates in each 1 hectare plot. Their dry weights were determined in the lab.

(d) Soils

Three soil cores were collected to 30cm depths within each of the ten 2mx5m plots, in which termites were collected. These were combined in one composite soil sample. The samples were analysed for:

- Light fraction by sieving, flotation and ashing (Anderson & Ingram, 1993; Appendix 4)
- Organic carbon using Walkley-Black's method (Nelson & Sommers, 1982;Appendix 4)
- Total nitrogen using Kjeldahl's digestion (McGill & Figueiredo, 1993; Appendix 4)
- Plant available phosphorus using Olsen's method (Shoenau & Karamanos, 1993; Appendix 4)

The C:N and C:LF ratios were calculated from the results obtained.

(e) Termites

The termite data used in this chapter were mainly presented in Chapters 6. However, the data are processed in additional ways, depicting the taxon presence, defined ratios thereof, functional groupings and the Shannon-Weaver and Simpson diversity indices for the farms Weerlig and Olifantputs, where baiting experiments were carried out.

Taxon presence - absence is displayed in the form of a matrix using binary values for presence and absence. Only data from the transects and searches are included because the baiting experiment was only established at Olifantputs and Weerlig but not at Halt. The data from the presence – absence matrix are also used in a cluster analysis.

(f) Additional data

Rainfall is acknowledged as a main determinant of ecosystem functioning in the study area. Rainfall patterns in the study area have been discussed in Chapter 2. No data directly from the study plots are available.

(g) Sampling effort

The ecological sampling protocol was conducted twice, once at the end of the perceived rainy season, hence at the peak of the growing season (March/April) in 1998, and a second time before the expected onset of the rains (October/November) 1998. This allowed for the measure of biological integrity at the relative seasonal extremes. However, it needs to be noted that rainfall was poor during the 1997/98 season.

(h) Analysis

The ecological data were analysed in various ways. Firstly, the mean and standard deviation of each variable at each of the six study sites were calculated to get a grasp of the dimension of the scores measured. The raw data were then used to compare the values of the variables measured, testing (1) seasonal variation and (2) variation amongst the low and high land use intensity plots. Two sample t-tests were applied or a Mann-Whitney U-test, if the samples were not normally distributed. To compare the measures across all six study sites the raw data were used in ANOVA or its non-parametric equivalent, Kruskal-Wallis test, if applicable. The March'98 and October'98 series were analysed separately since a significant seasonal variability was detected for most samples. A cluster analysis was performed on the termite presence/absence data.

8.3. Results

The results from the ecological survey conducted at two land-use intensity sites on each of the farms Halt, Weerlig and Olifantputs are summarised and presented in table 8.1.

Vegetation, litter & dung

Comparing the overall herbaceous composition, biomass and forage quality, various observations can be made. For example species numbers were generally higher and more diverse in March'98 compared to October'98 (Appendix 5) except at the low intensity site at Weerlig, where more species were recorded in the later sample. *Schmidtia pappophoroides*, *Eragrostis porosa* and *Andropogon schinzii* are the three most dominant grass species recorded from the farms. Whereas *S. pappophoroides* is recorded from all three study farms and on each plot, *E. porosa* was absent on various sites. *A. schinzii* only occurred on the farm Weerlig. Few other grasses were found, but a diversity of herbs and forbs occurred at the farms. Whereas most plants could be identified for the March samples, this was almost impossible for most of the October samples, either because they were heavily grazed or browsed or because they did not carry leaves, flowers or fruits towards the end of the dry season. It should be noted that a greater number of grass species was found in October'97 (Table 8.2).

Table 8.1: Data for the environmental parameters measured at Halt, Olifantputs and Weerlig in March and October'98

	HAL		HAH		OPL		OPH		WLL		WLH	
	March'98	*October'98*	*March'98*	*October'98*	*March'98*	*October'98*	*March'98*	*October'98*	*March'98*	*October'98*	*March'98*	*October'98*
VEGETATION												
Forage quality (score)	3.33	3.01	4.49	3.86	2.81	2.61	2.37	1.12	3.15	2.51	4.16	2.88
Herb biomass (kg/ha)	22.8	16.8	21.6	5.2	20.4	12.4	19.6	7.6	23.6	22.4	28.8	19.2
Woody biomass (% cover/ha)	3	5	1	0.2	5	3	1	1	8	5	5	4
Litter biomass (kg/ha)	903	1063	417	103	739	570	316	245	1071	497	945	521
Stdv.	*543*	*805*	*485*	*117*	*469*	*955*	*704*	*285*	*1733*	*490*	*2672*	*1256*
Dung biomass (kg/ha)	0	23	205	160	262	98	77	212	22	10	30	19
Stdv.	*0*	*39*	*474*	*553*	*1395*	*391*	*250*	*450*	*118*	*22*	*98*	*35*
SOILS												
N%	0.0031	0.016	0.0058	0.019	0.0069	0.024	0.0034	0.023	0.0065	0.026	0.0063	0.024
Stdv.	*0.0011*	*0.0025*	*0.0016*	*0.0034*	*0.0009*	*0.0068*	*0.0017*	*0.0029*	*0.0023*	*0.0056*	*0.0019*	*0.0075*
OC%	0.12	0.17	0.13	0.16	0.16	0.27	0.16	0.24	0.22	0.27	0.23	0.25
Stdv.	*0.02*	*0.04*	*0.02*	*0.02*	*0.03*	*0.06*	*0.02*	*0.03*	*0.05*	*0.05*	*0.05*	*0.06*
P ppm	5.82	2.63	5.25	2.63	6.61	2.63	6.97	2.63	9.55	2.63	12.3	2.63
Stdv.	*4.76*	*0.73*	*2.56*	*2.61*	*6.11*	*3.43*	*6*	*1.39*	*5.47*	*2.42*	*13.43*	*1.65*
C:N	40.17	10.44	23.44	8.41	23	11.45	53.22	10.47	35.82	10.02	37.72	10.41
Stdv.	*12.49*	*4.23*	*7.01*	*1.53*	*3.15*	*2.17*	*18.6*	*2.04*	*10*	*1.41*	*7.19*	*2.19*
C:LF	5.03	6.24	4.69	5.73	6.5	15.16	5.63	14.32	9.45	16.5	8.59	12.92
Stdv.	*2.55*	*2.1*	*1.77*	*1.74*	*2.52*	*10.93*	*2.7*	*2.1*	*3.17*	*5.13*	*2.66*	*8.87*
LF %	0.027	0.028	0.029	0.03	0.026	0.021	0.031	0.017	0.024	0.016	0.03	0.022
Stdv.	*0.011*	*0.004*	*0.007*	*0.009*	*0.005*	*0.005*	*0.01*	*0.003*	*0.004*	*0.003*	*0.016*	*0.007*

Herbaceous biomass was extremely low at all of the six study sites, not exceeding a dry weight of 28.8 kg/ha. Standing biomass varied between the seasons and was significantly lower in October (two sample t-test, p=0.03). Forage quality as described by palatability scores of the plant species present did not change between the seasons. Calculating the percentage of biomass loss between the seasons at the various sites indicated that the pre-categorised high intensity sites were indeed under higher grazing pressure. At Halt, 76% of biomass was lost between the seasons at the high intensity site compared to 26% at the low intensity site. At Olifantputs, 50% was consumed at the high intensity site, compared to 39% at the low impact site, and at Weerlig the comparison was 33% biomass loss at the high intensity site and only 5% at the low intensity site. The results from the dry-weight-ranking model (Figures 8.2 and 8.3) depict the condition of the grazing at each study site by plotting forage quality against forage quantity. According to the illustration both sites at Weerlig are in a better condition than all other sites. Whereas the high intensity site at Weerlig was classified as both of high forage quality and quantity especially in March after the rainy season, the forage quality was poor at the low intensity site. Although the forage quality at the high intensity site at Halt was the best of all, this site, situated close to the waterhole, had an extremely low biomass especially later in the year. The high intensity site at Olifantputs was the most constrained, both for forage quantity and quality.

The fixed-point photographic series depicting the study sites over the seasons reflects the extreme variability of herbaceous biomass (Appendix 7).

Tree density data were collected in March and October'98. Density is calculated as percentage per hectare and was always higher at the low intensity sites. The highest tree density was measured at Weerlig, where tree density was between 5-8% at the low impact site and 4-5% at the high impact site. Both at Halt and Olifantputs tree density was similar, ranging between 3-5% at the low intensity sites and between 0.2-1% at the high intensity plots.

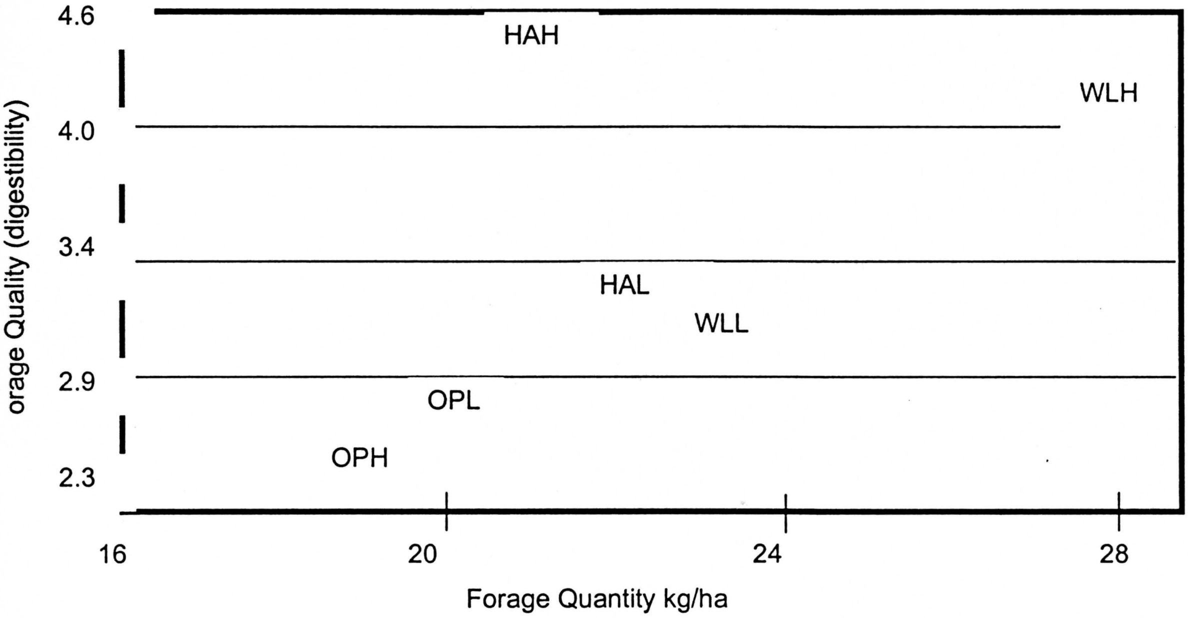


Figure 8.2: *Herbaceous forage quality and biomass per hectare at study sites March 1998*

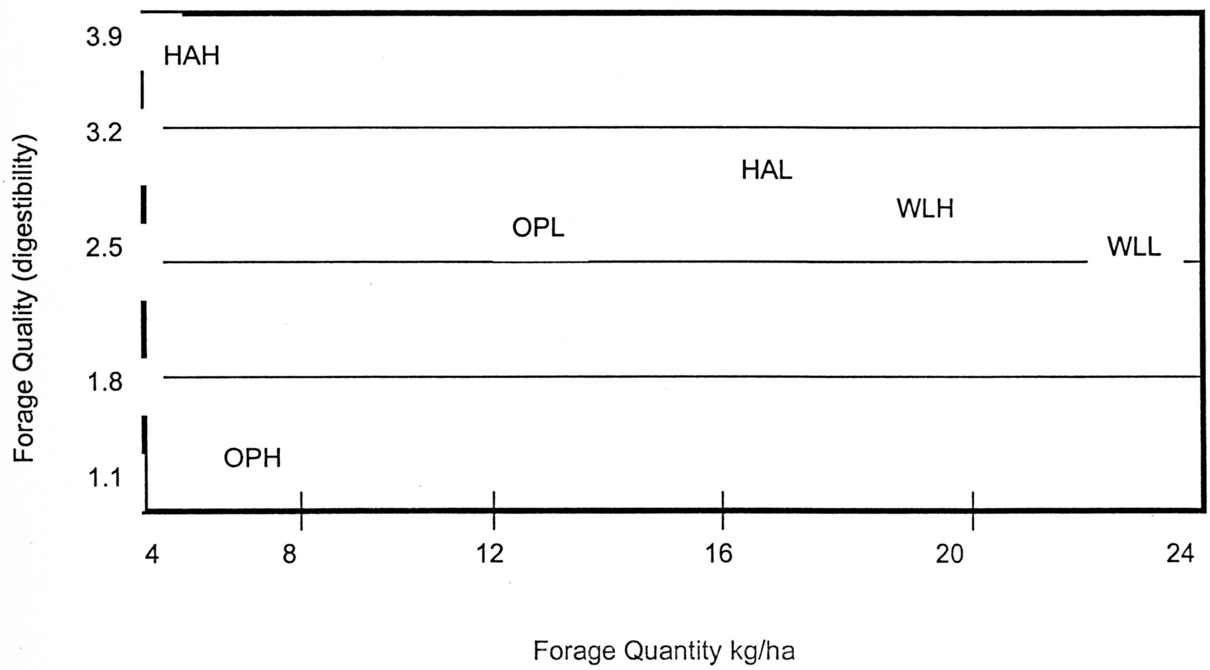


Figure 8.3: *Herbaceous forage quality and biomass per hectare at study sites October 1998*

The most abundant tree species were recorded from the study sites (Table 8.2). *Colophospherum mopane* is the most conspicuous and abundant tree species in the area and occurs at all sites. Additionally at Olifantputs, *Catophractes alexandri* was found abundantly at the low intensity and *Acacia tortilis* and *A. senegal* at the high intensity site. *A. erioloba* grew at Halt's high intensity site. *Boscia albitrunca* was recorded from the Weerlig low intensity site and *Catophractes alexandri* and *Acacia tortilis* from the high intensity plot.

Litter inputs varied between seasons and were higher in March, however a significant difference was only detected at Halt high intensity site (Mann-Whitney U-test, $p<0.001$) between the seasons. Litter inputs were always higher at the low intensity study sites, and significantly so at Halt and Olifantputs (Mann-Whitney U-test, $p<0.001$). Litter mass was highest at Weerlig's low intensity site where it measured 1071kg/ha in March'98 (Table 8.1). This litter mass was reduced by 50% to 497kg/ha in October'98 at the same site. Litter was low at the high intensity site at Halt. In March'98 417kg/ha litter biomass were measured here. A decline of 75% to 117kg/ha in October'98 was recorded from this site.

Dung inputs differed less dramatically seasonally as well as between the low and high land use intensities (Table 8.1). Generally dung inputs were always higher in March compared to October, however, at Olifantputs high intensity site this relationship was reversed. The dung inputs at HAH, OPH and OPL were up to 10 times higher than at HAH, WLH, WLL possibly reflecting an intensive animal passage at the first set of sites.

Soils

Soil characteristics measured at the six study sites show seasonal as well as possible related patterns to land-use intensity. Results collected from each farm are presented, and seasonal as well as site related differences and similarities are indicated. Farm and site comparisons follow. All results are summarised in Table 8.1. Only the main points will be presented in the following.

Table 8.2: Grass and tree species recorded from 3x 100m line transects across a 1 ha study plot at each of the three study farms during a preliminary assessment done in October 1997. More grass species were identifiable at that stage compared to the sampling events in 1998, a year characterised by a poor rainfall season.

	HAL	HAH	OPL	OPH	WLL	WLH
Grass species	*Eragrostis porosa* *Schmidtia pappophoroides* *Eragrostis sp.* *Pogonarthria squarrosa*	*Eragrostis porosa* *Schmidtia pappophoroides* *Eragrostis sp.* *Eragrostis curvula*	*Anthepoa schinzii* *Eragrostis porosa* *Panicum* *Schmidtia pappophoroides* *Eragrostis sp.* *Stipagrostis uniplumis*	*Eragrostis porosa* *Schmidtia pappophoroides* *Eragrostis sp.*	*Anthepoa schinzii* *Eragrostis porosa* *Panicum* *Schmidtia pappophoroides* *Eragrostis sp.* *Eragrostis curvula* *Stipagrostis uniplumis* *Enneapogon scoparius* *Aristida*	*Anthepoa schinzii* *Eragrostis porosa* *Panicum* *Schmidtia pappophoroides* *Eragrostis sp.* *Eragrostis curvula* *Stipagrostis uniplumis* *Panicum maximum*
Tree species	*Colophospermum mopane*	*Colophospermum mopane* *Acacia erioloba*	*Catophractes alexandri* *Colophospermum mopane* *Acacia mellifera*	*Colophospermum mopane* *Acacia erioloba* *Acacia tortilis* *Acacia senegal*	*Catophractes alexandri* *Colophospermum mopane* *Boscia albitrunca* *Acacia mellifera*	*Catophractes alexandri* *Colophospermum mopane* *Acacia tortillis*

At Halt, comparisons of soil characteristics between perceived low and high land-use intensity were noted as significant in March'98 for N (two-sample t-test, $p<0.001$) values and the calculated C:N ratios (two-sample t-test, $p<0.001$). The higher N content was recorded from the high intensity site and, because OC levels were similar at both sites, a lower C:N ratio was calculated for the low intensity site. In October P was the only component showing a significant difference (two-sample t-test, $p=0.01$). All other components were relatively similar. Synthesising the main results from Halt it is apparent that seasonal variability is greater than the difference between the high and low land-use intensity. The N, OC and consequently also the C:N ratio are extremely variable, both within each study site as well as seasonally. At Halt the LF and C:LF ratio both remained relatively stable, as did the P values. However, P was extremely low at the low intensity site in October.

At Olifantputs differences between the various soil parameters measured at the low compared to the high land-use intensity sites were significant for N (Mann-Whitney U-test, $p<0.001$) and C:N ratio (Mann-Whitney U-test, $p<0.001$) in March'98. Lower N values were recorded from the high intensity site, and because OC levels were the same at both sites, the C:N ratio at the high intensity site calculated higher. No significant differences were detected for October. Comparing seasonal differences in soil parameters at either land use intensity site reveals that all were significantly different except for P. In summary, it can be concluded that P seems to be vary little, whereas especially the N and OC values are more variable, both seasonally as well as between sites. Overall seasonal variability was much greater at Olifantputs than variations between sites of different land-use intensity.

The selected high and low land-use intensity sites at Weerlig show only very little soil variation. In fact, only the LF shows a statistically significant difference with higher values at the high intensity site in October (two-sample t-test, $p=0.03$). Between seasons various components were different in the values they scored. These were for Weerlig's low intensity site N, C:N ratio, LF and C:LF ratio and for the high intensity site N and C:N ratio. Overall, the soil components measured were variable seasonally, however, much less so at the high intensity site compared to the low intensity site.

Because an extremely strong seasonal variability was detected by testing the mean values obtained at two study sites on a single farm, seasons were analysed separately in the ANOVA's and Kruskal-Wallis statistics. The statistical results are presented in Appendix 8.

Across the six study sites, Nitrogen (N) values measured in March'98 ranged between 0.0031% at the low intensity site at farm Halt (HAL) and 0.0069% at the low intensity site at Olifantputs (OPL). HAL and the high intensity site at Olifantputs (OPH) both range at the low end in N content of soils when compared with all sites. They differ significantly from all other sites, comparing the z-values of the Kruskal-Wallis statistics (Appendix 8). The four sites ranging at the upper end of the scale do not differ significantly from another. In October'98 N values varied from 0.0164% at HAL to 0.0264% at the low intensity site at Weerlig (WLL). The Kruskal-Wallis statistics revealed that the HAL site with relatively low values differed significantly from all but the high intensity site at Halt (HAH). The three sites with relatively high N content in the soil, OPL, Weerlig high intensity (WLH) and WLL, are also significantly different from HAH. OPL measured medium high N values compared to the other sites and only differed significantly from HAL. As already indicated through the t-tests, N values measured in March were much lower across all study sites compared to October.

Organic Carbon (OC) content ranged between 0.11 and 0.23% in March'98 (Figure 8.4). The sites at Halt both had the lowest OC content, low and high land use intensity sites at Weerlig ranged at the high level and the two sites at Olifantputs ranged in between. At all farms the OC content was higher at the high land use site compared to the low intensity site but not statistically so. Both sites at Weerlig differed significantly from all other sites (Kruskal-Wallis, see Appendix 8). The sites at Olifantputs differed significantly from all sites but not from HAH.

The mean values for OC were overall higher in October, reaching from 0.16 (HAH) to 0.27% (OPL). The two sites at Halt still contain the overall lowest C content and differ significantly from all other sites (Kruskal-Wallis, see Appendix 8). The sites at both other farms are very close in magnitude and do not differ.

The C:N values calculated from the above are very scattered and range between 23:1 and 53:1 in March and 8:1 and 11:1 in October. This dramatic drop in the C:N ratio over one season needs to be discussed in the light of the great seasonal variability depicted above.

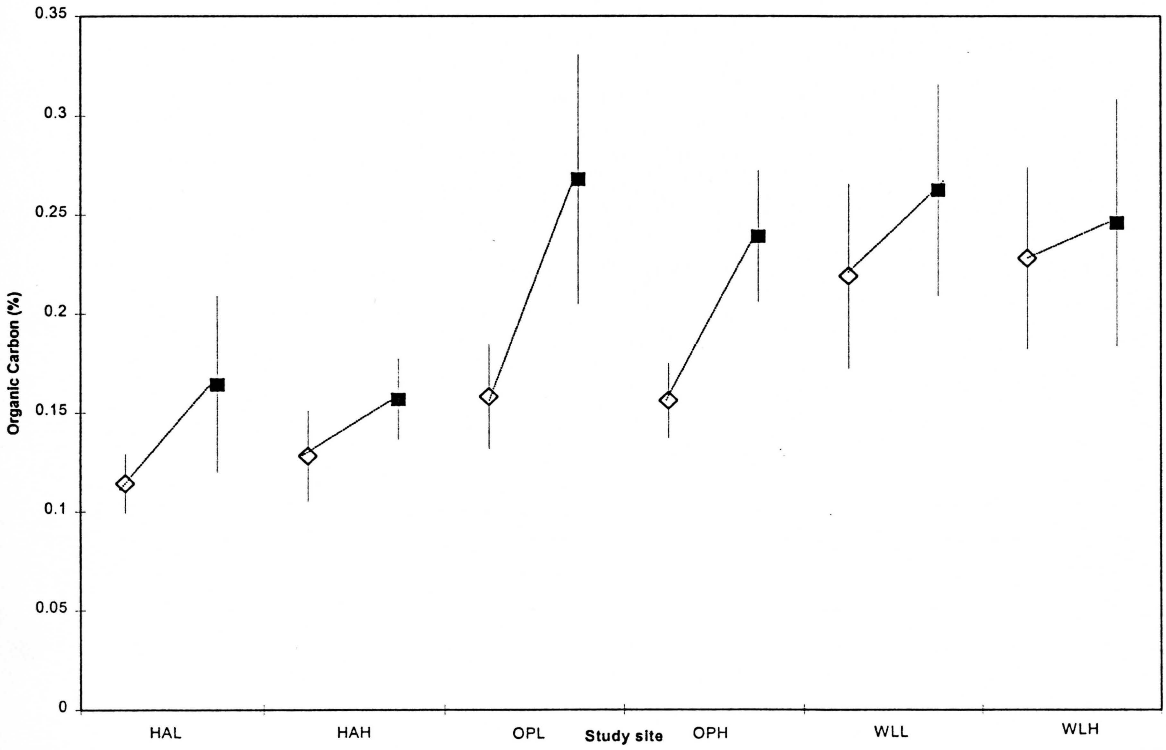


Figure 8.4: *Mean Organic Carbon (%) and standard deviation measured at the six study sites during March'98 (◊) and October'98 (■).*

Phosphorus (P) contents ranged between 5.3ppm (HAH) and 12.3ppm (WLH) in March. Largely, the sites at one farm were more similar to one another than to sites on different farms, a finding corroborated by the t-test results, which depicted no significant differences between sites on one farm. Only the two low and high extremes, HAH and WLH, differed significantly from another (Kruskal-Wallis, Appendix 8).

Although the P values did not differ much between the seasons at each individual site (see above), they did differ across the full range of all six farms. In October the P values were low with a minimum of 2.6ppm recorded at HAL and a maximum of 7.7ppm at WLL. The low intensity site at Halt is significantly different from all other sites except OPH (Kruskal-Wallis, Appendix 8). WWL differed from all other sites but WLH, and the other sites differed from individual sites at the two extremes.

Light fraction (LF) content of the soils was between 0.024 % (WLL) and 0.0314 % at OPH in March'98. In October these values ranged between 0.017 % at WLL and 0.03 %g at HAH. In March it was always the high intensity sites that contained higher levels of LF compared to the low intensity sites. Variability was much lower at Halt compared to the other two farms. However, the only significant difference between LF values across all farms, was between OPH and WLL, the two extremes (Kruskal-Wallis, Appendix 8). In October the values scored for the LF were lower for the sites at Olifantputs and Weerlig, but not for Halt. At both HAH and HAL measures for LF remained fairly similar compared to the measurements made in March. The relationship described for March, where it was always the high intensity site that had higher levels of LF than the low intensity sites, was not maintained at Olifantputs in October'98. Both sites at Halt were significantly different in LF content of soils from the other sites except WLH (Kruskal-Wallis, Appendix 8).

The ratio of C and LF was calculated from the above measurements. The mean values for the study sites (Figure 8.5) ranged between 4.7:1 at HAH and 9.4:1 at WLL in March and 5.7:1 at HAH and 16.5 at WLL in October'98. The values found at each farm were close and variability between farms was generally larger. Both sites at Weerlig differed significantly from HAH, HAL and WLL also from OPH, but not from OPL (Kruskal-Wallis, Appendix 8). Weerlig maintained the highest C:LF ratio, Olifantputs' values were in the middle range and Halt maintained comparatively low ones. In October '98 the relationships between the sites had changed considerably. At Olifantputs the C:LF ratio increased the most by 57% at OPL and by 61% at OPH. These values now ranged in the dimensions of ratios obtained at Weerlig, which also increased at both sites by 43%, thus at a lower rate. At Halt the C:LF ratio did increase, but only very slightly. Only the two sites at Halt were significantly different from the other sites (Kruskal-Wallis, Appendix 8).

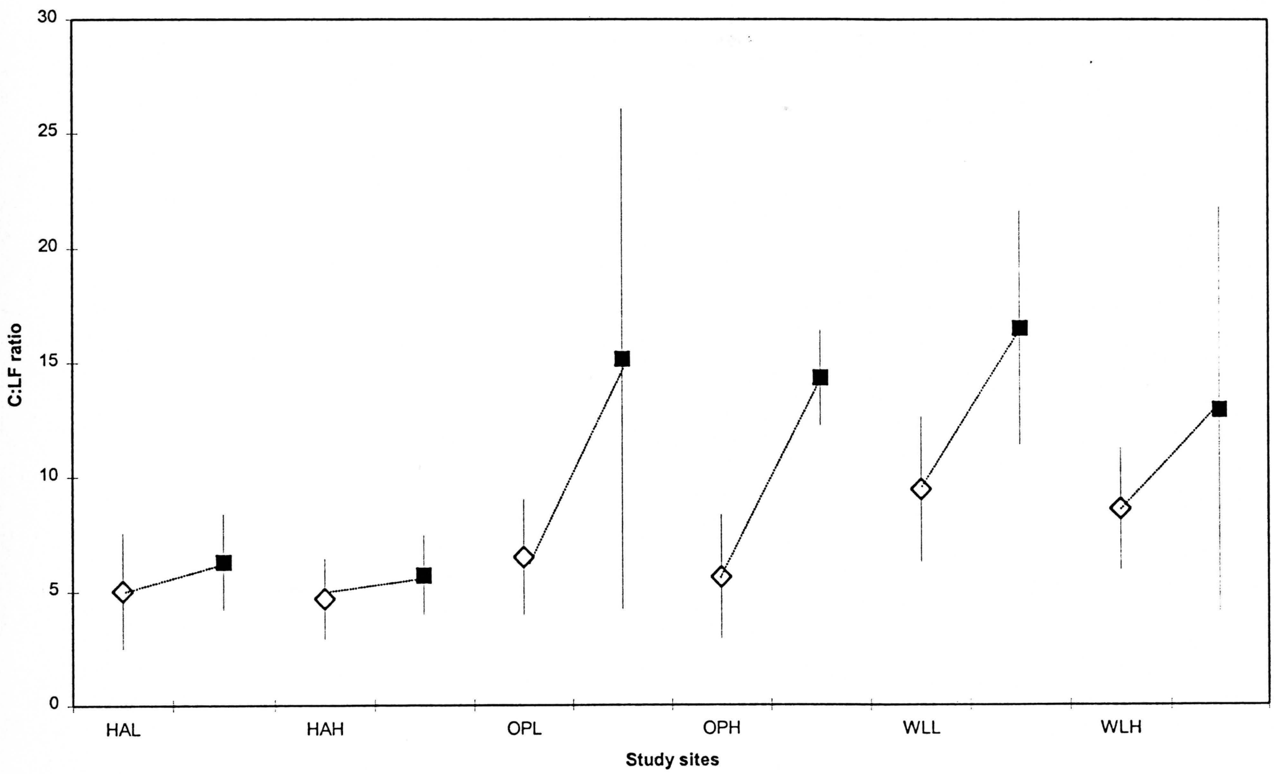


Figure 8.5: *Mean C:LF and standard deviation calculated for each study site in March'98 (◊) and October'98 (■).*

Termites

Table 8.3. depicts the taxon presence – absence matrix drawn for the two sampling events in March and October'98. Taxon numbers found at each site are summarised from these data. The results from the cluster analysis produce a "tree" which is shown in figure 8.6. Sites that are more similar in taxon composition are grouped closer together than sites that are very different. OPH and OPL group together at the lowest level. They are very similar both in the taxa found at each site as well as in overall taxon number. At OPH, eight termite taxa could be unequivocally distinguished and at OPL, nine. This "Olifantputs group" links with the HAH branch at a higher level, thus describing a relative similarity. The three remaining sites linked up with the first three at a very high level only. Thus there are two distinct groups. HAL and WLH link at a relatively low level, which indicates a fair similarity. Numbers of taxa found at WLH are by far the highest (13). WLL seems to be the most different from all other sites, linking only at a very high level with the second overall group.

Table 8.3: Termite taxon presence/absence matrix from transects and searches at the six study sites done in October'97, March'98 and October'98 (1=present, 0=absent).

	HAL	HAH	OPL	OPH	WLL	WLH
Amitermes	1	1	1	0	1	1
Angulitermes sp.	1	0	0	0	0	1
Baucaliotermes sp.	0	0	0	0	0	0
Cubitermes sp.	1	0	1	1	1	1
Macrotermes	1	1	1	1	0	1
Macrotermes michaelseni	0	1	0	0	0	0
Macrotermes subhyalinus	0	0	0	0	0	0
Macrotermes vitrilatus	1	0	0	0	0	0
Microcerotermes	0	0	0	0	0	1
Microtermes sp.	1	1	1	1	1	1
Odontotermes	1	1	1	0	1	1
Psammotermes allocerus	1	1	1	1	1	1
Rhadinotermes	0	0	0	0	0	1
Trinervitermes	1	1	1	1	1	1
Trinervitermes dispar	0	1	1	1	1	1
Trinervitermes rapulum	0	1	0	0	1	1
Trinervitermes rhodesiensis	1	1	1	1	0	0
Trinervitermes trinervoides	1	1	0	1	1	1
TOTAL number of taxa present	**11**	**11**	**9**	**8**	**9**	**13**

```
TREE DIAGRAM

     HAH     ------------------------------------
                                                +-----------------
     OPH     ---                                I                I
               +---------------------------------                I
     OPL     ---                                                 I
                                                                 +--------
     HAL     --------------------------                          I
                                      +--------------------      I
     WLH     --------------------------                     I    I
                                                            +--------
     WLL     ----------------------------------------------
```

Figure 8.6: Dendrogramme of the cluster analysis performed on the termite presence/absence matrix for taxa found at transects and during searches at the six study sites. The average linkage method was used measuring Euclidean distance.

The results from the termite baiting experiment were partially presented in Chapters 6 & 7. In the context of this chapter, diversity indices such as the Shannon-Weaver and Simpson indices were calculated for the farm Weerlig, based on the same assumptions made in Chapter 7 for Olifantputs. The calculated values for WLL ranged between 0 and 1.39 for the Shannon-Wiener index of diversity and between 1 and 0.31 for the Simpson index of dominance. For WLH, the values were between 0 and 1.48 for the Shannon-Wiener and between 1 and 0.35 for the Simpson index. On two occasions no termites were found at all at WLH.

8.4. Discussion

This study aimed to apply and further develop the vegetation, soil and termite indicators used for habitat assessment at Olifantputs (Chapter 7) to discriminate useful indicators of biological integrity (Figure 1.4, Part I). This would allow an objective assessment of range condition at three farms with varying land tenure system and management practices and study sites under varying land use intensity.

The overall sampling protocol was improved compared to the pilot study, increasing sampling numbers across the 1ha study plots and sampling twice a year, covering a wet and a dry season sample. This provides more robust data. In addition the seasonal sampling allows for examining ecosystem processes over time. The baseline data collected from Olifantputs in October 1997 are used in the interpretation of the data resulting from this study, however, because of the differences in sampling design and methodologies used these data are not rigorously comparable. Also the location of the study plots were not strictly overlapping.

The vegetation data collected from the three study sites are extremely variable and their dimensions seem sometimes extreme. For example the herbaceous biomass on all plots seems very low especially when compared with the litter biomass inputs, which are up to 10 times as high at a site. It was observed that especially at sites where animals were passing frequently, litter biomass was mainly made up of broken grass stalks. At other sites, as e.g. both sites at Weerlig, litter biomass constituted a large proportion of tree leaf litter. The large variability in litter distribution can be explained primarily by the nature of the terrain, which is characterised by a patchy distribution of soil depressions, grass tussocks and trees. Most litter is windblown and accumulates in such patches.

Comparing the herbaceous biomass values for the March and October samples with the fixed point photographs corroborates the notion that standing crop is indeed exceedingly low. Expanding this evidence to the herbaceous biomass measured for a 1ha plot at both, OPH and OPL, in October 1997 (Table, 7.2, Chapter 7) a succession is visible. Biomass deteriorated from March 1997, when herbaceous biomass was high after a good rainfall season (see photograph Appendix 7). The rainy season 1997/98 was poor in the study area (Chapter 2) and herbaceous vegetation could not recover. Sites such as HAH, OPH and OPL had almost no standing biomass left by October 1998, and what was left was often of poor forage quality. Forage quality also declined steadily between the seasons (Table 8.1), which can be explained by preferential grazing of plants of high digestibility values. All six study sites were heavily grazed by October 1998, however, OPH and HAH were used the most and had on average 7.6 and 5.2 kg/ha standing biomass left at that time. Land use intensity especially through grazing and trampling was the most intense at these two sites (Chapters 2 & 3).

The dung inputs over time and between the intensity sites can be interpreted as a reflection of land use intensity. Dung inputs at HAH, OPH and OPL were by far the highest, and were at least 10 times higher than at the farm Weerlig and Halt's low intensity site. At Halt the differences of dung inputs between HAH and HAL reflect that HAL is a site far from a water point, a factor limiting high land use intensity. At Olifantputs land use intensity is generally high and so are dung inputs. It is astonishing that in October 1998 dung biomass was still very high at OPH. This could be explained by the fact that most animals would move past this area to and from the waterhole, including the browsing stock especially goats, which were still numerous at that time of the investigation (Chapter 3). However, it could also be speculated that decomposition of dung at that site was slow, possibly indicating some limiting factor in the cycling of organic matter. The high variability of the dung data can also be explained by the nature of its distribution and type. Droppings are very scattered. Droppings of different animals such as goat, cattle, wild animals, produce faeces dissimilar in size and weight.

Woody biomass measured as percentage cover, points to the low tree density close to the settlements at Halt and Olifantputs. This could possibly be a result of the exploitation of the resource by the villagers. Woody vegetation density was much greater at Weerlig compared to any other site, a factor that might be important when interpreting the collected termite data (see below).

Although the data on the vegetation are extremely useful in revealing the intensity of the land use and especially the grazing impact on the study sites as well as indicating potential organic matter inputs, they also have a few shortcomings that should be mentioned. In this study area a major problem is the ephemeral nature of the herbaceous parameters. Herbaceous resources, in this study described by species composition, biomass and forage quality, are only truly assessable after a good rainy season. As illustrated by the fixed point photographs from the study sites (Appendix 7) and supported by the database on the herbaceous resources, it is extremely difficult to collect reliable and meaningful data if all you find are a few grass stalks. In years of little or no rainfall it is difficult to discriminate between sites that are degraded or are resting under condition of natural variability of the system.

The measurement of soil condition at the study sites provides some useful clues not only of the fertility of the sites but also of shorter and longer-term impacts of land use practice. Additionally functional connections can be made between measured soil properties and prevalent biota. The conceptual framework to this was presented at the beginning of the thesis (Figure 1.4, Chapter 1).

The main assumption made for the interpretation of the soil data collected at the six study sites is similar to the argument led in Chapter 7. All study sites are situated on the same geological parent material, namely gneiss (Figure 2.3, Chapter 2), and it can be assumed that the inherent soil fertility is similar at all six sites. The land use impacts, however, differ between them (Chapters 2 & 3 & 4). Although pastoralists have used the region for centuries (Chapter 2), it has only been more recently that the farming areas under investigation were permanently settled. The relatively shorter-term impacts of prevailing land-uses at the three farms are thought to be reflected in the current soil data, and the data will now be discussed.

The soil data suggest that the soils at the six study sites are all fairly rich in phosphorus, averages ranging between 5 to 12 ppm. Usually 2 ppm P would be considered low in agricultural production systems in similar areas and fertilisers would be recommended.

The nitrogen data collected are extremely low especially in the March'98 sample. Variability is high both seasonally as well as between sites. This is very unusual and difficult to explain in this magnitude. However, as will be discussed later some trends may be related to variability similarly observed for total carbon. Also it should be mentioned that N concentrations as low as those of this study are not measured very accurately. Errors in both field sampling procedures and laboratory analysis are relatively large so that it is difficult to detect meaningful differences between sites. However, also considering the samples taken from Olifantputs in 1997, it seems that N levels are higher in October than March, which could possibly indicate that the N pool is restored before the onset of the rains and ultimately the growing season, when plants would need soil nutrients for production.

The pilot study conducted at Olifantputs in October 1997 pointed to the fact that the soils at that particular farm were extremely poor in total carbon content (Chapter 7). The data from three farms and six sites of varying land use intensity corroborate this point. Although the dramatic difference in OC% at two sites of varying land use intensity found during the October 1997 survey is not manifested as strongly in these data, the OC% values are low overall, ranging between 0.11 and 0.23 % OC in March'98 and 0.16 and 0.26 % OC in October'98. The 0.47 % measured in October'97 at OPL was not maintained at any farm in 1998. The strong seasonal variability of OC% was illustrated in figure 8.4. An increase of OC levels after the growing season even in a year of poor rainfall, as 1998, is remarkable. Processes must be in place that allow for organic matter cycling and transformation from above ground to below ground.

The role of termites as a link in such processes has been conceptualised in Part I of this thesis (Figure 1.4) and has been addressed at various points. The main thread is the role termites play in the translocation of organic matter from the soil surface into the soils (Anderson, 1988), as well as their contribution to the humification of organic matter (Lavelle *et al.*, 1994; see Chapter 7). The light fraction is thought to be directly influenced by the translocation activities of the termites. This is why it is of interest to also study the light fraction dynamics in the soil, particularly in relation to total OC levels. The results of this study indicate that by March OC levels are relatively low as are the C:LF ratios. This indicates that the LF, thus the "active" OC pool, makes up a large part of the overall OC. The "slow" pool, made of transformed SOM, is small in relation to the unmodified LF fraction. By October overall OC levels have increased, however the light fraction is comparatively lower. This is indicated by larger C:LF ratios. This finding points to the fact that the modification of LF to SOM is taking place between March and October, thus this is the time when soil fauna mediating such transformation processes are active. In addition it would indicate that between October and March, the perceived growing season, soil nutrients are "used" e.g. for primary production.

Interpreting the data over the seasons, a scenario can be depicted that suggests how termite and microbial activity support the replenishment of the "slow" OC pool, contributing to the generation of SOM through translocation and transformation processes (Figure 8.6).

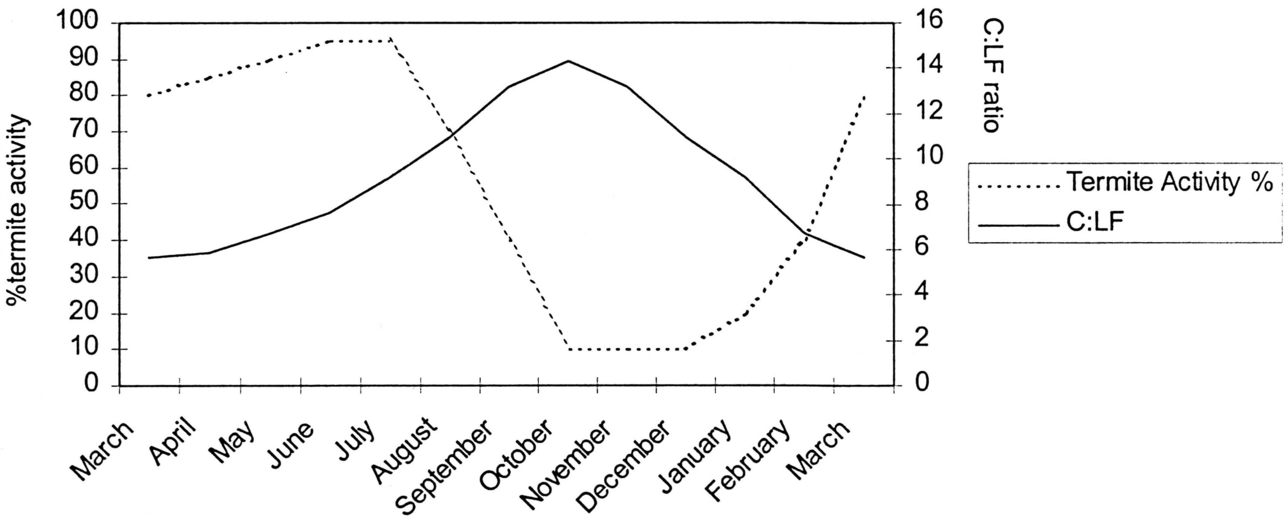


Figure 8.7: *The C:LF ratio is lowest around March, when (1) OC levels are comparatively low as well as (2) the LF ratio of the OC is great (low C:LF). Between March and October this relationship changes and the C:LF ratio increases and it can be assumed that the conversion of LF into SOM is taking place during this time period. It could be speculated that termites as well as soil microbes mediate OC replenishment and regeneration of the "slow" SOM pool.*

Basically OC levels are the lowest during the growing season, when most of the resources have been taken from the soils into the plant material. Termite activity and diversity are increasing during this time as well, partially because of favourable climatic conditions closer to the soils surface but also because of resource availability. Termite activity and diversity were reported to be high in March compared to October (Chapter 6), however, relicts of termite activity such as above surface gallery sheeting are particularly conspicuous during the already much drier months of June and July in the study area (pers. obs.). It can be speculated that during this time the termites relocate most of the organic material from the surface into the ground, other species may be involved in the transformation of LF into humified OC. During the modification of LF to SOM other nutrients such as N would also be released. This would explain the increase of N measured in October 1998 compared to March 1998, as well as decrease of the C:N ratios.

It should also be mentioned that the soils are low in clay content and thus might vary a lot in OC levels. Clay facilitates the stabilisation of OC.

It can be calculated how much organic matter theoretically needs to be translocated over the season to account for a 0.05% increase in OC%, the average increase observed at the sites (Table 8.1). The following figures give an idea of the magnitude needed. The calculations are speculative in nature, however illustrate interesting ideas. Assuming that 41% of plant material will be transformed into OC (Miller & Donahue, 1990) the amount of plant material needed to replenish the soil carbon pool by 0.05 g per 100 g (0.05 OC%) over one hectare (soil depth 0.15 m, bulk density 1.6), calculates to 292.68 kg. The measured herbaceous biomass at the sites would not be able to contribute this amount (Table 8.1), however, including litter and dung inputs and considering seasonal biomass increases could amount for this demand.

An important observation is that in figures 8.4 and 8.5 the OC and C:LF characteristics are more similar within each farm than they are between farms. At Halt OC levels are the lowest and they also do not change dramatically over the seasons. At Olifantputs the OC levels are initially low, however they increased up to 88% between March 1998 and October 1998, and reach levels comparative to OC levels measured at Weerlig later in the year. The slope of increase of the C:LF ratio is the greatest at Olifantputs. These clues all indicate that the transformation process of LF into C is in fact the most active at Olifantputs. It seems that the nutrient status at Olifantputs varies the most between seasons. This extreme variability of OC levels and percentage contribution of the various pools to the OC, seems to require equally extreme responses e.g. by the soil fauna who are mediating these processes.

It should be noted that the differences in slope between seasonal nutrient levels at the various farms might also have been triggered by unequal rainfall. Since rainfall monitoring at the sites could not be continued over the time period of the study, no evidence of this nature can be provided. Soil faunal activity might be triggered by rainfall events (Crawford & Seely, 1994), therefore it could be possible that Halt did receive less rainfall then the two other farms.

A number of interesting questions arise from this research. Firstly it would be important to understand if the low OC% levels measured in March '98 are an absolute low or whether they would further deteriorate over the next season, particularly at sites where organic matter inputs are so low that they will be a limiting factor for resource translocation. This could particularly pose serious problems at sites that are heavily overgrazed and browsed. Since the OC% levels measured at Olifantputs in October '97 and October '98 already indicate a dramatic drop of 43% (from 0.47 to 0.27 OC%) at OPL, it is probable that the soil OC pool and associated nutrients are strongly dependent on rainfall and primary productivity but are also impacted by prevailing land uses in the study area. It should be investigated whether the observed patterns in soil carbon dynamics are indeed dependent on termites. If such correlation of soil fertility related processes and soil fauna, particularly termites, hold, the study of their biodiversity and community composition becomes more necessary.

Results from this research point to various biodiversity measures of termites as potential indicators. Termite taxa diversity seems to respond to pressures other than environmental variability. At six study sites with relatively similar environmental characteristics, termite taxa diversity and composition varied. Looking at changes of dominance of functional groupings and "tolerant" species seems to be an interesting approach to indicator research. Although the sampling procedures tested and recommended from this study (Chapter 6) seem to provide a reliable picture of the aforementioned diversity measures, the question on how to determine termite abundance and effects on the ecosystem remain unresolved by this study. Other authors have dismissed the termite taxa as potential bio-indicators for this reason (Eggleton & Bignell, 1995).

In summary, the following patterns were derived for the study sites: The assessment of termite parameters illustrated that the taxon composition at OPH and OPL were relatively similar, and more similar to what was found at HAH than to all other sites. Conversely HAL and WLH showed relative similarity of termite taxon composition. WLL was different from all other sites. Termite parameters analysed in this manner, taking taxon presence and overall taxon numbers into consideration, seem to be related to the grazing intensity established for each site (Chapter 2 & 3) and to vegetation biomass (Table 8.1). Termite taxon richness seems to be reduced under high grazing pressure. From the baiting experiments carried out at Weerlig and Olifantputs, however, it cannot be established if termite abundance is affected. The data collected do not indicate significant differences in relative termite abundance between the various study sites.

From the literature, provisional functional or feeding groups for termite taxa occurring in Namibia were established (Chapter 6) and taxa composition found at the six sites of this study was interpreted in the light of functional attributes. In the context of soil parameters, it is conspicuous that grass feeding termites are a lot more dominant at OPH, OPL and HAH than anywhere else. Do they facilitate organic matter translocation e.g. in the form of grass stems into the soils and thus guarantee the necessary link to soil nutrient status in soils? In the literature, the grass feeding termite species *Hodotermes mossambicus* is reported as a competitor to large herbivores especially under drought conditions in southern Africa (Coaton, 1958; Braak, 1995), and many farmers refer to that species as a pest (van Vuuren, *pers. comm.*). No *H. mossambicus* were found in this study, although the species was recorded from the area before (Chapter 5). This does obviously not mean that *H. mossambicus* is not occurring in the area however, indicates a much lower presence than expected. It could be considered that the smaller bodied, grass feeding species of the genus *Trinervitermes*, namely *T. dispar*, *T. rhodensiensis* and *T. trinervoides*, occupy that "niche". Whether this is only temporarily, during the time horizon of this study, is not clear. However, farmer D. van Vuuren maintains that *H. mossambicus* occurs on Weerlig farm during prolonged periods of drought. As indicated in Chapter 2 of this thesis, the study was conducted after a period of relatively good rainfall, excluding the rainfall year 1997/98 itself.

This study discriminated some potential indicators of habitat condition as well as establishing baselines of habitat condition at six sites during a wet and a dry season sample. Now that the ecological baselines of three study farms of different land tenure and management and two land-use intensities at each farm are established, these data can be used in the development of a preliminary Index of Biological Integrity (IBI) (Chapter 9). The following chapter summarises the baseline data presented here and uses these for the calibration of the metric underlying the IBI. IBI ratings scored by the six study sites can then be interpreted against the land use background data, and conclusions can be drawn on the effects of land use intensity, land use practise and land tenure on the natural resource base.

PART IV

CHAPTER 9

SYNTHESIS OF A PRELIMINARY INDEX OF BIOLOGICAL INTEGRITY (IBI) FOR RANGELANDS IN NORTH-WESTERN NAMIBIA

The pressure to provide sound tools for the sustainable management of natural resources world-wide lead to the generation of a great number of concepts for habitat condition assessment over the past decade. Among others, concepts such as ecosystem health (e.g. Shrader-Frechette, 1994; Waltner-Toews, 1996; Rapport *et al.*, 1998) and biological and ecosystem integrity (e.g. Fausch *et al.*, 1984; Fausch *et al.*, 1990; Karr, 1996) have enjoyed particular popularity. The aim of this study was to develop tools for the monitoring of biological integrity in Namibian rangelands, using a process oriented approach to the study of biodiversity. This approach has been adapted to include the concept of biological integrity into a geophysical, climatic as well as socio-economic context to provide a meaningful indication of rangeland condition. This was done because rangeland condition is not only constituted by habitat condition in the narrow sense, but also by the socio-economic value of the sources available to sustaining and improving the livelihoods of Namibian rural farmers.

This chapter includes recommendations for the definition of thresholds for a first approximation for an Index of Biological Integrity (IBI) based on termite related and geophysical parameters.

Figure 9.1 summarises the conceptualised idea of developing a metric for measuring biological integrity, including vegetation, invertebrate biodiversity and soil faunal aspects, as well as soil condition which is providing the process oriented link.

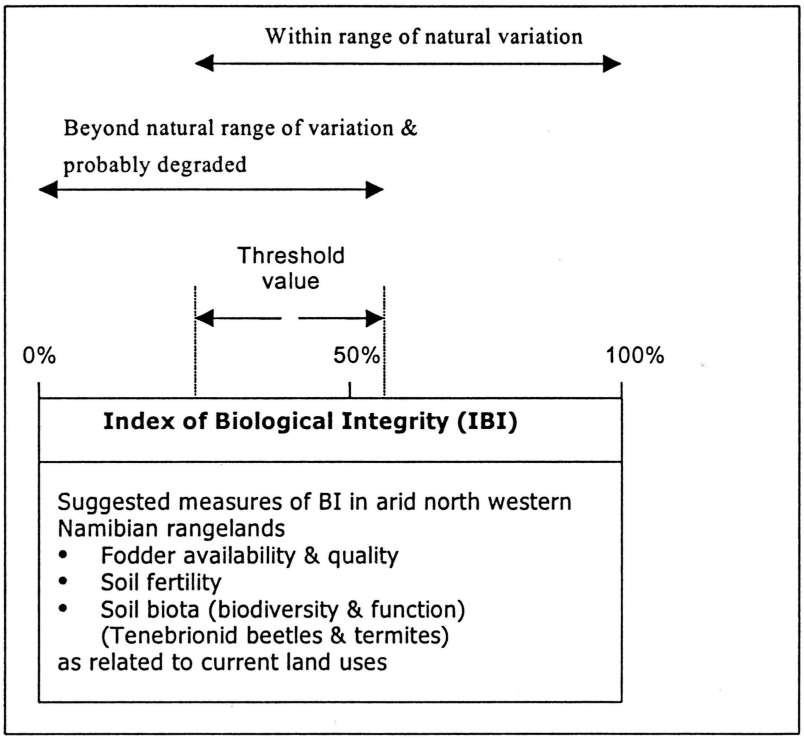


Figure 9.1: The IBI, which provides a measure of biological integrity (BI), serves as a tool to assess range and habitat condition. By establishing threshold values of the IBI, areas that are degraded can be identified. Establishing critical threshold values of the IBI also helps differentiate between natural changes or human induced causes of apparent degradation.

Developing a multi-metric approach, measuring various ecosystem components, for establishing criteria and measuring rangeland condition requires a step-wise approach. Barbour *et al.* (1995) suggest a model for development and aggregation of bio-metrics, which includes:

(1) classification of reference sites to partition natural variability and to identify homogenous regions,

(2) a survey of the biota to characterise the biological attributes that will serve as the basis for the metrics,

(3) selection and evaluation of candidate metrics, then calibration of the core metrics for discrimination of impairment,
(4) transformation of the metrics through calibration to normalised scores,
(5) aggregation of the core metrics into an index, and
(6) development of bio-criteria thresholds for assessment.

The research presented in the preceding chapters has laid the foundation for the synthesis of environmental metrics and the establishment of criteria of range condition on Arenosols, in the mopane savannah in arid north western Namibian rangelands, including commercial and communal farming settings. In the first step, suitable indicators were conceptualised and reference sites were selected. Based on the model assumptions, extensive surveys of biota and habitat were undertaken and standardised field survey methods were developed and tested. The data were analysed and evaluated.

Synthesis of conceptual framework

Classes of environmental factors that may affect the biological integrity were summarised in the conceptual framework presented in Part 1 of this study. A summary of the kinds of effects that can be expected from degrading factors are listed in Figure 9.2.

Score system development from collected baseline data

The scoring system underlying the index is derived from the collected data from the six study sites. Optimally sites of maximum integrity would be included in the development of such a system to establish a benchmark against which to measure the biological integrity to be expected in a particular habitat type. However, in this study only six sites were included in the survey and all of these have been under differing land use and land-use intensity for many years (Chapter 3). It can be expected that some impacts have occurred on all of the six sites. Therefore the sites are only compared relative to one another and not against an absolute "best scenario" benchmark, which has not been established for the study area.

Parameter	**Expected impacts**
1.) Soil biota • Termite species richness & composition	• decrease in species numbers and diversity • changes in functional groups e.g. termite trophic groups from wood/litter dominated to grass/fungus growing dominated communities
2.) Soil fertility • N • OC • P • C:N • LF • C:LF	• decrease in soil nutrient values • disruption of LF to OC transformation
3.) Vegetation • Vegetation richness & composition • Forage quality • Herbaceous biomass • Woody biomass • Litter biomass • (Dung biomass)	• impaired forage quality • decline of vegetative biomass
4.) Climate • Rainfall	• deteriorating rainfall conditions • frequent occurrence of droughts

Figure 9.2.: *The major classes of environmental factors, which determine biological integrity (see conceptual framework, Part 1) that were measured in the scope of this study.*

The ecological data reflecting vegetation, soil, and termite "condition" at the six study sites were presented in Chapter 8 and partially in Chapter 6. These data are now used to develop a scoring system, which allows the comparison of the ecological status of each of the sites taking all measured parameters into consideration.

The data from Chapter 8 were plotted for each of the parameters, and the minimum, 25% percentile, 75% percentile and maximum were marked. It was decided that three different scores would be distinguished, score 1 describing a poor condition, score 3 a medium condition and score 5 a good condition. A score of 1 would be given for measurements that ranged between the minimum value measured for a parameter up to the 25% percentile calculated from the entire range of measurements. A score of 3 would include a wider range of data, lying between the 25% and 75% percentile. A score of 5 would only be assigned to sites at which measurements were particularly high, ranging from the 75% percentile to the maximum value measured. The range of data and cut-off points for the three scores that could be obtained are presented in Figure 9.3 below.

Whereas the data and resulting scoring system for the soil and vegetation are straightforward, the termite parameters included in this concept need to be described and discussed in some more detail. The development of an IBI is an elaborate process and it needs to be kept in mind that the research presented in this study is only taking the first steps towards integrating termites into an IBI developed for western Namibian rangelands.

Barbour et al. (1995) suggest that attributes of community structure, taxonomic structure, individual condition and biological processes should be incorporated into a biological assessment (Figure 9.4), because these are thought to provide a good reflection of biological systems.

SOIL PARAMETER

	Score 1	Score 3		Score 5
1.) Nitrogen		*25% - 0.006*	*75% - 0.024*	
	0.0031%			0.028%
2.) Organic Carbon		*25% - 0.156*	*75% - 0.2435*	
	0.114%			0.267%
3.) Phosphorus		*25% - 5.12*	*75% - 7.52*	
	2.63ppm			12.3ppm
4.) C:N ratio		*25% - 10.4*	*75% - 37.2*	
	8.4:1			53.2:0
5.) Light fraction		*25% - 0.021*	*75% - 0.029*	
	0.017%			0.031%
6.) C:LF ratio		*25% - 5.6*	*75% - 13.9*	
	4.7:1			16.5:1

VEGETATION PARAMETER

	Score 1	Score 3		Score 5
1.) Forage quality		*25% - 2.54*	*75% - 3.73*	
	1.12			4.49
2.) Herb. biomass		*25% - 13.5*	*75% - 22.7*	
	5.2kg/ha			28.8kg/ha
3.) Woody cover		*25% - 1*	*75% - 5*	
	0.2%			8%
4.) Litter biomass		*25% - 167*	*75% - 475*	
	51kg/ha			535kg/ha

Figure 9.3.: *Scoring system developed from the ecological data (here soil and vegetation parameters) presented in Chapter 8. Score 1 is given for attributes who's values range from the minimum measurement to the 25% percentile, score 3 from the 25% to 75% percentile and score 5 from the 75% percentile to the maximum measurement.*

Caption for figure on previous page

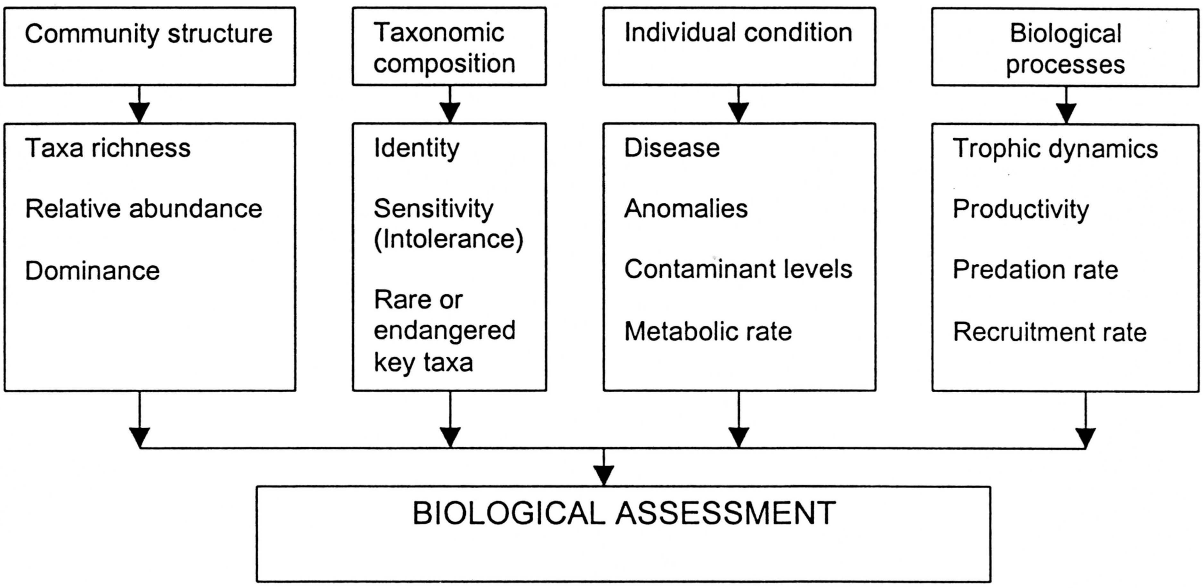


Figure 9.4: *Organisational structure of the types of attributes that should be incorporated into biological assessment (from Barbour et. al, 1995)*

As it was established in the conceptual framework of this study, termites were chosen as key organisms because they play an important role in supporting crucial ecosystem processes such as the translocation of organic matter into the soils (Figure 1.4, Part I; Chapters 7 & 8). In adapting the above concept (Figure 9.4) for termites in particular, attributes such as functional group composition, colony size, and others could be included. It should be noted that because of the particular nature of social insects "individual condition" should possibly be interpreted as "colony condition".

Various termite assemblage attributes were measured in the scope of this study, including aspects of taxa richness, relative abundance, dominance, identity, rare and endangered species and trophic groups (Chapters 6 & 8). However, only a small selection of these was measured at all six study sites, because the baiting experiment was only conducted at Olifantputs and Weerlig, but not at Halt. It was decided to include only a few selected attributes in the development of an IBI based on termite assemblages at this stage, because it was the aim of this study to derive measures that would help distinguish the condition of six study sites of varying land use practices and intensities.

The termite attributes selected were (1) taxa richness as described by generic richness and (2) the ratio of four differentiated trophic groups, namely wood/litter, humus, fungus and grass feeder (Chapters 6 & 8). It was assumed that higher numbers of taxa present would be a positive biological attribute. The valuation of the trophic groups was based on the research presented in Chapter 8, where it was argued that a high percentage of wood/litter feeders in the community composition might be a positive attribute. The reverse was assumed for the other three trophic groups (Chapter 8). It is acknowledged that these relationships need to be tested and further investigated in future, however they were thought to be useful for this study, considering its preliminary and exploratory nature. The following scoring system was derived for the termite parameters (Figure 9.5).

TERMITE PARAMETER

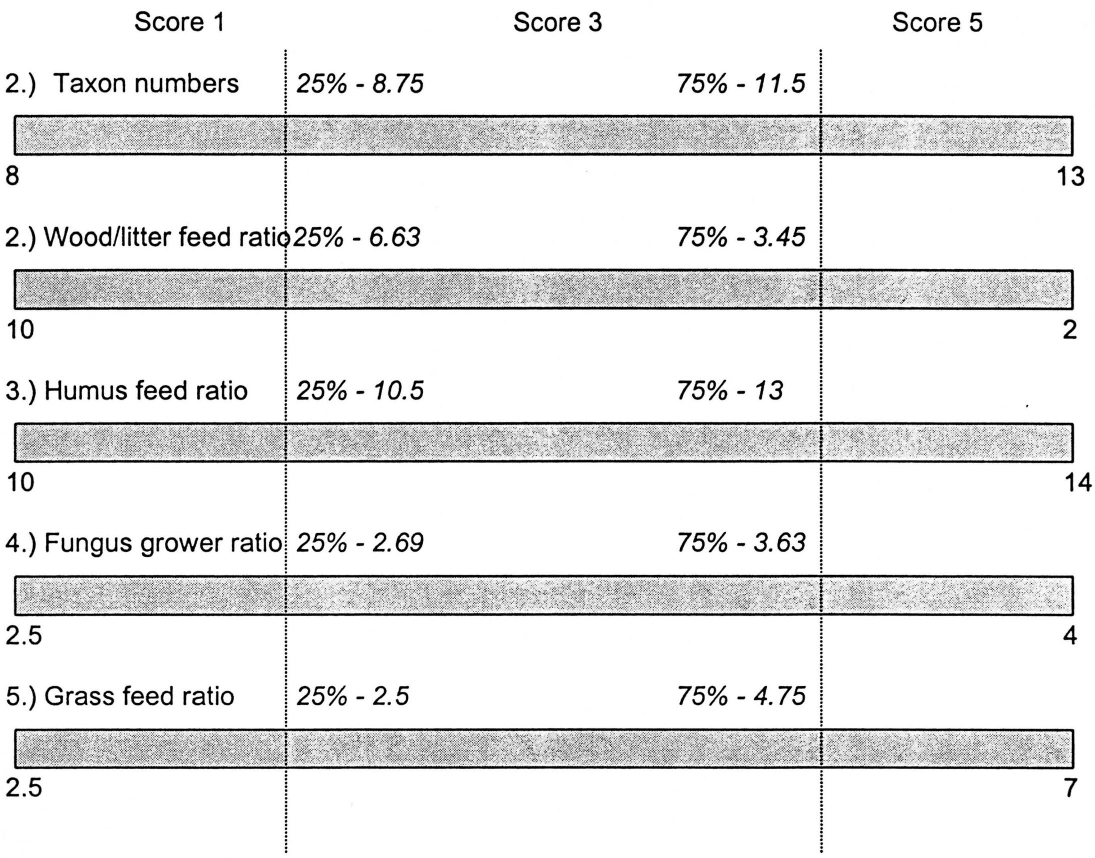


***Figure 9.5**: Scores developed for the termite parameters (see also Figure 9.3).*

Table 9.1: Scores obtained from the six study sites on the soil and vegetation metrics.

		N	OC	P	C:N	LF	C:LF	Soil score	Forage quality	Herb. b.	Wood. b.	Litter b.	Veg. score	**TOTAL**
HAL	March'98	1	1	3	5	3	1	14	3	5	3	3	14	**28**
	October'98	3	3	1	3	3	3	16	3	3	3	5	14	**30**
HAH	March'98	1	1			3	1	12	5	3	1	3	12	**24**
	October'98	3	1		1	5	3	16	5	1	1	1	8	**24**
OPL	March'98	3	3	3	3	3	3	18	3	3	3	3	12	**30**
	October'98	5	5	3	3	1	5	22		1	3	3	10	**32**
OPH	March'98	1	1	3	5	5	3	18	1	3	1	1	6	**24**
	October'98	3	3	1	3	1	3	14	1	1	1	1	4	**18**
WLL	March'98	3	3	5	3	3	3	20	3	5	5	5	18	**38**
	October'98	5	5	5	1	1	5	22	1	3	3	3	10	**32**
WLH	March'98	3	3	5	5	5	3	24	5	5	3	3	16	**40**
	October'98	5	5	3	3	3	3	22	3	3	3	3	12	**34**

Table 9.2: Scores obtained from the six study sites including the termite metrics.

	Taxon #	Wood/litter	Humus	Fungus	Grass	Termite score	Termite and soil & veg. Score (Tab 9.1)
HAL	3	3	3	3	5	17	**46**
HAH	3	5	3	3	1	15	**39**
OPL	3	3	3	3	3	15	**46**
OPH	1	1	1	1	1	5	**26**
WLL	3	5	3	5	3	19	**54**
WLH	5	5	5	3	5	23	**61**

The absolute scores obtained on soil and vegetation condition by the various study sites clearly allow for distinction of the sites. Drawing these along a line (Figure 9.6), show that OPH (21 scores) and HAH (24 scores) range at the lower end, indicating poor conditions. The other sites classified as follows: HAL (29), OPL (31), WLL (35) and WLH (38).

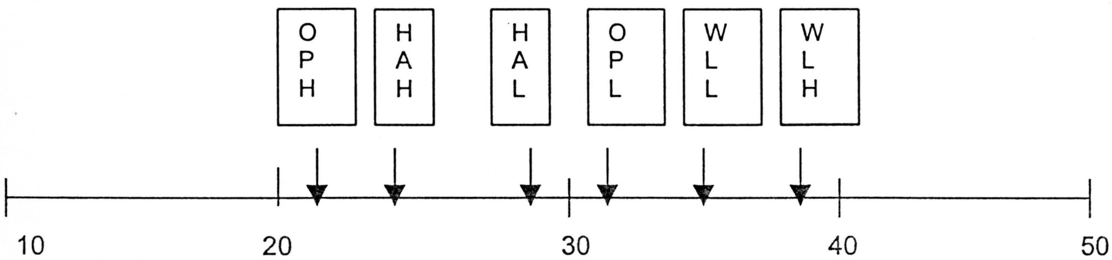


***Figure 9.6**: Rating of scores of the six sites along the vertical distribution of soil & vegetation parameters*

Depicting the rating scored by the termite parameters alone, the following picture emerges:

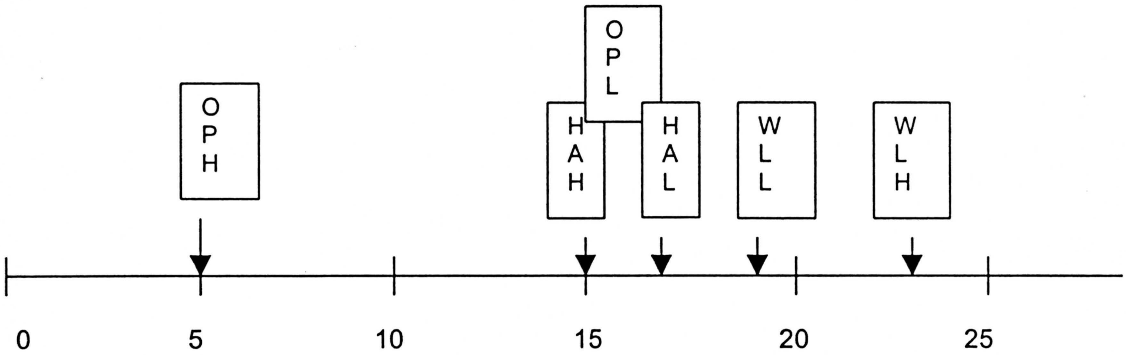


Figure 9.7: *Rating of scores of the six sites along the vertical distribution of termite parameters only*

Adding the scores of the termite criteria (Figure 9.8), the picture changes slightly, marginalising OPH as the lowest reading and grouping HAL and OPL together.

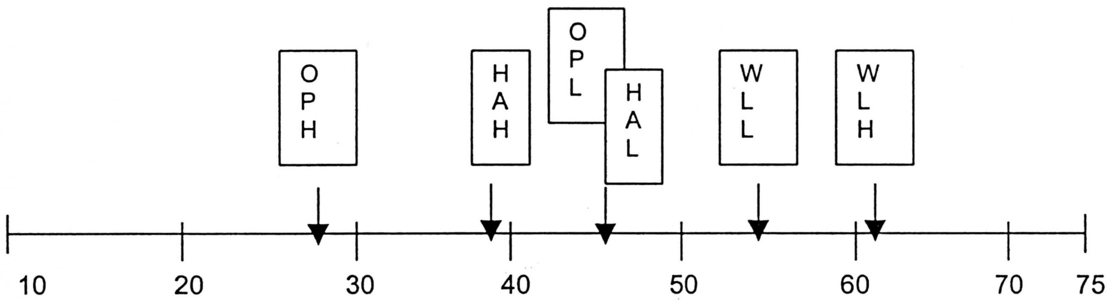


Figure 9.8: *Rating of scores of the six sites along the vertical distribution of termite, soil & vegetation parameters together*

Discussion

According to the scoring system a clear distinction can be made between the habitat condition of the six examined study sites. OPH is clearly in the poorest condition, followed by HAH. HAL and OPL come next along the scale of habitat condition, ranking somewhere in the middle of the range, and are succeeded by WLL. According to the scoring system WLH is in best habitat condition. In Chapter 3 of this study, land use intensity was defined for each of the three farms and six study sites. Chapter 3 forms the basis for the following discussion.

Although the arm Weerlig has been under agricultural land use for the longest time span, this farm seems to be in the best condition compared to the other farms. Looking at stocking numbers over the past eight years (Chapter 3), it is indeed this farm that keeps the most animals with an average of 441 LSU (330 cattle, 664 sheep & goats) and additional 15 horses and donkeys. These figures compare to 372 LSU (237 cattle, 808 sheep & goats, 41 horses and donkeys) kept on average at Olifantputs and 356 LSU (182 cattle, 1043 sheep & goats, 44 horses & donkeys) at Halt. Stocking numbers were above the suggested carrying capacity for all farms for most years (Chapter 3).

The argument that overstocking *per se* is the prime cause of habitat degradation does not explain very well why the communally owned farms are more impaired than the commercially owned farm included in this study.

As outlined in Chapters 2 & 3, land use intensity cannot only be blankly determined by stocking numbers obtained by annual livestock counts by MAWRD staff. Livestock numbers are extremely variable, as documented for Olifantputs and Halt. The farmers apparently seldom keep records of the actual livestock numbers they own, and many owners do not like to reveal the actual number of animals they keep. It is very difficult to establish actual permanent populations and transfer rates during "droughts".

Grazing management also seems to be very important. The farmer at Weerlig practices rotational grazing, whereas on the communal farms, especially at Olifantputs, permanent grazing is practised. In communal farming areas it is illegal to fence off grazing areas or water resources. Although this policy has been put into place to protect farmers in the communal areas from individuals fencing off the best part of the land for "private" purposes, this may also place a serious land management constraint on the farms (Chapter 4). Community grazing rights are in place and certain people use specified areas for their own livestock, but strictly speaking there are no areas that are left to rest at any time of the year.

Another extremely important point made in Chapters 2 and 3 is the importance of emergency grazing and migration. When the grazing resource is very poor, animals are usually moved off the farms. This is common practice at the communal as well as commercial farms. The commercial farmer in this case can count himself extremely lucky having access to another farm. Most communal farmers also find emergency grazing, at least for a short while, but there are serious constraints. In 1998, for example, most cattle were moved from Olifantputs by June. By October several farmers had returned their livestock in anticipation of the forthcoming rainy season, and because they did not consider their animals "safe" on the other farms that still had grazing. Either livestock theft were recorded as a problem or scare ground water resources. In 1998 there were a few rain events recorded in October and November and the new seedlings were consumed almost immediately. Early consumption can have negative effects on future grazing potential (Illius & O'Connor, 1999).

All these points are just a few examples to corroborate the observations made in Chapters 2 and 3 indicating that land use intensity is a much broader and complex problem than stocking numbers only. Stocking numbers, which can be assessed relatively quickly, are often used for the purpose of studies like this. Considering that all three farming areas are of similar size and of similar land use intensity it seems that land management practices are of vital importance in ensuring lasting habitat condition. Water points, emergency grazing, reliable stocking numbers, as well as communal farming community dynamics are important to take into consideration.

An important question is whether sites, which are already impaired remain stable and resilient enough not to deteriorate faster than other sites when continued pressure is put on them. This needs to be investigated urgently. The development of appropriate management interventions for rehabilitation of impaired systems has to be made a priority (e.g. Chapter 8).

Some of the above arguments will be taken up and further developed in the final conclusion (Chapter 11). However, in the scope of this chapter it is important to make a few points on the methodology used for the development of a preliminary IBI in this study.

At this stage of the study, clearly defined integrity classes (see e.g. Karr, 1991) were not established nor were true biocriteria defined (Barbour *et al.*, 1995), both vital components of an IBI. However, this study has laid the foundation for the full establishment of such indices. It should be mentioned again that the study area is considered to be marginal in all measured components, including termite biotic diversity measures (Zeidler, 1997). Therefore the study sites under inspection should possibly be classified as "lower end benchmark" compared to sites elsewhere in Namibia. However, it should be stressed that it is particularly in these marginalised areas, where slight variations in habitat condition might make a big difference for performance and productivity (e.g. OC% content, see chapter 8). The rule of the lowest limiting factor to plant growth for instance, might be significantly affected by soil nutrient status.

The developed termite related criteria of the IBI should be refined in future. The termite research might open an interesting avenue to biodiversity and ecosystem functioning focused studies. Termites might not be "simple" indicators, considering both the sampling effort, and the difficulty of specimen identification, but they still hold conceptual value for ecosystem studies (Figure 1.4, Part I), and consequently could be particularly useful for incorporation into an IBI. Their general corroboration of a complex of environmental variables, as well as their crucial role in soil processes, support this.

This chapter has established the scientific condition rating of the six study sites. Chapter 10 presents the perceptions of the site condition by the local farmers.

PART IV

Chapter 10

FARMERS PERCEPTIONS AND INDICATORS OF HABITAT CONDITION AND BIOLOGICAL INTEGRITY

10.1 Introduction

Since the 1970s, the role of local participation has been an important focus of rural development programmes. More recently the need to involve the people in research, conservation, and the active management of the natural resources has been underlined, and many programmes take a community-based approach (e.g. Cernea, 1985; Paul, 1987; Little, 1994; Western *et al.*, 1994). In this research, the participation of the local farmers was linked to the ongoing work of Napcod, a development programme that was based at Olifantputs throughout the period of this study.

Farmers' involvement in this research was important for two reasons. Firstly, it is generally appreciated that the farmers themselves know best how their farms work, what the management constraints are and local and indigenous knowledge may be a rich source of information when looking for suitable indicators of range condition (e.g. Oba, 1994; Homann *et al.*, 1996). Secondly, it is the local farmers who will become the ultimate users of range assessment tools. It is considered that an early involvement of the farmers in the formulation of indicators as well as the generation of suitable field methodologies is crucial to make this work. The interactions between the farmers and the researchers are therefore seen as an important information exchange and mutual training process.

10.2 Methods

Two different approaches to data collection and verification were used: transect walks and a field site evaluation by the farmers.

Transect walk

The list of indigenous and local indicators used for the assessment of grazing potential, livestock production and biological integrity was cross-validated and expanded through transect walks (e.g. Nagel *et al.*, 1992; Westphal *et al.*, 1993) across the farm.

Farmer site evaluation

A group of five (self) selected farmers and farm workers from the three farms Olifantputs, Halt and Weerlig together visited the six study sites for site evaluation. These were namely Ernest Unaeb and Frederick Nanuseb from Olifantputs, Albert Giel from Halt, Jesajas Haraeb the foreman of the farm Weerlig and Dudu Murorua, Napcod field facilitator, former communal farmer and now owner of a commercial farm near the study area. The relative habitat condition at each site was assessed based on their own qualitative criteria. The six sites were ranked by each farmer from high to low integrity as a measure of habitat condition by scoring each of the selection criteria. A list of indicators used by the farmers was compiled from the answers provided.

10.3 Results

Table 10.1 is a synthesis of the indicators each individual farmer has used in their field assessments. The full set of indicators used for the assessment of each individual site is included in Appendix 6. The rank of each site was decided on in a collective manner after discussions among the farmers. There was general consensus on the condition of the various sites compared to one another. The ranks are depicted in Figure 10.1.

Table 10.1: Indicators used for habitat assessment by farmers from Olifantputs, Halt and Weerlig

a) Ernst Nunaeb	b) Albert Giel	c) Dudu Murorua	d) Frederick Nanuseb	e) Jesajas Haraeb
Vegetation • Tree condition • Veld condition • Regeneration potential of seedling after rain • Vegetation condition • Grass biomass and condition • Frequency of perennial grass Schmidtia • Grass (forage) quality **Climate** • Rain **Topography** • Topography and water flow **Soil** • Soil fertility (litter content)	**Vegetation** • Grass cover • Trees • Mopane trees • Vegetation condition • Grass biomass • Regeneration potential after rainfall • Vegetation cover – bare ground **Climate** • Rainfall **Topography** • Topography **Soil** • Soil condition (crust formation) • Water infiltration **Livestock** • Dying animals **Biota** • Biota	**Vegetation** • Grass stems • Grazed to specific limit • Perennial grasses • Vegetation biomass • Condition and density of grass • Shrub density • Overgrazing • Condition of vegetation • Bare ground vs vegetation cover • Tree density • Vegetation biomass • Tree density • Grass vs Acacia bushes (bush encroachment) **Climate** • Rainfall **Soil** • Soil type • Erosion (stems and roots of grasses are visible) • Soil condition **Biota** • Termite activity • Trampling	**Vegetation** • Bare ground vs grass cover • Tree density • Mopane trees • Tree condition • Seedlings establishment • Vegetation condition • Condition of individual indictor plants e.g. "!Awa-ti"/"Staal bosies" has white flowers • Litter "density" • Seeds **Soil condition** • Soil condition • Erosion (bare roots) **Biota** • Tracks of domestic vs wild animals • Biota • Trampling • Ants/biota • Porcupine tracks **Water** • Condition of ephemeral river courses • Ground water availability	**Vegetation** • Grass biomass • Veld condition • Vegetation condition • Tree condition • Bare ground vs grass cover • Grass (forage) quality • Regeneration potential after rainfall **Climate** • Rainfall **Soil** • Soil type • Soil condition • Water infiltration • Soil fertility **Overall** • "Desertification"

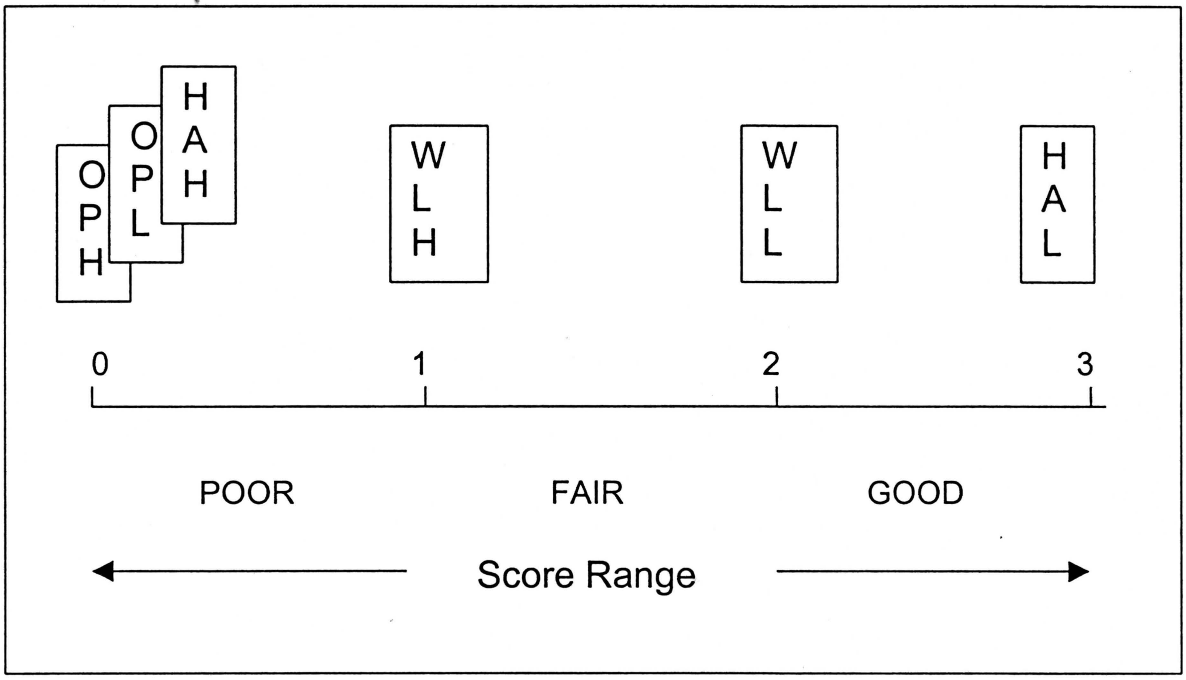


Figure 10.1: Ranks attributed to the various study sites by local farmers during a field evaluation excursion conducted in November 1998.

It is apparent that all farmers most frequently used vegetation-related indicators. Veld condition, generally interpreted as grass cover and grazing limit, was possibly the most frequently applied indicator.

Others were grass species composition, with a high frequency of *Schmidtia pappophoroides* being interpreted as favourable. Tree and overall vegetation condition, especially pinpointed to mopane trees, was used frequently. The frequency of *Acacia* species as encroaching species was mentioned. The regeneration potential of vegetation after rainfall was one of the main features. However, this regeneration potential could not be used as a definite indicator especially at the time of the field evaluation, which took place before the onset of the rainy season in November'98. Litter and seed presence at sites was also registered. However, the latter could not easily be assessed visually. Nevertheless, depletion of the seed bank was acknowledged as a factor of degradation.

Climatic conditions, especially rainfall, were recognised as the main indicator of habitat condition. Also the geographic situation and overall environmental character of the study site were identified as pre-requisites for habitat evaluation, partially also influencing rainfall at a specific study site. Topography, resulting water flow patterns, soil type and soil condition were mentioned frequently by the farmers. Soil related indicators suggested included soil compaction and crusts, hardness, rocky or stony contents, soil colour and litter/organic matter content. One farmer only (Frederick Nanuseb) mentioned ground water availability and the condition of ephemeral watercourses as an important indicator of habitat condition.

Animal related indicators were also named occasionally. Some of them pointed to the livestock and their condition, others were directed at the "natural' fauna, including invertebrates. Livestock dying of starvation and trampling intensity were mentioned in connection with livestock, the occurrence of wild animals indicated by their tracks and the activity of ants and termites were noted. However, whether the latter was seen as positive or negative could not be established.

The causal connections made between indicators and habitat condition are more explicitly shown in the full data set presented in Appendix 6.

The site evaluation by the farmers was very straight forward (Figure 10.1). There was consensus amongst all the farmers as to the quality ranking of the six sites. The ranks of habitat condition assigned by the farmers grouped HAH, OPH, and OPL together under a zero rank, indicating a poor habitat condition. This was followed by WLH, ranked as one, WLL ranked as two and HAL ranked as three, thus indicating the best condition observed among all six study sites.

10.4 Discussion

The local farmers who took part in the site evaluation excursion seem to use a great diversity of indicators when assessing habitat condition. Although most indicators are based on vegetation parameters, rainfall, ground water and animal attributes are also used. Generally all farmers who joined the group had a good understanding of habitat condition although it was apparent that some individuals had a better understanding of using quantitative assessment methods than others.

Compared to the ranking of study sites by the IBI method (chapter 9), the results of the farmers evaluation show some differences. Whereas the rating of condition of OPH and HAH are also right at the bottom, therefore the poor end of the scale, OPL was characterised as being very similar. WLH was evaluated as being of poor to fair condition by the farmers, however, was rated the best by the IBI method. HAL was thought to be of good condition by the farmers, however, this site is, according to the ecological rating, of fair condition at best.

How did this discrepancy of assessment come about? The types of indicators mainly mentioned by the farmers were soil condition, tree condition (esp. mopane), herbaceous and litter biomass and grass species composition. Soil condition was generally described by surface hardness, which would prevent rainfall infiltration. Tree condition was mainly described by whether the trees were carrying green or dry leaves. But grass parameters and litter were used mainly as indicators. These indicators taken together probably identify HAL as being in a good condition, as it was mainly the soil parameters (Table 8.1 and chapter 9) that were poor at Halt. It seems that using primarily vegetation characteristics as indicators gives a reflection of recent grazing intensity, but not a good understanding of longer term impacts and ecosystem function and related processes.

It is also apparent that Halt is generally considered to be a good farm (Answer to the question of which farm in the area is considered being in good condition, Questionnaire, Appendix 1). This seemingly prevailing notion could have masked the objective assessment of the low intensity site at Halt.

However, the discussions with the farmers were most interesting and a number of questions were raised by the farmers, mainly revolving around issues of management opportunities, possible interventions to enhance habitat condition and constraints to communally owned resources.

PART IV

Chapter 11

Final conclusions and recommendations of the study

With the assumptions made at the onset of this study, that all study sites started with similar ecological conditions, it can be concluded that communal land tenure and management are more constraining on the ecological resource base than commercial land tenure at the selected study sites in north-western Namibia (chapter 9 and summary Figure 11.1).

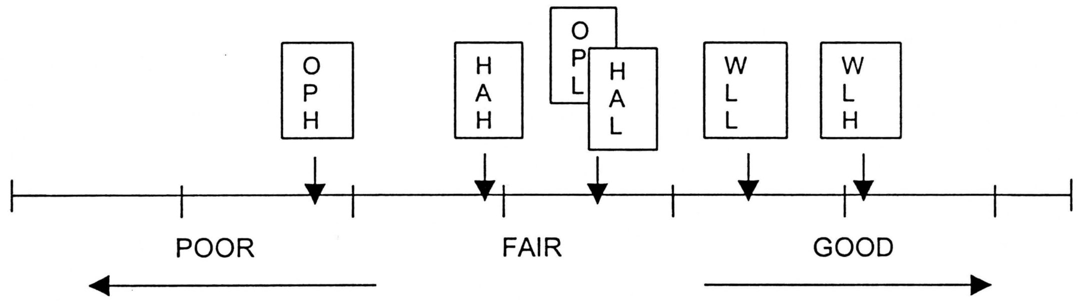


***Figure 11.1** : Rating of habitat condition of the six sites, considering the IBI scored based termite, soil & vegetation parameters together. Olifantputs (OP) and Halt (HA) are communal farms, Weerlig (WL) is a commercial farm situated in the same area. (L) and (H) indicate the low and high land-use intensity study site respectively.*

Local farmers rated the condition of the six sites differently from the scientific method (Figure 10.1), and used a great diversity of indicators for qualitative assessment of the natural resource base (Table 10.1). These included indicators of soil and tree condition, herbaceous and litter biomass as well as grass species composition. Soil condition was generally described by surface hardness, which would prevent rainfall infiltration. Tree condition was mainly described by whether the trees were carrying green or dry leaves. But mainly grass parameters and litter were used as indicators. It seems that using primarily vegetation characteristics as indicators gives a reflection of recent grazing intensity, but not a good understanding of longer term impacts and ecosystem function and related processes. Quantitative assessment methodologies such as the IBI seem to provide superior and more reliable results.

The research results of this study provide field data that negates the notion that rangelands that are situated in arid areas and are non-equilibrium systems, are not threatened by land degradation (e.g. Behnke et al., 1993; Sullivan, 1998; Ward *et al.*, 1998). However, the findings are in line with Illius & O'Connor (1999) who state that "rather than ignoring degradation, policy-makers and ecologists should seek to identify the characteristics of grazing systems that predispose some systems toward degradation, while others appear to be resistant."

In an area as arid and variable in climate as north-western Namibia, indicators have to be found which reliably distinguish between areas that are degraded, thus suffer from a decline in productivity, and areas that are only resting under natural climatic variability, but retain their productivity. The results of this study suggest that a combination of vegetation parameters, including biomass and palatability of herbaceous plants, litter biomass and tree cover, soil parameters, including measurements of soil fertility such as P, N, C, and LF levels and ratios thereof, as well as biodiversity measures of termites as suitable indicators, all combined in an index of biological integrity (IBI) may serve as a reliable indicator. This index focuses particularly on the link between biodiversity and ecosystem functioning, which, in the scope of this study, was conceptualised at the onset of the study (summary Figure 11.3) and later established through the research, between termites, other soil fauna and the OC translocation and transformation in the soils. It is recommended that the IBI be further developed and refined at the sites, as well as adapting it to other habitats and areas throughout the country.

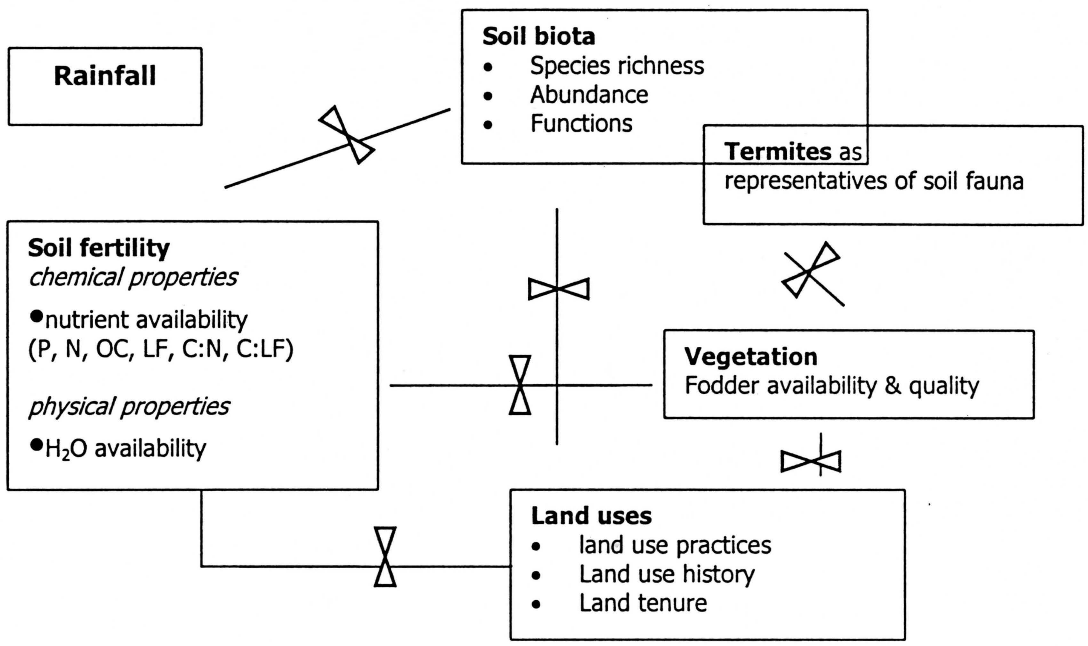


Figure 11.3: *Summary of the conceptual framework of Biological Integrity (Figure 1.4, chapter 1). Process links between the measured parameters are indicated by the "bow-tie".*

The field collection of the ecological baseline data have been streamlined and a practical sampling design encompassing a wet and dry season sample is suggested for use in comparative sites. Laboratory analysis, e.g. in form of termite and vegetation identification, as well as soil analysis, is elaborate and costly and it would be desirable to identify simplified indicators providing clues to the actual levels of the same parameters. Termites are fairly elaborate to sample as well as difficult to identify, especially if no soldiers are found. A reference collection could be a useful tool for field identification, or alternatively other associated biological indicators, easier to handle should be searched for.

The study could not establish whether the impoverished integrity of the sites could be reversed by certain management interventions. However, looking at the nature of the impacts and the extent of the farming areas it is unlikely that cost effective and practical interventions of regulating land use intensity can be applied. Sandford (1995) indicates that it might be more cost-effective not to use scarce financial resources for the rehabilitation of rangelands but rather to prepare the pastoral population for non-pastoral occupations. However, innovative research could possibly help to find other solutions, and Bayer & Waters-Bayer (1995), for example, suggest supply of alternative food supplies to range animals especially in drought as one of several management strategies for range improvement .

This research attempted to cross the border from pure ecological research to incorporate some more sociological research, particularly in the need to establish land use intensities and pressures on the resource base more appropriately than using annual stocking numbers only. The study clearly indicates that the use of such numbers are not providing a good reflection of the actual land use intensity, both because the numbers are often not reliable and also do they not reflect the stocking dynamics over a year nor land use management practices.

Comparing the recorded stocking numbers for 1998 derived from two different sources, namely data from the annual census of the Ministry of Agriculture, Water & Rural Development (MAWRD) and data from a questionnaire answered on the individual basis by all household especially on the communal farms (Table 3.7 reproduced in Table 11.1), do not correspond.

Table 11.1: LSU recorded at the farms by MAWRD (12/98) and a questionnaire based census (06/98)

	MAWRD (12/98)	Census (06/98)	% difference
Weerlig	483	251	52
Halt	393	76	19
Olifantp.s	454	666	147

Comparing the LSU values provided by MAWRD for December 1998 and the questionnaire data from June 1998, it is apparent that at Weerlig and Halt the census recorded much lower animal numbers. This relationship was reversed at Olifantputs, were animal numbers (LSU) in June were 147% of the numbers counted by MAWRD in December. It seems to be particularly important to count stock on a household level on communal farms, where ownership structures can be confounded (see also chapter 4).

It is recommended that in future, stocking numbers be tracked more accurately by the farmers themselves. As rainfall tracking is a prerequisite to qualify for drought relief (National Drought Policy; Anon, 1997), policy incentives should be set encouraging the farmers to record stocking numbers on a monthly basis. This concept should be based on participatory monitoring and research principles particularly empowering the farmers to make informed decisions about land and animal management (DRFN/Nepru, 1999). The tools could be propagated through programmes such as Namibia's National Programme to Combat Desertification (Napcod), the Sustainable Animal and Rangeland Development Prorgramme (Sardep), the Northern Livestock Development Programme (Nolidep) at the commercial and communal farms as well as through MAWRD extension personnel. It should be noted in this context that it might be useful to adapt rainfall analysis and interpretation in the realm of the (drought) policy context mentioned above, by considering a more qualitative approach (chapter 2). One of the main draw backs on the drought policy and the tracking of rainfall have been that relief is only granted after the disaster has struck (Devereux *et al.*, 1993; Moorsom *et al.*, 1995). This dilemma can possibly be avoided by including the continuous tracking of stocking rates, as well as practicing drought proofing strategies (DRFN/Nepru, 1999).

However, although stocking numbers seem to be a major component of land use intensity, other components such as management opportunities are a major constraint to sustainable land use especially in the communal areas (chapter 4). The reasons for this are manifold and need to be urgently addressed in order to prevent land degradation. It is not stocking numbers as assessed through annual livestock counts by the MAWRD *per se* that explain the amplified impoverishment of the natural resource base at the communally owned farms. Stocking numbers were in fact the highest at Weerlig with an average number of 441 LSU, followed by Olifantputs with an average stocking rate of 372 LSU and Halt with 356 LSU. Whether the high stocking rate at Weerlig can be maintained because stock are regularly moved to another farm or supplement fodder is given, cannot be established. All three farms are continuously stocked above the recommended limits (chapter 3). The generalized call for de-stocking should be qualified, and ownership, decision making and livelihood dependency structures should be taken into consideration when monitoring land degradation (desertification) and planning interventions to prevent it.

A major discussion revolves around the issue of emergency grazing. The way grazing is practiced today in north-western Namibia seems to be a modified form of nomadism (Rhode, 1993, 1994). When grazing on a farm is depleted, livestock owners usually try to move their animals to farms that still have sufficient grazing available. The commercial farmer at Weerlig, for example, owns a second farm onto which he can move his livestock in periods of prolonged drought. The communal farmers usually depend on their personal connections to negotiate for their livestock to be lodged at other communal or even commercial farms (chapter 4). Usually no compensations are paid. However, with increasing stocking numbers as well as over longer time periods even emergency areas become scarce. If we consider the emergency grazing areas available as "key resource" areas (see Illius & O'Connor, 1999), the problem arises that large livestock populations are maintained over a prolonged period, which may lead to degradation. Little research has been done on the assessment of range condition of emergency areas and the impact of high stocking intensities under periods of prolonged drought. Considering that important ecosystem processes such as soil nutrient replenishment are possibly naturally reduced during extreme situations such as drought (chapter 7 & 8), maintained high land use intensities could threaten the sustainability of emergency grazing areas.

High land use intensity at communal farms is confounded by aspects of the degree of dependency of many individual livelihoods on the farms, difficulties associated with communal ownership and management, as well as the legacy of a disabling policy framework that prevents appropriate land management decisions to be taken especially on the communally owned farms. As farmers at Olifantputs describe it, it is the management of the grazing in the "open access" area that is of special concern. Also the inaccessibility and unreliability of emergency grazing that drives the farmers to apply bad management, such as overgazing and untimely grazing (chapter 4). The ground water resources are threatened due to high livestock numbers (DRFN, unpubl.).

These frame conditions ought to be improved and evidently the farmers yearn for more independent and site based land use and land management rights. This would require a high sense of responsibility of communities to manage the land in a democratic and just fashion. In the case of Olifantputs, the results of this study raise concerns. A few residents own large livestock herds, including absentee farmers, and some do own only a few animals. However, the same contribution to the maintenance of the water point is to be paid by each household (DRFN, unpubl.). An enabling but just and protecting policy framework needs to be developed, considering especially the marginalised people in rural communities.

If Namibian rangelands can only be used at a limited intensity without jeopardising the natural resource base irreversibly, it needs to be considered who the people are that really depend on farming to sustain their livelihoods. One option is that people who do not have other alternatives to make a living should be promoted to make use of the rangeland land. It needs to be carefully examined at which 'environmental' price some of the beef is produced and long-term cost-benefit analysis should be conducted.

Alternatives to livestock husbandry as the main usage of rangelands should be considered. Game farming has been promoted as a viable alternative in the past, but it is not clear yet how the international meat market and consumer will accept this alternative (e.g. Conservancy CBNRM programme, WILD). Game farming is not only contributing to meat production but opens other avenues for income generation such as photo and hunting tourism, and associated businesses. However, some constraints remain – firstly the land use intensity may not be significantly reduced through a shift from livestock to game farming. Secondly, the markets will possibly never develop to the size of the beef market. Thirdly it needs to be recognized that livestock farming is a lifestyle in Namibia, a traditional pastoral society. However, alternatives have to be found, both to guarantee the protection and sustainable use of the environment but also to guarantee sustainable development to a level that is desirable for all Namibians.

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Appendix 1

Database of all socio-economic survey data, questionnaires, PRA activities

The full database is made of two main components:

1.) PRA data from Olifantputs
2.) Natural resource management questionnaire designed by Penda Shimali and answered for all households at Olifantputs, Halt and Weerlig

Both parts have been computerized in ACCESS'97 database programme and can be run from the provided diskette.

Appendix 2

Termite taxa occurring in Namibia (National Survey of the Isoptera, 1963-68). A classification of feeding and nesting groups is derived from the literature. Genera that are not idientified to species level are marked as 'n.f.i.'.(After Zeidler, 1997)

Taxon	Feeding group	Nesting group	Reference
KALOTERMITIDAE			
Kalotermitinae			
(1) Neotermes	wood feeder	arboreal	Coaton & Sheasby, 1972
(2) Bifiditermes	wood feeder	arboreal	Coaton & Sheasby, 1972, 1980
Bifiditermes sibayiensis Coaton			
(3) Epicalotermes (n.f.i.)	wood feeder	arboreal	Coaton & Sheasby, 1972
(4) Cryptotermes	wood feeder	arboreal	Coaton & Sheasby, 1972, 1979
Cryptotermes havilandi Sjöstedt			
HODOTERMITIDAE			
Hodotermitinae			
(5) Hodotermes	grass feeder	hypogeal	Coaton, 1958, 1981; Coaton & Sheasby, 1972, 1975b
Hodotermes mossambicus Hagen			
(6) Microhodotermes	litter/dung feeder	hypogeal	Coaton & Sheasby, 1972, 1974b
Microhodotermes viator Latreille			
RHINOTERMITIDAE			
Psammotermitinae			
(7) Psammotermes	wood & litter feeder	hypogeal	Coaton & Sheasby, 1972, 1973c
Psammotermes allocerus Desneux			

Taxon	Feeding group	Nesting group	Reference
Coptotermitinae			
(8) Coptotermes	wood feeder	arboreal	Coaton & Sheasby, 1972, 1976
Coptotermes amanii Sjöstedt			
Rhinotermitinae			
(9) Schedorhinotermes	wood feeder	arboreal	Coaton & Sheasby 1972, 1973b
Schedorhinotermes lamanianus Sjöstedt			
TERMITIDAE			
Apicotermitinae			
(10) Skatitermes	litter/dung feeder	hypogeal	Coaton & Sheasby, 1972
Skatitermes psammophilus Coaton			
Skatitermes watti Coaton			
(11) "Anoplotermes" branch	wood/soil feeder	hypogeal	Coaton & Sheasby, 1972
Termitinae			
(12) Amitermes (n.f.i.)	wood & litter feeder	arboreal	Coaton & Sheasby, 1972
(13) Microcerotermes (n.f.i.)	wood & litter feeder	arboreal	Coaton & Sheasby, 1972
(14) Cubitermes (n.f.i.)	humus feeder	epigeal	Coaton & Sheasby, 1972
(15) Ovambotermes	humus feeder	arboreal	Coaton & Sheasby, 1972
Ovambotermes sylvaticus Coaton			
(16) Okavangotermes	humus feeder	not known	Coaton & Sheasby, 1972
Okavangotermes giessi Coaton			
(17) Lepidotermes (n.f.i.)	humus feeder	hypogeal	Coaton & Sheasby, 1972
(18) Noditermes (n.f.i.)	humus feeder	hypogeal	Coaton & Sheasby, 1972
(19) Unicornitermes	humus feeder	hypogeal	Coaton & Sheasby, 1972
Unicornitermes gaerdesi Coaton			

Taxon	Feeding group	Nesting group	Reference
(20) Unguitermes	wood/soil feeder	arboreal	Coaton & Sheasby, 1972;
Unguitermes unidentatus Ruelle			Ruelle, 1973
(21) Promirotermes (n.f.i.)	wood/soil feeder	hypogeal	Coaton & Sheasby, 1972
(22) Termes (n.f.i.)	wood/soil feeder	hypogeal	Coaton & Sheasby, 1972, 1978
(23) Angulitermes (n.f.i.)	wood & litter feeder	hypogeal	Coaton & Sheasby, 1972
Macrotermitinae			
(24) Allodontermes	fungus grower	hypogeal	Coaton & Sheasby, 1972;
Allodontermes rhodensiensis Sjöstedt			Ruelle, 1979
Allodontermes schulzei Silvertry			
(25) Macrotermes	fungus grower	epigeal	Coaton & Sheasby, 1972;
Macrotermes subhyalinus Rambur			Ruelle, Coaton & Sheasby, 1975
Macrotermes vitlalatus Sjöstedt			
(26) Odontotermes (n.f.i.)	fungus grower	epigeal	Coaton & Sheasby, 1972
(27) Ancistrotermes	fungus grower	hypogeal	Coaton & Sheasby, 1972, 1975a
Ancistrotermes latinotus Holmgren			
(28) Microtermes(n.f.i.)	fungus grower	hypogeal	Coaton & Sheasby, 1972
Nasutermitinae			
(29) Baucaliotermes	litter/dung feeder	epigeal	Coaton & Sheasby, 1972, 1973a
Baucaliotermes hainesi Fuller			
(30) Trinervitermes (n.f.i.)	grass feeder	epigeal	Coaton & Sheasby, 1972
Trinervitermes dispar Sjöstedt			
Trinervitermes rapulum Sjöstedt			
Trinervitermes rhodesiensis Sjöstedt			
Trinervitermes trinervoides Sjöstedt			
(31) Fulleritermes	humus feeder	arboreal	Coaton & Sheasby, 1972, 1973d
Fulleritermes contractus Sjöstedt			
(32) Rhadinotermes	wood & litter feeder	hypogeal	Coaton & Sheasby, 1972, 1974a
Rhadinotermes coarctatus Sjöstedt			
(33) Spatulitermes	humus feeder	hypogeal	Coaton & Sheasby, 1972
Spatulitermes coolingi Coaton			

Appendix 3

Database of all termites data from the study area

The full database includes a full reference to the

- termite taxon found with fullest identification possible
- date of sampling
- location of sampling
- method used to retrieve the sample

The data have been computerized in ACCESS'97 database programme and can be run from the provided diskette.

Appendix 4

Methods used for lab analysis of soil samples

- Total Nitrogen by Kjedahl Oxidation
- Organic Carbon by Walkley-Black Method
- Plant Available Phosphorus by Olsen Method
- Light fraction extraction

1.) Nitrogen by Kjeldahl Oxidation

1. Reference Method
Modified from: McGill W.B. and Figueirdo C.T. 1993. Total Nitrogen, pages 201-211 in Soil Sampling and Methods of Analysis, M.R. Carter, Ed., Canadian Society of Soil Science, Lewis Publishers.

2. Introduction
Nitrogen is an essential nutrient which is taken up largely in mineral form by plants as nitrate and ammonium ions. Most soil nitrogen is present in organic forms which are converted into mineral forms by microorganisms. The amount of nitrogen present in the soil bears a definite relationship with organic carbon or organic matter content calculated as the carbon to nitrogen ratio. The C:N ratio varies within a narrow range in similar soils in the same climatic region. This relationship helps to cross-check the soil analysis results for consistency and reliability.

3. Scope
The method can be used to determine the total nitrogen as organic-N plus ammonium-N content of soil, manure, and plant tissue. The particular oxidants and catalysts used here are specifically designed for the oxidation of all forms of nitrogen found in soil humus. Different digestion systems may work equally well for plant materials but they are generally not suitable for soils.

4. Principle
In the Kjeldahl procedure organic matter is oxidised by treating soil with concentrated sulphuric acid. Potassium or sodium sulphate is added to raise the temperature and selenium powder and copper sulphate are added as catalysts. The procedure determines total soil nitrogen (including adsorbed NH_4^+) except that in nitrates. The organic nitrogenous compounds are converted into ammonium sulphate during the oxidation. Ammonia is liberated from the digest by steam distillation at high pH following the addition of excess sodium hydroxide. The distilled ammonia is absorbed in a boric acid solution thereby increasing its pH. The amount of ammonia trapped is estimated by back titration with standard sulphuric acid to the original pH of the boric acid.
The method described here is for use with a Buchi commercial digestion and distillation system.

5. Method Validation
The method has only been validated against one external soil standard.

6. Supporting Documents
SOP Soil-100 Sample reception and documentation
SOP Soil-101 Sample preparation
SOP Plant-200 Plant leaf tissue preparation and ashing

7. Interferences and Other Considerations
Care must be exercised that the digestion proceeds to completion but without undue loss of the sulphuric acid digestion mixture or of soil from bumping or splattering out of the digestion tubes into the air manifold. The potential temperature of digestion increases as the amount of salts are increased in the digestion mixture. It is important that the initial low temperature digestion is carried out to completion to the clearing stage at about 220 °C before the heating is increased to about 360 °C for the final digestion. Soil digestions take considerably longer than those with plant matter due to the presence of compounds that are difficult to oxidise such as those containing nitrogen bound in heterocyclic rings. It is also important to ensure that a slight excess of sodium hydroxide is present for the steam distillation step. Due to the different intensities of digestion and composition of samples it is unwise to assume that the same amount of sodium hydroxide will be needed as for other forms of Kjeldahl digests using the same amount of sulphuric aid.

8. Sample requirements
Samples should be air-dried and ground to pass a 2 mm sieve. Though acceptable results are normally obtained with such samples, more consistent results may be obtained with more finely ground samples. Samples stored in an air-dry state in a cool place will show little deterioration. However, as moisture and temperature of storage increase there

will be a tendency for biological activity to increase and cause the slow conversion of organic-N into ammonium-N and nitrate-N with some potential for losses of nitrogen.

9. Equipment and Supplies

- Analytical balance
- Buchi digestor, model B-426/B-43F.
- Buchi distillator/titrator model B-323/B-339.
- Large volumetric flasks.
- Large plastic or glass containers for reagent storage.
- Kjeldhal digestion tubes ~250 ml

10. Reagents

- *Catalyst mixture (100:10:1 w/w potassium sulphate: cupric sulphate: selenium):* This catalyst mixture may be prepared in bulk and then finely ground and evenly mixed. At present for each analysis we use two of the pellets normally used for feed nitrogen determination (each contains 1 g sodium sulphate and 0.05 g selenium) to this is added 4.0 g potassium sulphate and 0.7 g copper sulphate ($CuSO_4.5H2O$).
- *Boric acid (2%)* :Dissolve 60 g of boric acid in about 2000 ml of distilled water in a 3 litre volumetric flask and make to volume with distilled water. Transfer to the plastic container on the titration/distillation unit.
- *Sulphuric acid concentrated (96%, 1.84 S.G.)*
- *Sulphuric Acid (0.1N)* : Pipette 8.46 ml of conc. H_2SO_4 (96%; sg 1.84g/ml) into a 3 litre volumetric using a variable digital pipette and make to volume with distilled water. Standard solutions may also be prepared from commercial ampules.
- *Sodium Hydroxide (40%)*: Dissolve 1200 g NaOH in about 2500 ml of distilled water in a 3 litre volumetric flask: Cool the solution with the flask stoppered to prevent absorption of atmospheric CO_2. Bring to volume with distilled water. Transfer to the plastic container on the titration/distillation unit.

11. Safety and Special Precautions

Extreme caution should be exercised when handling concentrated sulphuric acid and sodium hydroxide. The working area in and around the fume hood should be kept clean of any acid or alkali spills. Condensation of acidic vapour tends to occur on the digestion apparatus. Drips and spills of caustic soda are likely around the steam distillation apparatus. Make sure to take sufficient safety measures to prevent damage to your skin and clothing.

12. Test Procedure

- Weigh out enough batches of the catalyst-salt mixture onto weighing dishes or filter paper. Add carefully to each digestion tube. Add two boiling chips.
- Weigh 2.00 to 4.00 g of air-dry ground soil (or 0.500 to 1.000 g of dried manure or plant material) onto weighing dishes and transfer into the digestion tubes. Prepare two blank tubes per run with only catalyst-salt mixture.
- Add 6 ml de-ionised water, swirl and let sit for 10 minutes.
- Add 20 ml concentrated sulphuric acid from an automatic dispenser and mix again.
- Heat on the digestion rack without the air condensers attached at ~ 220 °C for 1.5 to 2.0 hours. A setting of 2 or 3 for the heater should be sufficient to maintain the required temperature. The digests will produce white fumes and eventually boil to gradually remove the water. After about 1 hour the charred digests will gradually clear to a uniform green-blue colour.
- When all the tubes have cleared, continue heating for an additional 3.5 hours at ~ 360 °C with the air condensers attached and with the sulphuric acid condensing no more than 1/3rd of the way up the tube. A heater setting of 5 or 6 should be sufficient.
- Allow tubes to cool and add 20 ml de-ionised water.
- Start up the distillation/titration apparatus and perform the pH calibration and purging/rinsing steps as outlined in the manual. Program the machine to add 40 ml de-ionised water and enough sodium hydroxide to provide an excess of alkali. This is currently set at 75 ml. Strongly alkaline conditions are indicated by the green-blue digest turning brown to black in colour. If in doubt check after one distillation that the pH was ~11 with pH indicating strips.
- Program the machine for the distillation step to add 60 ml of boric acid and titrate using 0.1N sulphuric acid to a pH of 4.65. Enter the sample numbers and sample weights.
- Attach one of the blank digestion tubes, make sure it is entered as a blank, start the machine and allow the distillation to run and eventually come to a completion and print the result. Make sure that the tube is firmly attached and that no leaks occurred during the distillation.
- Proceed with further blanks. Calculations will be made using the data from the last blank run or using data manually added.
- Proceed with the remaining sample by removing the old tube, clearing up any spills and attaching a new tube.
- When all the tubes have been distilled the machine may be shut down.

13. Data Acceptance and Quality Control

Each sample should be run in duplicate and each batch of 24 samples should contain two blanks and at least one standard sample for each type of material being analysed. Three standard soils are currently being tested. There is a choice of several standard plant tissues (tomato, geranium, and palm etc.). One standard manure sample is available. The run is deemed in control when the standard sample results are within 2 standard deviations of their respective means. Individual sample results are accepted if the duplicates are within 5% of the mean value or within 50 ppm at low values. Blank values should be consistent with historical means for their titration values.

14. Calculation and Presentation of Results

Results are calculated automatically and printed out on a tape which should be attached to the work sheet. Results should be quoted for soils in % to 3 decimal places and for plant tissue and manure in % to 2 decimal places. Manual calculations may be made using the following:

$$\boxed{\%N = \frac{(a - b)}{s} \times N \times 0.014 \times 100 \times mcf}$$

Where:

a	=	ml of H_2SO_4 required for titration of sample
b	=	ml of H_2SO_4 required for titration of blank
s	=	air-dry sample weight in grams
N	=	Normality of H_2SO_4 (here 0.1 N)
0.014	=	meq weight of nitrogen in g
mcf	=	moisture correction factor (if used)

Note: 1 % = 10,000 ppm or ug/g

15. Other References

Bremner, J.M. 1965. Total Nitrogen, pages 1149-1178 in C.A. Black Ed., Methods of Soil Analysis, Agronomy No. 9, American Society of Agronomy, Madison, WI.

Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen - total, pages 595-624 in A.L. Page Ed., Methods of Soil Analysis, 2nd ed. Agronomy No. 9, American Society of Agronomy, Madison, WI.

2.) Organic Carbon (Standard Walkey-Black Method)

1. Reference Method

Nelson D.W and Sommers L.E. 1982. Total Carbon. Organic Carbon and Organic Matter, pages 539-579 in A.L. Page et. al. Methods of Soil Analysis Part 2, 2nd ed., Agronomy No. 9, American Society of Agronomy, Madison, WI.

2. Introduction

Measurement of organic carbon content gives a way of estimating the organic matter content of the soil. The amount and type of organic matter can be directly related to moisture holding capacity, the reserves of exchangeable cations, storage and supply of plant nutrients such as nitrogen and phosphorus, and the maintenance of stable soil structure and aeration.

3. Scope

To measure the content of organic carbon in soil to give an estimate of organic matter content and the C:N ratio. The method is suited to the measurement of the organic carbon content of all soils except those classified as organic (e.g. ~>20% organic matter). The method can also be adapted to measure the organic carbon content of humus extracts and the soluble carbon content of soil water using a colourimetric variation which is described in a separate SOP.

4. Principle

Organic matter is oxidised with an excess of a concentrated oxidising mixture containing sulphuric acid and potassium dichromate. The amount of unused $K_2Cr_2O_7$ is determined by titration with ferrous ammonium sulphate or ferrous sulphate using a diphenylamine indicator to detect the first appearance of unoxidized ferrous iron. Phosphoric acid is added to form a complex with ferric iron providing a sharper colour change of indicator.

5. Method validation

By sample exchange through the Agri Laboratories Association of Southern Africa (ALASA).

6. Supporting Documentation

SOP Soil-100 Sample Registration and Documentation
SOP Soil-101 Sample Preparation

7. Interferences and Other Considerations

Inorganic constituents that are in a reduced state will also be oxidised by the dichromate and cause the result to be too high. The sample weigh must be adjusted so that between about 35 to 75% of the dichromate is used. The amount taken normally varies between 0.25 g to 2.5 g for surface soils and 2 g to 10 g for sub-surface soils or soils with very low organic matter content. Note that in the method it is assumed that only 77% of the organic matter is oxidised and a factor is included in the calculations to take this into account. The efficiency of oxidation will vary between different soils and this introduces an error.

8. Sample Requirements

Soils should be aid-dried and ground to pass a 2 mm sieve. Samples may be stored at low humidity indefinitely. More consistent results may be obtained if a small sub-sample is ground to 60 mesh (~ < 0.4 mm).

9. Equipment and Supplies

- Burettes, 500 ml Erlenmeyer flasks
- Reagent dispensers 10 ml and 20 ml.

10. Reagents

- *Potassium dichromate solution, 1 N:* Dissolve 49.04 g $K_2Cr_2O_7$ (dried at 105 °C) in distilled water in a 1 litre volumetric flask and make to volume with distilled water ; store in a glass stoppered bottle.
- *Concentrated sulphuric acid (Sp. Gr. 1.84) 98 % (w/w).*
- *Concentrated orthophosphoric acid (H_3PO_4) (Sp. Gr. 1.75).*
- *Barium diphenylamine sulphonate indicator, 0.16 %:* Dissolve 0.16 g of barium diphenylamine sulphonate in 100 ml of distilled water.
- *Ferrous sulphate solution 0.5 N :* Dissolve 139 g $FeSO_4.7H_2O$ in 750ml of water, add 20 ml concentrated H_2 SO_4, transfer to a 1 litre volumetric flask and make to volume with distilled water.
- *Or Mohr's salt ($Fe(NH_4)_2(SO_4).6H_2O$):* Dissolve 196.10 g of pure ferrous ammonium sulphate in 800ml of distilled water in a 1 litre volumetric flask, add 20 ml concentrated H_2SO_4 and make to volume with distilled water.

11. Safety and Special Precautions

Care should be taken in handling the sulphuric acid-potassium dichromate mixture.

12. Test Procedure

- Weigh between 0.25 and 5.0 g of air-dry soil (<2 mm) and transfer to a 500 ml Erlenmeyer flask. During the reaction with ferrous sulphate, it is necessary that the drop in the burette reading should be between 7 and 15 ml. All samples in which less than 7 ml or greater than 15 ml of ferrous sulphate 0.5 N were consumed should be repeated.
- Add 10ml 1 N $K_2Cr_2O_7$ solution from a dispenser. Include two blanks (Erlenmeyer flasks without soil) to standardise the ferrous sulphate solution.
- Carefully add 20 ml concentrated H_2SO_4 with measuring cylinder in the fume cupboard and swirl the flask and allow to stand on an asbestos or cork pad for 30 minutes.
- Then add 200 ml distilled water and allow to cool.
- Add 10 ml conc. Orthophosphoric acid and just before titration, add 0.5 ml of barium diphenylamine sulphonate indicator.
- Titrate with 0.5 N ferrous sulphate solution the colour changes to purple or blue then add ferrous sulphate solution drop by drop until the colour flashes to green then continue to a light green end point. The end-point is easily overshot, in that case add 0.50 ml of the dichromate solution and titrate again dropwise (change calculation accordingly).
- Carry out a blank titration the same way as for the sample.

13. Quality Control and Data Acceptance

Within each run of 24 samples or less include two blanks, one set of duplicates and one standard soil. The results are accepted if the result for the standard soil is within two standard deviations of the mean and the duplicates are within 5% or 0.05% for samples with very low carbon contents.

14. Calculation and Presentation of Results

A calculation program is available in SUNRISE.XLS

In this method it is assumed that about 77 percent of the C is oxidised by potassium dichromate, so a correction factor of 100/77 = 1.33 is used in the calculation.

$$\boxed{\%C = N \times \frac{V_1 - V_2}{s} \times 0.39 \times mcf}$$

Where:

N = normality of ferrous sulphate solution (from blank titration).
V_1 = ml ferrous sulphate solution used for blank.
V_2 = ml ferrous sulphate solution used for sample.
S = weight of dry-air sample in gram
0.39 = $3 \times 10^3 \times 100\,\% \times 1.3$ (3 = equivalent weight of carbon).
mcf = moisture correction factor (if used).

Conversion of % carbon to % organic matter is done with the following empirical factor of 1.724:

$$\boxed{\%\ \text{Organic matter} = 1.724 \times \%\ \text{carbon}}$$

15. Other References

Soil Science Society of South Africa. 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes, pages 34-1 to 34-2.
Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37:29-38.

3.) Available Phosphorus in Soil (Olsen Method)

1. Reference Methods

Shoenau, J.J. and Karamanos, R.E. 1993. Sodium Bicarbonate-Extractable P, K and N, pages 51-58 in Soil Sampling and Methods of Analysis, M.E. Carter Ed., Canadian Society of Soil Science, Lewis Publishers.
Soil Science Society of South Africa. 1990. Pages 24-1 to 24-3 in Handbook of Standard Soil Testing Methods for Advisory Purposes, SSSSA, Pretoria, RSA.

2. Introduction

Phosphorus is an essential element for plant nutrition and prediction of the availability of phosphorus in the soil is vital for optimum crop yield. A number of methods have been proposed for the determination of available phosphorus which appear to give rational estimates of the plant available phosphorus under different soil conditions. The Olsen Method is described here is recommended for alkaline to neutral soils.

3. Scope

The extraction method is recommended for neutral to alkaline soils. As long as criteria for pH control are in place, the colourimetric method can be used to measure phosphate-P in other soil extracts, water samples and acidic extracts or digests of plant tissue and manure.

4. Principle

The sample is extracted with a 0.5M sodium bicarbonate solution at pH 8.5. Phosphate in the extract is determined colourimetrically by the blue ammonium molybdate method of Murphy and Riley using ascorbic acid as reducing agent.

5. Method Validation

By direct reference to results of ALASA soil samples. See ALASA files.

6. Supporting Documentation

SOP Soil-100 Sample Reception and Documentation
SOP Soil-101 Sample Preparation
SOP Plant-100 Dry Ashing of Plant Leaf Tissue.

7. Sample Requirements

Soils should be air-dried and ground to pass a 2mm mesh sieve. Samples may be stored at low humidity with little change in available-P. Extractable phosphate may be less stable under hot moist storage condition.

8. Interferences and Other Considerations

None identified.

9. Equipment and Supplies

- Spectrophotometer suitable for measurement at 882 nm.
- Extraction flasks
- Reciprocating shaking machine
- Funnel racks, filter funnels and collecting containers such as plastic or glass test tubes (16x120 mm)
- Whatman No. 40 or 42 filter paper, volumetric flasks and pipettes

10. Reagents

- *Sodium Bicarbonate Solution, 0.5 M, pH 8.5 (extracting solution):* Dissolve 420 g $NaHCO_3$ in distilled water and make to 10 litres. Adjust to pH 8.5 by adding 50% NaOH (10 g/20 ml). Check and readjust the pH if the extracting solution has been stored for some time.
- *Sulphuric Acid, 4 M:* Slowly add 56 ml conc. H_2SO_4 (96 %) to about 150 ml of cold distilled water in a 250 ml volumetric flask make up to 250 ml with distilled water.
- *p-nitrophenol indicator:* Dissolve 0.1 g of p-nitrophenol in 100 ml ethanol.
- *Stock Colour Reagent;* Dissolve 12g of $(NH_4)_6Mo_7O_{24}.4H_2O$ in 250 ml of de-ionised water. Dissolve 0.291 g of potassium antimony tartrate ($KSbOC_4H_4O_6$) in de-ionised water and make to 100 ml. Carefully add, with stirring, 148 ml of concentrated sulphuric acid to 1000 ml of de-ionised water. Add the ammonium molybdate solution and then the potassium antimony tartrate solution to the sulphuric acid and make up to 2000 ml. Store at room temperature. Replace every three months.
- *Working Colour Reagent (made up daily):* Dissolve 1.056 g of ascorbic acid in 200 ml of the stock colour reagent. If the reagent has any blue colour discard and make up again.
- *Washed activated charcoal:* Shake 100 g of activated charcoal with 200 ml of sodium bicarbonate extracting solution. Filter under slight suction through a Buchner funnel. Rinse with fresh extracting solution until free of phosphate (if needed, test portions of filtrate with colour reagent).Oven dry and store in a wide-mouthed plastic container.
- *Standard Phosphate solution, 100 mg/l P:* Dissolve 0.4390 g KH_2PO_4 (dried at 110 °C for 2 hours in an oven) in distilled water in a 1 litre volumetric flask and make to volume with distilled water. Also diluted standards can be made from commercial standards.
- *Standard Phosphate Solution, 4 mg/l P:* Pipette 10 ml of the 100 mg/l P standard solution into a 250 ml volumetric flask and make to volume with extracting solution.
- *Working Standard series:* Pipette into 100 ml volumetric flasks 0-10-20-30-40-50 ml of the 4 mg/l P standard solution. Make to volume with extracting solution. The standard series is 0, 0.4, 0.8, 1.2, 1.6, 2.0 mg/l. Store refrigerated. New working standards should be prepared each month.

11. Safety and Special Precautions

None identified.

12. Test Procedure

Soil extracts

- Weigh 5 g of air dry < 2 mm soil (accuracy 0.01 g) into a 125 ml flask. Prepare one blank without any soil.
- Add 1 scoop (about 0.3 g) of activated charcoal and 50 ml of extracting solution and shake for 30 minutes.
- Filter through a Whatman No. 40 or 42 filter paper into clean containers (test tubes or flasks).
- Determine the amount of 4M sulphuric acid needed to change 5 ml of extracting solution from pH 8.5 to pH 5 to 5.5 (colour change of p-nitrophenol from yellow to colourless). This should be about 300 uL.
- Pipette 5 ml of the standard series, the blanks and the sample extracts into 25 ml volumetric flasks.
- Add about 10 ml de-ionised water and 1 drop of p-nitrophenol indicator.
- Add the determined amount of sulphuric acid and carefully mix (CO_2 evolution).
- If the solution is still yellow add more acid drop-wise until the yellow colour changes to colourless.
- Add 4 ml of colour reagent and mix well to release any more bubbles of carbon dioxide. Add de-ioinised water to almost fill the bulb of the flask. Shake again and allow the blue colour to develop for about 30 minutes.
- Fill each flask to the mark with de-ionised water and read absorbance on spectrophotometer at 882 nm. Blank the spectrophotometer with the zero standard.
- Samples that give readings greater than the highest standard should be diluted 5 times (1 part in 4 parts of sodium bicarbonate) and the colour developed as previously described.

Water Samples

- Carry out analysis as for soil extracts.

Plant Leaf Digests

- Use 50 to 200 uL of the original nitric acid extract from the ashing process. The pH should be adjusted with a few drops ~ 0.5M sodium hydroxide until the p-nitrophenol indicator turns yellow. Dilute the 4M sulphuric acid and add drops until the indicator just turns colourless again. Proceed with the colour development as outlined for soil extracts. Carry out the same procedure with the "ash blank" and an "ash blank" spiked with phosphate-P to test the recovery.

13. Data Acceptance and Quality Control

In each run of 24 samples include one reagent blanks, one duplicate and one standard soil (P Standard 821834). Check the drift during the colour measurement by inserting the 4th standard between every 12 samples. Quality control samples should fall within two standard deviations as calculated on the control sheets. Duplicates will fall within 5% of each other.

14. Calculation and Presentation of Results

Results may be calculated manually or using the calculation facilities on the spectrophotometer. Whatever the method, a calibration graph of absorbance against P concentration should be prepared and filed with the results.

$$P(\text{ppm or mg/Kg soil}) = (a - b) \times \frac{50}{1000} \times \frac{1000}{s} \times mcf = (a - b) \times \frac{50}{s} \times mcf$$

Where:

a	=	mg/l P in the sample extract
b	=	mg/l P in blank
s	=	sample weight in gram (5 g)
mcf	=	Moisture Correction Factor (if determined)
50	=	ml of extracting solution.

Farm soil results should be quoted to the nearest ppm. Research samples may be quoted to 0.1 ppm.
Conversion factor P_2O_5 = 2.31 x P

15. Other References

Murphy, J. and Riley, J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27: 31-36.
Olsen, S. R., and L. A. Dean. 1965. Phosphorus pages 1044 - 1046, in C. A. Black (ed.). Methods of Soil Analysis, Agronomy No. 9. American Society of Agronomy, Madison, WI.

4.) Light fraction (Standard floatation method)

1. Reference Method

Ingram, J.S.I & Anderson, J.M.. Tropical Soil Biology and Fertility – A handbook of methods. P. 66-68, Soil litter seperation, adapted by Dr. Mike Rowell, Soilslab, Ministry of Agriculture, Wtaer & Rural Development, Windhoek, Namibia

2. Introduction

Measurement of soil litter or light fraction gives a way of estimating the resource inputs for soil organic matter formation of the soil. Soil litter and light fraction are translocated from the soil surface e.g. by soil macrofauna and then transformed into soil organic matter through the function of many different soil organisms. The ratio of transformation of soil litter and light fraction into soil organic matter may be a good indicator for the actual functioning of soil processes.

3. Scope

In this study all material which passes a 2mm sieve and floats in water is defined as light fraction.

4. Sample Requirements

Soils should be air-dried and large clumps ground to pass a 2 mm sieve. Samples may be stored at low humidity indefinitely.

5. Test Procedure

- Sieve sample though 2mm sieve, break up sand particles and put ALL samples into bucket and mix
- Take out 2 250g samples – weight into plastic beakers
- Sieve each beaker of soil through a 250Ym sieve. Transfer sieved material into tall glass beaker
- Fill glass beaker with tap water, stir with glass rod, collect floated material onto 106Ym sieve
- Repeat about 10 times until all light fraction is collected
- Transfer into previously weighted crucible
- Dry crucible at 100°C overnight – reweigh
- Ash crucible at 550°C overnight – reweigh again

6. Calculation and Presentation of Results

The results follow the simple calculation:

Ash-free mass (g) = dry mass – ash mass

If the initial sample was only a fraction of 1kg soil sieved and used in the floatation these results need to be calcuated to the kg.

7. Other References

Smucker, A.J.M., MCBurney, S.L. and Srivastava, 1982. Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system. *Agronomy Journal* **74**: 500-504

Appendix 5

1.) Dry-weight rank programme calculations for March 1998

Slope = 0.56
Intercept = 0

Habitat assessment from 1ha transects (3x100m): Farm=Halt LI=High 01-02/04/1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
sp	5	Schmidtia pappophoroides	79.5	0.43
ia	3	Indigofera auricoma	9.5	0.05
fa	1	unknown	2.7	0.01
tp	3	Tribulus pterophorus	2.6	0.01
ld	1	Limeum dinteria	1.9	0.01
tz	3	Tribulus zeyheri	1.7	0.01
lm	3	Limeum fenestratum	1.1	0.01
eg	1	Euphorbia glanduligera	0.6	0.00
ta	3	Tetragonia arbuscula	0.2	0.00
no	0	bare ground	0.0	0.00

Weighted average quality score 4.49
Total standing crop (g/0.25m²) 0.54

Habitat assessment from 1ha transects (3x100m): Farm=Halt LI=Low 01/04/1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
sp	5	Schmidtia pappophoroides	43.6	0.25
tz	3	Tribulus zeyheri	20.2	0.11
fa	1	unknown	19.9	0.11
lm	3	Limeum fenestratum	7.2	0.04
ld	1	Limeum dinteria	5.8	0.03
eg	1	Euphorbia glanduligera	1.1	0.01
la	3	Limeum aethiopicum	0.8	0.00
tp	3	Tribulus pterophorus	0.7	0.00
ta	3	Tetragonia arbuscula	0.6	0.00
no	0	bare ground	0.0	0.00

Weighted average quality score 3.33
Total standing crop (g/0.25m²) 0.57

Habitat assessment from 1ha transects (3x100m): Farm=Olifantsputs LI=High 27/03/1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	55.0	0.21
fa	1	unknown	20.3	0.08
ci	2	Cassis italica	12.9	0.05
sp	5	Schmidtia pappophoroides	3.2	0.01
za	1	unknown (Sp 14)	3.2	0.01
zc	1	unknown (Sp 17)	2.7	0.01
no	0	bare ground	1.4	0.01
la	3	Limeum aethiopicum	1.3	0.00

Weighted average quality score 2.37
Total standing crop (g/0.25m²) 0.39

Habitat assessment from 1ha transects (3x100m): Farm=Olifansputs LI=Low 24/03/1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	64.0	0.32
sp	5	Schmidtia pappophoroides	13.3	0.07
zd	1	unknown (WLL Sp 8)	7.0	0.04
cp	1	Cardiospermum pechuelii	6.1	0.03
fa	1	unknown	4.5	0.02
zb	1	unknown (Sp 15)	2.4	0.01
za	1	unknown (Sp 14)	2.0	0.01
zc	1	unknown (Sp 17)	0.7	0.00
no	0	bare ground	0.0	0.00

Weighted average quality score 2.81

Total standing crop (g/0.25m²) 0.51

Habitat assessment from 1ha transects (3x100m): Farm=Weerlig LI=High 20/03/1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
sp	5	Schmidtia pappophoroides	64.0	0.46
ep	3	Eragrostis porosa	27.7	0.20
fa	1	unknown	5.9	0.04
as	5	Andropogon schinzii	1.1	0.01
eg	1	Euphorbia glanduligera	0.5	0.00
s8	1	unknown	0.3	0.00
hm	1	Hermania modesta	0.3	0.00
s7	1	unknown	0.3	0.00
no	0	bare ground	0.0	0.00

Weighted average quality score 4.16
Total standing crop (g/0.25m²) 0.72

Habitat assessment from 1ha transects (3x100m): Farm=Weerlig LI=Low 21/03/1998 Eight years independence

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	40.7	0.24
sp	5	Schmidtia pappophoroides	30.5	0.18
zd	1	unknown (WLL Sp 8)	21.0	0.12
fa	1	unknown	2.5	0.01
td	4	Tephrosia dregeana	1.6	0.01
as	5	Andropogon schinzii	1.6	0.01
hm	1	Hermania modesta	1.1	0.01
ze	1	unknown (WLL Sp 7)	1.0	0.01
no	0	bare ground	0.0	0.00

Weighted average quality score 3.15
Total standing crop (g/0.25m²) 0.59

Plot Totals:

Plot	% of Full Area	Standing crop (g/0.25m²)	Weighted Avg. Quality Score
1. Habitat assessment from 1ha tr	16.5	0.54	4.49
2. Habitat assessment from 1ha tr	16.7	0.57	3.33
3. Habitat assessment from 1ha tr	16.7	0.39	2.37
4. Habitat assessment from 1ha tr	16.7	0.51	2.81
5. Habitat assessment from 1ha tr	16.7	0.72	4.16
6. Habitat assessment from 1ha tr	16.7	0.59	3.15
Centroid		0.6	3.38

2.) Dry-weight rank programme calculations for October 1998

Slope = 0.59
Intercept = 0

Habitat assessment from 1ha transects (3x100m): Farm=Halt LI=high 06 October 1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
sp	5	Schmidtia pappophoroides	71.4	0.09
xh	1	unknown (Sp 7)	28.6	0.04
no	0	bare ground	0.0	0.00

Weighted average quality score 3.86
Total standing crop (g/0.25m²) 0.13

Habitat assessment from 1ha transects (3x100m): Farm=Halt LI=low 03 October 1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	52.4	0.22
sp	5	Schmidtia pappophoroides	24.1	0.10
xg	1	unknown (Sp 6)	8.7	0.04

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
xd	1	unknown (Sp 4)	8.4	0.03
xf	1	unknown (Sp 5)	6.5	0.03
no	0	bare ground	0.0	0.00

Weighted average quality score 3.01
Total standing crop (g/0.25m²) 0.42

Habitat assessment from 1ha transects (3x100m): Farm=Olifantputs LI=high 01 October 1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
xa	1	unknown (Sp 1)	90.4	0.17
xb	1	unknown (Sp 2)	6.7	0.01
sp	5	Schmidtia pappophoroides	2.9	0.01
no	0	bare ground	0.0	0.00

Weighted average quality score 1.12
Total standing crop (g/0.25m²) 0.19

Habitat assessment from 1ha transects (3x100m): Farm=Olifantputs LI=low 02 October 1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	47.0	0.15
xh	1	unknown (Sp 7)	36.1	0.11
sp	5	Schmidtia pappophoroides	16.9	0.05
no	0	bare ground	0.0	0.00

Weighted average quality score 2.61
Total standing crop (g/0.25m²) 0.31

Habitat assessment from 1ha transects (3x100m): Farm=Weerlig LI=high 05 October 1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	73.6	0.35
xa	1	unknown (Sp 1)	14.1	0.07
sp	5	Schmidtia pappophoroides	10.2	0.05
xg	1	unknown (Sp 6)	2.1	0.01
no	0	bare ground	0.0	0.00

Weighted average quality score 2.88
Total standing crop (g/0.25m²) 0.48

Habitat assessment from 1ha transects (3x100m): Farm=Weerlig LI=Low 04 October 1998

Sp. Code	Forage Quality	Species Name	% Bulk Contribution	Forage Quantity (g/0.25m²)
ep	3	Eragrostis porosa	42.9	0.24
xa	1	unknown (Sp 1)	23.2	0.13
sp	5	Schmidtia pappophoroides	16.4	0.09
xd	1	unknown (Sp 4)	5.3	0.03
xg	1	unknown (Sp 6)	4.8	0.03
xb	1	unknown (Sp 2)	2.5	0.01
xf	1	unknown (Sp 5)	2.3	0.01
xe	1	unknown (Acacia)	1.4	0.01
xc	1	unknown (Grass 4)	1.3	0.01
no	0	bare ground	0.0	0.00

Weighted average quality score 2.51
Total standing crop (g/0.25m²) 0.56

Plot Totals:

Plot	% of Full Area	Standing crop (g/0.25m²)	Weighted Avg. Quality Score
1. Habitat assessment from 1ha tr	16.5	0.13	3.86
2. Habitat assessment from 1ha tr	16.7	0.42	3.01
3. Habitat assessment from 1ha tr	16.7	0.19	1.12
4. Habitat assessment from 1ha tr	16.7	0.31	2.61
5. Habitat assessment from 1ha tr	16.7	0.48	2.88
6. Habitat assessment from 1ha tr	16.7	0.56	2.51
Centroid		0.3	2.66

Appendix 6: How farmers from Olifantputs, Halt and Weerlig classified the status of the study farms. Field evaluation November 1998

	a) Ernst Nunaeb	b) Albert Giel	c) Dudu Murorua	d) Frederick Nanuseb	e) Jesajas Haraeb
Weerlig Low	• Low intensity site looks better than both study sites at Olifantputs • The trees are in good condition	• Low intensity site is not a good a place for grass cover • with good rainfall the grass will grow high There is no rain but the trees are growing • The area will be improved if it will receive more rainfall	• Lots of old grass stems are left • The area grazed to a very good limit • There are mainly perennial grasses left over • The area is having very little biomass • The soil is clay and sand mixture	• Dry ground • Bare ground, no grass because of too little water • Environment looks good – there are many trees • Mopane trees which are used by animals, look good-green trees • Tracks of domestic animals much more than that of wild animals • River with no evidence of water • Bare roots wherever one looks	• The area has low quantity of grass probably because of clay soil • This area is better than the other sites
Weerlig High	• High intensity site at Weerlig is in a very poor condition. • The trees are dry and they are in a very bad condition	• This place is not good. All the vegetation appears dry except for the Mopane trees • The surface soil is hard and compacted and because of this it is difficult for water infiltration. • If the rain comes the	• The grass stems are drier than at the low intensity site but more dense • The soil seems to be more clayish then sandy • Termite activities is abundant • The grass stems are slightly higher	• Trees are lying on the ground • It is hard ground • Ground/land – evidence of semi-desert • no trace of green seedlings sprouting (grass) • Tracks of dangerous wild animals	• The soil of this area seems very hard • Water might find it difficult to penetrate • It is difficult for the trees to obtain enough water because the soil is bare

		soil will become much harder than before	• The area has more shrub trees	(leopard)	
Olifantputs Low	• Veld condition looks poor • Trees look better • The rain moves to the middle (is hampered in the area)	• No grass but green Mopane trees • Lack of rain in the area can cause animals to die • Weerlig has got more grass in some other areas compared to this site • The rain is influenced by the mountains • There are musk drawer	• The area is overgrazed (grazed beyond its limit) • The stems and roots of grasses are visible • The soil is sandy rather then loamy and contains rocks • Bare spaces in between the grasses • Little biomass • Rocky areas looks bare • Spaces between trees much smaller (are closer to each others)	• Dry to driest • Mopane trees look good • Hard soil • "!Awa-ti"/"Staal bosies" has white flowers • Area shows traces of living organisms	• It's a poor habitat condition and the veld looks very dry • No grass
Olifantputs High	• This site looks very good • The trees on the surrounding mountains are green • After the small shower of rain grass seedling start sprouting • Water flows downward from the surrounding	• This site look the same as the first one (OPL) • The Mopane trees at this site look green • If the area receives more rainfall the grass will grow • The trees on the surrounding mountains are green • There are green	• This is worse than the previous sites • There is no biomass at all • The area is trampled • The area has received rainfall 10 days ago • The spaces in between trees are very big • There are many	• Mopane trees are green • Many tracks of animals-grass is trampled • "Staal bosies" has white leaves • There are birds singing in the trees • The soil is fertile but there is too little rain	• This site is much better than the low site • The area looks green • It has good soil which will improve more after a good rainfall • The site has more green trees compared with the

	mountains to inundated low lying areas	plants • But this place is not the same as Weerlig, it has no grass.	rocky areas • There is no grass, only Acacia bushes		other site (OPL) • This area look very different from the other sites because here there is few grass • This site has got sandy soil but Weerlig farm has bare soil
Halt Low	• The grass and tree stems look good and if the rain comes they will start to grow very well • The site is closer to the mountain which attracts rains. • The grasses are plenty and in good condition • The perennial grass Schmidtia is the dominant species in the area • These grasses are good for the livestock • The soil seems very fertile because of much litter	• The site has grass and green trees • If the site receive enough rain more grass will grow • If the sprouting seedlings and the medium sized grasses get enough water they will increase in number	• Very good biomass cover • Very good grass cover (higher then all other places) • The spaces between trees also very good • Well developed shrubs and trees • The soil is more sandy than loamy	• Bare ground-there are no traces of grass or living organisms • Infertile soil as a result of trampling by cattle • Mopane trees show evidence of green • Different soils on the farm, only a shortage of water	• This site still has enough palatable grasses • Needs only enough rain so that the plants can recover very well • The soil is of good qualities (still in good condition) • The trees are also in good condition
Halt High	No information	• This site is almost like the other two	• The area is very trampled	• Old grass (litter) still lying on the ground	No information

		farms • The area look dry and some trees are even dying • There are no grasses, • it looks like a cleared field (e.g. soccer field)	• The soil is very sandy • There is no biomass • Perennial grass stems are not visible due to covering of sand • The spaces between the trees are very big • There are no shrubs of any kind present	• Can see seeds of grass which has been trampled by cattle • Ants which eat grass can be seen • There are trees in the environment • Holes dug by small animals • Porcupine tracks in veld	

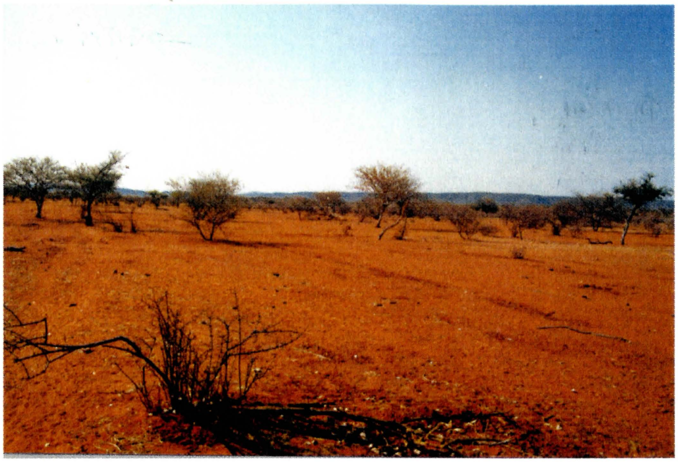
Appendix 7

Fixed point photographs from the six study sites

1. Olifantputs near OPL in March 1997. View across the gardens to the village.

2. OPH – October 1997

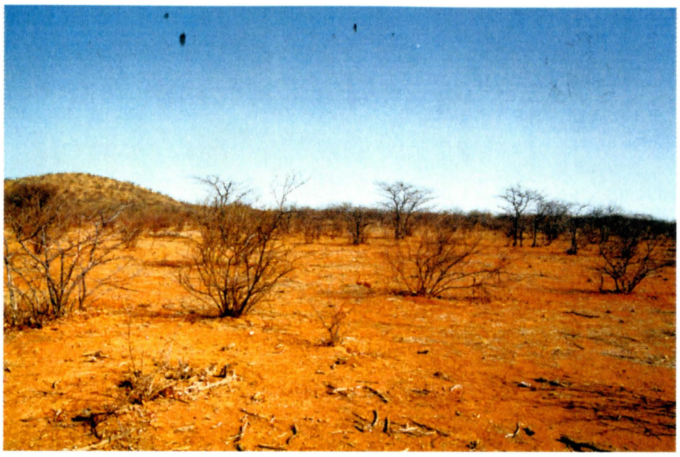
3. OPH – March 1998



4. OPH – October 1998

5. OPL – October 1997

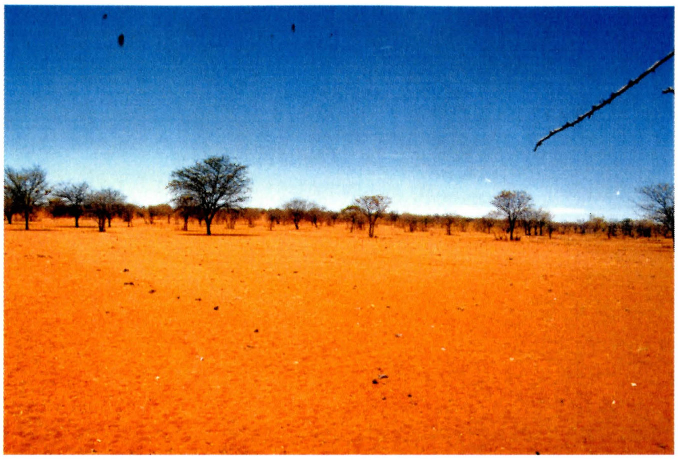
6. OPL – March 1998



7. OPL – October 1998

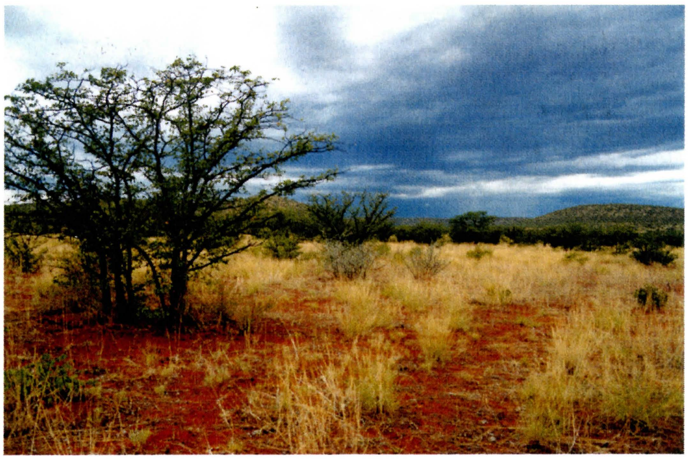
8. HAH – October 1997

9. HAH – March 1998



10. HAH – October 1998

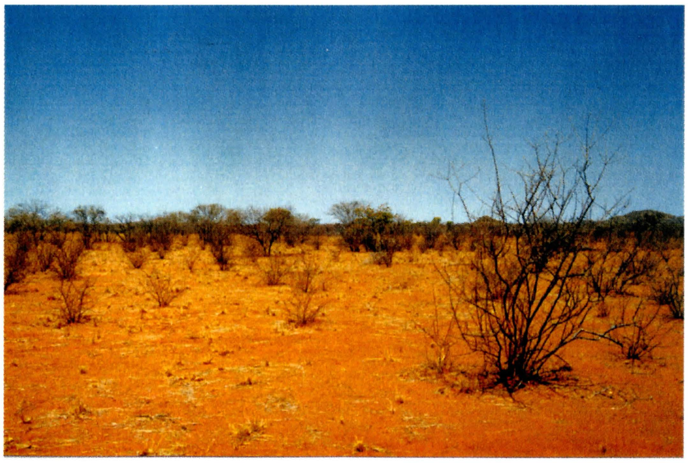
11. HAL – October 1997



12. HAL – March 1998

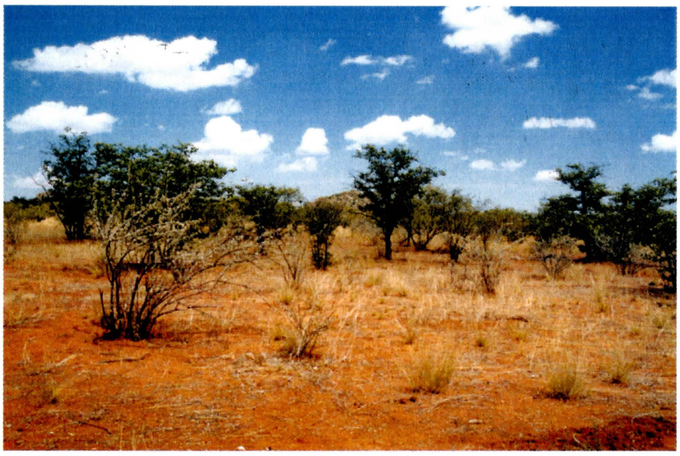
13. HAL – October 1998

14. WLH – March 1998



15. WLH – October 1998

16. WLL – October 1997



17. WLL – March 1998

18. WLL – October 1998

Appendix 8

Statistical reports: Analysis of Variance – Kruskal Wallis

SOILS

A. March 1998

1.) Nitrogen

Tests of Assumptions Section

Assumption	**Test Value**	**Prob Level**	**Decision (0.05)**
Skewness Normality of Residuals	2.7283	0.006365	Reject
Kurtosis Normality of Residuals	2.0668	0.038754	Reject
Omnibus Normality of Residuals	11.7154	0.002858	Reject
Modified-Levene Equal-Variance Test	1.3904	0.242509	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	**DF**	**Chi-Square (H)**	**Prob Level**	**Decision(0.05)**
Not Corrected for Ties	5	29.8782	0.000016	Reject Ho
Corrected for Ties	5	30.58873	0.000011	Reject Ho

Number Sets of Ties	8
Multiplicity Factor	5016

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	2.9214	4.2169	0.3304	3.3035	3.3359
HAH	2.9214	0.0000	1.2955	2.5910	0.3822	0.4146
OPL	4.2169	1.2955	0.0000	3.8865	0.9133	0.8809
OPH	0.3304	2.5910	3.8865	0.0000	2.9732	3.0056
WLL	3.3035	0.3822	0.9133	2.9732	0.0000	0.0324
WLH	3.3359	0.4146	0.8809	3.0056	0.0324	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

2.) Organic Carbon

Tests of Assumptions Section

Assumption	**Test Value**	**Prob Level**	**Decision (0.05)**
Skewness Normality of Residuals	2.5803	0.009871	Reject
Kurtosis Normality of Residuals	1.7611	0.078213	Accept
Omnibus Normality of Residuals	9.7596	0.007598	Reject
Modified-Levene Equal-Variance Test	2.6017	0.035208	Reject

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	**DF**	**Chi-Square (H)**	**Prob Level**	**Decision(0.05)**
Not Corrected for Ties	5	43.71656	0.000000	Reject Ho
Corrected for Ties	5	43.98543	0.000000	Reject Ho

Number Sets of Ties	14
Multiplicity Factor	1320

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.8284	2.5622	2.4915	4.8739	5.2335
HAH	0.8284	0.0000	1.7338	1.6632	4.0455	4.4051

OPL	2.5622	1.7338	0.0000	0.0706	2.3117	2.6713
OPH	2.4915	1.6632	0.0706	0.0000	2.3824	2.7420
WLL	4.8739	4.0455	2.3117	2.3824	0.0000	0.3596
WLH	5.2335	4.4051	2.6713	2.7420	0.3596	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

3.) Phosphorus

Tests of Assumptions Section

Assumption	**Test Value**	**Prob Level**	**Decision (0.05)**
Skewness Normality of Residuals	5.9791	0.000000	Reject
Kurtosis Normality of Residuals	4.8553	0.000001	Reject
Omnibus Normality of Residuals	59.3232	0.000000	Reject
Modified-Levene Equal-Variance Test	0.7410	0.596143	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	**DF**	**Chi-Square (H)**	**Prob Level**	**Decision(0.05)**
Not Corrected for Ties	5	8.885246	0.113730	Accept Ho
Corrected for Ties	5	8.891422	0.113474	Accept Ho
Number Sets of Ties	7			
Multiplicity Factor	150			

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.1217	0.2049	0.3586	2.0365	1.9276
HAH	0.1217	0.0000	0.0833	0.2370	1.9148	1.8059
OPL	0.2049	0.0833	0.0000	0.1537	1.8316	1.7227
OPH	0.3586	0.2370	0.1537	0.0000	1.6779	1.5690
WLL	2.0365	1.9148	1.8316	1.6779	0.0000	0.1089
WLH	1.9276	1.8059	1.7227	1.5690	0.1089	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

4.) C:N

Tests of Assumptions Section

Assumption	**Test Value**	**Prob Level**	**Decision (0.05)**
Skewness Normality of Residuals	0.7683	0.442310	Accept
Kurtosis Normality of Residuals	1.2138	0.224841	Accept
Omnibus Normality of Residuals	2.0635	0.356386	Accept
Modified-Levene Equal-Variance Test	4.7452	0.001151	Reject

Expected Mean Squares Section

Source Term	**DF**	**Term Fixed?**	**Denominator Term**	**Expected Mean Square**
A (...)	5	Yes	S(A)	S+sA
S(A)	54	No		S(A)

Note: Expected Mean Squares are for the balanced cell-frequency case.

Analysis of Variance Table

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=(0.05)
A (...)	5	6425.095	1285.019	10.82	0.000000*	0.999976
S(A)	54	6411.828	118.7376			
Total (Adjusted)	59	12836.92				
Total	60					

* Term significant at alpha = 0.05

Scheffe's Multiple-Comparison Test

Response: HAL,HAH,OPL,OPH,WLL,WLH
Term A:

Alpha=0.050 Error Term=S(A) DF=54 MSE=118.7376 Critical Value=2.092245

Group	Count	Mean	Different From Groups
OPL	10	22.99286	WLL, WLH, HAL, OPH
HAH	10	23.4369	WLL, WLH, HAL, OPH
WLL	10	35.8131	OPL, HAH, OPH
WLH	10	37.71587	OPL, HAH, OPH
HAL	10	40.16667	OPL, HAH, OPH
OPH	10	53.21429	OPL, HAH, WLL, WLH, HAL

5.) LF

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)
Skewness Normality of Residuals	4.1215	0.000038	Reject
Kurtosis Normality of Residuals	3.9766	0.000070	Reject
Omnibus Normality of Residuals	32.7998	0.000000	Reject
Modified-Levene Equal-Variance Test	1.2920	0.281009	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	5.548033	0.352708	Accept Ho
Corrected for Ties	5	5.548187	0.352691	Accept Ho

Number Sets of Ties	1
Multiplicity Factor	6

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.9347	0.1280	1.3828	0.7362	0.2113
HAH	0.9347	0.0000	0.8066	0.4481	1.6709	0.7234
OPL	0.1280	0.8066	0.0000	1.2548	0.8643	0.0832
OPH	1.3828	0.4481	1.2548	0.0000	2.1190	1.1716
WLL	0.7362	1.6709	0.8643	2.1190	0.0000	0.9475
WLH	0.2113	0.7234	0.0832	1.1716	0.9475	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

6.) C:LF

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)
Skewness Normality of Residuals	2.9951	0.002744	Reject
Kurtosis Normality of Residuals	1.3948	0.163074	Accept
Omnibus Normality of Residuals	10.9159	0.004262	Reject
Modified-Levene Equal-Variance Test	0.5525	0.735734	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	22.73328	0.000380	Reject Ho
Corrected for Ties	5	22.73391	0.000379	Reject Ho

Number Sets of Ties	1
Multiplicity Factor	6

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.2561	1.4981	0.5250	3.2842	2.9385
HAH	0.2561	0.0000	1.7541	0.7810	3.5403	3.1946
OPL	1.4981	1.7541	0.0000	0.9731	1.7861	1.4404
OPH	0.5250	0.7810	0.9731	0.0000	2.7592	2.4135
WLL	3.2842	3.5403	1.7861	2.7592	0.0000	0.3457
WLH	2.9385	3.1946	1.4404	2.4135	0.3457	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

B. October 1998

1.) Nitrogen

Tests of Assumptions Section

Assumption	**Test Value**	**Prob Level**	**Decision (0.05)**
Skewness Normality of Residuals	4.8437	0.000001	Reject
Kurtosis Normality of Residuals	3.8817	0.000104	Reject
Omnibus Normality of Residuals	38.5289	0.000000	Reject
Modified-Levene Equal-Variance Test	0.6913	0.632259	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	**DF**	**Chi-Square (H)**	**Prob Level**	**Decision(0.05)**
Not Corrected for Ties	5	28.64815	0.000027	Reject Ho
Corrected for Ties	5	28.65066	0.000027	Reject Ho

Number Sets of Ties	3
Multiplicity Factor	18

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	1.2694	3.1833	3.8147	4.3853	3.4632
HAH	1.2694	0.0000	1.9139	2.5453	3.1497	2.1938
OPL	3.1833	1.9139	0.0000	0.6314	1.2869	0.2799
OPH	3.8147	2.5453	0.6314	0.0000	0.6723	0.3515
WLL	4.3853	3.1497	1.2869	0.6723	0.0000	1.0145
WLH	3.4632	2.1938	0.2799	0.3515	1.0145	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

2.) Organic Carbon

Tests of Assumptions Section

Assumption	**Test Value**	**Prob Level**	**Decision (0.05)**
Skewness Normality of Residuals	2.8675	0.004138	Reject
Kurtosis Normality of Residuals	1.8828	0.059726	Accept
Omnibus Normality of Residuals	11.7673	0.002785	Reject
Modified-Levene Equal-Variance Test	0.8654	0.510536	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	32.18269	0.000005	Reject Ho
Corrected for Ties	5	32.23922	0.000005	Reject Ho

Number Sets of Ties	17
Multiplicity Factor	360

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.3714	3.6550	2.8862	3.5603	2.7233
HAH	0.3714	0.0000	4.0264	3.2576	3.9218	3.0947
OPL	3.6550	4.0264	0.0000	0.7688	0.0028	0.9317
OPH	2.8862	3.2576	0.7688	0.0000	0.7511	0.1629
WLL	3.5603	3.9218	0.0028	0.7511	0.0000	0.9096
WLH	2.7233	3.0947	0.9317	0.1629	0.9096	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

3.) Phosphorus

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)
Skewness Normality of Residuals	4.9198	0.000001	Reject
Kurtosis Normality of Residuals	3.9393	0.000082	Reject
Omnibus Normality of Residuals	39.7220	0.000000	Reject
Modified-Levene Equal-Variance Test	0.9401	0.462819	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	32.59526	0.000005	Reject Ho
Corrected for Ties	5	32.61433	0.000004	Reject Ho

Number Sets of Ties	17
Multiplicity Factor	120

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	2.5394	2.4548	1.5953	4.8490	4.4473
HAH	2.5394	0.0000	0.0846	0.9441	2.3773	1.9078
OPL	2.4548	0.0846	0.0000	0.8595	2.4597	1.9925
OPH	1.5953	0.9441	0.8595	0.0000	3.2963	2.8520
WLL	4.8490	2.3773	2.4597	3.2963	0.0000	0.5204
WLH	4.4473	1.9078	1.9925	2.8520	0.5204	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

4.) C:N

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)
Skewness Normality of Residuals	3.3819	0.000720	Reject
Kurtosis Normality of Residuals	3.0696	0.002143	Reject
Omnibus Normality of Residuals	20.8601	0.000030	Reject
Modified-Levene Equal-Variance Test	0.7546	0.586470	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	10.33424	0.066300	Accept Ho
Corrected for Ties	5	10.33424	0.066300	Accept Ho

Number Sets of Ties	0
Multiplicity Factor	0

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	1.2889	1.7315	0.5859	0.3928	0.9894
HAH	1.2889	0.0000	3.0204	1.8747	1.6473	2.2783
OPL	1.7315	3.0204	0.0000	1.1457	1.2925	0.7421
OPH	0.5859	1.8747	1.1457	0.0000	0.1774	0.4036
WLL	0.3928	1.6473	1.2925	0.1774	0.0000	0.5702
WLH	0.9894	2.2783	0.7421	0.4036	0.5702	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

5.) LF

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)
Skewness Normality of Residuals	2.0365	0.041700	Reject
Kurtosis Normality of Residuals	2.1271	0.033415	Reject
Omnibus Normality of Residuals	8.6718	0.013090	Reject
Modified-Levene Equal-Variance Test	1.3993	0.240307	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	30.70535	0.000011	Reject Ho
Corrected for Ties	5	30.70535	0.000011	Reject Ho

Number Sets of Ties	0
Multiplicity Factor	0

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.2572	2.3402	3.8390	4.0038	1.9084
HAH	0.2572	0.0000	2.2094	3.7990	3.9687	1.7513
OPL	2.3402	2.2094	0.0000	1.5897	1.8183	0.4580
OPH	3.8390	3.7990	1.5897	0.0000	0.2710	2.0477
WLL	4.0038	3.9687	1.8183	0.2710	0.0000	2.2641
WLH	1.9084	1.7513	0.4580	2.0477	2.2641	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352

6.) C:LF

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.05)
Skewness Normality of Residuals	6.2236	0.000000	Reject
Kurtosis Normality of Residuals	4.9791	0.000001	Reject
Omnibus Normality of Residuals	63.5253	0.000000	Reject
Modified-Levene Equal-Variance Test	1.0021	0.426062	Accept

Kruskal-Wallis One-Way Anova on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.05)
Not Corrected for Ties	5	35.99174	0.000001	Reject Ho
Corrected for Ties	5	35.99174	0.000001	Reject Ho

Number Sets of Ties	0
Multiplicity Factor	0

Kruskal-Wallis Multiple-Comparison Z-Value Test

Variable	HAL	HAH	OPL	OPH	WLL	WLH
HAL	0.0000	0.2381	2.8864	3.7882	3.9831	2.2894
HAH	0.2381	0.0000	3.3141	4.2705	4.4582	2.6809
OPL	2.8864	3.3141	0.0000	0.9565	1.2326	0.6332
OPH	3.7882	4.2705	0.9565	0.0000	0.3016	1.5897
WLL	3.9831	4.4582	1.2326	0.3016	0.0000	1.8489
WLH	2.2894	2.6809	0.6332	1.5897	1.8489	0.0000

Regular Test: Medians significantly different if z-value > 1.9600
Bonferroni Test: Medians significantly different if z-value > 2.9352