Bush Encroachment
in Namibia

REPORT ON PHASE 1 OF THE BUSH ENCROACHMENT
RESEARCH, MONITORING AND MANAGEMENT PROJECT

JN de Klerk

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Contents

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List of abbreviations

AEZ	agro-ecological zone
DSS	Decision Support System
EEI	Etosha Ecological Institute
EIA	environmental impact assessment
ETTE	evapotranspiration tree equivalent
FSC	Forest Stewardship Council
GIS	Geographic Information System
ha	hectare
K	potassium
LSU	large stock unit
MAWRD	Ministry of Agriculture, Water and Rural Development
MET	Ministry of Environment and Tourism
Mg	magnesium
N	nitrogen
NAP	National Agricultural Policy
NAU	Namibia Agricultural Union
NDVI	Normalised Difference Vegetation Index
NNFU	Namibia National Farmers' Union
NOAA	National Oceanographic and Atmospheric Agency
NRSC	National Remote Sensing Centre
NWMC	Namibia Woodland Management Council
OCFU	Otjozondjupa Communal Farmers' Union
P	phosphorus
ppm	parts per million
TE	tree equivalent

Executive summary

Bush encroachment is defined as "the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, and a decrease in carrying capacity", causing severe economic losses for Namibia – in both the commercial (freehold) and communal (non-freehold) farming areas.

The phenomenon of bush encroachment in Namibian savannas is seen to be part of the process of desertification.

The main species causing the encroachment problem are *Acacia mellifera* subsp. *detinens* (Black thorn), *Dichrostachys cineria* (Sickle bush), *Terminalia sericea* (Silver terminalia), *Terminalia prunioides* (Purple-pod terminalia), *Acacia erubescens* (Blue thorn), *Acacia reficiens* (False umbrella thorn[1]) and *Colophospermum mopane* (Mopane). *Prosopis* species also occur in high densities, mainly in the Nossob, Olifants and Auob Rivers and are spreading outside the river lines into the Kalahari. Large areas in the southern parts of the country are also affected by mainly *Rhigozum trichotomum* (Three thorn) and even Black thorn.

Phase 1 of the Bush Encroachment Research, Monitoring and Management Project was launched to determine

- the causes of bush encroachment
- the methods most suitable to combat invader bush
- the impact of problem bushes on land productivity, biodiversity and the socio-economic situation of farmers
- the best methods to monitor long-term changes in terms of bush densities and composition
- shortcomings in existing policies and legislation related to the problem, and to propose policy reform, and
- outputs such as creating an awareness about bush encroachment and networking to combat the problem.

The causes of bush encroachment

The causes of bush encroachment are elaborated upon against the background of two important models:

- **Walter's Two-layer Model**, which maintains that, if the grass layer is overutilised, it loses its competitive advantage and can no longer use water and nutrients effectively. This results in a higher water and nutrient infiltration rate into the subsoil. Such a scenario will benefit trees and bushes and allow them to dominate.
- **The State-and-Transition Model**, which recognises the dynamic nature of savanna ecosystems. Savannas are event-driven where rainfall and its variability plays a more important role in vegetation growth (and composition) than the intensity of grazing. It implies, therefore, that bush encroachment is not a permanent phenomenon and a savanna could be changed to its grass-dominated state by favourable management or environmental conditions.

The major factors determining the functioning and dynamics of savannas are the following:

- **PRIMARY DETERMINANTS**, such as **rainfall, soils and nutrients**, are functions of a specific geographical region and are to a certain extent beyond the farmer's control. Rainfall, together with soil moisture balance, has an overwhelming effect on vegetation structure, composition and productivity. Rather than a gradual annual increase in bush numbers, the general view is that woody plants establish in large numbers during certain years, and at varying intervals. Prolonged denudation of soils caused by droughts and grazing, followed by above-average rainfall years with frequent rainfall events, favour mass tree recruitment.
- **SECONDARY DETERMINANTS**: These act within the constraints imposed by primary determinants. They can often be directly modified by management. The exclusion of occasional hot veld fires, the replacement of most of the indigenous browsers and grazers by livestock, injudicious stocking rates, poor rangeland management practices, and artificial water points are regarded as the major causes of bush encroachment.
    - In the past, **high-intensity** fires played a major role in maintaining open savannas. With the introduction of cattle farming, veld fires were suppressed – and this is regarded as a major factor contributing to bush encroachment. Although fires kill tree seedlings and saplings, mature woody plants are seldom killed and most coppicing species are able to regenerate and grow actively.

[1] No differentiation is made between *Acacia reficiens* subsp. *reficiens* and *Acacia luederitzii* var. *luederitzii* (Ross 1979); any reference to *Acacia reficiens* in this document includes both these subspecies. (Full reference is given in the list at the end of Chapter 2.)

High-intensity fires are regarded as a prerequisite for effective burning. These fires depend largely on the amount and structure of the fuel, its moisture content, the prevailing atmospheric humidity, and wind speed. Thus, fire is not effective where high bush densities occur, but it can serve as an effective management tool for modifying the structure of the woody layer and as an aftercare treatment.

- Together with an increase in domestic livestock (grazers) and a **decrease in game numbers (browsers)**, the pressure on the grass layer has increased, the competitive advantage of a vigorous perennial cover has declined, and a more favourable environment for the woody component has been created. Invader bushes have started to produce seeds in abundance and so create opportunities for the establishment of new generations of bush. Each generation has been able to reach maturity and has produced more and more seeds. Although some research findings indicate that the seeds of *Acacia mellifera*, for example, are not transferable from one season to another, for many of the other problem species this is known not to be the case. Because of factors like seasonal dormancy, hard-seededness and the presence of allelochemicals, the seed content in the soils has gradually built up, resulting in several hundred – even several thousand – seeds per square metre. Furthermore, the absence of ungulates in tandem with the suppression of fire creates favourable conditions for bush encroachment.
- Although relatively **high stocking rates** were applied during the above-average rainfall cycle from 1948 to 1957/8, stocking rates declined dramatically during the ensuing years. Since 1966, the applied stocking rate has never exceeded 10 ha per large stock unit (LSU). Even with stocking rates between 20 and 30 ha per LSU during the 1990s, farmers have not succeeded in reversing the process. It can further be concluded that grazing pressure, even with declining stocking rates, was still inherently too high to utilise the rangelands in a sustainable way and resulted in a form of vicious cycle. Fear has been expressed that the bounds of resilience of the former ecosystem have been exceeded. Only by means of external inputs will the original status of our rangelands be able to be restored.
- There are indications that **other factors beyond farmers' control**, like poor rainy seasons or droughts followed by years with above-average rainfall with frequent rainfall events, have probably made a substantial contribution to the problem of bush thickening. It is reasonable to hypothesise that new generations of bushes established themselves during the first half of the 1960s, after 1973 and again after the 1980s. These periods represent a few dry years followed by a few good rainy seasons. It should be emphasised that the natural rangelands have deteriorated to such an extent that the process has not been reversed – even with much lower stocking rates.
- **Other determinants influencing the composition and structure of savanna vegetation** are comprehensively discussed. These include the interaction and competition between trees, bushes and grass, the impact of temperature on bush encroachment and the mechanisms of seed distribution.
- **Other important restraining factors** seemingly beyond farmers' control relate to the socio-economic policy framework in which they perform their task. This framework includes factors such as –
  - the restriction of animal movement and the marketing of animals as a result of foot-and-mouth in the early 1960s, preventing farmers from timeous destocking
  - poor marketing policies during the late 1960s to the end of the 1970s, which delayed the issuing of permits for cattle to be slaughtered and therefore the off-take of marketable cattle
  - fire policy and legislation: the Soil Conservation Act, 1949 (No. 6 of 1949; implemented in then SWA in 1952; as amended in 1969) prohibited the burning of veld and only applied in commercial farming areas), and
  - drought subsidies, which encouraged farmers to keep more animals during periods of grazing scarcity.

The impact of bush encroachment

The impact of bush encroachment on land productivity, biodiversity and the farmers' socio-economic welfare was studied. The following findings are of importance:

- Bush encroachment on approximately 26 million ha of woodland savannas in Namibia resulted in a loss of land productivity of as much as 100% or more. This means that the carrying capacity declined from 1 LSU per 10 ha to 1 LSU per 20 or 30 ha, for example. In the entire bush-affected area, only Okombahe can be regarded as low-density in respect of bush encroachment. Epikuro, Grootfontein, Okahandja, Okakarara, Okonjatu, Otavi, Otjinene, Otjituuo, Otjiwarongo, Outjo, Tsumeb and Windhoek fall in the "very high" density areas, while densities in the remaining districts vary from high to medium. In this respect it is important to note that present cattle numbers in the commercial farming areas represent only 36% of what they were in 1959. The concomitant economic loss of more than N$700 million per annum has had a direct impact on the livelihoods of 65,000 households in communal areas and 6,283 commercial farmers and their employees. Especially in communal areas, bush encroachment exacerbates prevailing problems like lower food security and nutrition, increased efforts to maintain living standards, and higher demands on wages and income transfers. Losses related to increased artificial drought events caused by bush encroachment are not included in the loss figure calculated above, but they have a drastic negative impact on the economy. Namibia, being a drought-prone country, cannot afford an artificial increase in vulnerability to droughts.

- Bush encroachment also impacts adversely on biodiversity, water-use efficiency and underground water tables, thereby contributing to the process of desertification. Surveys done in bush-affected areas show a highly significant negative correlation between increasing problem bush densities and the occurrence of a perennial and total grass cover. Furthermore, although bush densities in commercial areas are higher compared with communal areas, the high number of bushes smaller than 0.5 m in communal areas is a matter of great concern since they are the source of future bush thickening.
- A large number of mammals, bird species, reptiles and anthropoids are associated with problem bush species in one way or another and would be affected positively or negatively by bush control measures, depending on the method implemented. Bush thickening is seen as a major threat to the botanical diversity in Namibia and may even change the mammalian diversity, with the net effect likely to be negative. However, with the right densities and a sound mix of trees, bushes and shrubs, a more favourable sub-habitat is established, resulting in a greater variety of herbaceous species. Farmers should, therefore, include biodiversity considerations in their bush-thinning programmes.
- With respect to the large amounts of water intercepted by invader bushes it is reasonable to conclude that the underground water table is being negatively affected by bush encroachment through increased evapotranspiration, water run-off and less infiltration to subsoils.
- The value of the various bush species as a source of fodder is recognised, especially during times of drought, and many communal farmers rely heavily on this source when grazing is scarce. The complete removal of bushes, therefore, should not be considered.
- The huge potential for increased carrying capacity and productivity implies that the introduction of effective bush control programmes at a national level will simultaneously make an important contribution to the objectives of the land reform programme in Namibia. Once the encroachment problem is solved, many of the present land units that are uneconomical to manage can provide much higher returns and, consequently, create room for more farmers. In communal areas, more people can earn their living from the land, and those that reside there will benefit in terms of increased income and quality of life. At the same time, the high national unemployment rate could be addressed through labour-intensive bush control techniques.

The magnitude and occurrence of invader species

The magnitude and occurrence of invader species together with their interaction with the herbaceous layer were also investigated. The main findings are summarised as follows:

- Except for Omaruru, all the non-treated sites in commercial farming districts showed highly significant amounts of (a) total problem bushes, (b) thorny problem bushes, (c) non-thorny problem bushes, and (d) total bushes and trees, compared with communal farming areas in the east and west of the country. Even if commercial sites are compared with sites in eastern communal areas, the difference in the prevalence of problem bush is still highly significant. The fact that veld fires were suppressed and controlled for a much longer period in the commercial area seems to be one of the main reasons for this difference. Total bush densities in more than 80% of the affected area varied between 2,000 and 4,000 bushes per hectare, with the Tsumeb district being the worst off.
- There is no pattern showing a clear relationship between agro-ecological zones (AEZs) and bush density. Most of the AEZs are interspersed with problem bush densities varying from low to very high. The trend, however, is that 77% of the "very high" and 52% of the "high" density sites lie north-east of the Otjiwarongo-Gobabis axis, while 58% of the "medium" and 58% of the "low" density sites lie south-west of this same axis.
- Treated areas showed an alarming increase in total problem bush numbers for the height classes <0.5 m and 0.5–4.0 m. This phenomenon clearly illustrates how important follow-up treatments are.
- With an increase in the number of total problem bushes, thorny problem bushes, non-thorny problem bushes, and total bushes and trees, a highly significant decline in the percentage of perennial grasses as well as total grass cover (perennial plus annual) was found for each of these groups.

- For sites with more than 600 thorny bushes per hectare, the percentage of perennial grasses was highly significantly less than sites with less than 600 bushes per hectare.
- There was a significant positive correlation between the percentage of bare areas and the percentage of forbs with problem bushes.
- The survey showed that natural mortalities of invader bush varied between 2–3% and do not seem to pose the long-term solution some had hoped for.
- When the occurrence of invader bush is considered against the various vegetation units in the study area, only the Acacia Hilly Shrubland and Inselbergs are least encroached, with 15% of plots in either the "very high" or "high" density category. The Tamboti Woodlands, although represented by only 18 sampled plots/sites, show the highest degree of encroachment, with 83% of plots in the "very high" density category and a further 11% in the "high" density category. The Loam and Turf Karstveld, the Dolomite Karstveld, and the Tree Savanna and Woodlands all show a very high degree of encroachment, with more than 75% of sampled plots in either the "very high" or "high" density category. The Camelthorn Savanna has 62% of plots in the two highest density categories. The remaining vegetation units show intermediate levels of bush encroachment.
- There is a strong trend of increasing bush density in the four categories ("very high", "high", "medium" and "low") with increasing rainfall. The "very high density" plots predominantly occur in the 400–450 mm interval, with a considerable number in the 350–400 and 450–500 mm intervals. One set of analyses showed that rainfall could contribute between 80–85% to the density distribution of bush on a macro-scale. The conclusion is that rainfall has a significant effect on bush density, but is not the only contributing factor.
- *Acacia mellifera* is clearly the most widely distributed encroacher species, with *Dichrostachys cinerea* in a strong second place.
- *Colophospermum mopane* is concentrated towards the north-west, while *Terminalia prunioides* is found mainly in the Otavi–Tsumeb–Grootfontein–Mururani area. *Terminalia sericea* is found overwhelmingly (95% of problem bush plots) east of an axis through Omitara and Otavi.
- It is interesting to note that each of the vegetation units is characterised by a specific dominant encroacher, namely –
    - *Acacia mellifera* dominates in the Highland Shrubland, Thornbush Shrubland and Camelthorn Savanna
    - *Dichrostachys cinerea* dominates in the Burkea–Baikiaea Woodlands, the Dolomite Karstveld and the Tamboti Woodlands, while showing a strong presence in the Loam and Turf Karstveld, the Shrubland of the Central Escarpment, the Thornbush Shrubland and the Tree Savanna and Woodlands
    - *Terminalia prunioides* is the dominant species in the Loam and Turf Karstveld, while showing a strong presence in the Dolomite Karstveld
    - *Terminalia sericea* is significant in the Burkea–Baikiaea Woodlands, Camelthorn Savanna, and the Tree Savanna and Woodlands
    - *Acacia reficiens* dominates in the Acacia Hilly Shrubland and Inselbergs, and the Shrubland of the Central Escarpment
    - *Dichrostachys cinerea* is widely distributed north of the Windhoek–Gobabis road (91% of problem bush plots), and
    - *Acacia reficiens* is distributed widely and occurs further west than any of the other encroachers.
- The occurrence of the six main encroacher species shows a strong correlation with rainfall. *Acacia reficiens* dominates the lower rainfall plots (150–250 mm) and shares dominance with *Acacia mellifera* in the 250–300 mm range. In the 300–450 mm range, *Acacia mellifera* takes over dominance. *Dichrostachys cinerea* appears at the 250–300 mm range, and increases steadily in importance up to 600 mm, which is the maximum rainfall of the study area. *Terminalia sericea* peaks around 400–450 mm, while *Terminalia prunioides* forms a constant percentage of problem bush in the 450–600 mm range.

Policies and legislation

For many years we have thought that problems in the agricultural sector should and could be counteracted through scientific and technological solutions alone. Today we realise that the degradation process, with bush encroachment as a prominent symptom, could also be ascribed to policy failures, mainly in the socio-economic field.

This problem has already been acknowledged by Government and is reflected in several new policies and laws, namely the National Agricultural Policy, the National Drought Policy and Strategy, the Soil Conservation

Act, the Namibia Forest Development Policy, and the Poverty Reduction Strategy of Namibia.
Article 95(l) of The Constitution of the Republic of Namibia stipulates that the State is obliged to actively promote and maintain the welfare of the people by, amongst other things, adopting policies which regulate the maintenance of ecosystems, essential ecological processes and the biological diversity of Namibia; and the utilisation of living natural resources on a sustainable basis for the benefit of all Namibians. Addressing the problem of bush encroachment is, therefore, a matter of obligation.

Indeed, Namibia can boast a policy environment that is conducive to resolving the problems it faces in respect of bush encroachment. As far as these problems are concerned, Government has committed itself in terms of direct involvement and support to the agricultural sector. However, the study showed that there are still certain shortcomings in policies and legislation which need some attention. These include the following:

- The formulation of a policy to manage woodlands and savannas needs to be seen as an urgent priority. In this regard, the use and control of veld fires as a management tool should be provided for.
- A woodland management policy and plan should be introduced under the Forestry Act, 2001 (No. 12 of 2001) to incorporate issues pertaining to woodlands that fall outside the current definitions of *forest* and areas classified as forests.
- It is also recommended that policy instruments provide the Namibia Woodland Management Council (NWMC) with statutory powers similar to those of the Meat Board of Namibia and the Namibian Agronomic Board.
- The NWMC should function under the Ministry of Environment and Tourism and mainly be responsible for legal aspects and law enforcement pertaining to harvesting and bush control programmes.
- Extension and research, the implementation of sustainable management practices, marketing, and long-term monitoring should fall under the Ministry of Agriculture, Water and Rural Development.
- There is an urgent need for proper coordination at a very senior level of all strategies and activities relating to natural resource management. For this purpose it is recommended that a national Forum for Integrated Resource Management be established.

Proposal of a long-term research, monitoring and management strategy

The action plans and activities needed to achieve the overall goal to combat bush encroachment are discussed in relation to each of the expected results, namely that –

- environmentally sound principles of bush control are established and adhered to at national and local levels
- guidelines for sustainable harvesting are established
- target species are identified, and
- methods to control invader bush are selected, which include –
  - chemical control with foliar, stem and soil-applied herbicides, and
  - economically viable biological and manually-oriented mechanical methods. These include sound rangeland management practices, labour-intensive methods (stumping/felling) focusing on job creation, and the use of veld fires, stem burning, browsers and bio-agents.

All the recommended methods were subjected to an environmental impact assessment and found to be environmentally friendly when used in a judicious way.

The first operation in regard to combating bush encroachment should be the often drastic one of **thinning** down to some predetermined density. In this regard the following rule of thumb is proposed:

- The number of tree equivalents per hectare should not exceed twice the long-term average rainfall (mm). A *tree equivalent* (TE) is defined as a tree (shrub) of 1.5 m in height. Thus, a 3-m shrub would represent 2 TE, a 4.5-m shrub 3 TE, etc. Land should, therefore, never be completely cleared.

Post-thinning management programmes will also be needed to keep the area open. If such management is neglected, it could lead to even worse problems. Methods recommended for this purpose are discussed in the text in detail.

Where wood harvesting is considered, it is imperative that such operations do not become more important than ecological considerations.

Since most of the methods to combat bush encroachment are expensive, recommendations are also made herein to Government to introduce a number of socio-economic incentives that would encourage farmers to participate in restoring the land, this precious Namibian asset, to a more healthy and ecologically balanced state.

Information management

The project also attended to the establishment of practical information systems. In order to monitor changes in bush density and composition over the long term, certain indicators of pressure, state and response were identified for future use. This report recommends a monitoring system that land-users can employ to measure changes in vegetation on their own farms. The data so obtained will be stored in a database known as the *Mandarax Decision Support System*. It is proposed that this database be managed and maintained by an appropriate institution at national level. This information will serve a very important purpose for decision-makers involved in natural resource management, allowing for decisions to be based on sound knowledge and an understanding of what the indicators have measured.

Access to information regarding environmentally sound methods to carry out bush control programmes seems to be a serious problem, especially in the communal areas. Apart from information obtained from research data, the results originating from a large number of case studies on commercial farms were recorded in a database (Bush Expert), developed under the Bush Encroachment Research, Monitoring and Management Project. The database is designed to allow data to be accessed via the Internet by anyone who wishes to embark on a bush control programme. For those who only have access to a computer with a CD-ROM drive, all the information will be available on CD. The database will be jointly managed and maintained by the two Namibian agricultural unions.

Socio-economic incentives for participating in bush control programmes

Bush encroachment should explicitly be regarded as a community and societal problem and not simply as a private problem for farmers. This means that it should be approached as a problem that Government, farmers, the public and the private sector need to take ownership of. The following recommendations are made for future support to farmers affected by the problem of bush encroachment:

- **An institutional framework:** A future wood industry would benefit from the establishment of a suitable institutional framework. This could be in the form of a cooperative, parastatal or private company responsible for buying and marketing wood products at a national as well as an international level. Government, with the assistance of conor countries should provide strong financial and technical support for the stabilisation and growth of a wood industry. In the long term, a wood industry offers the best option for a sustainable solution of the problem, and will simultaneously create job opportunities for several thousand people. The potential wood available for harvesting varies between 10 and 20 tonnes per hectare in the different areas studied and therefore, if the full potential for charcoal production in Namibia is utilised, a labour force of 44,000 contractors will be needed.
- **Subsidisation of labour-intensive bush control measures:** Almost all the practices recommended herein for controlling bush encroachment are very expensive. The vast majority of farmers, particularly communal farmers, cannot afford to launch bush-clearing programmes on a significant scale. It is of paramount importance, therefore, to consider subsidising labour-intensive bush-clearing methods by means of the following:
  - Subsidies for the manual clearing of 5 million ha of commercial and communal land over a 20-year period will cost Government N$17.5 million per year. Five labourers can clear about 200 ha per annum, which means a potential of employing 6,250 people each year.
  - By subsidising 4% of the prevailing interest rate on loans granted by the Agribank of Namibia to farmers for undertaking bush control programmes, Government will spend N$5.3 million per annum so that 4 million ha can be cleared over a 20-year period.

  Government can expect to retrieve the cost of either form of subsidy within 13–15 years through increased tax revenues.
- **Loans for small-scale entrepreneurs**: The production of poles and droppers would be a viable industry for entrepreneurs, especially in the communal farmlands. However, the prevailing lack of start-up capital for this kind of business should be resolved by means of soft loans for those that can provide a sound business plan.
- **Food-for-Work Programme**: Bush-clearing programmes could also form part of this Government initiative.
- **Drought-mitigating strategy:** Bush-clearing programmes can play a very important role in mitigating the effects of drought because farmers will become less vulnerable and less dependent on financial

support from Government. In this way important aspects of Namibia's Drought Policy and Strategy will be addressed.

Other incentives elaborated upon in the document include addressing the research needs related to a viable wood industry, political assurances, and training programmes for farmers and extension staff.

Conclusion

The study concluded that bush encroachment is the single most important factor hampering sustainable livestock production and improved standards of living in rural areas. Addressing this problem effectively will also offer significant opportunities for employment and settlement, and should be taken up as an integral part of the Second National Development Plan (NDP2) and "Vision 2030".

Chapter 1
Problem statement

1.1 Bush encroachment as an integrated part of desertification

Desertification has been identified as a major threat for the Namibian population as a whole and has led to the establishment of the National Programme to Combat Desertification (NAPCOD). NAPCOD represents one cross-sectoral component of the strategy to operationalise the Green Plan, which gave rise to the Programme. The Green Plan recognises that poverty, population growth and desertification are intimately linked. With a population growth of approximately 3%, the pressure on and subsequent degradation of natural resources will increase – which will inevitably lead to worsening poverty. External inputs are, therefore, of crucial importance to break this vicious cycle.

Indicators of desertification (i.e. land degradation) comprise –

- the lowering of groundwater tables
- soil erosion
- loss of woody vegetation (trees)
- loss of grasses and shrubs
- decrease in preferred grasses and shrubs
- bush encroachment
- increase in soil salt content, and
- decreased soil fertility.

Desertification can, therefore, be defined as a cumulative set of processes which lead to land degradation in arid, semi-arid and semi-humid areas resulting from various factors, including both climatic variations and human interference. Land degradation can be equated with desertification, as both processes lead to reduced productivity (Seely & Jacobson 1996)

The phenomenon of bush encroachment in Namibian savannas is regarded as part of the desertification process since the increase in the extent and density of woody vegetation occurs at the expense of other desirable grasses and forbs, resulting in an alarming reduction in productivity. The following definition of *bush encroachment* was accepted by rangeland experts in Namibia during a brainstorming session:

> *Bush encroachment* is the invasion and/or thickening of aggressive undesired woody species, resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, a decrease in carrying capacity and concomitant economic losses.

The first reference to bush encroachment was made by the explorer Anderson (1856), who complained about the dense thorn bush encountered between the Omatako Mountains and Lake Otjikoto during his party's trek through the area in 1851. An extract from Anderson's book reads (ibid.): "Our poor cattle were cruelly lacerated, and it was with the utmost difficulty we succeeded in getting the wagons through". Chapman, also an early explorer, stated in 1863 that the area to the east of Gobabis was dense bush, "offering safe cover for lions, quaggas, koodoos and pallahs" (Tabler 1971).

Walter and Volk (1954) identified bush encroachment as a serious problem in the 400 mm rainfall zone of Namibia. They observed that the problem was more prominent around water points and concluded that the problem could be ascribed to overstocking and the exclusion of veld fires. The best treatment against encroachment, in their opinion, was a dense perennial grass cover. However, no quantitative description regarding densities, height classes or canopy cover was given in any of the cases presented by them.

Anecdotal evidence supplied by a few farmers in the Otjiwarongo and Outjo districts showed that land was fairly open during the 1940s and 1950s – to the extent that they could hunt jackal on horseback without fear of getting injured by bushes. During 1954 to 1959, in this author's own experience at least, one could run fast between the bushes. Thus, bushes were always present; it is their density and composition, however, that have changed dramatically over the years.

The problem of bush encroachment and how further thickening could be prevented was also described by Joubert (1966). Since the latter study there has also been a gradual increase in the invasion/thickening of *Acacia mellifera*, *Acacia erubescens* and *Terminalia sericea*, particularly in the sandy soils of the Omaheke and Otjozondjupa Regions. Today, bush encroachment in these areas is regarded as a serious problem.

According to Bester (1996), most of Namibia had its original vegetative characteristics up to the 1940s, but by the mid-1960s, bush thickening was regarded as an environmental disaster.

Based on the need expressed by farmers to address the problem of bush encroachment, the first experimental work to combat bush by means of chemicals started in 1972 at the Omatjenne Research Station. Several methods were tested during the years that ensued, including chemical control by means of Tordon 225, the use of bulldozers, root ploughs and chopping with axes. Biological methods, i.e. the use of goats, were also attempted.

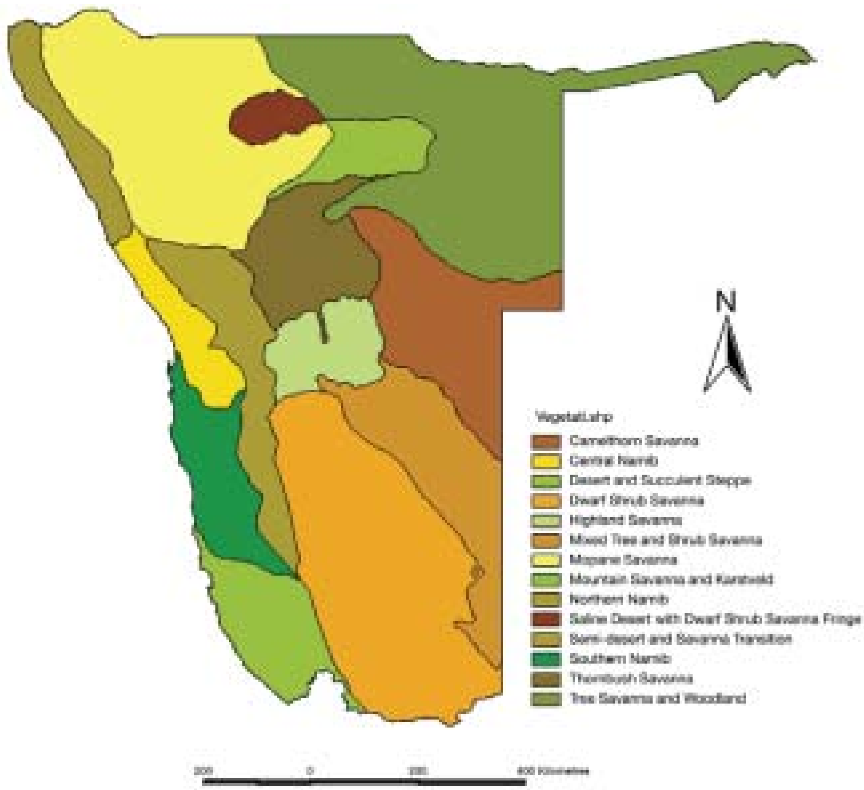
Since 1972, an unknown number of innovative farmers applied methods recommended by the former Department of Agricultural Technical Services. It was only in 1988 that farmers established the first formal body to combat and utilise invader bush, namely the Bush Utilisation Association. During the Association's inaugural meeting, the following objectives were set:

- Primary objective: To reclaim agricultural land with a view to utilising it in a sustainable way, and
- Secondary objective: To utilise invader bush in an economically viable way.

1.2 Magnitude and occurrence of intruder bush

Almost 64% of the country is covered by savanna range types, most of them with a discontinuous, open to moderately dense stand of nitrogen-fixing *Acacia* trees and bushes, and an apparently continuous herbaceous layer dominated by grasses. About 20% of the country is characterised by dry woodland with a fairly dense and highly diverse stand of trees and a dense undergrowth of grasses (Rothauge et al. 2001).

According to Giess (1971), six of Namibia's 14 major vegetation types are types of savanna (see Figure 1.1). These include the areas generally associated with bush thickening, i.e. Dwarf Shrub Savanna, Camelthorn Savanna, Highland Savanna, Mixed Tree-and-Shrub Savanna, Mountain Savanna, and Thornbush Savanna.



Source: Giess (1971)

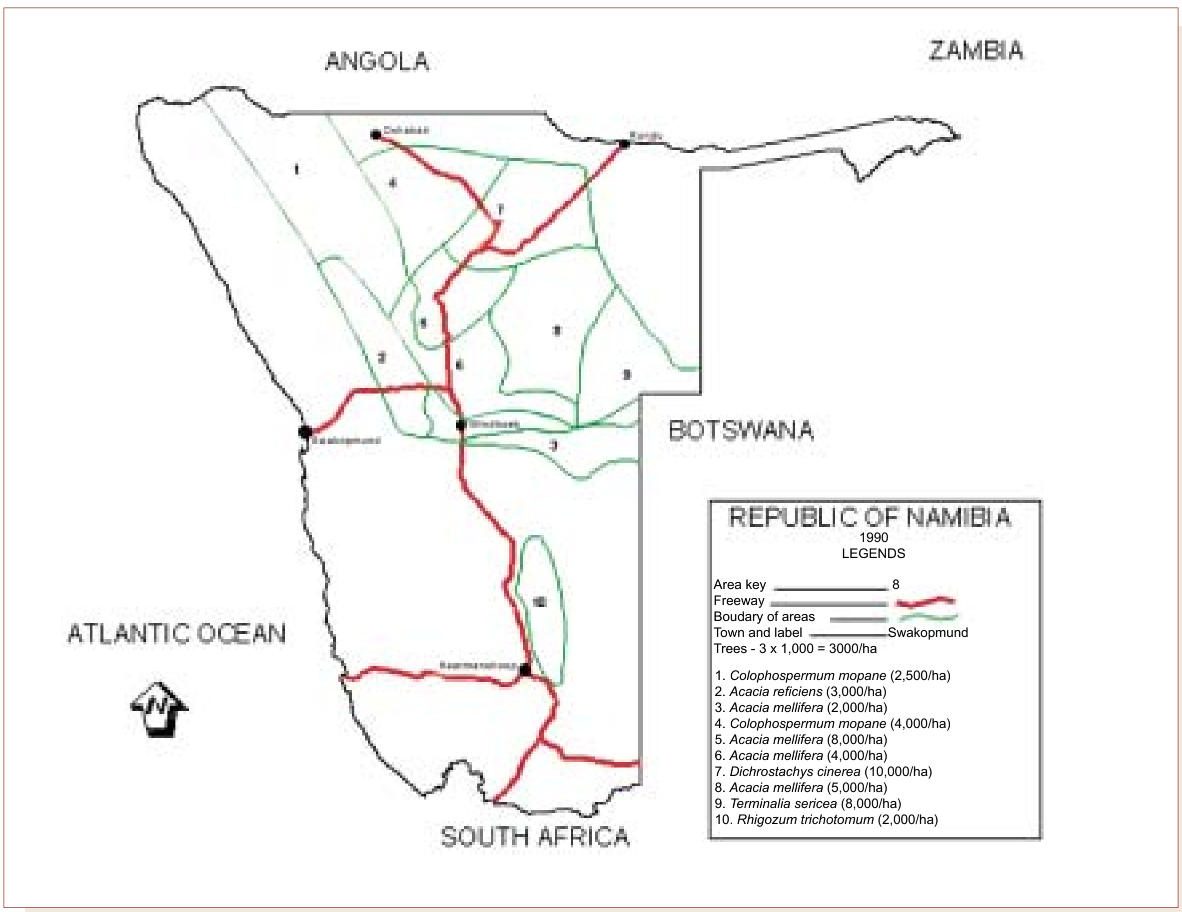
Figure 1.1: Savanna types in Namibia

The approximate areas covered by the most important invader species in commercial and communal tenure areas are illustrated in Table 1.1 below (Bester 1999).

Category of thickened bush			Hectares	
No. on map	**Main bush species**	**Density of bushes**	**Commercial land**	**Communal land**
1	*C. mopane*	2,500 per hectare	1,451,000	2,986,000
2	*Acacia reficiens*[2]	3,000 per hectare	1,676,000	691,000
3	*Acacia mellifera*	2,000 per hectare	3,360,000	195,000
4	*C. mopane*	4,000 per hectare	482,000	1,090,000
5	*Acacia mellifera*	8,000 per hectare	2,067,000	13,000
6	*Acacia mellifera*	4,000 per hectare	2,692,000	210,000
7	*Dichrostachys cinerea*	10,000 per hectare	2,513,000	1,220,000
8	*Acacia mellifera*	5,000 per hectare	950,000	2,453,000
9	*Terminalia sericea*	8,000 per hectare	586,000	1,624,000
Total			**15,777,000**	**10,482,000**

Table 1.1: Approximate area covered by the different dominant bush species in commercial and communal areas

The demarcations of dominant invader species for the commercial areas are illustrated in Figure 1.2 below.



Source: Bester (1996)

Figure 1.2: Occurrence of dominant invasive species in the commercial farming areas of Namibia

[2] No differentiation is made between *Acacia reficiens* subsp. *reficiens* and *Acacia luederitzii* var. *luederitzii* (Ross 1979) and any reference *to Acacia refienciens* in this document includes both these subspecies.

According to Bester (1999), an area of approximately 26 million ha suffers from bush densities which vary between 2,500 and 10,000 bushes per hectare. The main species causing the encroachment problem are *Acacia mellifera* (Black thorn), *Dichrostachys cineria* (Sickle bush), *Terminalia sericea* (Silver terminalia), *Terminalia prunioides* (Purple-pod terminalia), *Acacia erubescens* (Blue thorn), *Acacia reficiens* (False umbrella thorn) and *Colophospermum mopane*. Areas 1 to 9, as depicted in Figure 1.2, were therefore selected as the core area for the present study.

Prosopis varieties also occur in high densities mainly in the Nossob, Olifants and Auob Rivers, and are spreading outside the river lines into the Kalahari.

Six *Prosopis* species have been introduced and have become completely naturalised in southern Africa, while the introduction to Namibia in 1971 of a seventh species, *Prosopis cineraria*, failed. The latter is naturalised to a zone stretching from the Arabian Peninsula to India. It occurs in areas with an annual rainfall as low as 75 mm and can tolerate dry seasons of eight months and more. It was introduced to Namibia because of its ability to grow at low altitudes and on shallow and poor soils with a pH value as high as 9.8 (Smit 2002).

It is generally accepted that the decline in the carrying capacity of Namibia's rangelands could be anything from 100% or more, with a concomitant loss in income (at present prices) of more than N$700 million per annum. Subsistence losses in the communal areas are reflected in lower food security and nutrition, increased time and effort spent in maintaining living standards, higher demands on wages, and income transfers (Dewdney 1996; Quan et al. 1994).

Approximately 2 million ha in the southern parts of the country are also invaded, mainly by *Rhigozum trichotomum* (Three thorn). Even Black thorn is becoming a problem in certain areas.

The overriding problem caused by high densities of invader bush is its absolute superiority in competing for water in the upper layers of the soil.

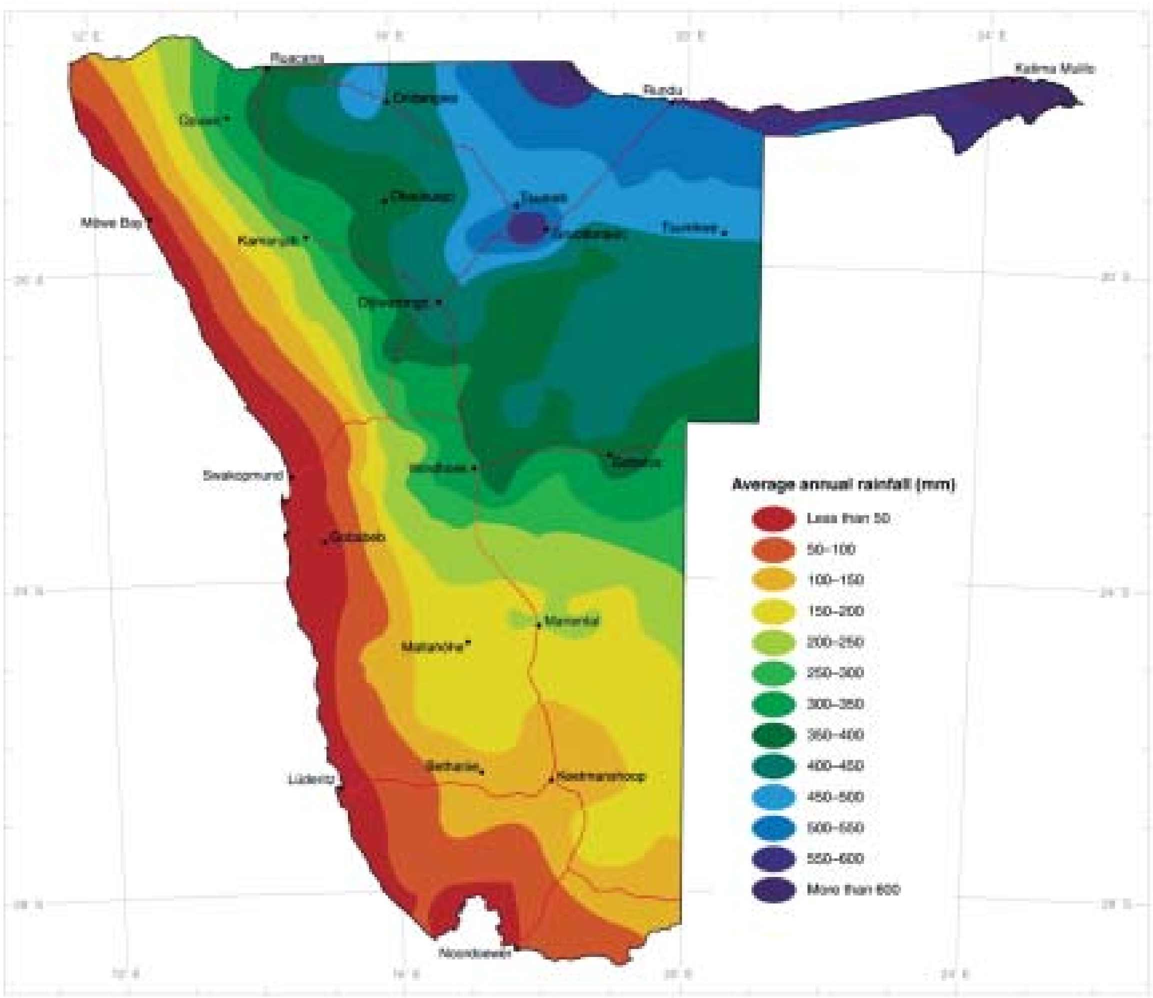
1.3 Climatic features

Namibia is the driest country in Africa south of the Sahara, and its highly seasonal climate is characterised by frequent droughts (Hutchinson 1993). The adverse impact of bush encroachment in terms of biodiversity, soil:water balance, groundwater, livelihoods, food security and nutrition, as well as the entire economy needs to be considered against the country's climatic features.

Some 22% of Namibia is classified as desert, while 33% is classified as arid, 37% as semi-arid, and 8% as semi-humid. Figure 1.3 below shows the rainfall pattern across the country.

There is a gradual increase in the long-term average rainfall in a north-easterly direction, from 250 mm in the western communal areas affected (Okombahe and Omatjette) to 500 mm in the north-eastern part of the bush-affected area. The rainfall for the vast majority of the problem area lies between 300–450 mm. A small area between Tsumeb, Grootfontein and Otavi is much better endowed, having an average rainfall of 500 mm, and at times even as high as 600 mm. The latter also represents the highest bush densities in Namibia's savannas.

The average water deficit caused by evaporation (see Figure 1.4) is also much more prominent in the lower rainfall areas. It is expected, therefore, that the impact of bush encroachment – although lower in density – in these areas could be just as dramatic as for the higher rainfall areas.



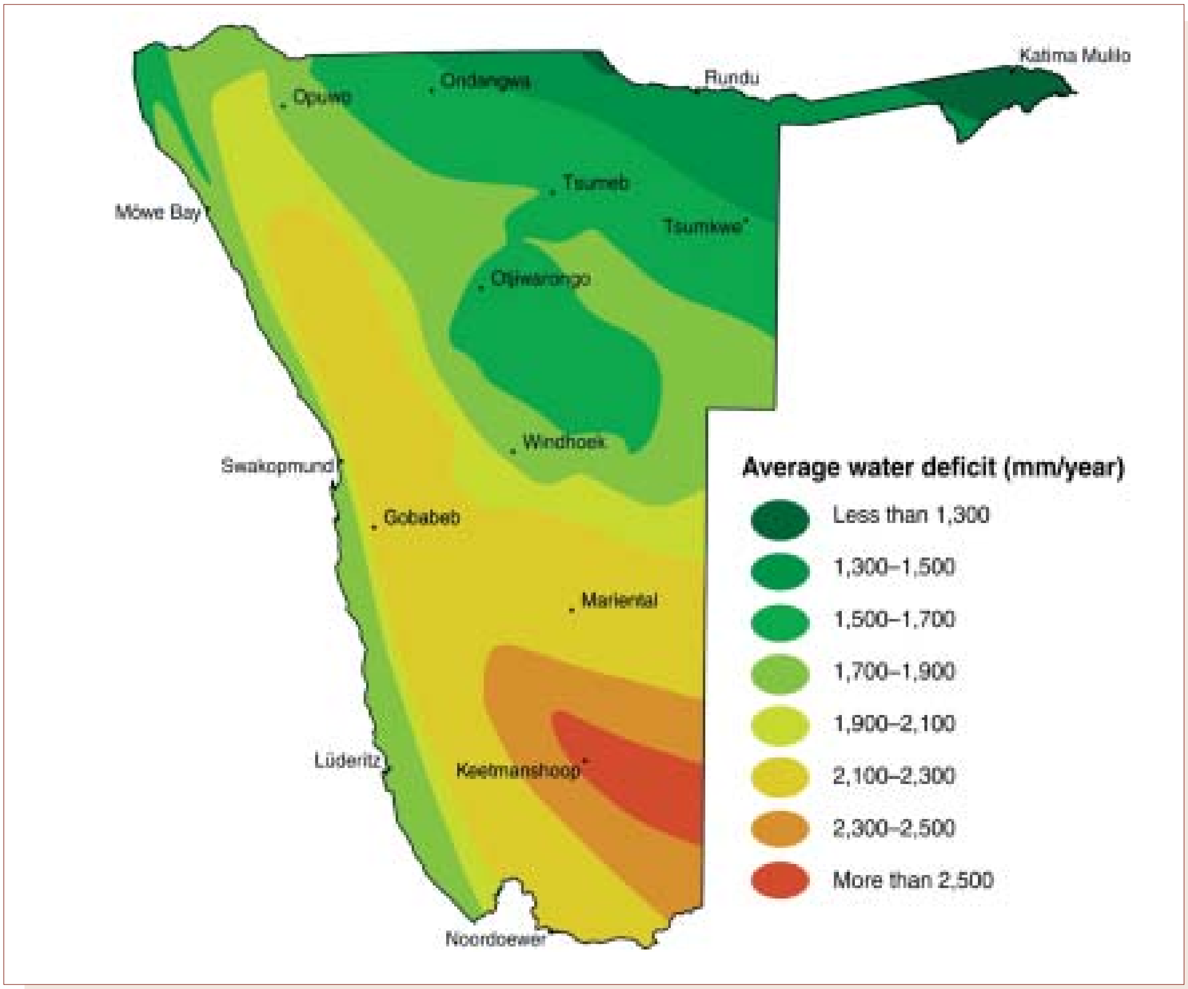
Source: Atlas of Namibia (*Mendelsohn et al.* 2002)

Figure 1.3: Average annual rainfall (mm)

The high water deficit could be expected since Namibia is generally considered to be a hot country. September, October and November are usually the least humid months because of high levels of radiation and high temperatures. Average relative humidity values are higher than 80% in the most humid months in northern Namibia, compared with 50–60% in the south (Mendelsohn et al. 2002). Average maximum temperatures during the hottest months are usually above 30°C over most of the country. Windhoek, which is situated in the southern part of the study area, has an average maximum of 30°C, while over the rest of the central parts of the country the average maximum is 36°C. The average minimum temperature for most of the bush-encroached area is 6°C. Since the frequency of frost is also a factor in curbing the establishment of seedlings, it is interesting to note that on average frost occurs less than five times a year in the Otjiwarongo, Otavi, Tsumeb and Grootfontein areas. On the other hand, in the Okakarara and Otjinene areas where bush densities are highest, the figure goes up to between 10 and 20 frost days per annum. East of Windhoek towards Gobabis, the corresponding figures vary between 20 and 30 (Mendelsohn et al. 2002).

Thus, Namibia is a dry country, in which low and variable rainfalls are normal (ibid.). Predictability of rainfall is low and there are large fluctuations between and within years. The little rainfall the country receives on average is subject to high rates of evaporation (ibid.).

This loss of water is exacerbated by high evapotranspiration rates associated with bushes. For example, the evapotranspiration rate of *Acacia mellifera* – 32,500 *l* per day for every 500 trees, according to Donaldson (1969) – is seven times higher than those of the benign fodder bushes, e.g. *Grewia flava*. Thus, it is justified to say that, after good rains, an average farm with 1,000 *Acacia mellifera* trees per hectare can be compared with two windmills per hectare that pump water out of the soil at a rate of more than 7,000 *l* per hectare per hour for 8 hours a day (or 280,000 m^3 per day over a 5,000-ha farm). This clearly illustrates how much water is lost through evapotranspiration due to the bush problem.



Source: Atlas of Namibia *(Mendelsohn et al. 2002)*

Figure 1.4: Average water deficit (mm per annum)

Although presented as an oversimplification, the impact of bushes on grass production and water-use efficiency can schematically be illustrated as follows:

It is of utmost importance that the productivity of our natural rangelands is maintained at the highest possible level. Namibia cannot afford to have a biological system where, because of bush encroachment and a veld in poor condition, more than 50% of the annual rainfall is lost. The practical implication is that, even if a farm gets 300 mm of rain, it will effectively be reduced to 150 mm. The frequency of artificial droughts created in this way cannot be afforded.

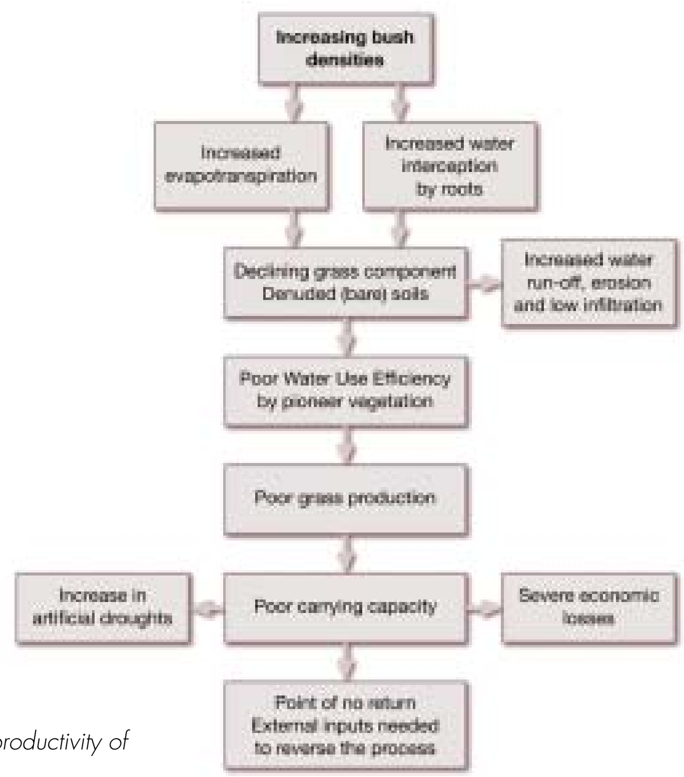


Figure 1.5: Impact of bush encroachment on productivity of agricultural land

1.4 People affected

Approximately 65,000 households in communal areas and 6,283 commercial farmers with around 35,000 workers are dependent on livestock farming in the bush-affected area. At present, the average number of dependants per household is 4.03 (Agricultural Employers' Association 2002). This brings the total number of dependants on commercial farms to 140,000. The potential for increased income and quality of life for each of these groups is enormous and should be pursued at all costs.

1.5 Introducing the Bush Encroachment Research, Monitoring and Management Project

The Bush Encroachment, Monitoring and Management Project, sponsored by the Government of Finland, was introduced in September 2000 and has since been implemented under the auspices of the Directorate of Environmental Affairs in the Ministry of Environment and Tourism (MET).
The overall (long-term) project objective is to promote and establish appropriate systems for diverse and sustainable land management in bush-encroached areas. The project aims to develop a common information base on, and understanding of, the issues related to bush encroachment and prepare a long-term programme to reverse the adverse effects of bush thickening.

The Bush Encroachment Research, Monitoring and Management Project was envisaged to be implemented in two phases:

- **Phase 1:** Establishment of a common information base, and participatory preparation of an integrated monitoring and management programme and action plans. Phase 1 was launched on 1 September 2000, and was due to end on 31 August 2002. It has since been extended on a no-cost basis until the end of December 2003.
- **Phase 2:** Implementation of the monitoring and action plans proposed.
  However, the Government of Finland has meanwhile decided that it will no longer finance the implementation of Phase 2.

The expected results under Phase 1 of the project are the following:

- Improved understanding of the process and causes of bush encroachment, and best methods of combating it
- Improved understanding of the impact on land capability and biodiversity
- Updated and time-sequenced, historical information in the form of maps and data for the Geographic Information System (GIS) database, made available to, for example, researchers, planners and the general public
- Improved monitoring systems and methodologies for assessing vegetation change and land capability
- Sustained and functional mechanisms and capacity to operate and manage the project (being developed and made operational for Phase 2)
- A policy analysis of bush encroachment-related issues for policy reforms, and
- Increased awareness of bush encroachment dynamics, and operational networks for sharing information and experience.

The achievements of these results are reflected in the chapters concerned in this report.

The project will benefit the following target groups:

- Researchers, students and planners of natural resources management, through compilation and analysis of previous research as well as farmers' experiences and perceptions
- Decision-makers and communities, through information dissemination
- Extension services, through closer collaboration and sharing of information and experience
- Private-sector development, through the opening up of new opportunities for income-generation and marketing (e.g. the production of charcoal and other wood products), and
- Community-based development programmes, through closer collaboration and exchange of the compiled scientific information. Community-based development programmes can also be incorporated in the development of private sector programmes.

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Chapter 2
Causes of bush encroachment[3]

[3] Constituted Component 1 in the original Terms of Reference

One of the major outputs of this study is to develop a proper understanding of issues related to bush encroachment and to identify factors that have caused the problem.

Figure 2.1: A. mellifera *invasion in the Okahandja district (Thornbush Savanna)*

Figure 2.2: D. cinerea *and* T. prunioides *in the Grootfontein district (Mountain Savanna and Karstveld)*

Figure 2.3: A. mellifera *and* A. reficiens *in the Omaruru district (Thornbush Savanna)*

Figure 2.4: A. mellifera *and* A. reficiens *in the Outjo district (Thornbush Savanna)*

In their overview of the relations between woody and herbaceous components in southern African savannas, Teague and Smit (1992) summarise and explain the most important research findings against which the phenomenon of bush encroachment needs to be pragmatically considered. This study serves as a very important knowledge base and point of departure when possible causes of bush encroachment and future strategies are discussed.

Teague and Smit (1992:60) offer the following views on the subject:

> When managing natural resources there are two issues of concern: productivity and sustainability. Although, by definition, all savannas consist of grass and a woody component, functionally each situation is unique. Not only are there differences in physical determinants, but the biological interactions that are based on these determinants and individual species properties are unique to each spatial and temporal situation. A good knowledge of ecological functioning is required to understand how the problem originated and how to manage for any given objective and situation to achieve high productivity that is sustainable.
>
> Of importance to productivity and sustainability are the concepts of stability and resilience: how and how much does a savanna change when we use it and how much can it change and still recover its original composition (Walker 1985), function and productivity. A knowledge of stability and resilience is necessary to calculate long-term costs and benefits and the wider ecological aspects related to holistic conservation. This is just as important as determining short-term productivity.

The factors determining the specific vegetation type in any given area are diverse and complex. Teague and Smit (1992) divide them into the following:

- **Primary determinants** (climatic features and soil properties), as they are a function of the specific geographical region and beyond the control of the manager, and
- **Secondary determinants**. Although they act within the constraints imposed by primary determinants, they can often be directly modified by management. Some examples cited by Smit (2002) are the exclusion of occasional hot fires, the replacement of most of the indigenous browsers and grazers by domestic livestock (largely grazing), often at extremely high stocking rates, the restriction of movement of herbivores by the erection of fences, poor grazing management practice and artificial watering points.

Have we already exceeded the boundaries of resilience of our ecosystem?

2.1 Primary determinants

Teague and Smit (1992:61) explain the influence of these factors as follows:

> All savannas are characterized by wet summers and dry winters. They occur over a wide range of rainfall from 300 mm to 1 000 mm per year. Although plant species composition is influenced by such soil properties as nutrient status, pH, salinity and texture, the overwhelming factor determining the spatial distribution and productivity of forest savanna and grassland is soil moisture balance (Tinley 1982; Walker 1985).
>
> Fine-textured soil (high clay) is much more xeric. They can hold more water but less is available to the plant because of adsorption. In such soils, water is limiting for much of the year. With the same climatic conditions on sandy soils, moisture is much less limiting to plants (Knoop & Walker 1985). They hold less water since they are more susceptible to deeper drainage, but most of it is available to the plant. In clay soils the prominence of fine capillary pores is conducive to unsaturated flow while in sands, the large pores encourage saturated flow (Tinley 1982). An increase in the proportion of rocks in the profile and residual moisture in the soil prior to rain, increase infiltration depth and favour woody plants (Walter 1971; Stuart-Hill 1985).
>
> These differences in soils are important to productivity, vegetation structure and species composition (Dye & Spear 1982; O'Connor 1985). After clearing on heavier soils, there are large variations in yield from year to year and marked species changes with time. Differences are less on sandy soils.
>
> In higher rainfall areas, differences in vegetation between heavy and sandier soils are small, in comparison. With lower rainfall, mesophytes occur only on loam and sandy soils. The herbaceous vegetation on heavier soils shows greater sensitivity to the availability of soil moisture and greater changes in species composition during droughts. The higher fertility on the heavier soils results in much greater yields in wet years (Dye & Spear 1982).
>
> In southern Africa a characteristic soil and vegetation catenal sequence occurs (Walker 1985). Dense woodland savanna occurs on the coarse-textured upper slopes, scrubbier mixed savanna occurs on the shallower mid-slope soils and taller trees, usually *Acacia* spp., occur on the deeper, finer soils in the illuvial zone. The woody cover on duplex soils can be self-sustaining where evapotranspiration prevents the pan horizon from being waterlogged for too long. It is believed, but has not been scientifically tested, that woody plants establish in a waterlogged area in severe drought years and then maintain themselves by utilizing all the water and preventing the previous waterlogged conditions from developing for long enough to kill the woody plants. Removal of these woody plants immediately re-establishes the previous waterlogged condition which then maintains itself (Tinley 1982).
>
> The dominant effects of moisture are modified, often considerably, by light, nutrients and temperature. Temperature plays an important role in southern Africa, since the high altitude of the southern African plateau is characterized by low winter temperatures and low humidity relative to other savannas. Temperatures (below 15°C and 35°C) are thus severely limiting at certain times of the year to both the woody (Teague & Walker 1988a) and the grass components (Walker 1985), influencing productivity and species distribution.
>
> There is an interaction between rain and soil nutrients. High rainfall is associated with highly-leached soils. This results in a gradient from arid/eutrophic to mesic/dystrophic savannas (Huntley 1982). Parent material modifies this. These large differences in nutrient status have a considerable impact on plant structure, defences, nutritional value and growth potential. …
>
> Phenological patterns also differ between mesic and arid savannas. In mesic areas, the rainfall is relatively predictable. There is usually a pre-rain flush of woody species and a predictable sequence of activity of forbs and grasses (Malaisse et al. 1975; Rutherford & Panagos 1982). Arid areas, on the other hand, have a much less predictable and more variable rainfall. Plants are more opportunistic, responding closely to rainfall events (Dye 1983; Matthews 1984; Teague & Walker 1988a).

Some secondary determinants have a major influence on the effect of climate and edaphic factors with specific reference to fire and herbivores. These factors and their contribution to the specific bush encroachment problem in Namibia are analysed in section 2.2 of this chapter.

Two models – which are not necessarily mutually exclusive – were proposed by Walter (1971) and Doughill et al. (1999), where the processes in relation to bush encroachment are explained. These are presented in more detail below.

2.1.1 Walter's Two-layer Model

The hypothesis underlying this Model states that the roots of trees are at the surface as well as the deeper layers of the soil, while the roots of grasses only occur in the top layer. The hypothesis suggests preferential rather than exclusive access of the roots of trees to water in the subsoil. The two layers are, therefore, in direct competition with each other.

If the grass layer is overutilised, it loses its competitive advantage and can no longer utilise water and nutrients effectively. This in turn results in a higher infiltration rate of water and nutrients into the subsoil. Such a scenario will benefit trees and bushes and allow them to become dominant.

Figure 2.5

Figure 2.6

Figure 2.5 and 2.6 show extreme example of denudation as a result of overutilisation, which supports Walter's Two-layer Model.

If a vigorous grass layer is present the opposite effect will be achieved. The Two-layer Model assumes that water is the major limiting factor for both grasses and woody species, that the savanna ecosystem is relatively stable, and that the equilibrium is dominated by grass (Doughill et al. 1999). Smit and Rethman (2000), however, point out that not all the water will penetrate the deeper layers of the soil when grasses are overutilised; instead, the water will be partly lost because of higher run-off and, therefore, less infiltration.

Some empirical evidence in support of the Two-layer Hypothesis does exist (Hesla et al. 1985; Knoop & Walker 1985; Sala et al. 1989) while a few studies reject it (Belsky 1994; Belsky et al. 1989; Sieghieri 1995; Weltzin & Coughenour 1990). Teague and Smit (1992) regard this model as an oversimplification of the interaction between trees and grasses.

Smit and Rethman (2000) note that no spatial separation of soil water existed in a *Hardwickia mopane* study area. *Hardwickia mopane* trees and grasses were found to be in direct competition for soil water in the top 300-mm layer. Moreover, *Hardwickia mopane* at high densities utilise the available soil water to such an extent that they prevent the establishment of grasses.

2.1.2 State-and-Transition Model

Doughill et al. (1999) proposed the State-and-Transition Model, which recognises the dynamic nature of savanna ecosystems. This model is based on non-equilibrium ecological theories, and suggests that savannas are event-driven where rainfall and its variability play a more important role in vegetation growth (and composition) than the intensity of grazing. They describe savannas as distinct states of vegetation communities, with several transitions between these states. Environmental degradation can occur rapidly and may be triggered by management practices, natural events or a combination of these factors.

This model implies that bush encroachment is not a permanent phenomenon, and that a savanna could be changed to its grass-dominated state by favourable management or environmental conditions.

Ward (n.d.) is in strong disagreement with Walter's Two-layer Model. He (ibid.) instead suggests that bush encroachment occurs when disturbances such as –

- human impact (Jeltsch et al. 1998b; Jeltsch et al. 2000; Scholes & Archer 1997)
- fire (Higgins et al. 2000)
- herbivory (Scholes & Walker 1993)
- drought (Scholes & Walker 1993), and
- spatial heterogeneities in water, nutrient, and seed distribution (Jeltsch et al. 1996)

shift savannas from the open grassland towards the forest end of the environmental spectrum.

2.1.3 Applicability of the two hypotheses

The two hypotheses proposed here may be valid for specific situations, but they may lack generality. None of these purported mechanisms of bush encroachment has been demonstrated under field conditions (Ward n.d.). Ward (ibid.) believes that there is a need to go back to the drawing board as far as theory is concerned, and develop a general theory of *Acacia* savanna function that considers the mechanisms of plant coexistence.

The major factors determining the functioning and dynamics of savannas are rainfall, soils and nutrients, grazing, browsers and fire. The soil:moisture balance has an overwhelming effect on vegetation structure, composition and productivity.

2.2 Secondary determinants

2.2.1 Fire

2.2.1.1 Natural fire regime

Trollope (1982) shows that there is virtually no information available on the ancient fire regime that existed prior to the advent of humans or before their presence had a significant effect in the savanna areas of South Africa. Nevertheless, based on a knowledge of fire behaviour it is logical to expect that the factors playing the greatest role in the season, frequency and intensity of natural fires in the savanna were fuel load, fuel moisture and the incidence of lightning. The savanna areas of South Africa are largely confined to the summer rainfall region, which is characterised by a dry season extending from approximately May to October. At the end of this dry season the herbaceous/grass fuel layer is very dry.

The importance of lightning as an ignition source is illustrated by Siegfried (1980). He reported that, in the Etosha National Park, where a policy of fire exclusion is applied, at least 54% and probably as much as 73% of all fires that occurred during the period 1970–1979 were caused by lightning (ibid.). The average frequency of all fires in Etosha between 1968 and 1995 range from 5.5 years, according to unconfirmed records, to a more likely figure of 9.1 years, as far as confirmed records show (Du Plessis 1997).

In the Kruger National Park, Gertenbach and Potgieter (1979) found that lightning caused 45% of all unscheduled fires during the 1977/78 season.

As part of ancient tradition and indigenous knowledge, human beings in Africa were and still are a source of veld fires (Smit, pers. comm.). Early humans modified the natural fire regime (Trollope 1999). Smit (pers. comm.) further states that the frequency of fire due to humans is presently higher than those due to natural causes.

According to Trollope (n.d.), –

> [T]he frequency of burning in the natural fire regime would have been largely influenced by the rate of accumulation of sufficient grass fuel to support a fire. Rainfall is the most important factor affecting the productivity of the grass sward under veld conditions and therefore the accumulation of grass fuel. Thus fires were undoubtedly more frequent in the moist savannas (>600 mm per annum) than in the arid savannas because of the more rapid accumulation of grass fuel in response to higher rainfall and the loss in acceptability of the grass herbage to herbivores on reaching maturity. Present[-]day research would suggest that the natural frequency of fires in the moist savannas must have ranged between annual and biennial burning, depending upon the seasonal rainfall and the degree of utilization of the vegetation by wild ungulates. Scott (1971) states that complete protection of the grass sward for three years caused it

to become moribund and die out. Conversely annual and biennial burning maintained a vigorous grass sward with a far superior basal cover. Furthermore, in the Kruger National Park, where fire is an important component of the veld management strategy, it has been concluded from burning experiments initiated in 1954 that the most desirable burning frequency under grazing conditions in the moist savanna areas is annual or biennial burning depending upon grazing and grass fuel conditions (Gertenbach & Potgieter 1979). In the arid savannas the frequency of fire must have been far lower because the rainfall is both less and highly erratic and the grass sward remains acceptable to grazing animals even when mature, thus reducing the rate of accumulation of grass fuel. The frequency of fires would have been determined by the occurrence of exceptionally wet seasons. Thus the frequency of fire in the arid savannas would have varied according to the prevailing type of rainfall cycle as it affected the production and accumulation rate of grass fuel. Considering the intensities of fires occurring during the natural fire regime, it is reasonable to assume that fire intensities were far greater in the past.

This is because Acocks (1975) has presented widely accepted botanical evidence indicating that the grass component of the veld in South Africa has been drastically altered and reduced in all veld types, including the savanna, since settled agricultural conditions came into being. The effect of a drastic reversal in the grassland succession to a more pioneer stage of the production of grass fuel is illustrated by data presented by Danckwerts (1982). He found that in the False Thornveld of the Eastern Province (South Africa) the phytomass of grass produced per unit area by pioneer veld, dominated by species like *Aristida congesta*, was only 13% of that produced by climax veld dominated by *Themeda triandra*. Bearing in mind that grass constitutes the major component of the fuel load in savanna fires and is the most important factor influencing fire intensity, it clearly indicates why the fires of the natural fire regime were probably far more intense.

The natural fire regime in the savanna areas undoubtedly resulted in a fire mosaic of areas burnt by different types and intensities of fire occurring at various times and frequencies, all of which maintained a diversity of vegetation types providing ideal habitat for a wide range of animals.

Teague and Smit (1992) concluded that fires usually occur in savannas as surface fires during the dry season. Their incidence depends on the season's standing crop of grass, itself a product of the amount of rainfall and plant production during the preceding wet season and the extent of herbivory. In most savannas, fires generally occur at frequencies of between one and three years. As the annual rainfall declines, the interval between successive fires increases and becomes more variable. As a consequence, species in mesic savannas are fire-adapted. Without fire, there is evidence that the grass sward degenerates and productivity declines markedly (McNaughton 1985; Walker 1985).

Fire intensity is variable and depends largely on the amount and structure of the fuel, its moisture content, and prevailing atmospheric humidity and wind speed (Trollope 1983,1999). In addition, the type of fire influences fire intensity and its effect on the vegetation. Burning during the growing season causes a significant reduction in grass production and basal area if fires are intense (Trollope 1983). However, if fires in the growing season are less intense owing to higher grass moisture content and prevailing weather conditions, no adverse effects on grass productivity or basal cover may result (Danckwerts 1989).

High-intensity fires kill tree seedlings, saplings and small trees, and damage the above-ground parts of larger woody plants, retarding their growth (Trollope 1983) and reproductive organs (Donaldson 1966). The hottest fires normally occur during the late dry season and reduce the woody canopy to coppice. However, mature woody plants are seldom killed by fire and most species are able to regenerate under less intense fires such as those in the early dry season (Frost et al. 1986).

Bester (1996) states that fire only kills between 15% and 25% of bush and the remaining bushes are responsible for dense coppice thereafter. However, fire can retard their growth rate, change the height strata, and suppress the establishment of saplings. For this reason it is best used as a preventative rather than curative measure against bush thickening. Coppicing species will continue to grow actively and regenerate.

Protection from fire results in a decrease in grass production. In fact, a once-off fire can increase tree density, and stimulate germination of the tree seedlings through scarification of the seeds. In mesic areas, woodland develops. In the dry savannas, fires usually occur too infrequently to limit the density of woody plants. However, dry savanna plants are more susceptible to fire than mesic savanna plants and the grass layer will take longer to recover. Thus, when fires do occur in these drier areas, they may cause considerable mortality of woody plants (Frost et al. 1986).

A back fire or a cool head fire can promote bush encroachment by removing the grass layer (and, thus, competition) without damaging any of the woody plants (Smit, pers. comm.).

Frequent burning has little direct effect on the soil. Most effects are indirect and result from changes in the vegetation. Such effects include reduced organic matter and nitrogen and slightly increased phosphorus (Frost et al. 1986). Burning may speed up the rate of nutrient cycling, but nitrogen, carbon and sulphur are lost through volatilisation and as smoke and ash. The importance of these losses has not been determined.

Trollope (1999) is of the opinion that the interaction between fire and browsing by wild ungulates plays a major role in bush encroachment. The role of the fires was rather to maintain the bush at an available height and in a highly acceptable state for the wild browsing species. Elephants in combination with fire convert tree savanna to shrub savanna (Smit, pers. comm.).

The maintenance of open grassland through the interaction of burning and browsing is clearly demonstrated in the game parks of southern Africa (Trollope & Tainton 1986). Belsky et al. (1989) are of the opinion that fire currently plays the main role in maintaining open grasslands and savannas in many regions of the Tsavo National Park in Kenya. Belsky et al. (ibid.) explain that a fire occurred in the Park during September 1986. It removed all the above-ground herbaceous biomass, killed the stems of shrubs (predominantly *Acacia mellifera*, *Acacia tortilis* and *Commiphora africana*), and scorched or killed the lower branches of large trees (predominantly *Acacia tortilis* and *Adansonia digitata*).

Van Niekerk (1990) is also convinced that veld fires have played a crucial role in maintaining open savannas, and that they should form an integral part of farm management in future.

High-intensity fires played a major role in maintaining open savannas in the past. With the introduction of cattle farming, veld fires were suppressed. This is regarded as a major factor contributing to bush encroachment: fires kill tree seedlings and saplings, while mature woody plants are seldom killed and most coppicing species are able to regenerate and grow actively.

High-intensity fires are regarded as a prerequisite for effective burning, which depends largely on the amount and structure of the fuel, its moisture content, prevailing atmospheric humidity, and wind speed.

Figure 2.7: Regular burning of a plot in the Kruger National Park, South Africa

Figure 2.8: Adjacent control plot, showing dense and tall bushes

2.2.1.2 Perceived effects of fire control in Namibia

The Caprivi Strip (comprising the Caprivi Region and part of the Kavango Region in northern Namibia) receives an annual average rainfall of more than 600 mm. Veld fires, whether caused by humans or by lightning, are frequent phenomena in that part of the country. Bush encroachment has not been identified as a problem in the Caprivi and the woody vegetation can be described as open dry forests.

The Sachinga Agricultural Research Station was established in the Caprivi Strip in 1970. Since it came into being, the land has only been used for research on extensive livestock farming and rangeland management. The farm was managed in accordance with the principles of rotational grazing. Furthermore, because the yield of the boreholes on the farm is fairly poor, the stocking rate was fairly conservative. As part of the management policy the farm was protected from veld fires. Today, bush thickening/encroachment is experienced on the entire farm, with densities varying from 3,000 to 5,000 bushes per hectare (Brand, pers. comm.). The obvious conclusion for this phenomenon is that bush established itself because the fire regime on the farm was completely changed [author's observation].

Figure 2.9: An excellent Brachiaria/*mopane veld in the Caprivi where veld fires occur regularly*

Following the inception of the Soil Conservation Act, 1949 (No. 6 of 1949; implemented in then SWA in 1952; as amended in 1969), the use of fire was prohibited in the commercial areas of the country. Farmers were only allowed to burn rangelands with the permission of the Executive Committee of the former Administration of South West Africa or the Minister of Agricultural Technical Services of South Africa. In practice, however, it was extremely rare for farmers to deliberately ignite their grazing.

When one travels along the border between Namibia and Botswana, the much higher densities of bush on the Namibian side are very obvious (see Figure 2.10). The only explanation for this difference lies in the fact that bush/veld fires have been suppressed on commercial farms since the 1950s.

Together with the increase in domestic livestock (herbivores) and the decrease in game numbers (browsers), –

- the pressure on the grass layer increased
- the competitive advantage of a vigorous perennial cover declined, and
- this created a more favourable environment for the woody component.

Figure 2.10: Open savanna prevails on the Botswana side of the border (left) while substantial encroachment occurs on the Namibian side (right)

Invader bush started to produce seeds in abundance and created opportunities for the establishment of new generations of bush. Each of these generations could reach maturity and was able to produce more and more seeds. Although some research findings (Hagos 2001) indicate that the seeds of *Acacia mellifera*, for example, are not transferable from one season to another, it is also known that this may not be the case for many of the other problem species. Moreover, because of factors like seasonal dormancy, hard-seededness and allelochemicals, there has been a gradual build-up of the seed content in the soils. Smit (1999) mentions that such seed banks may contain several hundred to several thousand seeds per square metre. Seeds like *Acacia nilotica* and *Acacia tortilis* may remain viable for one to five years. Even if a large percentage of these seeds is destroyed through natural processes, there will still be enough available – waiting for favourable conditions to establish themselves.

In general, the sensitivity of different invader species to burning has not yet been properly researched and should be attended to in future research programmes.

2.2.2 High stocking rates

2.2.2.1 Research findings

Apart from the clear interaction and competition between grass and bush described above, Knoop and Walker (1985; cited by Smit et al. 1996) reported that the growth of mature trees in an *Acacia* community was reduced by competition from the grass-dominated herbaceous layer. This was ascribed to the grasses taking up topsoil water (0–300 mm) rapidly enough to reduce drainage into the subsoil (300–1,300 mm), thus decreasing the amount of subsoil water available to the trees. The roots of *Colophospermum mopane* trees are able to utilise soil water at a matric potential lower than that of grasses (<1,500 kPa), which means that these trees are physiologically adapted to use soil water that is not available to grasses (Smit 1994b). This exclusive source of soil water resulted in *Colophospermum mopane* trees growing more quickly in areas with low tree density and good grass cover, compared with trees from areas with a high tree density and an absence of grass cover.

Van Vegten (1983) identified the overgrazing of grasses as the main cause of woody plant increase in savanna areas of eastern Botswana. Elsewhere in Botswana, shrub densities showed no consistent change in areas with little or moderate grazing, but in areas with heavy grazing, shrub densities increased (Skarpe 1990b). The increase in shrub abundance with heavy grazing was mainly accounted for by two species, *Acacia mellifera* and *Grewia flava* (Skarpe 1990b). Overgrazing is most frequently cited as a cause of bush encroachment (Joubert 1966; McPherson & Wright 1990; Madany & West 1983; Perkins & Thomas 1993; Schultka & Cornelius 1997; Skarpe 1990a, 1990b; Smit & Rethman 1992; Van Vegten 1983).

Overgrazing reduces the competitive ability of grasses in the top 300 mm layer of the soil, allowing more water to penetrate to the subsoil and favouring the growth of woody species. Seedling establishment and increase in shrub densities are directly related to the occurrence of a poor herbaceous layer. In Namibia there are strong indications that factors other than high stocking rates were more decisive in the process of bush thickening.

Britton and Snewa (1981) also state that poor grazing practice would seem to be particularly severe during dry seasons because of its greater negative effect on grass growth than on the tree growth during periods of severe water stress.

2.2.2.2 Historic overview of cattle numbers in affected area

During the years before colonial occupation the state of natural resources in Namibia was dictated only by natural forces like rainfall, temperature, droughts, veld fires mainly caused by lightning, and other forces that may have prevailed over the millennia. The extent to which cyclic changes in weather occurred and the degree to which such phenomena may have influenced changes in vegetation are unknown. According to the literature (Aigams Professional Services 1997), the first Europeans arrived in the country about 200 years ago. One could assume that the small number of human beings present at that stage owned a small number of livestock and lived in harmony with nature. The natural rangelands were wide and open, animal movement was dictated by available grazing, open water or wells, rain, and the occurrence of wild fires. The absence of modern technology like vaccines and medicines limited increases in livestock numbers, and the equilibrium was more or less maintained and dictated by natural determinants (Ibid.)

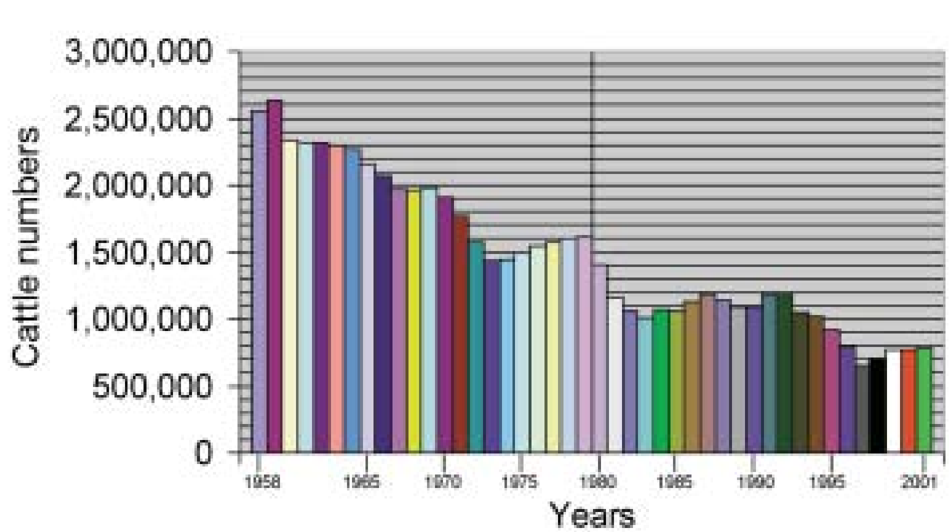
With the arrival of German settlers in 1884, the main focus was to establish the country's economy by way of livestock farming. To achieve this objective, German farmers were settled on farms, duly surveyed and fenced off with at least one water point. While the number of settlers gradually increased, farmers were able to buy their assigned farms under very favourable terms.

By 1912, a total of 1,245 farms had been allocated to 1,038 new owners, while another 106 people benefited from a leasehold scheme. Approximately 13 million ha were occupied and utilised by 140,500 cattle and 631,000 small stock (Rawlinson 1994), meaning that the average stocking rate amounted to 92 ha per large stock unit (LSU). The outbreak of World War I, together with the extremely harsh economic situation which culminated in the Depression of 1933, slowed down the pace of resettlement.

By 1946, the influence and impact of resettlement had reached a meaningful level in terms of production and income for the country. Some 4,565 farms had been demarcated, which carried 1.34 million cattle on approximately 33.6 million ha of land. At that stage, the area utilised for communal farming was 21.8 million ha. Thus, 1946 can be regarded as a watershed for commercial utilisation, as its impact on the natural rangeland of the country began to be felt. By 1959, cattle numbers in commercial districts had increased drastically to reach their highest figure ever of 2.54 million (Rawlinson 1994). Historically, more than 90% of the total commercial cattle population was concentrated in the central and northern commercial districts, covering approximately 18 million ha.

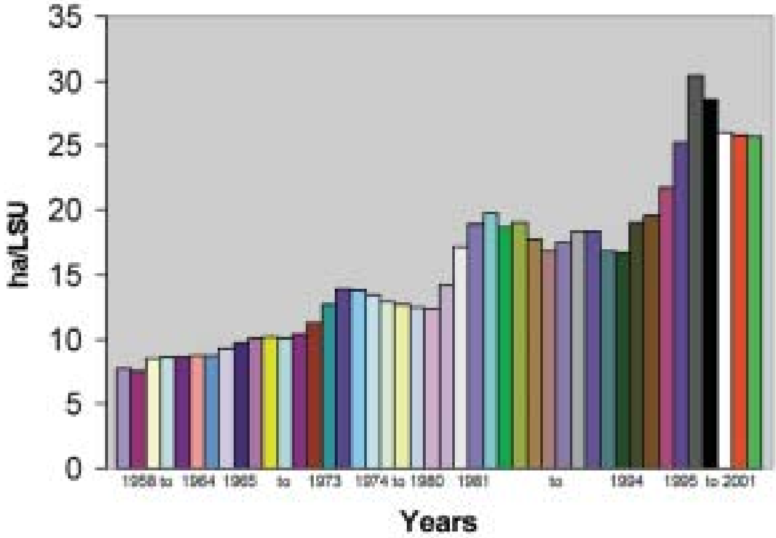
The actual numbers of the different game species are not known, but it can be assumed that domestic livestock were introduced in addition to and at the expense of the prevailing game population. Livestock figures for encroached areas in communal land (Otjozondjupa, Omaheke and Kunene South) are not available. The history of livestock numbers after 1958 is shown in Figures 2.11 and 2.12. Suffice it to say that, from late 1958 to the late 1990s, the number of cattle in commercial farming areas gradually decreased. If the assumption is made that 90% of the cattle were present in the bush-affected areas, then the applied carrying capacity never exceeded 1 LSU per 7.8 ha – excluding game and goats.

In their overview of cattle numbers, biomass, productivity and land degradation in commercial farming areas, Lange et al. (1998) found that, during the 20th century, the number of cattle on commercial farms grew rapidly at first, peaking at 2.6 million head in the late 1950s, but subsequently declining steadily to less than half that figure (1.2 million) by 1995. Numbers of small stock demonstrated a parallel trend (Directorate of Veterinary Services [various years]; Meat Board of Namibia [various years]; Rawlinson 1994). Rawlinson (ibid.) attributes the dramatic increase in the earlier period to the development of water points and camps in the commercial areas, which opened up new land for grazing. The equally dramatic decline in cattle numbers since 1958 has not been explained, and is all the more puzzling given the improvements in veterinary services, farm infrastructure, medicine and marketing facilities (Lange et al. 1998).



***Source:** Raw data:1958–1992, Rawlinson (1994); 1993–2001, Meat Board of Namibia (various years)*

Figure 2.11: Declining cattle numbers in the commercial farming areas, 1958–2001



Source: Raw data:1958–1992, Rawlinson (1994); 1993–2001, Meat Board of Namibia (various years)

Figure 2.12: Stocking rates relating to cattle in the affected area, 1958–2001

Relatively simple explanations for the declining number of cattle do not exist. There is no evidence of major data inaccuracies, no evidence of substantial substitution of small stock or wildlife for cattle (Barnes & De Jager 1996), and there has been no reduction of land area for grazing (Adams & Werner 1990). Some research suggests deteriorating environmental conditions over the past 40 years, notably land degradation, which may have reduced the land's carrying capacity (Dean & MacDonald 1994; Quan et al. 1994a).

Lange et al. (1998) found that annual rainfall records from 1914–1994 from more than 200 meteorological stations revealed no long-term decrease in rainfall: the trend line was flat. The trend line calculated for the period of declining cattle numbers, namely 1960–1995, shows a decline in average rainfall of 15%, but this is not statistically significant. The decline in cattle numbers of more than 50% over the period can only be due in small part to the effect of rainfall.

The average carcass weight of cattle slaughtered in Namibia has been fairly constant, or has increased only slightly over the past 35 years (Meat Board of Namibia [various years]; Rawlinson 1994). This would seem to indicate that there has been little change in the size of animals in herds. However, an investigation of breeding herds on two Government farms in the northern savanna areas, for animals of a given age, yielded live-weight increases of about 60% between the early 1960s and early 1980s (Venter 1982). Anecdotal evidence for an unspecified number of farms in the Otjiwarongo district indicated an increase of 25% in average live weight per head of cattle between 1967 and 1994 (Quan et al. 1994a).

Lange et al. (1998) found that, between 1956 and 1994, the trend line indicates a slight increase (6%, i.e. from 206 kg to 219 kg) in the average carcass weight of slaughtered cattle of all ages. It can be assumed that, since marketed cattle for various ages have not grown larger over time, the average weight of their progenitors, i.e. cattle in live herds, will also not have grown larger.

Quan et al. (1994a,1994b) investigated stocking rates of 20 farmers in the Okahandja district for the 1993/94 season. Their analysis shows that stocking rates in the preceding years preceding 1993/94 have rarely exceeded 20 ha per LSU (450 kg) in Okahandja. Apart from this it is difficult to deduce further information from these figures. They probably represent differences in types of management, management skills, income expectations, levels of debt, etc., as much as levels of bush encroachment or land degradation. From this limited data it was not possible for Lange et al. (1998) to deduce whether these farmers were overstocking. A comparison of actual stocking rates with the Ministry of Agriculture, Water and Rural Development's recommended carrying capacities is also of limited value. Carrying capacities vary from year to year and over longer periods of time. Good management enables some farmers to hold much higher densities of stock than those paying less attention to grazing management.

Over the years farmers have been accused of causing bush encroachment by overstocking their farms. However, the following facts suggest otherwise. It is interesting to note that the highest stocking rate ever – an average 8.3 ha per LSU – was applied during 1958–1964, probably because of the favourable rainy seasons preceding 1958. During the next eight years the stocking rate decreased to 10.8 ha per LSU. Despite the higher rainfall spell from 1974 to 1980, the average stocking rate for this period was 13.1 ha per LSU. A much lower rate, namely 18.1 ha per LSU, coincided with the poor average rainfall until 1994, after which the rate went down to 26.2 ha per LSU for the period 1995–2001 (see Figure 2.11). Farmers destocked for one reason or another and it can be assumed that they were compelled to do so because of declining land productivity. Lange et al. (1998) ascribed the drastic decline in livestock numbers to increased bush densities. This information suggests that other factors, seemingly beyond the farmers' control, were predominantly responsible for the problem.

2.2.2.3 Conclusions

There was a definite reduction in stocking rates, both in numbers as well as in animal biomass, which could be ascribed to a reduction in carrying capacity caused by bush encroachment.

It must be emphasised that the natural rangelands had deteriorated to such an extent in the past that the process could not be reversed during the last two decades – even with much lower stocking rates. It can further be concluded that, given the deterioration of the rangelands, grazing pressure was inherently still too high to utilise them in a sustainable way. This resulted in a rather vicious cycle, causing further degradation. The fear has been expressed that the bounds of resilience of the former ecosystem have been exceeded. External inputs to restore the original status of our rangelands, therefore, will now be inevitable.

The effect of prevailing stocking rates, combined with well-below-average rainfall during 1958–1962 and the beginning of the 1970s and the 1980s was exacerbated by the following:

- **The socio-economic framework in which farmers had to perform**: This should also be considered as one of the contributing factors for land degradation and subsequent bush encroachment. Immediately after the outbreak of foot-and-mouth disease the vast majority of cattle were trapped behind the veterinary cordon fence which was erected at the time. Very strict restrictions on the movement of animals were introduced. Farmers could not market their animals and the accrual of livestock during the ensuing years, until the veterinary restrictions were lifted, caused substantial damage to rangelands in the affected areas.
- **The enormous difficulties Namibian cattle farmers experienced in marketing their cattle during the 1960s and the first half of the 1970s because of alleged corruption:** Animals were kept longer, and the pressure on the veld was inevitably increased. These were factors beyond the farmers' control, and should be kept in mind in any future policy and legislative arrangements.
- **The artificially high stocking rate:** This, together with periodic spells of low average rainfall in many districts, caused extensive damage to the natural rangelands.
- **The declining numbers of perennial grasses and, therefore, inadequate or ineffective root systems in the upper layers of the soil:** The subsequent lower concentrations of CO_2, together with poor competition for available moisture in the upper layers of the soil, cultivated a favourable environment for woody seedlings to establish themselves.
- **The well-known fact that plant (grass) residues contain chemicals that can inhibit seed germination:** In the absence or scarcity of plant residues on the surface this factor was removed and conditions for woody seedling establishment improved.

Denudation of land during specific eras provided very favourable conditions for bush to establish itself. This conclusion is in line with various research results (Donaldson 1969; Teague & Smit 1992) that show woody plants establish themselves after periods of severe drought followed by a few wet years, and then maintain themselves by utilising most of the water. Rather than a gradual annual increase in numbers, the general rule is that woody plants establish in large numbers during certain years and at varying intervals (Donaldson 1969). This characteristically sudden increase of woody plants during certain years has also been recorded by Story (1952).

Although relatively high stocking rates were applied during the above-average rainfall cycle from 1948 to 1957/8, stocking rates went down dramatically during the ensuing years. Since 1966, the applied stocking rate has never exceeded 10 ha per LSU. Even with stocking rates between 20 and 30 ha per LSU during the 1990s, farmers could not reverse the bush encroachment process. It should be noted, therefore, that other factors beyond farmers' control – and not stocking rates – probably played a more decisive role in bush thickening.

From evidence collected during the current study, the lower bush densities in communal areas, as compared with those on commercial farms, can in all likelihood be ascribed to the higher occurrence of veld fires. In commercial areas farmers have generally suppressed fires, besides being prohibited by law from burning their veld.

After analysing rainfall data for Grootfontein, Okahandja, Otjiwarongo, Outjo and Tsumeb, it is reasonable to hypothesise that new generations of bush established themselves during the first half of the 1960s, between 1973 and 1976, and with another generation after 1985. These periods represent a few wet years followed by a few poor rainy seasons.

2.2.3 Herbivory

As Teague and Smit (1992:62–63) point out,–

> African savannas have an evolutionary history of high levels of grazing and browsing ungulate herbivory, capable of significantly modifying vegetation structure and composition (Owen-Smith 1989). High grazing and browsing herbivory reduces the growth and reproduction of individual plants, influencing competitive outcomes and community composition. Invertebrate herbivory is significant (Frost et al. 1986; Teague 1987) but has not been widely studied. Today, most of the indigenous browsing and grazing herbivores have been replaced by domestic livestock, mainly cattle. This has placed a great deal of pressure on grazing resources and is one of the main reasons for large increases in woody biomass.

Figure [2.13]: Indigenous game made an important contribution in maintaining open savannas

Arid/eutrophic savannas are characterized by relatively high animal biomass and high levels of grazing and browsing herbivory, which results in relatively low plant biomass. In contrast, mesic/dystrophic savannas have high plant biomass, low animal biomass and relatively little herbivory (Bell 1982).

High levels of herbivory have resulted in a wide range of plant mechanisms to reduce or recover from herbivory. Generally, woody plants in mesic/dystrophic areas are characterized by foliage that is unpalatable to ruminant herbivores, and physical deterrents are rare or absent. Examples include *Brachystegia* spp., *Burkea africana, Combretum* spp., *Euclea spp., Ochna pulchra* and *Julbernardia globiflora.*

In contrast, defence in woody plants in xeric/eutrophic areas generally takes the form of structural deterrents such as thorns which reduce leaf accessibility rather than leaf palatability (Owen-Smith & Cooper 1987). Examples include the various *Acacia* species. However, chemical defence does occur in these species too. Increases in condensed tannins, associated with a decline in digestibility and reduced intake, have been measured in *A. karroo* in a eutrophic environment (Teague 1989c).

Ungulate herbivory are capable of changing the composition and structure of savannas and in combination with fire they can make a significant contribution in the control of invader bushes.

In addition to these defences, woody plants, in particular palatable species, are very resistant to herbivory (Teague & Walker 1988b; Teague 1989a, 1989b). Consequently, browsers [with the exception of elephants (Barnes 1985)] have almost no effect on the numbers of mature woody plants, even when browsing is sufficient to markedly alter plant size and structure (Walker 1985). The only significant control browsers have on woody plants is through their effect on seedling survival (Joubert 1966; Taylor & Walker 1978; Pellew 1983). Young established woody plants, such as *Acacia karroo*, have exhibited higher levels of defences than mature plants (Teague 1989c). Re-growth following a burn that achieves a good top-kill is apparently palatable for a short period (Trollope 1983). Therefore, fire is usually necessary, in conjunction with browsers, to control these young plants (Trollope 1983).

The properties of grasses growing in these two different environments (mesic and xeric) are rather different. In nutrient-poor situations, where nitrogen, in particular, is limited, grasses tend to rely on structural features to defend themselves. They are characterized by a high culm to leaf ratio, high fibre and low protein production (Bell 1982). In nutrient-rich environments, the production of protein and the grass quality are higher (Bell 1982) in the presence of grass genera such as *Digitaria, Panicum* and *Urochloa* but the incidence of "taste" defences increases and problems with unpalatable grasses such as *Bothriochloa* and *Cymbopogon* increase (Walker 1985).

Under moderate levels of defoliation, some woody (Teague & Walker 1988b) and grass (McNaughton 1985) plants exhibit over-compensation for amounts removed, which leads to enhanced production. This is usually limited to situations where moisture and nutrient conditions are adequate and where graminoids are palatable and short or medium in height (McNaughton 1985) and trees are palatable (Teague & Walker 1988b). This influences the ability of such plants to compete for resources and, therefore, community productivity.

The consumption of vegetation by herbivores accelerates energy flow and nutrient cycling. Nutrients bound up in standing plant matter are recycled more rapidly, maintaining a high level of available nutrients for plants (McNaughton 1985). Palatable, productive grasses are encouraged by relatively frequent defoliation and enhanced nutrient status, which results in enhanced community productivity (McNaughton 1985; McNaughton et al. 1988). Where the potential for the leaching of nutrients from the soil exists, rapid recycling through the vegetation and soil by herbivores may be crucial to the maintenance of the long-term nutrient status (Botkin et al. 1981). By reducing transpiration, defoliation also contributes to lower water use and may extend the number of growing days in a season (McNaughton 1985).

2.2.4 Biological interactions

Teague and Smit (1992:63) point out the following in the above regard:

> Within the constraints set by the primary determinants and modified by the secondary determinants, biological interactions modify the determinants and structure of plant communities.
>
> Different growth forms can co-exist stably in savanna regions because of the spatial and temporal separation of resource use and different growth abilities in variable complex weather sequences. As a consequence, the different patterns of climatic factors present many different growth opportunities to the different plant forms. Westoby (1980) describes three types of growth phase: growth acceleration phase, maximum growth phase and growth decline phase. Growth forms compete most with each other if they grow at the same time. The impact of grazing on different life forms differs greatly in different situations. Grazing does not favour perennials since they are in the growth phase for longer. The timing of different favourable environmental events favours one plant growth form over another.
>
> Rangeland dynamics cannot be interpreted with the classical concepts of succession (Westoby 1980). Competition is not symmetrical, so there is more than one possible outcome to competitive interactions. The growth form that competes successfully depends not only on the growth forms involved but also on what are present as established adults and what is most abundant. Thus perennial grasses can out-compete woody seedlings, but lose to adult woody plants. Similarly, annual grasses that can out-compete seedlings of perennial grasses and woody plants are often defeated by adult woody plants or tillers of established perennial grasses.

2.2.5 Trees and grass modifying primary determinants

In this context, Teague and Smit (1992:63) explain that –

> [i]nterference among neighbouring plants of diverse sizes, longevities and resource demands greatly modifies their respective growth rates. Each accesses water and nutrients to different depths, at varying rates and at different times of the year (Westoby 1980). Interference can be positive or negative (Harper 1977). The growth rates of neighbours can be increased by modifications to the microclimate (temperature and humidity), nutrient enrichment (leachate, litter fall, stem flow) or water status improvement (shading, stem flow, enhanced infiltration).
>
> The soil beneath a canopy generally has a higher nutrient status than the soil in open areas, often considerably so. This includes most of the mineral elements and carbon (Bosch & Van Wyk 1970; Kennard & Walker 1973; Smith & Goodman 1987; Belsky et al. 1989), which are present mostly because of the leachate [throughfall] and litter enrichment. Nutrient levels under canopies can be enhanced by the modification of animal behaviour. Birds use trees as perches, concentrating defecation under

canopies. Grazing animals selectively graze plants under the canopies and spend loafing time in canopy shade (McNaughton et al. 1988). Nutrients are therefore recycled in such areas, maintaining high fertility as well as importing nutrients to these areas. …

- Perennial grasses can out-compete woody seedlings, but lose to adult woody plants. Similarly, annual grasses that can out-compete seedlings of perennial grasses and woody plants are often defeated by adult woody plants or tillers of established perennial grasses.
- The soil beneath a canopy generally has a higher nutrient status than the soil in open areas.
- Trees, therefore, effectively recycle plant nutrients and thus maintain a high soil fertility.

These higher levels of nutrients under canopies take some time to develop. Belsky et al. (1989) ascribe the gradients in soil organic matter and nutrients away from the trunks of mature *Acacia tortilis* and *Adansonia digitata* trees to increasing tree size. The increase in nutrients under canopies may be due to tree roots gathering nutrients from soil below the grass[-]root level or from horizontal gathering of nutrients by lateral roots (Dye & Spear 1982). It is hypothesized that in mesic savannas, which support a greater number of trees growing more closely together, nutrients are redistributed vertically, as in forests, rather than gathered horizontally. In drier areas with woody plants spaced further apart, nutrients are redistributed horizontally and vertically. The rooting patterns of different tree species differ. As a result, the spatial distribution of water and nutrient uptake and, as a consequence, the resource availability for neighbouring plants, differs according to tree species (Leistner 1967; Cole & Brown 1976; Timberlake 1980; Van Vegten 1983; Tolsma et al. 1987). These nutrient and carbon changes away from the tree trunk do not entirely explain the species composition under tree canopies (Belsky et al. 1989).

Water availability and patterns of water distribution are strongly influenced by tree stem location and the spatial distribution of tree crowns, grass tufts and roots of trees and grasses. Infiltration is highly dependent on grass cover, making it a critical element in community dynamics and productivity (Walker 1985).

Under-canopy sites are associated with higher rates of water infiltration and soil water-holding capacity (Kennard & Walker 1973; Olsvig-Whittaker & Morris 1982; Smith & Goodman 1987) due to soil textural and structural differences. In addition, the crown governs water availability distribution by intercepting precipitation which then either evaporates or moves to the ground surface from the leaves by throughfall or by stemflow (Stuart-Hill et al. 1987; Belsky et al. 1989). There are only small differences in throughfall, drip and stemflow between woody species. The major determinants are tree size, leaf area, and rainfall duration and intensity (De Villiers 1976, 1982; De Villiers & De Jager 1981). However, under-canopy sites also have a higher rate of soil water depletion. Soil moisture is adequate for grass growth on cleared treatments for much longer than on uncleared treatments (Kennard & Walker 1973; Olsvig-Whittaker & Morris 1982; Pratchett 1978; Pieterse & Grunow 1985).

In dry savannas, grass and trees use soil moisture at very different rates (Frost et al. 1986). Use of water by grasses appears to be governed largely by atmospheric demand, while that by trees appears to be governed more by soil moisture availability (Walter 1971; Pendle 1982). Grasses seem able to maintain relatively high transpiration rates, even at soil moisture levels close to wilting point, whereas trees regulate their water use as the soil dries out. Thus[,] grasses use soil moisture much more rapidly and completely than do trees, with obvious consequences for competition, growth patterns and productivity.

Shading reduces light intensity, ground[-]level temperatures and evapotranspiration (Wu et al. 1985) and increases air humidity slightly. High levels of shading limit the growth of under-canopy plants but with moderate levels of shade, the negative effect of reduced light intensity is insufficient to counter the combined influence of factors positively influencing growth. Thus, Kennard & Walker (1973) and Walker (1974) found that grass yield under open canopies was greater than that in the open, which in turn, was greater than that under closed canopies. Nevertheless, the degree of shading found under even light shade, such as *Acacia* spp., is limiting to the growth of under-canopy grasses and woody species. Although germination and seedling survival of *Panicum maximum* (Kennard & Walker 1973) was enhanced markedly under canopies, that of the open area grass species, *Heteropogon contortus* and *Hyparrhenia filipendula*, was not affected. The litter layer under trees reduced the germination of *H. contortus* and *H. filipendula*, but not that of *P. maximum*. *Digitaria eriantha* is also well known for its co-existence under trees [especially *Terminalia sericea:* author's personal observation in sandy soils of eastern and northern Namibia]. This partial tolerance of shade exhibited by seeds and seedlings was not exhibited at all by mature grass plants (Bosch & Van Wyk 1970; Kennard & Walker 1973). If good grass cover is maintained, bush has little effect on soil temperature (Pratchett 1978). A good cover of grass would, therefore, have a negative shading effect on grass and woody seedlings.

2.2.6 Bush–grass competition

Teague and Smit (1992:64) give the following insightful information in respect of the competition between bushes and grass:

> Negative interference can result from competition for water, nutrients and light and from allelopathic substances or accumulation of litter (Wu et al. 1985). The balance between the positive and negative interferences will result in productivity differences between the plants in the community. This will ultimately determine plant community structure and composition. Differences in levels of determinants and species composition result in site[-] and situation[-]specific differences.
>
> The generally accepted theory of bush–grass competition was first proposed by Walter (1954; cited by Skarpe 1990[b] and later developed in more detail by Walker et al. (1981), Noy-Meir (1982) and Walker & Noy-Meir (1982). It states that grasses are superior competitors for water in the upper soil layer so that trees compete successfully by virtue of their exclusive use of subsoil water. Although this model has been shown (Knoop & Walker 1985; Stuart-Hill et al. 1987; Stuart-Hill & Tainton 1989) to be an over-simplification, nevertheless, where the two exist together, grass roots are always at a higher concentration in the upper soil layers than tree roots, except under external mediation such as heavy grazing.
>
> Even very shallow-rooted trees like *Colophospermum mopane* do not co-exist with grass unless sufficient moisture is available below the soil dominated by grass roots (Dye & Walker 1980). *Colophospermum mopane* seedlings could not establish where the grass cover was dense (Thompson 1960). The outcome of competition depends largely, therefore, on the proportion of water which is retained in the upper soil layer and that which moves to the lower soil where tree roots predominate (Walker 1985). Factors which influence this, such as soil texture, rainfall intensity and pattern, therefore, also have a strong influence on the outcome of bush–grass competition. Other factors modify this primary factor, often considerably. Such factors include shading, temperature and nutrient differences (Walker 1985). The degree of modification and its effect on bush–grass competition depends on the level of the factor involved and the specific response to each factor for each species. Small differences can be additive and compound, resulting in large net effects (McNaughton et al. 1988; Westoby et al. 1989).

One of the important factors mentioned above is the distribution pattern of the roots of woody plants. According to Wu et al. (1985), this pattern is fundamental to the interaction between woody plants and herbaceous plants.

Rutherford (1980) found that the roots of some species in *Burkea* savannas extend linearly up to seven times the extent of the canopy.

In the case of *Colophospermum mopane* trees, Smit (1994b) pointed out that the roots extended horizontally to a distance of 7.6 times their height and 12.5 times the extent of their canopies. Thus, the larger the tree, the larger the area of resource depletion and the greater its competitive effect on its neighbours (Smit 2002). A large proportion of the roots are concentrated at a shallow depth (Rutherford 1983; Castellanos et al. 1991; Smit & Rethman 1998b), where they actively compete with shallow-rooted herbaceous plants.

Smit and Rethman (1998b, as cited by Smit 2002) found that the total root biomass of *Colophospermum mopane* ranged from 9,760 kg per hectare to 29,790 kg per hectare (mean 17,354 kg per hectare). A mean of 66.1% of the fine roots (<5 mm) was found within the first 400 mm of the soil. The highest concentration of the coarse roots was in a soil depth of between 200 and 400 mm, with virtually no fine roots in the 0–200 mm soil layer. The leaf biomass was significantly lower than the root biomass. Roots of *Colophospermum mopane* are able to utilise soil water at a matric potential lower than that of grasses. This feature, combined with high rainwater run-off losses due to lack of herbaceous cover, resulted in a dramatic reduction in the amount of water available to plants as well as an increase in tree density. This enables *C. mopane* to compete successfully with herbaceous plants and to prevent their establishment at high tree densities (Smit & Rethman 1998b, as cited by Smit 2002).

Teague and Smit (1992:64–66) offer the following further insight:

> The effects of positive interference can result in increased grass productivity when positive interferences exceed competitive interferences (Bosch & Van Wyk 1970; Kennard & Walker 1973; Walker 1974; Pratchett 1978; Aucamp et al. 1983; Stuart-Hill et al. 1987; Belsky et al. 1989). Competitive influence is proportional to a number of factors. These include plant size, leaf area, rate of metabolism, and the degree to which the competing plants access resources from the same area or at the same time, or deplete limited resources at other times or otherwise interfere with each other (Harper 1977). Competition

is highly dynamic so that more than one outcome is possible from a given situation, depending on different events and levels of determinants.

Any factor which negatively affects the woody component results in higher herbaceous productivity and vice versa. Thus, trees are favoured if undefoliated grass becomes moribund and less vigorous. Heavy grazing also favours tree growth owing to a decrease in competition and an increase of water to the subsoil (Story 1952; Du Toit 1966; Joubert 1966; Donaldson 1969; Trollope 1981; Knoop & Walker 1985; Friedel & Blackmore 1988; Stuart-Hill & Tainton 1989; Skarpe 1990[b]). Grass removal increases tree growth (Stuart-Hill & Tainton 1989). In contrast, grass rested during the growing season and grazed only in winter, or grazed lightly, has a strong competitive effect on woody plants (Walter & Volk 1954; cited by Skarpe 1990[b]; Joubert 1966; Donaldson 1969; Van Vegten 1983). Stimulation of woody plants by moderate defoliation (Teague & Walker 1988b) reduced grass growth (Stuart-Hill & Tainton 1989) while the reduction of tree growth and leaf area by heavy browsing, decreased competition with the grass component. Fire, too, can have a negative effect on grass (Trollope 1983; Friedel & Blackmore 1988) or on the woody component (Van der Schijf 1964; Joubert 1966; Trollope 1983), depending on the type of fire and conditions prevailing at the time.

Notwithstanding the number of references detailing maximum grass production at a low, compared with zero, tree biomass level (Bosch & Van Wyk 1970, Kennard & Walker 1973; Walker 1974; Pratchett 1978; Aucamp et al. 1983; Stuart-Hill et al. 1987, Belsky et al. 1989), by far the majority of trials that investigate the effect of clearing tree species show substantial increases in grass productivity with complete or nearly complete removal of trees (Joubert 1966; Kennan 1969; Donaldson & Kelk 1970; Louw & Van der Merwe 1973; Pratchett 1978; Grossman et al. 1980; Dye & Spear 1982; Moore et al. 1985; Moore & Odendaal 1987; Friedel & Blackmore 1988; Moore et al. 1988).00

- It is, however, important to realise that the increase in production after bush clearing is not permanent and invader bushes or their substitutes will re-establish. It is generally observed that there is a strong trend for bushes to reinfest after a few years. Therefore, aftercare becomes an indispensable part of wood management.

- Ludwig (2001) points out that these positive effects of bush clearing disappear after some years, depending on the soil type, and bushes start to repress grass productivity.

Proper rangeland management will certainly have a major influence on the extent and rate of reinfestation. In this regard Smit and Rethman (1997) conclude that the longer the period that severe grazing reduces the competitive ability of the grasses, the better the chances of woody seedling survival. Therefore, an increased rate of woody plant establishment is the response to an increase in the severity of grazing.

These differences can be partly ascribed to competitive release, nutrient release from decaying tree organs (above and below ground) and the enhancing of topsoil nutrient status through nutrient cycling by the tree component for a period before clearing. However, the explanation for such apparent discrepancies lies in understanding how different determinants and individual species characteristics influence competition. The use of a theoretical discontinuous function (see Figure [2.14]) explains these apparently contradictory situations.

As a general rule the quality of grass decreases following woodland management, especially on sandy soils (Scholes 1988). This is due to loss of high quality sub-canopy grass and, if soil disturbance takes place, an increase in low quality opportunistic grass species. Grass quality on dry, clayey sites may be improved by bush clearing due to a shift from unpalatable annuals to more moisture-loving perennials (Scholes 1988).

Given a hypothetical mesotrophic, medium rainfall savannah, it is hypothesized that with a vigorous grass sward under light to moderate grazing and browsing levels and periodic fires, the grass response to different levels of tree biomass would be represented by curve “a”. In contrast, curve “b” represents what usually happens under pastoral management. Heavy grazing pressure and an absence of fire and browsing pressure combine to reduce the competitive ability of the grass and increase the numbers and biomass of the tree component. Part of line “b” is broken since it is by no means certain that once an area has degraded it will return to the original point of departure.

An experiment to determine the relation between grass productivity and tree biomass in situations “a” and “b” would give very different results. In both situations, the nutrients accumulated from nutrient cycling by trees and those released above and below ground owing to the decay of woody material and competitive release would enhance grass productivity, but the extent would differ in each situation.

In addition, in situation "b", grass cover would have declined and the grass would be much less competitive (Pieterse & Grunow 1985; Skarpe 1990b) owing to: reduced grass vigour and decreased grass root mass (Opperman et al. 1970; Ruess 1988; Brown & Archer 1989) and rooting depth. Depending on the physical and chemical composition of the soil, soil "capping" (MacDonald 1978) may also take place as part of soil structural changes (Friedel & Blackmore 1988). These factors lead to reduced infiltration (Walker & Noy-Meir 1982) and lower water-use efficiency by the grass component (Snyman et al. 1980).

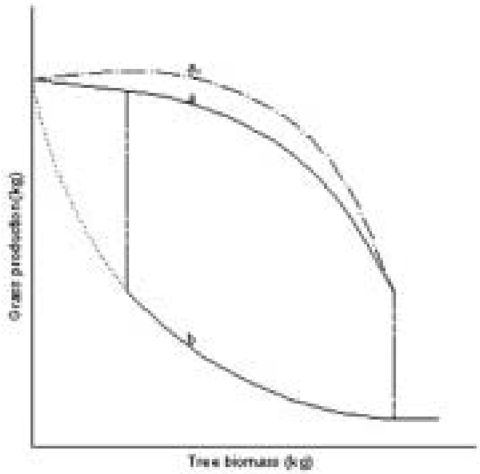


Figure 2.14 represents a hypothetical discontinuous function explaining the response of grass production to increasing tree biomass within and between sites differing with respect to past management, different levels of determinants and species compositions. (a) [r]epresents sites with a history of lenient grazing and sites where the majority of determinants favour the grass component. (b) [r]epresents sites with a history of heavy grazing and sites where the majority of determinants favour the tree component. (a1) [r]epresents the extreme of situation (a). Vertical, broken lines indicate the theoretical area of discontinuity.

Figure [2:14]: Relation between grass productivity and tree biomass in two hypothetical situations

A number of studies have indicated that moderate utilization of grass reduces the establishment of tree seedlings and decreases the growth of mature trees (Joubert 1966; Brown & Booysen 1967; Du Toit 1967; Strang 1969; Friedel & Blackmore 1988; Moore et al. 1988). Some observations indicate that trees may even eventually be killed by lightly-utilized or totally-rested grass (Walter & Volk 1954; cited by Skarpe 1990[b]; Van der Schijf 1964; Joubert 1966; Van Vegten 1983).

Trees may also be adversely affected by the decreased infiltration of moisture into the soil as a result of reduced grass cover. However, the woody component is relatively less affected, since stem flow ensures that a significant amount of incoming rainfall enters the soil and there is reduced competition from the grass component (Walker & Noy-Meir 1982). The tree roots probably move into spaces left in the upper soil layers by the decrease in grass roots, giving the trees a competitive advantage, probably preventing grass recovery, even with the removal of adverse grazing levels (Story 1952; Du Toit 1966; Joubert 1966; Donaldson 1969; Du Toit 1972; Trollope 1981). Sites where animals congregate, such as near gates and watering points, are the first to degrade. Thicket formation is often the result.

Thickets often have almost no grass growth under them or for some distance surrounding them, since stock have to move around them. Grass production is severely limited and bare areas result. These degraded situations spread to other parts of the paddock as grazing and hoof pressure shift to them. Eventually, large portions of paddocks are dominated by thickets and accompanying bare ground.

All the factors in situation "b" constitute an inertia that would make recovery to situation "a" very difficult (Moore et al. 1988). It is probable that only complete tree removal, some soil surface modification and reseeding with desirable grasses will overcome this inertia. Such a situation may constitute a different domain of attraction as outlined by Walker & Noy-Meir (1982) and could indicate that the bounds of resilience of the former system have been exceeded. An alternative hypothesis is that such thickets might break down within one generation of the woody species present and that grass could then re-establish, depending on prevailing grazing pressure. However, we do not have information covering such time scales.

The basic model presented (Figure [2.14]) is modified considerably according to the properties of different species and the levels of determinants pertinent to each site and situation. Tree species differ considerably in the degree to which they compete with grasses (Teague 1989d). Acacias and similar microphyllous tree species provide very little shade, unlike many broad-leaved and evergreen species (Teague 1989d) which provide dense shade, often resulting in much-reduced grass production. Acacias in the same situation provide only enough shade to slightly reduce grass productivity (Stuart-Hill 1985).

Conversely, Belsky et al. (1989) found very little difference between two very different tree species in regard to nutrient accumulation under canopies. Similarly, redistribution of intercepted rainfall was not significantly different for a number of southern African woody species (De Villiers 1976, 1982; De Villiers & De Jager 1981). Rooting depths differ significantly between tree species (Leistner 1967; Cole & Brown

1976; Timberlake 1980; Van Vegten 1983; Tolsma et al. 1987). Acacias generally have a well-developed tap root and a well-developed lateral root system. Many of the smaller *Acacia* spp. colonize readily. They are able to compete favourably with grasses since they rapidly develop a strong tap root (Du Toit 1966) and later consolidate by developing a strong lateral root system. Their ability to fix nitrogen (Dye & Spear 1982) probably enables them to compete in a wider variety of circumstances. In some savanna areas (Smith & Walker 1983; Smith & Goodman 1986), evergreen tree and shrub species tend to be shallow-rooted and canopy-tolerant. Being bird-distributed, they establish under acacias, eventually growing through the *Acacia* canopy and dominating. Their dense shade and shallow root systems exclude grasses completely. Therefore, when they are the dominant part of the tree component, the situation is represented by situation "b" (see Figure [2.14]).

As indicated, changes in both primary and secondary determinants influence bush–grass competition enormously. Curve "a" is possible only when all, or most, conditions favour grass. Relevant factors include: tree species that give low shade, tree species that have a root system separate from that of the grass component; the presence of elevated sub-canopy nutrient levels; fine soil texture; the presence of an impeding soil B horizon; low[-]intensity rainfall, which falls during the grass growing season; low grazing intensity and high browsing intensity.

The more the determinant factors favour the tree component, the more the situation will be represented by curve "b" (Figure [2.14]). The extreme situation is represented by broad-leaved trees with dense canopies growing in deep, well-drained, sandy soils, a short rainy season, a low incidence of low-intensity rainfall events and low levels of browsing pressure. *Miombo* savanna, containing tree species such as *Brachystegia boehmii, B. spiciformis* and *Julbernardia globiflora*, approaches this extreme situation "b". In addition *B. spiciformis* probably also has an allelopathic influence (Walker 1985).

Previously cultivated fields favour woody plants enormously, especially *Acacia* spp. which are able to fix nitrogen and rapidly develop a tap root and lateral roots. They are able to compete easily with shallow-rooted herbaceous weed species (Joubert 1966). The surface soil structure of old lands usually facilitates water movement into the subsoil, further favouring woody plants (Van Vegten 1983; Tolsma et al. 1987).

In dry savannas, grass and trees use soil moisture at very different rates (Frost et al. 1986). Use of water by grasses appears to be governed largely by atmospheric demand, while that by trees appears to be governed more by soil moisture availability (Walter 1971; Pendle 1982). Grasses seem able to maintain relatively high transpiration rates, even at soil moisture levels close to wilting point, whereas trees regulate their water use as the soil dries out. Thus, grasses use soil moisture much more rapidly and completely than do trees, with obvious consequences for competition, growth patterns and productivity.

2.2.6.1 Conclusions

- Grass roots are mainly present in the topsoil layers, while those of bushes are mainly in the deeper layers.
- Grasses are superior competitors for water in the upper soil layer until wilting point is reached, whereafter some woody species have exclusive use of the remaining water. Trees compete successfully by virtue of their exclusive use of subsoil water.
- Grass–tree competition is also influenced by the proportion of water retained in the upper soil layer and that which moves to the lower soil where tree roots predominate.
- Any factor which negatively affects the woody component results in higher herbaceous productivity, and vice versa. Thus, trees are favoured if undefoliated grass becomes moribund and less vigorous.
- By far the majority of trials that investigate the effect of clearing tree species show substantial increases in grass productivity with complete or nearly complete removal of trees.
- It is by no means certain that once an area has degraded it will return to its original harmonious state.
- From the research findings in this section it is clear that moderate utilisation of grass reduces the establishment of tree seedlings and decreases the growth of mature trees. Some findings indicate that trees may even eventually be killed by lightly-utilised or totally-rested grass.
- The tree roots probably move into spaces left in the upper soil layers by the decrease in grass roots, giving the trees a competitive advantage, probably preventing grass recovery. Grass production is severely limited and bare areas result.
- Acacias generally have a well-developed tap root and a well-developed lateral root system. Many of the smaller *Acacia* spp. colonise readily. They are able to compete favourably with grasses since they rapidly develop a strong tap root (Du Toit 1966) and later consolidate by developing a strong lateral root system.
- Previously cultivated fields favour woody plants enormously, especially *Acacia* spp., which are able to fix nitrogen and rapidly develop a tap root and lateral roots.

2.2.7 Effect of tree competition on trees

Teague and Smit (1992:66) offer the following views on this topic:

> Competition between trees is an important mechanism controlling grass production and the size and density of trees (Smith & Walker 1983). The growth and subsequent size that any individual tree can achieve is a function of the resources to which it has access. This, in turn, is a function of available water and nutrient levels and of the proximity and size of neighbouring individuals. The larger the tree, the larger the area of resource depletion and the greater the competitive effect on neighbours (Smith & Goodman 1986). As individuals die, due to competition or to factors extrinsic to the population such as fire, herbivory or drought, the resulting gaps will allow either the increased growth of neighbouring individuals or the establishment of new individuals.
>
> Tree[-]on[-]tree competition is very species[-]specific. Many species can co-exist with little, or no, competition if they differ in factors such as root distribution (Leistner 1967; Cole & Brown 1976; Timberlake 1980; Van Vegten 1983; Smith & Goodman 1987; Tolsma et al. 1987) and life strategy traits (Teague 1989d) which make use of different areas of space or times of the year, or in more efficient use of scarce resources. Thus, Smith & Walker (1983) and Smith & Goodman (1986, 1987) found an apparent lack of competition between *Acacia* and broad-leaved tree components. The acacias showed little regeneration under the canopies of trees. In the area in which they worked, the broad-leaved evergreen tree species are apparently canopy-tolerant, either being clumped under the canopies or independent of established acacias. These studies indicate that where the potential exists, African acacias probably facilitate the invasion of broad-leaved woody plants, eventually leading to dominance by them. Many of the broad-leaved evergreen woody plants compete more strongly with grasses (Teague 1989d). Since most of the tree species co-occurring with acacias are palatable to browsers (Trollope 1981, 1983), fires and browsing maintain a low population of mature *Acacia* trees that compete very little with the grass layer and compete strongly with small *Acacia* plants.
>
> Since grass and tree root distribution is most similar on soils with a high clay content (Knoop & Walker 1985, Stuart-Hill & Tainton 1989), tree–tree competition is more likely to benefit grass production on sandy, well-drained soils where there is more separation of grass and woody roots and where rainfall events result in deeper moisture penetration. However, this needs testing.
>
> It is hypothesized that, in many areas where trees cause encroachment problems, a relatively low number of larger trees in conjunction with the use of periodic fires, the managed presence of browsers and moderate grazing pressure, will result in the highest level of sustainable pastoral productivity, the lowest recurring management input costs and a high level of floral and faunal diversity.

2.2.8 Effect of clearing on animal performance

The views of Teague and Smit (1992:66–67) on this subject are as follows:

> Although the primary aim of thinning or removing woody plants is usually to increase grazing animal output, very few studies have used animals to evaluate the response to clearing. Indications are that increases in animal performance with clearing are much less than the increases, if any, of grass production (Louw & Van der Merwe 1973).
>
> Although they did not measure animal performance, Grossman et al. (1980) measured higher grass biomass in the open sub-habitat than in the canopy sub-habitat. However, the total *in vitro* digestible organic matter yield was the same in the two sub-habitats. They suggest that clearing would not influence animal production very much. Similarly, although Pieterse & Grunow (1985) measured increased dry matter, crude protein and digestible organic matter production without deterioration in the quality of the different species, the highest increase in production was for *Themeda triandra* which had the lowest quality of all the grasses. As a consequence, they did not expect an increase in animal production to be as high as the increase in grass production following clearing.
>
> The above examples suggest the following hypotheses. Firstly, when clearing in oligotrophic or dystrophic situations, maintenance of a threshold woody biomass would be necessary for sustainable use, since clearing beyond this level would not result in increased animal performance. The primary limiting factor in such situations is fertility, as discussed by Bell (1982), and complete clearing may lower long-term soil fertility.
>
> Secondly, when clearing in eutrophic or mesotrophic situations, the increase in animal performance is not as great as the increase in grass production. In these situations, a much lower threshold of woody plant density would be necessary for the highest sustainable animal production. This level would relate to the density necessary to offer adequate shelter and to allow for the highest sustainable production of digestible

forage. This latter point is closely related to the maximum margin of positive over negative interference factors, for the site and situation.

The use of browsers in combination with cattle could pose a solution to the poor performance level, provided enough woody biomass is still available (Aucamp 1976; Aucamp et al. 1983; Stuart-Hill et al. 1987; Bester & Reed 1998).

2.2.9 Temperature

According to Donaldson (1969), it appears that *Acacia mellifera* (Black thorn) does not tolerate excessively cold or warm humid conditions since it does not occur naturally in these climatic areas. Other biotic and biological factors may also account for its absence in these areas.

Acacia mellifera is mainly found in relatively hot arid areas with a rainfall varying between 200–500 mm. The mean annual precipitation within the range of Black thorn in Namibia and in the Northern Cape Province in South Africa is, on average, about 306 mm per annum.

Donaldson (1969) found that there was a decrease in maximum temperatures and an increase in minimum temperature values from the 1-foot (30-cm) to the 15-foot (4.5-m) positions.

The mean maximum temperature figures for the 1-foot (30-cm) and 4-foot (120-cm) thermometer positions of the bush area were much higher than the temperature values obtained from these respective positions for the grass area. Furthermore, there was virtually no difference in the mean maximum temperature readings at the 15-foot (4.5-m) positions of the two study areas (Donaldson 1969).

It can be concluded that the lower air layers (outside the canopy spread of woody plants) of moderately dense bush were much warmer than the respective air layers of the pure grass area of the veld.

2.2.9.1 Conclusions

The occurrence of a new bush generation during the 1960s as well as abundant canopy growth in adult plants during subsequent favourable rainy seasons in the 1970s could have had a major influence on the frequency and occurrence of frost at grass-root level. It can be assumed that these conditions favoured seedling establishment.

These findings suggest that frost could not reach ground level but instead occurred at a 3-m or higher level. Therefore, frost-sensitive seedlings like *Dichrostachys cineria* had a better chance for survival under these circumstances than in open grasslands (Smit 1990).

Anecdotal evidence in support of the above research findings is the occurrence of *Acacia mellifera* thickets on the slopes and top of the dunes between Seeis and Omitara. This area is well known for temperatures that occasionally drop to extremely low levels during winter, and the plains between the dunes do not show any (significant) bush encroachment problems. It can be concluded that the lower areas are much more exposed to frost and, therefore, the establishment of seedlings, and bush thickening is kept under control.

Research work done on the impact of frost on invader species is still very limited and should be attended to.

2.2.10 Droughts and rainfall

Donaldson (1969) concluded that rather than a gradual annual increase in numbers, the general rule is that woody plants establish in large numbers during certain years and at varying intervals. This characteristic sudden increase of woody plants during certain years has also been recorded by Story (1952).

Hagos (2001) and Smit (pers. comm.) found that *Acacia mellifera* seeds are not transferable from one year (season) to another. This means that seeds produced during early summer need to germinate and become established during the subsequent rainy season. This view is supported by Bester (pers. comm.). His observations/findings are that the vast majority of seedlings in a specific rainy season will not survive. Even those that do survive need at least two or three good rainy seasons in succession to become established for good.

During periods of drought most of the grazing is depleted and very often soils are denuded. This situation creates a vacuum where seedlings of invader bushes – amid one, two or more good rainy seasons – can establish themselves because they are favoured by the initial absence of competition. Kraaij and Ward (n.d.) conclude that above-average rainfall years with frequent rainfall events are required for mass tree recruitment.

Grass defoliation makes space and resources available for tree seedlings. Contrary to conventional wisdom that says grazing alone causes encroachment, we suggest that there are complex interactions between factors like moisture, nutrients, fire and herbivory, as well as "trigger" events such as unusually high rainfall.

2.2.11 Distribution of seeds

Donaldson (1969), in his review of the process of seed production, dispersal of seeds and seedling establishment, states that –

> [T]he invasion of blackthorn into the Savannah veld is characterised by a concentration of a number of plants in clumps or thickets, which appear to be contagiously distributed. In the initial stages of invasion these thickets generally consist of one or more large mother plants surrounded by younger plants of two or more age groups.
>
> Blackthorn propagates essentially from seed. Unlike most of the other woody plants growing in the Molopo area of South Africa, the blackthorn flowers only during spring (September–October). The seed ripens towards the middle of November or beginning of December. There is a great variation in the gross yield of seed-pods from year to year and the yield of individual plants is also irregular.

As was mentioned previously, the seeds of *Acacia mellifera* are not transferable to the next season (Hagos 2001).

Donaldson (1969:10–24) also has the following insights in this regard:

> The total number of seeds of four average-sized blackthorn plants was calculated during the 1963 season. The mean height, canopy diameter and number of stems of these plants were 10 feet, 12 feet and 6 feet, respectively. The data showed that the average number of seeds produced per tree equaled 12,246 seeds; 4,678 seeds were shriveled and wrinkled and 306 had been damaged by insects. From observations of seeds in the field and those stored in the laboratory it was evident that blackthorn seeds were not attacked by insects as readily as those of other woody plants such as *Acacia erioloba* and *Acacia hebeclada* which have a much harder testa. A possible explanation for this phenomenon may lie in the fact that the cotyledons of blackthorn seed are very much thinner and smaller than those of the other plants mentioned. The apparently normally developed seeds and shrivelled seeds were subjected to germination tests. The greater portion of seeds shed fell within the leaf canopy of the mother plant. Despite this potential source of seed, the presence of seedlings or juvenile plants underneath the crown spread was the exception rather than the rule. The presence of relatively large numbers of plants of various age groups in the area around the mother plant is a typical characteristic of blackthorn and various other woody plants.
>
> Seeds of blackthorn while still attached to the papery pods were blown into this zone by winds. Animals may to a lesser extent transport seed to areas away from the parent plant. The likelihood of seeds and pods being transported over long distances by whirlwinds cannot be overlooked.
>
> Of further interest and importance is perhaps the fate of the thousands and thousands of seeds after they have been dislodged from the parent plant. From careful observations in the field of the seeds lying scattered on the soil underneath and around the mother plant the following facts came to light: ***it was noticed that after good rains practically all the seeds absorbed moisture, increased in size and, on drying, shriveled and ultimately disintegrated. No seedlings emerged during these observations.*** [Emphasis added]
>
> ***It was found that out of 895 seeds only 4 blackthorn seeds appeared to be unaffected by rains. Approximately 891 partially disintegrated seeds were recorded. That means that 99.5% of the seeds were initially destroyed by rainfall moisture.*** [All emphases added]
>
> 100 dung pats were selected at random from the area and examined for seed. From the 100 dung pats a total of 60 *Acacia reficiens*, 33 *Acacia hebeclada* and 45 *Acacia erioloba* seeds were collected. These seeds were subjected to a germination test in the laboratory for a period of three weeks at a temperature range of 75° to 90° F; 18%, 20% and 33% of the respective *Acacia hebeclada, Acacia reficiens* and *Acacia erioloba* seeds germinated, while 37%, 35% and 27% of the seeds rotted and shrivelled up. The apparently normal seeds which were not affected by the germination tests were scarified with a file and subjected to further germination tests. The results revealed that 86%, 66% and 50% of the respective *Acacia hebeclada, Acacia reficiens* and *Acacia erioloba* seeds germinated. The entire absence

of blackthorn seeds in the dung pats examined as well as in cattle faeces examined on many previous occasions suggests that cattle do not distribute seeds through their dung.

In a follow[-]up trial where 600 blackthorn seeds were included in the rations of steers it was found that only 59 (10%) were recovered in the faeces. Most of these seeds rotted and shriveled on drying. Of them only 18 (30%) germinated. This means that only 3% of the total number of seeds consumed by cattle ultimately germinated in the laboratory.

The experiment was repeated with the exception that each steer received 100 seeds of blackthorn plus 100 seeds of *Acacia erioloba*. The results indicated that 34 blackthorn seeds were recovered out of the total of the 300 seeds ingested. Most of these had been damaged by the digestive juices of the rumen. Only six seeds germinated, or in other words two per cent of the total number of seeds. From the 36 *Acacia erioloba* seeds recovered only 24 (8%) of the total number consumed germinated.

From the results above it can theoretically be calculated and deducted [*sic*] that out of the approximately 12,000 seeds produced by an average[-]sized blackthorn either 60 seeds may survive destruction from rain water or should all the seeds be ingested by cattle approximately 240 would survive via the dung. These facts also emphasize the importance of the animal as an agent for the dispersal of seeds of woody plants, provided that the pods and seeds of the plant can be consumed in large amounts. [It should, however, be emphasised that *Acacia mellifera* seeds are not distributed by animals (Smit[,] pers. comm.) and are not transferable from one season to the other (Hagos 2001).]

The characteristic dormancy of the seeds of woody plants may also ensure a steady build[-]up in numbers of seed in the soil. Despite this characteristic and the constant annual supply of relatively large numbers of potentially viable seed it is a significant fact that there has been no gradual increase in seedling numbers (large or small) from season to season. Not a single seedling of blackthorn has been observed during the three-year period at the experimental sites.

The invasion of woody plants into grassveld areas is made possible by a complete and complex process of which migration, ecesis, and competition are essential parts. Comparatively speaking, it is evident that the size of the seed of most undesirable woody species is such that, in the absence of the action of distributing agents such as birds and animals, migration will generally be limited to the area of seed production. Water as an agent of dispersal in spreading seed of these plants over long distances and into new areas, is limited to low[-]lying and [downstream] areas. Normal winds are capable of distributing seed only to limited areas within the immediate vicinity of the plant. The dispersal of seed into distant areas by whirlwinds, etc., should, however, not be overlooked as a means of migration.

Under normal conditions, however, there is no doubt that animals and birds are the most important agents responsible for the dispersal of the seed of most woody plants. Evidence in support of this statement is referred to in this paper and elsewhere (Bews 1917; Galpin 1926; West 1951; Acocks 1953; Mostert 1957). The seeds of woody plants are subject to much damage and injury prior to, during and after dispersal. The seeds of plants such as blackthorn, which ripen evenly and are quickly dislodged from the pods and hence are accessible to animals for dispersal for a relatively short period, generally suffer mass destruction by natural causes.

As previously mentioned, approximately 0.5% of blackthorn seeds may initially survive from rains falling after seed dispersal. The seed enclosed in the ripe pods of plants which retain their pods over a longer period (e.g. *Acacia erioloba and Acacia hebeclada*) and which are therefore more likely to be taken by animals, are more likely to suffer damage from insects. That a host of natural enemies is responsible for the destruction of large quantities of seed every season has been reported by Potts & Tidmarsh (1937) and Story (1952).

For blackthorn the accumulation of seed supply may mainly be restricted to an area within the canopy spread and also a zone adjacent to the plant. For plants which retain their pods for a considerable period and of which the pods are readily eaten by animals, the accumulation of seed will take place in areas where they are deposited via the faeces of the animal. The seeds accumulated in a specific area may remain dormant until conditions for germination become favourable. The long life of seeds of *Acacia* species is a well-known characteristic (Story 1952).

Alternatively, it is suggested that exceptionally moist and favourable conditions following immediately after the dispersal of seeds may result in an abundance of seedlings during good seasons. Evidence in support of this theory may be obtained from Story (1952). It was found necessary for *Acacia* seed to become buried at least partially if satisfactory germination was to result (Story 1952). The poor germination of 1.4% of *Acacia karroo* seed obtained from seed germinating on the surface was due to the rapid drying out of the seed (Story 1952). This drying out of seed as demonstrated by Story and as observed for blackthorn may explain why favourable seasons may be expected to bring on an abundance of seedlings, thus explaining the observation that blackthorn and other woody plants (West 1951; Story 1952; Acocks 1953) occur in thickets of the same size.

Bester (pers. comm.), however, observed that even after a good rainy season only a small percentage – if any – of the seedlings may survive.

Thus, the chief causes of the failure of woody plants to survive the seedling stage would include drought or absence of moisture in the root zone, lack of success in competition with the grass species, and damage by other causes such as veld fires and predation. In normal years the predation of insects on seeds is so severe that they hardly survive (Smit, pers. comm.).

Woody and bushy plants and trees of the Molopo area can be classified into two main groups according to their mode of seed dispersal and manner of invasion into grassveld, namely a Black thorn group and a Camelthorn group. The first group includes plants such as Black thorn (*Acacia mellifera* subsp. *detinens*) *Rhigozum obovatum* and *Dichrostachys cinerea*. The second group of plants consists of single-trunked trees such as *Acacia erioloba*, *Boscia albitrunca*, *Terminalia sericea* (confined exclusively to a sandy type of soil) and multi-stemmed bushy plants like *Grewia flava*, *Acacia haematoxylon* and *Acacia hebeclada*.

Bell and Van Staden (1992) postulate that *Dichrostachys cinerea* is a major contributor to the bush encroachment problem in Mkuzi Game Reserve. They explain that dormancy is imposed by the smooth, hard and impermeable testa. Scarification or cracks in the testa allow imbibition through the lens, which is followed by germination. The percentage of germination for *Dichrostachys cinerea* is higher in light than in dark[ness] and there is a loss of temperature sensitivity with time. The behaviour of *Dichrostachys cinerea* seeds was dissimilar from that typically reported for mimosoid seeds, since germination improved with storage, and light enhanced the germination of scarified seeds. This has important ecological implications, since seeds would germinate more easily where canopy has been removed or the soil has been disturbed.

Dichrostachys cinerea grows on a variety of soils within the Game Reserve and is one of the major contributors to the bush encroachment problem. It is a thorn bush belonging to the Leguminosae, subfamily Mimosaceae. Due to climate, stocking densities and management practices, dense thickets of this plant have formed, preventing grazing animals from reaching available grass. While the plant can make a valuable contribution as feed for browsing stock, it nevertheless reduces the carrying capacity of the veld.

The occurrence of hard-seededness in members of Leguminosae is well established (Bewley & Black 1982; Van Staden et al. 1989). It would appear, therefore, that *Dichrostachys cinerea* is not behaving exactly like other mimosoid seeds, since the removal of the characteristic water impermeable condition did not result in 100% germination. Instead, the germination of *Dichrostachys cinerea* improved with storage, while light appears to promote germination once seeds have been scarified. The improved response to light may be an important factor for seedling establishment in areas where fire occurs frequently or used as part of a veld management procedure. Canopy removal results in higher light intensities and may well increase seedling establishment and subsequent bush encroachment.

Drawing from research by Donaldson (1969:24–27) again, –

> ***[the] general characteristics of the blackthorn group*** include the following [Emphasis added]:
>
> (i) a characteristic increase of plants around the parent plant giving an effect of clumps or thickets of plants with a contagious type of distribution during the initial stages of colonization;
> (ii) sparseness or complete absence of grass plants within and immediately outside the crown spread of the plants;
> (iii) except for *Dichrostachys*, flowering is restricted to spring;
> (iv) the pods and seed of both are easily dislodged from the plant and either fall on the soil underneath the plant or are blown or fall away from the plant. The pods and seed are therefore only accessible to animals for a relatively short period. Although the pods and seed are taken by animals, the relatively papery and leather-like pods appear to be less palatable than those of plants belonging to the camelthorn group.
>
> ***Important features of the camelthorn group*** of plants may include [Emphasis added] –
>
> (i) the plants appear to be evenly scattered throughout the bushveld, tending to be randomly distributed;
> (ii) with the exception of *Acacia reficiens*, grass species appear to be able to grow within the crown spread of these plants;
> (iii) flowering generally commences during early summer and may take place throughout the summer period;

(iv) except for the plants that produce berries, the pods are relatively large, fleshy and pulpy.

The pods and seed are retained by the plants for long periods, often extending into the following season. The pods are readily eaten by livestock especially during the winter months. The berrylike fruits of *Grewia flava* and *Boscia albitrunca* are eaten by animals, but more so by birds and humans.

A characteristic phenomenon applicable to both groups of plants is the general absence of seedlings or juvenile plants within the canopy spread of the particular plant, despite the fact that most of the seeds shed, fall in this area. The presence of a seedling, a juvenile or a mature plant within the crown spread of a woody plant of a different species is often encountered.

An important factor which may assist in the establishment of woody plants (particularly plants of the blackthorn group) is the trampling effect of animals around mature woody plants.

The invasion into grassland of plants of the camelthorn group can be expected to be much slower than that of plants of the blackthorn group whose seed is not entirely dependent on animals for their dispersion. Furthermore, the seedlings of these plants ([c]amelthorn group) will be subjected to greater competition for light and moisture by grasses and more damage by veld fires than seedlings of plants growing in a relatively sparse grass cover adjacent to the parent plant.

Certain workers[4] suggest that the cause of bush encroachment is due to a change in the climatic conditions favouring the spread of these plants. From preceding discussions, however, it is apparent that it is not the normal relatively low yearly precipitation that assists in the establishment and spread of woody plants, but rather the relatively few and less frequent years with abnormally high rainfall that foster the spread of these plants.

Once the roots of the woody plants extend to the levels not occupied by grass roots, they will become less affected by competition for this factor provided that sufficient moisture in the underlying layers is available.

Approximately 100,000 ha are infested with different varieties and hybrids of *Prosopis*, mainly along Namibia's drainage systems. Dense stands of the four invasive species introduced occur along the Auob, Fish, Nossob and Swakop Rivers and their tributaries. Less dense stands occur also at scattered locations along the Khan, Oanob, Olifants, Omaruru, Schaap and Ugab Rivers. Many townlands are also infested to some extent, with Mariental, Okahandja, Omaruru, Rehoboth and Windhoek having the densest stands. Full-grown trees occur within most townlands of the central and southern parts of the country where they were planted by pioneers in the 20th century for shelter and forage (Smit 2002).

The *Prosopis* favours light-coloured soils and grows fastest on deep soils such as alluvial silt and wind-blown soil, but it thrives almost equally well on heavier, more clayey fluvial deposits and on loams containing loam concretions in the subsurface. Able to subsist on comparatively poor soil, it survives on shallow, gravelly or stony soils overlying limestone. It is very tolerant of brackish soils and is even able to withstand a certain amount of salt spray. Though *Prosopis* often grows near water, it is also sometimes found in areas so dry that few other plants would survive there. It survives – and even thrives – in soils of high salinity and low fertility. Although *Prosopis* usually needs a minimum annual rainfall of 250 mm, it can adapt to areas where the rainfall is as low as 75 mm or less per annum. *Prosopis* invasion does not occur in zones of high rainfall (above 400 mm per annum).

Figure 2.15: Prosopis *invasion along the Nossob River*

[4] Researchers

The *Prosopis* was introduced to southern Africa as a fodder and shade tree. The intention was to plant the trees in parts of southern Africa where the physical environment was similar to the arid zones of South America, where the genus originates. A major consideration with regard to Namibia was the similarity between the environments of the Atacama and Namib Deserts. Today, the *Prosopis* is common in Namibia and has become completely naturalised. It is often – mistakenly – assumed that the genus was first introduced to southern Africa via Namibia. Even the Afrikaans common name of the genus, namely Suidwesdoring, reflects this misinterpretation. Although early documents prove experiments with *Prosopis juliflora* had been conducted in Namibia since 1909, the exact date of its introduction is uncertain, and no consensus exists about the type of species introduced at the time. A couple of what can be assumed to be some of the original trees still exist on the old nursery site at Okahandja.

As regards the introduction of *Prosopis* to southern Africa in general, it appears that *Prosopis glandulosa* var. *torreyana* (Honey mesquite) was the first member of the genus to arrive, probably as early as 1880, having been brought in by a certain John Marquard and establishing itself near Vanwyksvlei (Smit 2002).

Stoltsz (2002) states that at least six species were imported to southern Africa, namely *Prosopis chilensis*, *Prosopis glandulosa* var. *glandulosa*, *Prosopis glandulosa* var. *torreyana*, *Prosopis juliflora* and *Prosopis pubescens*. As a result of hybridisation, a complex of hybrids with no clear identity occur over large parts of southern Africa.

The importation of especially drought-resistant *Prosopis* species was promoted by the Ministry of Agriculture in South Africa and led to large-scale establishment of the trees. The mass dispersal of seeds went unnoticed for more than a decade (approximately 1,300 seeds are excreted through animal dung for every kilogram of pods consumed). Seeds have the ability to survive the digestive processes in the animal's rumen, and after five days as many as 20% of the seeds can already germinate (Stoltsz 2002). One tree can produce as much as 100–140 kg of seeds (Smit 2002). It was after the extremely good rainy season of 1974 that an explosion of the *Prosopis* population in South Africa took place. Similar incidents followed in 1976 and 1981 and the situation got out of control (Stoltsz 2002).

The invasion of mesquite (*Prosopis glandulosa*) is unrelated to the presence of herbaceous biomass or density, indicating that release from competition with grasses is not required for mass tree recruitment to occur (Brown & Archer 1989, 1999).

Namibia has to learn an important lesson from the South African experience. Control measures will have to be introduced timeously in order to prevent the same kind of explosions and infestation – even outside the present drainage systems. Personal observations show that the dispersal of seeds is already happening on a small scale.

2.2.11.1 Conclusions

Much has been said about the seed production, distribution and establishment of *Acacia mellifera*. Very little is known about the seeds of other problem species.

One aspect not reported on in the literature is the time it takes from the seedling stage to seed production. Although this period will be influenced by factors like rainfall, soil type, and the occurrence of fire, observations indicate that this period could be ten years or longer for *Acacia mellifera*. Also of importance is the time an invader bush takes to produce seed once it has burned down. These aspects should still be investigated.

The fact that such a large percentage (99.5%) of *Acacia mellifera* seeds die after the first rains and that 2% or less of the seeds that germinate actually survive, poses an opportunity to reduce the seed content of the soils over the long term to a level where they are no longer a threat. Theoretically, such a strategy seems feasible if correct management practices are applied (see Chapters 5 and 9).

A general observation among farmers and researchers is that goats, which are predominantly browsers, can play a major role in the distribution of seeds (*Acacia mellifera* excluded).

2.2.12 Increased atmospheric CO_2 concentrations and climate change

Smit (1999) states that increased atmospheric carbon dioxide (CO_2) concentrations may also have an effect on the different floristic components of savanna ecosystems. Increases in atmospheric CO_2 improve water-use efficiency and increase carbon uptake in C_3 plants. All South African acacias are C_3 plants. However, there is as yet no conclusive evidence that CO_2 levels in the atmosphere contribute to the encroachment of *Acacia* species into C_4 grasslands.

Carbon dioxide concentrations expressed as [CO_2] can influence plants by altering water–use efficiency, photosynthetic rates, light- and nutrient-use efficiency (Drake et al. 1997) and the relative performance of C_3 [woody plants] and C_4 [grasses] photosynthesis (Ehleringer et al. 1997; as cited by Bond et al. 2003).

Growth rates of juvenile trees to sizes at which they can resist (fire) damage to stems may be sensitive to [CO_2]. This is because trees, unlike grasses, need to invest carbon into woody structure to attain height. This carbon demand can be met much more efficiently (Drake et al. 1997; as cited by Bond et al. 2003) and quickly (Ceulemans et al. 1995; as cited by Bond et al. 2003) under elevated [CO_2].

Therefore, increases in atmospheric CO_2 could very directly affect the probability of woody plants growing to fire-resistant size and thereby alter the tree:grass balance (Bond et al. 2003).

In practice it means that where veld fires are suppressed, increased atmospheric [CO_2] will favour bush encroachment.

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Chapter 3
Environmental and economic impacts of bush encroachment[5]

[5] Constituted Component 2 in the original Terms of Reference

3.1 Introduction

Joubert's (2003) findings in the environmental impact assessment (EIA) he carried out on behalf of the International Development Consultancy group for their client, the Bush Encroachment Research, Monitoring and Management Project, reflect some serious environmental and economic impacts as a result of bush encroachment, as follows:

> Bush thickening occurs in Namibia and has serious economic implications[,] especially when seen from a traditional grazer[-]orientated farming system (Barnard 1998; Bester 1996; Cunningham 1997, 1998; Joubert & Zimmermann [in press]; Quan et al. 1994; Versveld 1988; Zimmermann & Joubert 2002; Zimmermann et al. 2001). An estimated 26 million ha is currently affected by bush thickening in Namibia, resulting in severe economic implications (Zimmermann & Joubert 2002). From a commercial farmer's perspective, bush thickening results in a decline in livestock production and this can partially be explained in terms of loss in grassland diversity (Quan et al. 1994). The previous authors also mention that a move towards mixed game and livestock farming may help to arrest the problem. According to Von Wietersheim (1988) the biodiversity of commercial farmland in Namibia has drastically been altered by overgrazing – resulting in bush thickening – as well as the elimination of competitors to livestock farming (herbivores & predators) and overutilisation of wildlife without regard for the ecosystem. Bush thickening has caused a 47% reduction in cattle numbers on the commercial farmlands over the last 30 years (Schneider 1994) and has resulted in lowered productivity on Namibian farmlands (Nghikembua et al. 2002). Biodiversity of many commercial farms has been badly eroded through poor management, including overgrazing and bush thickening (Nghikembua et al. 2002; Quan et al. 1994; Strohbach 1992).
>
> Bush thickening is seen as a major threat to the botanical diversity in Namibia (Maggs et al. 1998). Bush thickening may even change the mammalian diversity or community structure with the net effect on the biodiversity of mammals likely to be negative (Griffin 1998). On the other hand, deforestation is a major assault on the survival of tree-dependent species such as Bush Babies, Vervet Monkeys, Tree Rats, Tree Squirrels and many tree-roosting bats (Griffin 1998). Teer & Drawe (1992) state that bush thickening is a critical issue in Namibia which reduces the carrying capacity for livestock and wildlife. According to Nghikembua et al. (2002), bush thickening has altered the local ecology and has potentially damaging consequences for Namibia's cheetah (*Acinonyx jubatus*) population, which is the world's largest remaining free-ranging population and is found mainly on the commercial farmlands. Furthermore Nghikembua et al. (2002) [state] that ungulate species on Namibian farmlands show a habitat preference for more open areas, with only 1.4% of ungulate recordings being made in thick bush[,] indicating that bush thickening may have important consequences for several ungulate species, and therefore also for rare carnivores such as cheetahs on the Namibian farmlands which [utilise] these species as a prey base. Game may use a wider range of plant species and use more of the vegetation, while cattle make a very limited use of, for example, woody plants (Walker 1979). Wildlife may also control woody species, which, through bush encroachment, can be a problem on cattle farms (Taylor & Walker 1978).
>
> According to Giess (1971) six of Namibia's 14 major vegetation types are types of savanna and have less than 2% representation under state protection. These include the areas generally associated with bush thickening – i.e. Mountain Savanna, Thornbush Savanna, Highland Savanna, Dwarf Shrub Savanna, Camelthorn Savanna and Mixed Tree & Shrub Savanna. Furthermore, Giess (ibid.) states that state protection in these unrepresentative areas is a national priority.
>
> Considerations of bush encroachment and its control have largely been economical [*sic*] and ecological, but until now biodiversity considerations have been neglected and poorly researched. The control of bush thickening by always consider biodiversity.
>
> Trees responsible for bush thickening in Namibia are generally accepted as the following species under certain conditions:
> - *Acacia mellifera* (Black thorn)
> - *Acacia fleckii* (Blade thorn)
> - *Acacia erubescens* (Blue thorn)
> - *Acacia reficiens* (False umbrella thorn)
> - *Colophospermum mopane* (Mopane)
> - *Dichrostachys cinerea* (Sickle bush)
> - *Rhigozum trichotomum* (Three thorn)
> - *Terminalia sericea* (Silver terminalia), and
> - *Terminalia prunioides* (Purple-pod terminalia).

The *Prosopis* species and *Catophractes alexandri* can be added to the latter list as well.

In order to properly assess the ecological implications of trees in bushveld areas, the following three aspects are the most important from an agricultural point of view:

- **Competition with herbaceous vegetation for soil moisture:** Trees affect soil moisture content because they intercept and redistribute precipitation, they reduce evaporation owing to shading, their roots penetrate deeply, and the intra-tree shading of leaves affects the rate of transpiration as well as inter-species differences in transpiration rates
- **Food for browsers:** Available browse refers to leaves, young twig material, bark, flowers and pods within a reachable height (Smit 1989), and
- **Creation of sub-habitats suitable for desirable grasses.**

However, there are huge nutritional and water-use differences in and between tree species. There is a need, therefore, to establish descriptive units to ensure the same interpretation to research findings.

Smit (ibid.) proposes the following quantitative descriptive units:

- the *evapotranspiration tree equivalent* (ETTE): defined as the leaf volume equivalent of a 1,5-m single-stemmed *Acacia karroo* tree
- the *browse tree equivalent* (BTE): defined as the leaf mass equivalent of a 1.5-m single-stemmed *Acacia karroo* tree, and
- the *canopied sub-habitat index* (CSI): defined as the canopy spread area of those trees in a transect under which *Panicum maximum* is most likely to occur, expressed as a percentage of the total transect area.

Acacia karroo is taken as a standard since it is the most widespread bushveld species.

Should bush control be necessary, the values of the various descriptive units will provide a guide to the selective removal or control of trees, depending on agricultural objectives. Leaving the bigger trees will benefit *Panicum maximum* in those areas where it occurs, but will reduce the amount of available browse material: the CSI will stay constant, but the BTE per hectare will diminish. Leaving the smaller trees will have the opposite result. In both cases the ETTE per hectare will diminish. Should these procedures be standardised, information obtained will be directly comparable with that of other areas (Smit ibid.).

3.2 Impact on soil temperature

In general, trees have a positive influence on soil temperature because of their shade effect. Low plant cover due to fire, compared with open locations, reduced soil temperatures under tree canopies by 5–11°C at 0.5 cm soil depth, by 2–8°C at 10 cm soil depth, and by as much as 20°C at the soil surface (Belsky et al. 1989). The presence or absence of trees may, therefore, also have far-reaching implications for seed germination. In this respect, Steenkamp (1975) found that soil temperature had a significant influence on the germination of *Anthephora pubescens* seeds. After 10 days at 15°C, no germination occurred. At 20°C, the highest percentage of germination was obtained, while the germination rate did not vary much up to 30°C. At 35°C and 40°C, the germination rate declined to 32% and 22%, respectively.

3.3 Impact on soil moisture

The productivity of savannas and grasslands is predominantly determined by the soil moisture balance (Tinley 1982; Walker 1985).

It follows, therefore, that aggressive woody species which intercept large amounts of scarce rainwater in the top layers of the soil drastically affect the productivity of the rangelands. In this respect, Donaldson's (1969) results are very significant. They are reflected below in Table 3.1.

Woody plant species	Approximate size and foliage spread of plants			Total leaf area (m²)	Mean relative transpiration per 8-hour day per plant (kg)	Mean daily relative transpiration per 500 woody plants or per 100,000 grass plants (kg)
	Height (m)	Crown diameter (m)	Canopy area (m²)			
Terminalia sericea	2.8	2.8	6.0	28.55	16.64	8,320
Acacia mellifera	2.5	2.8	6.0	55.68	64.80	32,400
Boscia albitrunca	1.2	1.5	2.0	13.58	13.84	6,920
Grewia flava	1.2	1.9	2.0	8.82	7.68	3,840
Anthephora pubescens	0.28	0.15	0.018	0.141	0.344	34,400
Eragrostis lehmanniana	0.21	0.15	0.018	0.038	0.075	7,500
Schmidtia pappophoroides	0.19	0.15	0.018	0.074	0.116	11,600

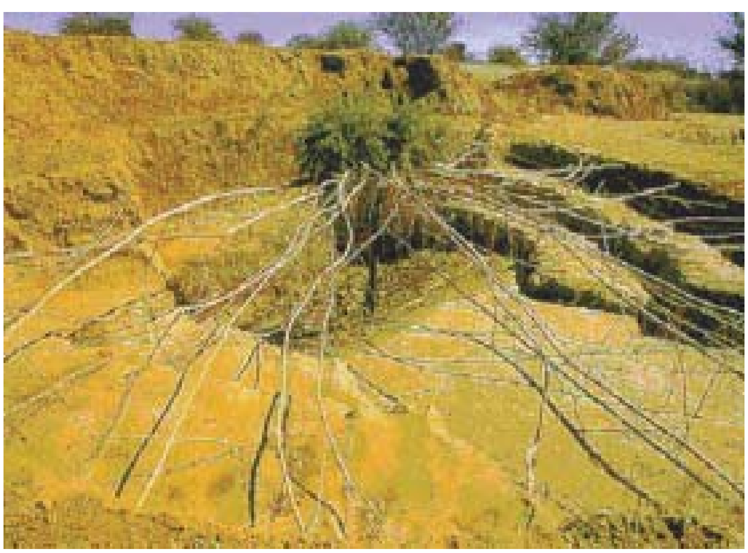
Source: *Donaldson (1969)*

Table 3.1: The size, leaf area and relative transpiration of woody plants and grasses

In Namibia, the total precipitation in approximately 60% of the rainy seasons is lower than the long-term average. In 21–30% of the years, the northern and central parts, respectively, receive less than 70% of the long-term average. Thus, the water-use efficiency in the total biological production chain is of extreme importance and should be kept at the highest possible level.

From Table 3.1 it is evident that problem species like *Acacia mellifera* compete very effectively with grass and are able to intercept a large proportion of the available moisture in the upper layers (see Figure 3.1) because of their extended root system in the same zone. As a result, grass production in most of the affected areas is severely hampered (see also section 3.6.1). Furthermore, it is obvious that the same number of *Acacia mellifera* trees use approximately seven times more water than desired fodder bushes like *Boscia albitrunca* and *Grewia flava*.

Acacia mellifera trees act as "windmills", pumping large amounts of water into the air every day.



Source: *Nico Smit, University of the Free State, South Africa*

Figure 3.1: An example of the extensiveness of the root system of Acacia mellifera *in the upper layers of the soil*

With increasing numbers of bush, a gradual change to an eventual predominant annual grass cover (pioneer or poor veld condition), which is much less efficient in its water use, also takes place. This statement is supported by Snyman and Van Rensburg (1990), who found that grass production on a good, average and poor veld was 2.4, 1.67 and 0.23 kg per hectare per millimetre, respectively. Snyman (1989) also documented grass production figures of 2.68, 1.58 and 0.93 kg per hectare per millimetre for climax, sub-climax and pioneer veld, respectively.

The water-use efficiency for veld in poor condition was, therefore, 3–10 times poorer than climax veld; stated differently, 3–10 times more rain is needed to produce the same amount of grass on a pioneer/poor veld.

The higher the annual rainfall, the smaller the difference in water-use efficiency between climax, sub-climax and pioneer veld, and vice versa (Snyman & Opperman 1984). Similar results can be expected in the bush-plagued savannas of Namibia where the rangeland responds very poorly to rain and artificial droughts are created – a situation which Namibian farmers can ill afford to experience.

Increased artificial drought events are, therefore, a direct consequence of bush encroachment. Namibia, being a drought-prone country, cannot afford this increase in vulnerability to droughts.

It can also be expected that the underground water table would be negatively affected by bush encroachment through increased water run-off and less infiltration to subsoils.

In areas with *Hardwickia mopane* densities of more than 6,500 ETTE per hectare, the shallow yet extensive horizontal spread of the roots extracted soil water in the 0–300 mm zone at a rate fast enough to prevent such water from reaching deeper soil layers. Only where all such trees were removed did the soil water manage to reach soil layers beyond 450 mm. Cleared areas had a markedly higher amount of water available for plants, while the low amount of such water in densely wooded plots[6] corresponds with the virtual absence of grasses. In cleared areas, the water-use efficiency was 2.51 kg of grass per hectare per millimetre, compared with the 0.28 kg of grass per hectare per millimetre in the high-density area (Smit & Rethman 2000).

The ability of *Hardwickia mopane* trees to survive and produce considerable amounts of leaf material under such poor soil water regimes clearly shows that this species is able to utilise soil water at a matric potential much lower than that of grasses (ψ<–1,500 kPa) (Smit & Rethman 2000).

Through-fall under *Acacia* canopies averaged 50–100% of ambient rainfall. During rainfall events of >20 mm, the average through-fall equalled ambient rainfall. During rainfall events of <20 mm, the average through-fall was less than ambient, and was zero for rainfall events of <2 mm. During rainfall events of <10 mm, the through-fall was reduced by 50–100%, while during heavier rainfall events, the reduction amounted to 10–25%. There are only small differences in through-fall, drip and stem flow between woody species. The major determinants are tree size, leaf area, and rainfall duration and intensity (De Villiers 1976, 1982; De Villiers & De Jager 1981).

In dry savannas, grass and trees use soil moisture at very different rates (Frost et al. 1986). The use of water by grasses appears to be governed largely by atmospheric demand, while that by trees appears to be governed more by soil moisture availability (Pendle 1982; Walter 1971). Grasses seem able to maintain relatively high transpiration rates – even at soil moisture levels close to wilting point, whereas trees regulate their water use as the soil dries out. Thus, grasses use soil moisture much more rapidly and completely than do trees, with obvious consequences for competition, growth patterns and productivity.

Shading reduces light intensity, ground-level temperatures and evapotranspiration (Wu et al. 1985; cited by Teague & Smit 1992), and slightly increases humidity. High levels of shading limit the growth of under-canopy plants; with moderate levels of shade, however, the negative effect of reduced light intensity is insufficient to counter the combined influence of factors positively influencing growth.

Trees can potentially increase the availability of water through hydraulic lift.[7] Except for Crassulacean Acid Metabolism (CAM) plants, this transport takes place during the night when the stomata are closed and the major water potential gradient is between the deep (wet) roots and the drier surface roots present in the topsoil. However, for plants with a CAM photosynthetic pathway which closes their stomata during the day and takes up CO_2 during the night, it has been shown that they exudate water during the day and take it up during the following night (Yoder & Nowak 1999; cited by Ludwig 2001).

Trees lose water during the night and take it up the next day, contributing to a higher water-use efficiency (Dawson 1993; Emmerman & Dawson 1996). By taking up water in the topsoil again, trees increase their

[6] *Sites* are referred to as *plots* elsewhere herein, but the two are synonymous in the context of the current study.

[7] *Hydraulic lift* is the process of water movement from relatively wet to dry layers through the roots of plants that have access to both deep and shallow soil layers. *Hydraulic lift* is a passive process driven by a difference in water potential.

potential nutrient uptake. Hydraulic lift might also contribute to keeping mycorrhizas and rhizobium bacteria in the topsoil functional during periods of drought. Higher water contents can also increase mineralisation rates, which have a positive effect on nutrient availability (Horton & Hart 1998). Therefore, trees facilitate understory plant growth through increased nutrient availability.

A higher soil fertility has been reported for a wide range of savannas. Ludwig (2001) found that species composition under *Acacia* trees is different from open grassland and is mainly caused by increased nutrient concentration under trees. However, competition for water between the herbaceous layer and the roots of trees limits grass productivity and, therefore, contradicts other findings in this respect. Furthermore, although nitrogen content in the soil is high, inadequate phosphorus levels also serve as a limiting factor for increased grass production (ibid.).

Acacia tortilis trees have a widespread root system. Ludwig (ibid.) found that these trees can lift a significant amount of water – between 70 and 235 *l* per night – into the rhizosphere and up to at least 10 m from the base of the tree. His findings (ibid.) suggest that a single tree can influence an area of at least 314 m^2 around itself. In this area, the tree itself as well as other shrubs and grasses have access to the hydraulically lifted water. During a dry year, however, very little evidence of hydraulic lift could be found (Ludwig 2001). Amongst other things, it is suggested that trees under such dry conditions may shut down their capacity for hydraulic lift in order to survive.

It was concluded that the facilitative effect of hydraulic lift in this study was overwhelmed by competition for water between trees and grasses and, therefore, did not result in grasses achieving higher production rates.

3.4 Impact on soil fertility

It is generally found that soil enrichment occurs under trees (Kellman 1979; Kennard & Walker 1973; Smit 1994b; Smit & Swart 1994; Young 1989). Various nutrients act as determinants of the composition, structure and productivity of vegetation. These nutrients include nitrogen, phosphorus, anions, cations and trace elements (Bell 1982).

Mineralisable nitrogen and microbial biomass were significantly higher in soils from the canopy than those from the root and grassland zones, whereas organic matter, phosphorus and potassium – but not magnesium – declined in soils from the base of trees towards open grassland. Soils under canopies of trees in semi-arid environments are often more fertile than soils from the surrounding grassland (Aggarwal et al. 1976; Bernhard-Reversat 1982; Bernhard-Reversat 1982, cited by Belsky et al. 1989; Bosch & Van Wyk 1970; Radwanski & Wickens 1967; Singh & Lal 1969; Teague & Smit 1992; Tiedemann & Klemmedson 1973). If all the trees are removed, the undercanopy habitat will disappear over the long term. When clearing in oligotrophic or dystrophic situations, maintaining a threshold woody biomass would be necessary for sustainable use, since clearing beyond this level would not result in increased animal performance. The primary limiting factor in such situations is fertility, and complete clearing may lower long-term productivity (Teague & Smit 1992).

Although the exact source of the nutrient enrichment of the soils under the two tree species was not investigated, it was probably partly due to nutrient inputs by tree litter, because trees transport nutrients from surrounding surface and subsurface soils to their canopy and drop the nutrients in leaf and stem litter. Bird droppings are also thought to be major inputs of nutrients since they densely covered the ground under the trees. The dung of large mammals, on the other hand, was not regarded as a contributor to increased fertility (Belsky et al. 1989).

The increased nutrient status under canopies could be ascribed to tree roots gathering nutrients from soil below grass-root level or from horizontal gathering of nutrients by lateral roots (Dye & Spear 1982). Nitrogen forms a key element in the functioning and productivity of ecosystems (Du Preez et al. 1983; Titema et al. 1992). One possible source of nitrogen enrichment is the fixing of this element due to microbial functioning under leguminous trees (Felker & Clark 1982; Höchberg 1986; Höchberg & Kvarn-Ström 1982; Shearer et al. 1983; Virginia & Delwiche 1982).

Chalk (1991; cited by Smit 2002b) shows that *Panicum maximum*, being a non-leguminous plant, contributes significantly to biologically fixed nitrogen. The potential input of *Panicum maximum* with regard to associated nitrogen fixation is in the order of 30–40 kg of nitrogen per hectare per annum.

In their overview, Aigams Professional Services (1997b) quote the work of Scholes (1988) who reported that increased penetration of moisture to the lower soil horizons following bush clearing could be expected. This would consequently increase the leaching of nutrients out of the upper horizons. This effect is greatest on sands that are initially low in nutrients and, furthermore, have a low capacity to retain them. This is of special importance for the sandy soils of the Kalahari.

If clearing is performed on the upper section of the catena[8], increased sodification in the lower regions of the catena can be expected. Increased herbivory due to bush clearing could be expected to greatly increase the rate at which sodic sites develop and spread. Furthermore, the clearing of upper catenas is unsatisfactory on grounds that have poor grass production and infertile soils.

As a general rule the quality of grass decreases following woodland management (utilisation), especially on sandy soils. This is due to the loss of high-quality under-canopy grass and, if soil disturbance takes place, an increase in low-quality opportunistic grass species. Grass quality on dry, clayey sites may be improved by bush clearing due to a shift from unpalatable annuals to more moisture-loving perennials (Scholes 1988).

Inputs to the litter layer due to leaf fall are likely to be higher under grasslands than under savannas. Nutrient cycling is more rapid under grasslands, but more vulnerable to depletion. The nutrients locked up in woody biomass buffer the system against rapid nutrient loss, and on nutrient-poor soils, these nutrients may represent a significant proportion of the total system nutrients (Scholes 1988). Woodland management might be responsible for nutrient-cycle disruptions and a loss of nutrients to the system. However, if stems and leaves not suitable for charcoal production are left on the soil in harvested areas, these should not only protect the soil against erosion and act as a grass-seed trap, but also contribute to the nutrient cycle in time (Aigams Professional Services 1997b).

3.5 Biodiversity

As is often the case, threatened species acquire their status because of negative human intervention and habitat destruction. Remaining populations have to be protected and managed in order to ensure their continued existence. *Aloe vossii* is no exception. Habitat destruction in the form of bush encroachment from both indigenous vegetation (such as *Leucociea sericea*) and exotics (such as *Pinus* spp. and Black wattle, *Acacia mearnsii*) is probably the main threat to the various populations of *Aloe vossii* in the northern Province (Soutpansberg vicinity) of South Africa (Willis & Willis 1995).

In bushveld, certain grass species occur in association with trees. An important association is that of *Panicum maximum* under trees, since this species can contribute significant amounts of forage (Smit 1989). Where excessive intruder bush is removed there is a clear trend that an increased variety of grass species appear and provide for a selection of palatable grasses at different stages during the year. Smit and Swart (1994), however, point out that the species composition is more homogeneous when total bush removal takes place, while with judicious thinning a more favourable sub-habitat is established, resulting in a greater variety of herbaceous species.

A study carried out under this project by Kruger (2001) found that, where real bush densities are used as a basis for comparison, no consistent pattern between the abundance of perennial grasses and bush density could be established. On the other hand, where subjectively pre-selected bush density classes (high, medium and low densities, according to visual observations) were used, it became clear that the density of perennial grass increased with a decrease in bush density. The abundance of *Aristida* species seems to decrease dramatically with decreased bush densities where pre-selected bush density sites are used, while just the opposite tendency is recorded where real bush densities are used. Veld condition scores seem to increase with a decrease in bush density where pre-selected bush density classes are used. Again, the opposite trend is evident where real bush densities are used.

It is not easy to explain this phenomenon. The abundance of smaller bushes (<50 cm–1 m) could have been underestimated when bush density classes were pre-selected. Taller bushes seem to play a more important role when bush densities are estimated and when bush density classes were selected. The good rainfall received during the past two seasons (2001–2002) in most of the study areas resulted in high and dense

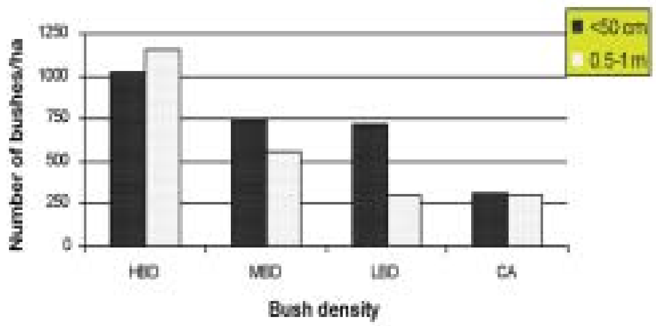
[8] *Catena* refers to the slope and leaching of nutrients over time down the slope, creating more fertile areas at the foot of the slope.

grass stands that hide most of the small bushes. It is only when bush counts are done that the high numbers of small bushes are recorded.

Despite the high number of smaller bushes, it seems as if they do not compete for water to the same extent as taller bushes and, therefore, do not impact on veld condition as much. It will be interesting to investigate the impact of bush height and canopy size on veld condition and productivity. Thick stands of taller bushes will definitely impact far more on veld condition and productivity than similar stands of smaller bushes. The fact that open or less dense areas are more accessible to grazing animals in an open communal system could lead to a situation where these areas are overgrazed, and desired perennial grasses disappear over time. On the other hand, high density areas were only utilised once grazing in other areas was depleted – resulting in more favourable conditions for the survival of some perennial grasses.

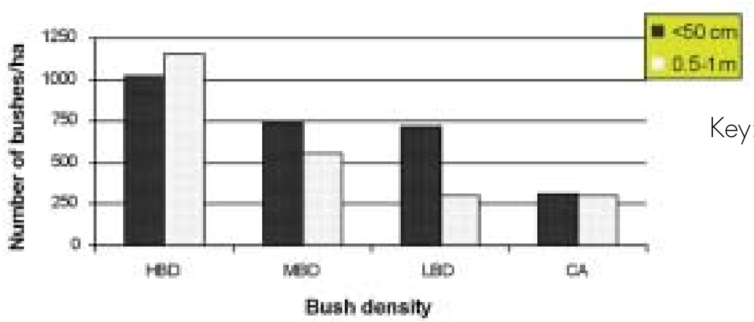
Shorter bushes seem to be dominant in all areas and over all the different bush density sites. This is an alarming phenomenon and regular monitoring of the situation is absolutely vital. It suggests that bush encroachment in the communal areas is still to take off in the near future.

Figures 3.2, 3.3 and 3.4 below indicate the number of smaller bush per hectare (<50 cm and 0.5–1 m) in relation to bush density on sites in parts of Otjinene and Epukiro as well as the Otjozondjupa Region (Kruger 2001).



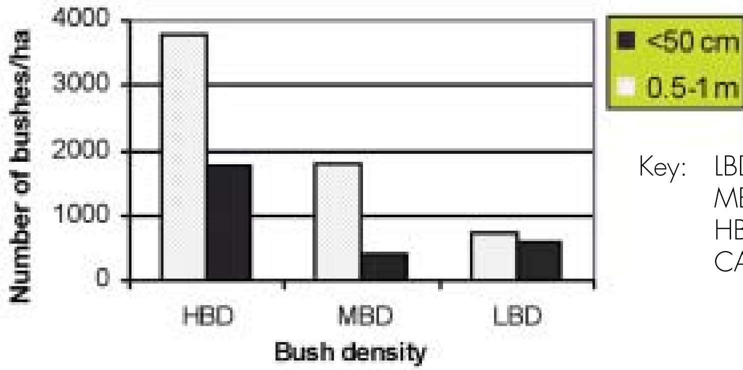
Key: LBD = low bush density
MBD = medium bush density
HBD = high bush density

Figure 3.2: Otjinene: Number of bushes per hectare in relation to bush density



Key: LBD = low bush density
HBD = high bush density

Figure 3.3: Epukiro: Number of bushes per hectare for different bush densities



Key: LBD = low bush density
MBD = medium bush density
HBD = high bush density
CA = cleared area

Figure 3.4: Number of smaller bushes per hectare for four different bush densities in the communal areas in the Otjozondjupa Region, in the 0.5–1 m height class

The surveys also indicate clear differences in the number of bushes per hectare. In both Otjinene and Epukiro, the non-fodder species seem to dominate, while in the Otjozondjupa Region fodder bushes seem to dominate. In Grootberg, fodder bushes dominate over non-fodder bushes by far.

In general, most communal farmers believe that bush encroachment is a huge problem in their areas and that it negatively impacts on grass production, livestock productivity and income-generation. Gender seems to have no influence on the perceptions of farmers regarding the impact of bush encroachment.

Several causes for bush encroachment are mentioned by the communal farmers. About half of the people interviewed felt they did not contribute towards bush encroachment at all. However, a large proportion of farmers believe they have contributed immensely to the bush problem.

The vast majority of farmers seem to be unaware of any methods to combat bush encroachment. A certain degree of ignorance about combating bush encroachment per se seems to prevail amongst farmers in general. In addition, most of them believe they do not have the means to combat bush encroachment.

3.5.1 Impact of bush control measures on vertebrates, invertebrates and plants

3.5.1.1 Impact on mammals

Joubert (2003), in his literature study on the habitat preference of mammals in the north-central part of Namibia, the area usually associated with bush thickening, suggests the following:

> [Some] 19 species are often associated with dense bush cover either as a habitat preference and/or for dietary preferences. Seven species prefer the ecotone areas, often using dense bush for cover and/or shade. 16 species prefer sparse woodland as a habitat … while 8 species make occasional use of dense bush (i.e. thickets and/or savanna woodland patches) either for shade or as a passage during migrations (Table [3.2]). Species not documented as selecting bush specifically in any way, although they might utilize bush thickets for shade, etc., have been excluded from this survey.

Figure 3.5: Bushes also serve as important sources of shade and fodder for animals

> Ungulate species most dependant on dense bush are the true browsers such as kudu, duiker, dik-dik, giraffe and black rhino as well as the elephant (near-ungulate). However, browsers can also be disadvantaged by dense stands of bush if [they impede] movement and result in a lack of available browse. [The] last[-]mentioned statement has been documented for Colophospermum mopane by Smit & Swart (1994), who show that dense stands of this species lose their leaves earlier and flush later, resulting in a lower leaf biomass available for potential browsers. Alternatively, species such as the blesbok, a short grass grazer, which requires open grassland, [have] also been documented as seeking dense patches of bush as cover during the midday heat (Estes 1995).

Carnivores depend on bush mainly for shelter from the elements such as the cavity users (i.e. genets) and or stalking prey (i.e. leopard).

Rodents use bush for shelter (i.e. cavity users) and food (i.e. seed predators).

The only primate depending on bush in the north[-]central part of Namibia is the bush baby[,] who is a cavity user and feeds on *Acacia* gum.

Four species of bats are cavity users.

Mammal	Dense bush	Ecotone use	Sparse bush	Occasional use
Ungulates and near-ungulates: Ruminants Non-ruminants	7	3	2	7
Carnivores: Canidae Felidae Hyaenidae Mustelidae Viverridae	7	2	6	1
Rodents	4	2	8	–
Primates	1	–	–	–
Bats	**---**	**---**	**---**	**4**

Source: *Estes (1995); Griffin (1998); Skinner & Smithers (1990)*

Table [3.2]: Vertebrate mammal association with regard to bush densities in north-central Namibia

The ecotone area is important for at least 7 species of mammals and such species would be advantaged if the habitat increases. This would depend on the size of patches of bush to be cleared as well as the shape of the cleared areas (i.e. elongate clearings separated by uncleared bush strips maximise the ecotonal boundary or "edge effect"). Patch harvesting increases the ecotone effect and maintains available browse while improving visibility. This is advantageous for game ranchers where [sightseeing], photographic safaris or hunting plays an important role (Cunningham 1997). According to Scholes (1988)[,] research in the USA and Australia, where bush clearing is extensive, indicates that patch clearing favours wildlife.

[The a]bove[-]mentioned indicates the importance that bush (browse, shelter, shade, etc.)[,] especially the importance of thickets, mature trees with necessary cavities and ecotone area[,] potentially has for a variety of mammal species throughout the north[-]central part of Namibia.

Any bush control measure would affect mammals to a certain degree specifically as a result of habitat change. Species most likely to be affected would be the browsers and cavity users. The degree to which mammals would be affected would depend on the control measures implemented as well as the extent of the area to be altered. Managers should take into consideration these possible effects that bush control/ clearing may have on mammal biodiversity.

Jeffares & Green Inc. (2000) also provided a brief review of the possible impact of bush thinning/eradication on the faunal composition of arid savannas. The thinning of bush-thickened areas is very likely to result in a shift in the proportions of game species. Populations of species requiring browse or dense cover for predator evasion (dik-dik, duiker, eland, giraffe, kudu and steenbok) are likely to decline unless some dense patches are maintained. Plains species and grazers, which rely on fleet-footedness in evading predators, may be favoured in such areas (e.g. blue wildebeest, oryx, red hartebeest, warthog and zebra).

Cheetah would be advantaged by tree thinning, partially because of their preference for open habitat, but also as a secondary impact of the increase in prey diversity. This may be offset by an increase in conflicts with farmers, resulting in more cheetahs being shot.

Figure 3.6:Cheetahs are more adapted to open savanna

Cheetah are an internationally declared endangered species under the Convention on International Trade in Endangered Species (CITES). Compared with a century ago, approximately one-tenth of the world's free-ranging cheetah population is still left. Namibia has the largest remaining population in the world (estimated at 2,500), of which 90% occur on freehold (commercial)[9] land. The creation of a favourable environment to thrive and survive is also a responsibility which lies with all decision-makers in the country (Marker et al. 1999).

3.5.1.2 Impact on birds

Joubert's (2003) EIA states that birds are mainly affected by bush control measures when the trees they require for nesting and/or feeding (i.e. cavity borers such as Scimitarbilled Woodhoopoe) disappear (Verdoorn, pers. comm. to Joubert 2003). At least 71 species are dependent on trees – mainly for nesting purposes – such as *Acacia* spp., *Colophospermum mopane*, *Dichrostachys cinerea* and *Terminalia* spp. These trees are often associated with bush thickening in the north-central part of Namibia. A few species such as Black-eared Finch-lark, chat, flycatcher and Rufous-eared Warbler are also associated with the problematic shrub, *Rhigozum* spp., which causes bush-thickening problems in southern Namibia. Of the 71 bird species referred to above, 10 raptors are associated with problematic tree species although mainly with regard to nesting – and mainly in terms of the bigger trees. Of possible economic importance are the 7 game bird species associated with problematic tree species.

A centre of high endemism for plants, reptiles and birds lies on the western edge of the area generally accepted as bush-thickened (Barnard 1998). Nine out of the 14 endemic birds found in Namibia occur in the bush-thickened area (ibid.). These are the Barecheeked Babbler, Carp's Tit, Hartlaub's Francolin, Monteiro's Hornbill, Rockrunner, Rosyfaced Lovebird, Rüppel's Parrot, Violet Woodhoopoe and White-tailed Shrike. However, these species are mainly associated with the endemically rich western escarpment and none are completely restricted to the bush-thickened area of north-central Namibia. Robertson et al. (1998) state that although the north-eastern section of Namibia shows the highest overall species diversity, the central and escarpment areas of Namibia are most important for species endemic to Namibia and southern Africa.

Birds may also have positive effects on ecosystems. Some game birds can, for example, control termites (that affect the grass layer) and improve grass germination through scratching the ground (Walker 1979).

At least six bird species favour less dense and/or cleared areas and would possibly benefit from bush control measures. The Ovambo Sparrowhawk, for instance, prefers open country mosaics (Tarboton 2001) and would, thus, benefit from a mosaic pattern of bush clearing. Another species that would possibly benefit from a mosaic pattern of bush clearing would be the Harlequin Quail, a game bird species that is not found in closed woodland areas. Other species such as the Black Korhaan (which prefers open, treeless plains or areas of flat open ground amongst trees and shrubs), the Red-billed Hornbill (which prefers areas where trees are widely spaced with sparse ground cover, especially in *Colophospermum mopane*-dominated areas) and the Burchell's Starling (which prefers a park-like savanna habitat with particularly associated withwell-scattered, tall trees and short grass) would all possibly benefit from bush control measures.

Before bush control is initiated the possible effects that it could have on the bird diversity should be investigated and taken into consideration.

There are six species of francolin (Crested, Coqui, Swainson's, Orange River, Hartlaub's and Red-billed) and one species of guinea fowl (Helmeted) in the general area considered for harvesting. Of these, only the Orange River Francolin may be favoured by the complete, or almost complete, removal of trees. The others, including the endemic Hartlaub's Francolin, all require either some tree cover or patches of dense bush for cover from predators. Thinning of trees, with the inclusion of patches of dense bush, should maintain healthy populations of these species. Excessive or complete removal of bush will lead to the local extinction of these species, if cleared areas are extensive. Game-bird hunting is rapidly becoming an economically important form of tourism in South Africa.

[9] *Freehold* and *non-freehold* land are usually referred to as *commercial* and *communal* land, respectively.

3.5.1.3 Impact on other birds and small mammal species

Jeffares & Green Inc. (2000) state that –

> [t]here are 141 species of birds which have been recorded in a $\frac{1}{4}$ degree square near Otjiwarongo [which] nest in forks of branches. Approximately 44 species of birds nest in cavities in trees in the affected area (Gibbons & Maclean 1997).
>
> The thinning of bush can have two contrasting effects. Excessive removal of trees will reduce nesting space for both branch[-]fork and cavity nesters. However, moderate thinning of bush, and the subsequent pruning of regrowth should favour these species, as trees released from competitive inhibition will grow taller and have thicker stem diameters more suitable for cavity users. Certain tree species, such as *Boscia albitrunca* and *Acacia erioloba*, have gnarled and twisted stems that form natural cavities favoured by hornbill species.
>
> Many small mammals, for example small spotted genets, Egyptian free tailed bats, Cape serotine bats, South African lesser bushbabies and black-tailed tree rats also use cavities for shelter and breeding, whilst woodland mice nest in trees (Skinner & Smithers 1990).
>
> The above examples serve to illustrate the importance of trees as [a] habitat for smaller vertebrates that are often overlooked. There are many species that prefer open grassy plains to thickets.
>
> The diversity of habitats which thinning, in combination with patches of dense bushes, provides, will also have a positive knock[-]on effect along trophic chains: the increased diversity of prey will result in an increased diversity of predators.
>
> Thinning of bush will have a positive effect on Cape Griffons, if they are reintroduced to Namibia, as has been recently proposed. Cape Griffons have the highest wing loading of all southern African vultures (Mundy et al. 1992). This means that they require a long "runway" to take off after eating. The bush cover in the affected areas does not allow for this, and, in fact, bush encroachment has been cited as one of the major reasons for the functional extinction of Cape Griffons in Namibia, along with poisoning by farmers. Wood harvesters who have "vulture restaurants" on their property can clear a few small areas of around 2 a hectare each to act as "runways" for these vultures.
>
> The trends for reptiles and invertebrates are likely to be the same as for small mammals and birds. Complete thinning will eliminate the arboreal niches, whilst thinning, pruning and the maintenance of patches will increase habitat heterogeneity and thus increase species diversity. There should always be representatives of all woody species, since there are many species[-] (or genus[-])specific associations. For example, the larva of the [Western Marbled] Emperor [M]oth, Heniocha dyops, is dependent upon *Acacia mellifera*, *Acacia hereroensis* and *Acacia erubescens* for its food supply.

Source of photos: *Chris Brown*

Figure 3.7: The Cape Vulture: Also disadvantaged by bush encroachment?

3.5.1.4 Impact on reptiles

Reptiles are often overlooked and are an under-researched group of vertebrates, especially in Namibia. The fact that reptiles could also possibly be affected by bush control measures is generally not even taken into consideration.

At least 23 snake species and 14 lizard species are closely associated with bush/trees in the north-central part of Namibia. Of these, 6 snake species are considered to be arboreal (tree-living) and include species such as the Bark/Mopane Snake, Boomslang, Egg-eater, Green/Bush Snake, Spotted/Variegated Bush Snake, and Twig/Vine Snake (Branch 1998; Broadley 1990; Marais 1992). Some 14 snake species are associated with bush/trees either for thermoregulation (i.e. basking on trees/shrubs) or as refuge when disturbed or whilst foraging. Three snake species are often associated with rotting logs and, thus, would benefit from harvested trees left to decompose, or be negatively affected if all the harvested trees were to be removed.

Five species of lizards are considered arboreal and include species such as the Bradfield's Dwarf Gecko, the Flap-necked Chameleon, the Kalahari Tree Skink, the Lawrence's Dwarf Gecko and the Tree Agama (Branch 1998). Nine other lizard species are often associated with bush/trees either for thermoregulation or as refuge.

Reptiles are usually sedentary and do not migrate long distances. Thus, they are likely to be the vertebrate group most affected by bush control measures. Namibia is also richly endowed with endemic reptile species (Griffin 1998) although most endemics occur west of the north-central area generally associated with problematic tree species. It is expected that the true arboreal reptiles would be negatively affected by excessive clearing. Before bush control is initiated, the possible effects that it could have on the reptile diversity should be investigated and taken into consideration.

3.5.1.5 Impact on arthropods

In the EIA, Joubert (2003) found that –

> [a] huge diversity of insect species is dependent upon trees, and *Acacia* trees in general. It would not be possible, or useful, to list the species which inhabit bush thickets, and bush encroaching species. There is [an] urgent need to study which species are dependent upon trees and thickets (directly and indirectly), and what sort of patch sizes and distances would maintain this diversity. For example, the larva of the Western Marbled Emperor Moth (*Heniocha dyops*) is dependent upon *Acacia mellifera*, *Acacia hereroensis* and *Acacia erubescens* for its food supply (Oberprieler 1995). Removal of *Acacia mellifera* from the area might negatively influence this species. It is not known what distances adults can disperse, from one tree or patch of trees to the next.
>
> The Topaz Spotted Blue Butterfly (*Azanus jesous jesous*) feeds on the flowers and buds of *Dichrostachys cinerea* (Roodt n.d.), and the adults of this species and *Azanus ubaldus* seem to be particularly associated with the flowers of acacias in general (Williams 1994). The bruchid weevils (Family Bruchidae) seem to be closely associated with acacias and other leguminous plants (Picker et al. 2002). These are a few examples of some of the undoubtedly many associations which excessive removal of bush thickening species may compromise.

3.5.1.6 Impact on plants

Joubert (2003) goes on to say that –

> Namibia is considered to be floristically diverse (Barnard 1998). Species richness and endemism are not particularly high in most of the vegetation types affected by bush thickening (Maggs et al. 1994). However, in the Mountain Savanna (Giess 1971) which is also affected by bush thickets, 31.6% of the total of Namibian plants are hosted, indicating a high diversity (Maggs et al. 1994). This area currently has no formal protection (Barnard 1998). Since the species associated with bush thickening in this vegetation type (*Dichrostachys cinerea*) is most likely reducing species diversity by displacing other tree species, an increase of plant species diversity is likely with moderate clearing, due to competitive release. The same is likely to be true for each of the vegetation types, provided clearing follows currently accepted guidelines (e.g. Joubert & Zimmermann 2002). A complete list of under-story plants associated with trees and thickets would not be possible, or useful at this stage. There are many associations of herbaceous species with *Acacia* trees. For example, shade-loving species, such as the high[-]yielding *Panicum maximum* (Guinea Grass), will disappear with excessive clearing. The authors have often observed woody species such as *Boscia albitrunca* (Shepherd's Tree) growing through *Acacia mellifera* trees which acted as protective nurseries.

3.6 Land productivity

3.6.1 Carrying capacity

Bush encroachment is one of the most serious and conspicuous results or imbalances in savanna ecosystems. Along with various other factors, this poses a serious threat to livestock farming in the affected areas. It is seen as the single most important restrictive factor in realising sustainable animal production in the savanna areas of the North West Province in South Africa. This is primarily due to the fact that bush encroachment has a profound effect on the productivity of the herbaceous component of the veld, involving mainly available soil water as the primary determinant of production (Meyer 2001). Good evidence of reduced productivity of the herbaceous layer exists for the savanna areas of the Vryburg region, where the grazing capacity can be reduced drastically with increased bush densities.

High bush densities decreased grass yields and was attributed to competition for water, nutrients and light (Dye & Spear 1982). The work of Kennan (1969a) revealed unusually shallow and extensive root systems, which means it is very difficult for herbaceous plants to compete effectively. In the Tuli Lowveld in Botswana, Dye and Spear (1982) found grass yields varying between 581 and 3,862 kg per hectare in cleared areas, as compared with under-canopy yields of 173 and 1,346 kg per hectare in untreated sites.

Stuart-Hill et al. (1987) propose that the net effect of the tree's beneficial (e.g. shade and tree leaf litter) and the detrimental effects (rainfall reduction through interception, competition for soil water) on the sward will depend on the density of the woody layer. Tree density is the single biggest biotic variable in predicting the productivity of savanna vegetation. Consequently, studies pertaining to the competition between trees and grass need to take bush density into account.

It seems clear that a consistent pattern of grass production does occur around *Acacia karroo* trees. This is characterised by high yields under the tree canopy and low yields immediately to the north of the canopy. The former is attributed to positive influences by the tree (shade and tree leaf litter) which, at low tree densities, override the competitive effects displayed by the tree, while the latter are probably a result of rainfall redistribution plus the high competition for water by the tree in this vicinity (Stuart-Hill et al. 1987). Higher dry-matter yields have been found under the canopies of leguminous trees (*Acacia erubescens*) compared with either under non-leguminous trees (*Combretum apiculatum*) or between tree canopies in the Bushveld (South Africa). This is due to the occurrence of *Panicum maximum* under tree canopies (Smit & Swart 1994). Belsky et al. (1989) recorded significantly higher production of herbaceous plants under the canopies of both *Acacia tortilis* and *Adansonia digitata* than outside their canopies in Kenya. Smit and Swart (1994) concluded that, contrary to most other grass species, the yield of *Panicum maximum* increased with an increase in tree density up to a point where the yield of *Panicum maximum* was also suppressed through competition from the trees. In contrast, Grossman et al. (1980; cited by Smit 2002b) measured significantly greater biomass in open veld than under *Burkea africana* and *Ochna pulchra* trees, although the canopy habitats yielded better quality forage.

The relatively high nutrient status of soil under – compared with between – tree canopies would be expected to lead to a relatively higher nutrient content of the grass growing under the canopy. Reported results are, however, variable (Smit 2002b). Grossmann et al. (1980) reported no difference in the *in vitro* digestible organic matter content, but a higher protein content of forage under *Burkea africana* trees that grow in open savanna. Clearing all woody plants in *Combretum* veld had no effect on forage quality (Pieterse & Grunow 1985). The findings by Muoghalu and Isichei (1991) showed no significant difference between the crude protein, lignin and fibre content of forb species growing in the open and under tree canopies in Nigerian savanna.

It should be appreciated, therefore, that trees may have positive effects on grass, and that the net result of the positive and negative interactions on grass production is dependent on tree density (Stuart-Hill et al. 1987). Established trees create sub-habitats which differ from the open habitat, and which exert different influences on the herbaceous layer (Belsky et al. 1989; Grossman et al. 1980; Hagos 2001; Kellman 1979; Kennard & Walker 1973; Smit 1994b; Smit & Rethman 1989, 1999; Smit & Swart 1994; Stuart-Hill et al. 1987; Tiedemann & Klemmedson 1973; Yavitt & Smith 1983; all cited by Smit 2002b).

Aucamp et al. (1983) concluded that grass production was enhanced with increased tree densities (*Acacia karroo*) until a critical value of 300 tree equivalents per hectare is reached. With further increases grass

production is adversely influenced. It is concluded, therefore, that trees at low densities have a beneficial influence on the herbaceous layer.
Woody plants form an essential component of certain savanna systems. Total clearing can, therefore, be detrimental to the livestock production potential of such areas. Furthermore, no economic advantages would be gained when the bush density in such areas is reduced below certain threshold values (Meyer 2001).

Grass production will increase with increasing bush densities until a critical stage (approximately 300–500 tree equivalents per hectare), whereafter further increases will seriously suppress the productivity of rangelands and livestock. Total clearing is to be avoided, and bushes should only be thinned out to a desirable number per hectare.

According to Snyman et al. (1988), there are also differences in water-use efficiency between different plant communities. Under optimal moisture conditions the water-use efficiency rates for climax, sub-climax and pioneer veld are 9.15, 7.55 and 5.65 kg of dry material per hectare per millimetre per annum, respectively.

Bosch and Van Wyk (1970), Cook and Harris (1968), Kelly (1977) and Walker (1974) also indicated that trees below a certain critical density may contribute positively rather than negatively to grass growth, and support the aforementioned findings. Areas with larger single- or few-stemmed trees generally seem to have a higher grass production than areas with many smaller, multi-stemmed bushes, regardless of the cover (Jeffares & Green Inc. 2000).

According to Meyer (2001), it is important to note the effect of bush density on the occurrence of pseudo-droughts. Sustainable cattle farming at the official grazing capacity norm would only be possible with less than 200 ± 155 *Acacia mellifera* trees per hectare. Furthermore, it is also clear that farming at the official grazing capacity norm would have been possible during five of the eight years of the trial if a sample farm had been cleared of all *Acacia mellifera* trees. In stark contrast, this would only have been possible for two of those eight years if between 70% and 90% of all *Acacia mellifera* trees on the sample farm had been cleared, while it would only have been possible for one of the eight trial years if more than 50% of all *Acacia mellifera* trees on such a farm remained. It was concluded that *Acacia mellifera* drastically affected both the species composition and productivity of the herbaceous layer. Based on the available data, total or near total removal of this species can be recommended (Meyer 2001).

The drastic effect of high bush density on carrying capacity was also evident from research results obtained at Pontdrif and Ellisras in South Africa (Smit 2001).

Site	Treatment (bushes left) per hectare	Hectare per large stock unit
Pontdrif (1991/92) 214 mm	0%	9.9
	20%	29.4
	50%	128.9
	100% (6,000 ETTE per hectare)	267.4
Pontdrif (1991/92) 440 mm	0%	9.4
	20%	12.3
	50%	25.5
	100% (6,000 ETTE per hectare)	81.7

Table 3.3: Carrying capacity of veld in relation to the percentage bush cleared at Pontdrif, South Africa

From Table 3.3 the following aspects are of importance:
- The vulnerability during a poor rainy season or even during an average season is very clear.
- The number of bushes needs to be cleared to below a certain threshold value. In this trial, the effect of less than around 75% of debushing on the carrying capacity was disappointing and not worthwhile under conditions of high densities.

At Ellisras the suppressive effect of bush encroachment showed the same trend.

Figure 3.8: In the same season the debushed area (left) has ample grazing while the farmer in the adjacent encroached area faces a drought.

With increased *Acacia mellifera* densities, the carrying capacity was lowered because the grass cover became poorer and poorer (Joubert 1962).

Case studies on a large number of commercial farms have revealed that carrying capacities can double and even triple once bush control has been carried out. This view is also supported by Bester (pers. comm.) as well as research findings at the Neudamm, Omatjenne and Uitkomst research stations.

Carrying capacities in bush-affected areas declined by 100% and more. In practice it means that the carrying capacity decreased from 1 LSU per 10 ha to, for example, 1 LSU per 20 ha (100%) or 30 ha (300%).

Although research results on *Colophospermum mopane* are sparse, significant increases in grass production are also evident where this species was cleared. In Botswana and Zimbabwe, Tinley (1966) and West (1967) reported that dense amounts of grass often occur underneath *Colophospermum mopane* trees. However, these yields vary considerably between years. The recovery of cleared *Colophospermum mopane* thicket in the Eastern Transvaal Lowveld in South Africa, to a level where its effect on grass production is similar to that in a pre-cleared state, occurs within 14 years. Based on certain assumptions, the "effective duration" of the increase in grass production after clearing is about half the recovery period (Scholes 1990). No *Colophospermum mopane*-related research results on carrying capacity in Namibia could be found despite the fact that mopane trees and shrubs occur over an area of approximately 4.8 million ha. De Villiers (1981) found that *Colophospermum mopane* is extensively used by large browsers, especially elephant, while Nott and Stander (1991) report on a light utilisation of *Colophospermum mopane* by browsers.

In mopane savanna, Smit (1994b) reported that sub-habitat differentiation by *Colophospermum mopane* trees provided some qualitative benefits. Some good forage grass species, which typically have high crude protein and *in vitro* digestibility values, prefer the canopied sub-habitat to the open sub-habitat and would probably be lost with the removal of all the mopane trees.

As a rule of thumb, the number of tree equivalents per hectare should not exceed twice the long-term average rainfall (mm). A *tree equivalent* (TE) is defined as a tree (shrub) measuring 1.5 m in height (Smit 2001); thus, a 3-m shrub would represent 2 TE, a 4.5-m shrub 3 TE, etc.

Teague et al. (1981) also defined 1 TE as an *Acacia karroo* tree, 1.5 m high.

Since stability in production and quality of forage are very important considerations in meat production, the total removal of bushes and trees is undesirable. The removal of large trees can definitely reduce forage quality. The problem, however, is that this effect only becomes clear after at least ten years. Initially after trees die, grass production increases. Grass production is higher around dead trees than in open grassland and under large trees. Grass nutrient concentration and the digestibility of organic matter are only slightly lower under dead than under large trees, but the forage quality is still much higher than in open grassland. However, after about ten years, the *Cynodon* species favoured by herbivores disappear around dead trees and the vegetation becomes as it is in open grassland, with species such as *Heteropogon contortus* and *Sehima nevervosum*. These species have a low leaf:stem ratio and low nutrient concentrations, indicating a low forage quality.

Grass biomass increases after trees are removed; but after about ten years, when the "positive" effect of dead trees has disappeared, bushes start to repress grass productivity (Ludwig 2001).

Teague and Smit (1992) concluded that when clearing in oligotrophic or dystrophic situations, maintenance of a threshold woody biomass would be necessary for sustainable use, since clearing beyond this level would not result in increased animal performance. The primary limiting factor in such situations is fertility, as discussed by Bell (1982), and complete clearing may lower long-term soil fertility.

Secondly, when clearing in eutrophic or mesotrophic situations, the increase in animal performance is not as great as the increase in grass production. In these situations, a much lower threshold of woody plant density would be necessary for the highest sustainable animal production.

Another form of land productivity or capability is the amount of production emanating from the woody component of the veld. Smit et al. (1996) summarised the findings of various researchers as follows:

> Hayashi (1992) recorded a mean annual height increase of 90 mm (from 147 mm to 238 mm) of *Acacia mellifera* seedlings. Pellew (1983) reported that *Acacia tortilis* trees between 5 m and 6 m in height increased at a rate of approximately 330 mm per annum. In most savanna tree species, young trees display a faster growth rate than older trees (Agnew & Waterman 1989). The potential role of soil nutrients was demonstrated by Henning & White (1974) who reported that the growth of *Colophospermum mopane* on eight different sites in southern Africa was found to be highly correlated with total N and extractable P in the surface soil.
>
> One of the few reports on the growth of remaining trees after selective thinning was given by Smith & Goodman (1986). They found that *Acacia nilotica* trees, whose neighbours within a 5 m radius were removed, showed a significant increase in both stem diameter increment and shoot extension when compared with control trees. From a study conducted in Botswana, an increase of 11–21% in stem basal area and 1.2–3.9% in tree height was reported for *Colophospermum mopane* on thinned plots compared with 3.5% and 1.1% respectively for trees in control plots (Coe 1991). Similarly, Smit (1994b) found that the mean seasonal leaf dry matter (DM) yield increases per tree of *Colophospermum mopane* on a plot thinned to 10% of the original tree density, ranged from 12.6% to 27.8% compared to mean increases of 8.9% to 17.9% of trees on a control plot. Over a period of three seasons, this resulted in a total leaf DM yield increase of 64.9% for trees on the thinned plot compared with an increase of 22.2% for trees on the control plot. Structurally this increase in vegetative growth, following thinning, was found to be due to increases in canopy spread rather than to increases in tree height.

Rhigozum trichotomum is another invasive species which occurs widely in Namibia and became a huge problem on approximately 2 million ha in the south-eastern part. A problem species map published by Bester (1996) shows densities of 2,000 per hectare. According to Moore (1989) *Rhigozum trichotomum* is a drought-evading plant in which dormancy is initiated by moisture stress. The plant has a well-defined pattern of phenological phases, with regrowth after a period of drought-induced dormancy. Regeneration is mostly vegetative from a well-developed, extensive root system. Root distribution covers a radius around the stem base of approximately three times the plant height. The plant has well-developed shallow and deep root systems, which respond very well to relatively small precipitations.

Shoot growth is very slow. Fodder production is low and erratic, and flowers and capsules in particular are at most opportunistic sources of animal feed.

Thickening-up of *Rhigozum trichotomum* from 0–1,000 bush equivalents per hectare suppressed grass production exponentially, and has the ability to thicken aggressively even under unfavourable climatic conditions, and to suppress grass production with the resultant reduction in grazing capacity. Over a three-season period, grass production was suppressed by 62%, 46% and 93%, respectively, with a calculated decline in grazing capacity of 43–93%.

In already dense stands, *Rhigozum trichotomum* is able to successfully suppress perennial grass establishment and grass production as a result of competition for soil water. Initially drastic control methods will be necessary to restore the natural balance between *Rhigozum trichotomum* and grass. Maintenance of a vigorous grass cover may then be able to retard reinfestation.

Grass extracted soil water mainly to depths of 350 mm, but was able to deplete all the water available for plants in a soil profile of 800 mm deep. *Rhigozum trichotomum* was also capable of depleting all the plant-available water in a 800 mm soil profile. In practice, this means competition for soil water after showers of up to 55 mm. Evapotranspiration from grass sites is higher than from *Rhigozum trichotomum* sites, so grass is thought to be the stronger competitor for soil water. For ecological stability and long-term animal production, it is proposed that *Rhigozum trichotomum* be controlled and managed to stands of 200–400 plants per hectare (Moore 1989).

Thickening of *Rhigozum trichotomum* can mainly be ascribed to vegetative growth from coppice buds of shallow, horizontal roots. Shoot growth is very slow (Moore 1989). The plant has both a well-developed shallow and a deep root system, which respond very well to relatively small precipitations and can compete with grass very successfully. As previously mentioned, root distribution covers a radius around the stem base of approximately three times the plant height. The specific nature of the root system favours broadcast application of chemicals and implies a possibly low application rate. From this perspective it became evident that artificial droughts would be caused where high densities of *Rhigozum trichotomum* occur. It should be part of a long-term strategy to combat bush encroachment, therefore, rather than to grant subsidies during times of drought.

Moore (1989) also refers to the findings of Moore et al. (1985), who report an increase of 220–740% in grass production in the thorn bushveld of the Molopo in South Africa after chemical control was applied. At the same time, grass densities in the treated areas increased between 73% and 136%. Similar results were obtained by Donaldson and Kelk (1970) in the Molopo area. In Zimbabwe, grass production at four different localities increased between 148% and 364% on debushed land over periods as long as 16 years (Barnes 1982).

Rhigozum trichotomum are utilised by a number of antelope, beetles and rodents. Fodder production for livestock is low and does not make up for the loss of grass production as a result of competition for soil water.

3.6.2 Browse, available browse and its relation to tree density

The importance and role of woody plants in different savanna ecosystems, provided they occur in a sound composition with and ratio to the herbaceous component, should be fully understood by all land-users. Apart from woody plants' indispensable role in soil enrichment and their value in terms of energy and shade, their leaves and pods contain high levels of crude protein and, therefore, serve as a very important source of nutrition to livestock and game. However, just because browse is available does not mean it will be eaten: food preferences also play a role. Browsers select among plant species as markedly as grazers do (Grunow 1980). These aspects of land productivity were also well reviewed by Smit et al. (1996), who elaborated as follows:

> It is important to have a clear understanding of what is meant by *browse* and *available browse* (Rutherford 1979). He defined *browse* as the sum total of that material of woody species that is potentially edible to a specific set of animals, and that *browse* is most commonly regarded as the current season's growth of both leaves and twigs. *Available browse* on the other hand is usually a more restricted quantity than *browse*, and in most studies *available browse* is simply determined on the basis of maximum height above ground to which a specified animal can utilize browse. The availability of browse below a specified browse height may be reduced by obstruction of browse material towards the centre of the plant by dense branch entanglements (Rutherford 1979), while leaf senescence of winter deciduous species will lower *available browse* during certain periods (Styles 1993; Smit 1994b). In savanna areas dominated by leguminous woody species, pods are important as forage, especially during the winter months (Fagg & Stewart 1994).
>
> Integrated quantitative data on browse, available browse, seasonal nutritional and phenological characteristics and how this is influenced by tree thinning, are poorly reported in the literature. Quantitative data on above-ground peak biomass of various woody species is summarized in Table [3.4].

Species and location	Reference	Above-ground biomass (tonnes per hectare)
Colophospermum mopane Standing crop Season's shoots (Zimbabwe)	Kelly & Walker 1976	19.940 – mean 1.506 – current
Combretum apiculatum Standing crop Season's shoots (Kruger National Park)	Dayton 1978	16.909 – mean 1.522 – current
Burkea africana–Ochna pulchra Mean standing crop Season's shoots (Nylsvley, Northern Province)	Rutherford 1982	16.273 – mean 1.100 – leaves 0.236 – current
Acacia karroo–Acacia tortilis Mean standing crop (Tugela Valley, KwaZulu-Natal)	Milton 1983	4.500–6.800 – mean
Colophospermum mopane Standing crop (Klaserie Private Nature Reserve)	Scholes 1987	21.641 – mean 20.840 – wood 0.801 – leaves
Colophospermum mopane Leaves (Pontdrift, Northern Province)	Smit 1994b	1.128 – 1.736

Table [3.4]: Summary of the above-ground peak biomass of different woody plant species as reported in the literature

A *preferred food species* is defined as one which is proportionally more frequent in the diet of an animal than it is in the available environment; and *food preference* as the extent to which food is consumed in relation to its availability (Petridges 1975). A *principal food species* is described as one making a large contribution to the diet (Grunow 1980). Owen-Smith and Cooper (1987) distinguished between two basic categories of acceptability of woody species to browsing animals: (1) species favoured year round; and (2) species generally rejected, except during certain periods. Barnes (1976) concluded that a proper understanding of animal–plant relationships in terms of intake will depend on knowledge of the diet of the animals, the amount of the different species on offer and their distribution and availability. In addition, the actual intake of available browse may be influenced by chemical defences of woody plants (Van Hoven 1984; Bryant et al. 1992), as well as nutritional characteristics of leaves in different phenological stages (Hall-Martin & Basson 1975; Cooper 1982; Owen-Smith & Cooper 1987; Cooper et al. 1988; Styles 1993).

Chemical defences of plants may include chemical substances which may be poisonous (Smith 1992; Taylor & Ralphs 1992) or reduce palatability (Robbins et al. 1987; Bryant et al. 1992). A diverse array of secondary metabolites deters feeding by mammals on woody plants. Condensed tannins are especially important as a defence mechanism in woody plants (Haslam 1974; Van Hoven 1984; Martin et al. 1985, Hagerman et al. 1992). Tannins are a diverse group of compounds, widespread among dicotyledonous forbs and trees, which precipitate protein (Asquith & Butler 1985; Robbins et al. 1987) and sometimes act as a toxin rather than as a digestion inhibitor (Hagerman et al. 1992).

Herbivory by mammals may affect the chemical defences of woody plants. In some cases browsing may result in increased defence (Baldwin & Schultz 1983; Van Hoven 1984), and in others decreased defence (Bryant et al. 1992). Plants known to have chemical defences against vertebrate herbivory are prominent on nutrient-deficient soils, while those with structural defences (e.g. spines) are predominant on fertile soils (Owen-Smith & Cooper 1987). The effectiveness of these defences may vary between browser and woody species. The success of chemical defences of trees of an *Acacia nigrescens*[-]dominant community was demonstrated by Furstenburg (1991) who observed giraffe selecting plants with a low tannin content. Regarding structural defences, Cooper (1982) observed that the presence of straight spines or thorns has little effect on the feeding of goats and impalas, while hooked thorns are more effective deterrents. In some species the physical defences of juvenile and mature trees differ. Juvenile *Acacia nilotica* trees were found to be physically more heavily defended than mature plants (Brooks & Owen-Smith 1994).

The percentage crude protein content of the diet selected by boer goats in the Valley Bushveld of the eastern Cape [South Africa] ranged from more than 14% during March–May to approximately 10.5% during October (Aucamp 1976). However, Teague (1989a) concluded that in the eastern Cape, goats did not appear to select a diet according to their nutritional needs, possibly due to protein indigestion caused by tannin complexed by *Acacia karroo*, luxury consumption of favoured food and differences in the palatability of browse and grass. No significant relation was found to exist between damage to *Colophospermum mopane* by elephant and the content of Ca, Mg, Na, K, total salts and crude protein of bark and leaves (Anderson & Walker 1974). In contrast, Williamson (1975) observed elephant in the Wankie National Park selecting plants with a high digestible crude protein content.

From a tree-thinning experiment in *Colophospermum mopane* veld, Smit (1994b) reported that tree thinning reduced the available browse at peak biomass, but trees from the low tree density plots displayed a better distribution of browse, having leaves in comparatively younger phenological states over an extended period. He concluded that high densities of *Colophospermum mopane* trees (bush encroachment) may thus also be detrimental to browsers, and not only grazers as is generally accepted. The mean percentage crude protein for leaves of *Colophospermum mopane* in different phenological stages was reported by Styles (1993) as 13.3% (very young leaves), 17.6% (young green leaves), 9.7% (mature green leaves) and 3.6% (senescing leaves). *Colophospermum mopane* is the host for nymphal stages of a psyllid insect (*Arytaina mopane*) which feeds on the phloem sap and produces an excretion product which reduces levels of photosynthesis and increases the palatability of leaves to cattle (Ernst & Sekhwela 1987). They ascribed the increase of palatability to a concentration of monosaccharides. In general, the diet selected by browsing animals is higher in protein content and digestibility than that of a randomly selected sample (by hand) (Monro 1982).

Obviously, the complete removal of trees in an area would reduce the browse to zero, at least in the short term. The value of reserve browse, even for cattle, in times of drought has been commented on by a number of people, and many communal farmers rely heavily on this when grazing is scarce (Jeffares & Green Inc. 2000).

3.6.3 Impact of bush encroachment on woody biomass

Aigams Professional Services (1997a) illustrated the importance of fuel wood as a source of energy in the rural areas of Africa and referred to several studies in this regard. Wood is the most widely used household fuel in non-industrialised areas of the world and, in many cities, wood and charcoal remain the predominant cooking fuels (FAO 1985). In rural areas of Africa, wood provides up to 96% of the energy used, with each person needing up to 1.5 m3 per annum (Prior & Cutler 1992). In the Southern African Development Community (SADC) Region, an estimated 79 million people out of a total population of 82.2 million in 10 southern African countries depend on biomass fuels as their major source of domestic energy (Karekezi & Ewagata 1994). Moreover, biomass energy is an important fuel for many small- and medium-scale industries in the region. Africa's expanding population means its demand for firewood keeps on increasing, and by 2000, over 50% of the population will face a scarcity of firewood (Prior & Cutler 1992), while close to 2,400 million rural people worldwide will experience fuel wood shortages (De Montalembert & Clement 1983). On the other hand, Pearce (1994) suggests that Africa may contain twice as much wood as previously believed, namely in trees on privately-owned farms that are simply ignored in official statistics.

It was further concluded that the following species and corresponding potential for harvesting are available in Namibia:

- Tree densities (all species) are highest in the Otjiwarongo, Outjo and Tsumeb areas. Species with highest densities in the above-mentioned areas are *Acacia mellifera* (Otjiwarongo), *Terminalia prunioides* (Outjo and Tsumeb), and *Colophospermum mopane* (Outjo). Certain areas are suitable for harvesting/ thinning due to dense stands of trees which decrease the grazing capacity, especially for domestic animals. Bush-thickened areas also detract from the aesthetics due to the lack of visibility. Hunting, photography and/or other tourist-related benefits would, therefore, also decline.
- The potential wood available for good quality charcoal production (>7–8 cm circumference) is highest for *Colophospermum mopane* trees in the Outjo area, with an expected weight of 17,952 kg per hectare. This was expected as *Colophospermum mopane* has very hard and heavy wood (Cunningham 1996). *Acacia mellifera* trees in the Otjiwarongo area have an expected charcoal potential of 13,208 kg per hectare, while *Terminalia prunioides* trees in the Outjo and Tsumeb areas have potential charcoal weights of 8,214 kg per hectare and 5,724 kg per hectare, respectively.
- With conservative harvesting rates of 25% and/or 50%, expected wood with a charcoal potential would vary between 4,398 kg per hectare and 8,796 kg per hectare for *Colophospermum mopane* in the Outjo area, to 198 kg per hectare and 396 kg per hectare for *Acacia mellifera* in the Omaruru/

Kalkveld area. Nott and Stander (1991) reported densities of *Colophospermum mopane* between 369 and 1,757 in the Etosha National Park. These yields seem very attractive from an income-generating point of view, but these considerations should not become more important than ecological considerations.

- If the wood "leftovers", i.e. that which is unsuitable for good quality charcoal production (<7–8 cm), could be mulched and compressed to form "log-like" structures to use as fuel, this would increase the economic benefits enormously. However, not all the "leftovers" should be removed for fuel production, due to all the ecological implications mentioned previously.

Jeffares & Green Inc. (2000), in their study on the availability of wood for charcoal and woodchip production, considered the variables which could influence the amount of wood that contractors would be prepared to harvest and that authorities would allow to be harvested. These variables include the price offered for the wood, the ease of cutting and debarking, the ease of reaching sites and transporting the wood from such sites, the management objectives of the farmers or communities, and the ecological sensitivity of the sites.

Their estimation of the total standing wood in the affected areas is 73.2 and 61.7 million tonnes for the commercial and communal areas, respectively. Several scenarios on how much wood could be harvested can be formulated.

A separate study, undertaken at the behest of the Namibian Ministries of Agriculture, Water and Rural Development and Trade and Industry is presently under way. The study aims to update information pertaining to the availability of wood and how much can be harvested in relation to available markets for the different commercial products emanating from problem bush.

Bester et al. (1999) found that the height of trees alone cannot be used as a parameter to estimate the biomass of a woody population. On the other hand, stem diameter had a large effect on biomass. Consequently, a regression equation was developed to estimate the standing biomass of the woody population.

The regression equations for each of the eight problem species are as follows:

- *Acacia mellifera*
  $Y = -10{,}970 + (0.768 \times \text{diameter}) - (0.0124 \times \text{diameter}^2) + (0.0000826 \times \text{diameter}^3)$
- *Acacia erubescens*
  $Y = +5{,}719 - (0.349 \times \text{diameter}) + (0.00719 \times \text{diameter}^2) - (0.0000173 \times \text{diameter}^3)$
- *Acacia fleckii*
  $Y = -0{,}946 + (0.0712 \times \text{diameter}) + (0.000514 \times \text{diameter}^2) + (0.00000609 \times \text{diameter}^3)$
- *Acacia reficiens*
  $Y = 5{,}093 - (0.2567 \times \text{diameter}) + (0.0059 \times \text{diameter}^2) + (0.0000116 \times \text{diameter}^3)$
- *Colophospermum mopane*
  $Y = 42{,}119 - (0.0680 \times \text{diameter}) + (0.00275 \times \text{diameter}^2) + (0.0000170 \times \text{diameter}^3)$
- *Dichrostachys cineria*
  $Y = 115 - (0.0680 \times \text{diameter}) + (0.00275 \times \text{diameter}^2) + (0.00000888 \times \text{diameter}^3)$
- *Terminalia sericea*
  $Y = 26{,}866 - (0.609 \times \text{diameter}^2) + (0.00463 \times \text{diameter}^2) + (0.00000572 \times \text{diameter}^3)$

The derivation of an equation, namely Mass = (diameter)2.5101 x 0.0549, from which total above-ground tree mass can be predicted from the stem diameter, is described in Zimbabwe savanna woodland (Guy 1981b). It is concluded that the inclusion of height in the equation marginally improves the accuracy of the prediction. Shrub mass in this study was best estimated as a function of canopy volume in the form –

$$\text{Mass} = (\text{canopy volume} \times 1.2102)$$

Interspecific differences were not large enough for the purposes of this study to warrant the use of individual species-specific equations. The mass of the annual production (W_I) of trees shows a linear relationship with diameter (W_D) for plants up to 70 cm in diameter, in the form –

$$W_I = (W_D)^{1.52} \times 0.0831.$$

The mass of the annual production of the shrubs was expressed by the function –

$$\text{Mass} = (\text{canopy volume})^{0.8074} \times 0.2064.$$

Bester (1999) provides a valuable overview and discussion which covers various formulae and other possibilities to predict wood mass on the veld.

Spatial tree volume proved to be a useful measure of tree biomass. Provided leaf densities are estimated accurately, estimated true leaf volume and true leaf mass from trees' spatial volume is possible.

The application of the proposed quantitative description procedure to other tree species, although developed from data obtained from *Acacia karroo* trees, seems viable (Smit et al.1996).

Cunningham (1996) found differences in the growth rate of *Colophospermum mopane* of 56–71 cm per annum in the Venitia Limpopo Nature Reserve in South Africa. At these growth rates, it will take 23–25 years to reach mean circumferences of approximately 14–16 cm. To reach a minimum cut-off circumference of 7 cm (big enough to provide quality charcoal) will take 12, 13 and 10 years for *Colophospermum mopane* woodland, *Colophospermum mopane* shrubland and *Colophospermum mopane–Combretum apiculatum* open woodland, respectively. In this respect, Von Breitenbach (1965) claims that mopane, because of its vigorous coppicing ability, can grow to a full dense forest within 15 years. Scholes (1990) states that the time span for *Colophospermum mopane* to regenerate from seed to a pre-cleared state can take up to 40 years.

The total weight of 23,668 kg per hectare was highest for *Colophospermum mopane* woodland while the lowest value was recorded on *Colophospermum mopane* shrubland (3,237 kg per hectare in the Venitia Limpopo Nature Reserve (Cunningham 1996). Cunningham (ibid.) also suggested regression equations of height and circumference for total weight per hectare for three different vegetation types.

3.7 Habitat

Woodland management results in significant changes in the micrometeorology of the cleared site. Light levels and wind speeds increase, exposing animals to greater extremes of temperature. Leaving a few trees per hectare will have little effect on grass production, but should provide some sort of natural cover and also allow animals to avoid unnecessary stress. Woodland management is unlikely to have undesirable consequences unless it is done on a very large scale (hundreds of hectares). Macroclimatic changes are also unlikely unless woodland management occurs on a regional scale (thousands of square kilometres) (Scholes 1988; Moore et al. 1985; Barnes 1982).

3.8 Conclusions

- The productivity of savannas and grasslands is predominantly determined by the soil moisture balance.
- Bush thickening results in a decline in carrying capacity of as much as a 100% and more. Livestock production is seriously hampered and this can be explained in terms of poor and highly variable grass yields, interception of a large amount of soil moisture, a loss in grassland diversity and increased vulnerability to droughts.
- The water-use efficiency of our natural rangelands has become extremely poor. Pioneer veld consisting of annual grasses and bare soils is a common phenomenon in bush-encroached areas and needs 3–10 times more water to produce the same amount of fodder compared with perennial grasses.
- Increased artificial drought events are, therefore, a direct consequence of bush encroachment. Namibia, being a drought-prone country, cannot afford an artificial increase in vulnerability to droughts.
- Considering the large amounts of water intercepted by invader bush it is reasonable to conclude that the underground water table is negatively affected by bush encroachment through increased evapotranspiration, water run-off and less infiltration to subsoils.
- Bush thickening is seen as a major threat to the botanical diversity in Namibia and may even change the mammalian diversity, with the net effect likely to be negative.
- However, with the right densities and a sound mix of trees, bushes and shrubs, a more favourable sub-habitat is established – resulting in a greater variety of herbaceous species and an increased nutrient status under canopies. Mineralisable nitrogen and microbial biomass were significantly higher in soils from the canopy than from the root and grassland zones, whereas organic matter, P and K (but not Mg) declined in soils from the base of trees towards open grassland. Trees can also potentially increase water availability through hydraulic lift and it is possible that a single tree can contribute to a favourable microclimate for other plant species in an area of at least 314 m^2 around itself.

- Grass production will increase with increasing bush densities until a critical stage (approximately 300–500 tree equivalents per hectare), after which further increases will seriously hamper productivity of rangelands and livestock. It is concluded, therefore, that trees at low densities have a beneficial influence on the herbaceous layer.
- Grass biomass increases initially after trees are removed, but after about ten years when the "positive" effect of dead trees has disappeared, grass productivity declines again. In sandy soils this phenomenon is more conspicuous.
- The value of the various bush species as a source of fodder is well recognised. Obviously, the complete removal of trees will reduce the browse to zero, at least in the short term. The value of reserve browse, even for cattle, in times of drought, has been commented on by a number of people, and many communal farmers rely heavily on this when grazing is scarce.
- Bush thinning rather than total clearing should, therefore, be pursued. As a rule of thumb the number of tree equivalents per hectare should not exceed twice the long-term average rainfall divided by 1.5.
- 1 tree equivalent = 1 *Acacia karroo* tree with a height of 1.5 m.
- Thickening of *Rhigozum trichotomum* (Three thorn) from 0 to 1,000 bush equivalents per hectare suppressed grass production by 43–93%. For ecological stability and long-term animal production, it is proposed that *Rhigozum trichotomum* be controlled and managed to stands of 200–400 plants per hectare.
- The potential wood available for harvesting varies between 10 and 20 tonnes per hectare in the different districts, and total yield is largely influenced by the prevailing invader species. Care needs to be taken that these considerations will not become more important than ecological considerations. Thus, harvesting should take place in accordance with ecological principles.
- A large number of mammals, bird species, reptiles and arthropods are associated with "problem bush" species in one way or another and would, thus, be affected positively and/or negatively, depending on the bush control measure to be implemented. Farmers, therefore, need to include biodiversity considerations in their bush-clearing programmes.

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Chapter 4:
Vegetation composition and land productivity[10]

[10] Constituted Component 3 in the original Terms of Reference

The major outputs under this component of the project were to –

- determine the impact of invader bush on land productivity. The data used for this exercise were collected on 192 sites within the commercial area of Namibia, and
- produce an updated and time-sequenced map providing historical and present information on bush densities and composition in the identified problem areas of Namibia.

This information was to be made available to researchers, extension officers, planners, land-users and the general public in the form of a GIS database.

4.1 Bush density and its interaction with land productivity

In order to study the interaction between bushes and land productivity, seven commercial farmers and four extension technicians from the Ministry of Agriculture, Water and Rural Development (MAWRD) were trained in the technique of doing surveys, while a combination of Polytechnic graduates and communal farmers were trained and used to visit 220 sites in communal areas. Chief extension technicians supervised the surveys undertaken in communal areas. Of the 192 sites within the commercial farming areas, 96 were from sites treated for bush encroachment while 96 served as control sites.

Photos 4.1–4.3: Extension staff, Polytechnic graduates and local farmers in communal areas trained to carry out surveys

The number of sites for the different site locations is shown in Table 4.1.

Site location	Untreated sites	Treated sites
Epukiro	20	0
Okakarara	20	0
Okondjatu	20	0
Otjinene	40	0
Total Communal Areas: East	**100**	**0**
Okombahe	60	0
Omatjette	60	0
Total Communal Areas: West	**120**	**0**
Gobabis	8	8
Grootfontein	26	26
Omaruru and Karibib	9	9
Otavi	6	6
Otjiwarongo	14	14
Outjo	7	7
Tsumeb	12	12
Windhoek	14	14
Total Commercial Areas	**96**	**96**
TOTAL	**316**	**96**

Table 4.1: Number of sites at different locations

Sites were sometimes combined. For instance, all untreated communal and commercial sites, making up 316 sites, were combined to collate the results for this sector as a whole. Communal East and West sites were also combined to show a fuller picture for communal sites. The following abbreviations were used for these sites and site combinations:

- Communal sites: C
- Communal East sites: CE
- Communal West sites: CW
- Commercial control sites: CC
- Commercial treated sites: CT
- Untreated sites (commercial and communal): U

For the purpose of the study, problem bushes were divided into different groups as follows:

- Thorny bushes
- Non-thorny bushes
- Fodder bushes, and
- Total bushes (problem and fodder bushes, as well as non-problem trees).

In order to ensure the same interpretation of the data presented here, it is important to attach a definite meaning to different levels of bush densities. Hence, experts in Namibia agreed on the following classification (expressed as total numbers per hectare, which includes all bushes and trees, i.e. problem as well as non-problem species):

- <1,000 low density (no problem)
- 1,000 to 2,000 medium density
- 2,001 to 3,000 high density
- 3,001> very high density (serious problem)

Once the height classes for all the different species are known, these numbers could be expressed in TEs per hectare, which would be more correct scientifically. Presently, one *Acacia karroo* tree measuring 1.5 m in height is regarded as one TE.

This study concentrated on –

- the densities of different groups in relation to different locations
- statistical correlations between groups and various variables/indicators of veld condition, and
- the effect of different groups of bushes on veld condition.

These correlations as well as statistically significant differences between veld condition indicators were also used to illustrate the impact of the different problem bushes on veld condition, and the differences within and between areas and sites.

Statistical analysis was performed using SPSS software (Cramer 1994; Anon. 2001). Main effects and differences between groups were evaluated by analysis of variance (ANOVA), using the multivariate general linear model (GLM) at a sensitivity (α-level) of 0.05. Factor interactions and differences within groups were determined by least significant differences (LSD). Significance was displayed as P values smaller than 0.01 (**) or 0.05 (*), respectively.

Relationships between factors were determined by calculating regression equations using SPSS. The correlation r^2 was used to evaluate the goodness-of-fit of linear, quadratic, exponential or polynomial regressions, and to decide on the most appropriate relationship between an independent and a number of dependent variables.

4.1.1 Problem bush

Problem bush consists of thorny and non-thorny problem species. Among the thorny group the most important problem bushes are *Acacia erubescens*, *Acacia fleckii*, *Acacia mellifera*, *Acacia reficiens* and *Dichrostachys cinerea*, and the most important non-thorny ones include *Colophospermum mopane, Terminalia prunioides* and *Terminalia sericea*.

4.1.1.1 Densities of problem bush

There were large differences between commercial control (CC), commercial treated (CT) and communal (C) sites. C sites had the lowest numbers of problem bushes for all height classes, except for problem bushes larger than 4 m. Even CT sites had more problem bushes smaller than 0.5 m than the C sites. Differences varied from significant ($P<0.05$) to highly significant ($P<0.01$) between CC and C sites.

According to Figure 4.1, CT sites had higher numbers of problem bushes smaller than 0.5 m (700 per hectare) than bushes above 0.5 m (555 per hectare). This is an indication that many sites were treated some years back and that reinfestation had already started. This means that the treatment or control method applied was not a once-off event; hence, the importance of aftercare treatment cannot be overemphasised. The CC sites had higher numbers of problem bushes above 0.5 m (1,369 per hectare) than below 0.5 m (1,139 per hectare).

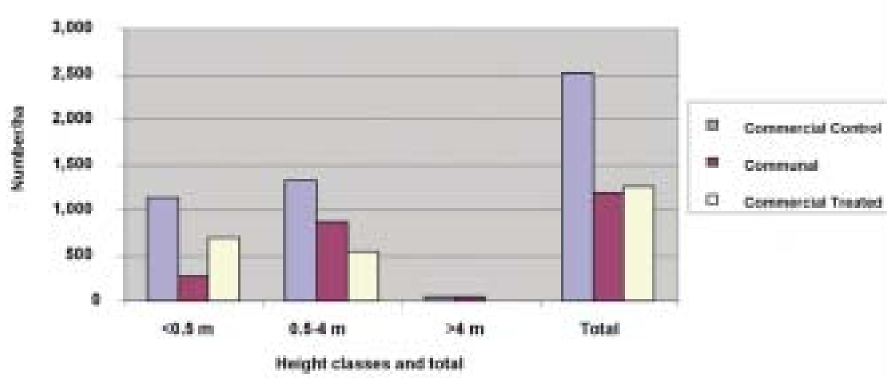


Figure 4.1: Total problem bushes in different height classes for CC, CT and C sites

The Windhoek area (see Figure 4.2) had the highest number of problem bushes per hectare below 0.5 m (nearly 3,500 per hectare), followed by the Tsumeb area (less than 2,000 per hectare). For the problem bushes above 0.5 m (see Figure 4.3), the Tsumeb area had the highest numbers by far (more than 3,000 per hectare), followed by the Okakarara and Okondjatu areas (just over 1,500 per hectare).

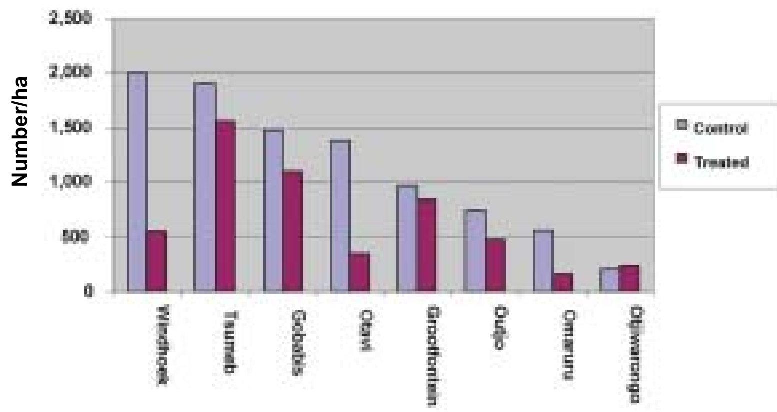


Figure 4.2: Number of problem bushes smaller than 0.5 m for CC and CT sites within the commercial farming area

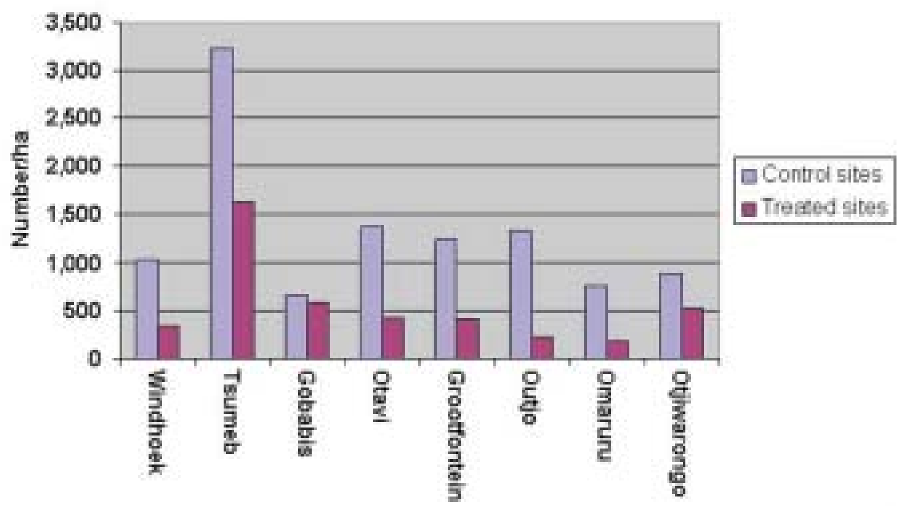


Figure 4.3: Number of problem bushes between 0.5 and 4 m for CC and CT sites within the commercial farming area

The C sites had highly significantly less smaller (<0.5 m) problem bushes than the CC sites, while the difference for problem bushes above 0.5 m was only significant at the 95% level.

Low sample numbers in certain commercial site locations and subsequent high standard deviations within these sites presented a problem in the statistical analysis of data. Ostensibly huge differences were eventually found not to be significant due to these reasons.

Statistically significant differences exist between CC and CT sites for problem bushes above 0.5 m. Although treated sites reflected lower densities, these differences clearly illustrate that the effect of single treatments are not long-lasting. Unfortunately the available data cannot differentiate between years of establishment for different height classes. Such information would be valuable in respect of determining gradual establishment versus more cyclic patterns of reinfestation. For the smaller bushes no significant differences could be found. In the Otjiwarongo area, the number of smaller bushes for CT sites was even higher than that of the CC sites.

For the higher problem bushes (see Figure 4.3), significant differences could be shown for five of the site locations between CC and CT sites, namely Grootfontein, Omaruru, Otavi, Outjo and Windhoek.

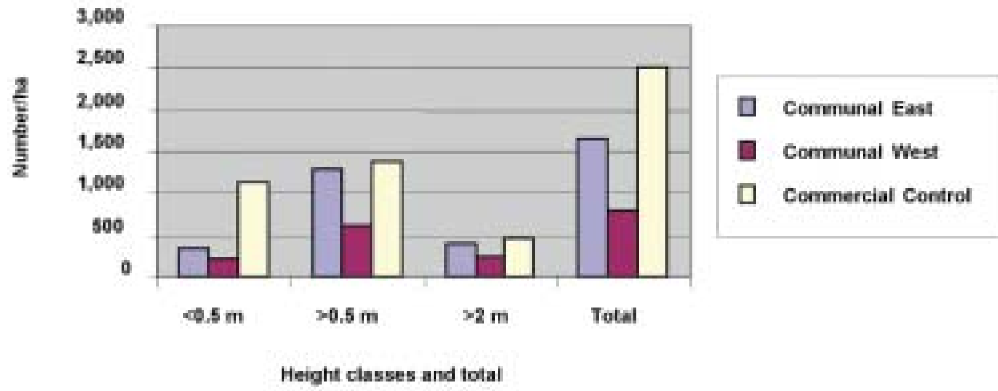


Figure 4.4: Numbers of problem bushes for CE, CW and CC sites

In the case of total problem bushes, the CC sites (2,508 per hectare) had highly significantly more bushes than the CT (1,254 per hectare), C (1,186 per hectare) and CE sites (1,639 per hectare). CT and C sites did not differ significantly.

The difference for total problem bushes for CE (1,639 per hectare) and CW sites (809 per hectare) was also highly significant. This huge difference could be ascribed to the much lower long-term average rainfall for the western communal areas.

Total problem bushes smaller than 0.5 m differed highly significantly ($P<0.05$) between CC (1,329 per hectare), CE (348 per hectare) and CW sites (208 per hectare) (see Figure 4.4). Research findings show that two to three wet seasons are required for *Acacia mellifera* seedlings to survive. Since all seedlings below 0.5 m were counted, follow-up surveys should be carried out at the same sites in the years ahead to determine how many of these seedlings are still present.

For total problem bushes between 0.5 and 4 m, the difference was statistically highly significant (Figure 4.4). The CE sites had 1,262 bushes per hectare, and the CW sites 561 per hectare.

The CE sites have approximately double the number of problem bushes per hectare than the CW sites in the different height classes. These differences are highly significant.

These figures are flashing red lights for most of the C and CE areas since the potential for increased seed production, seed content of the soil and reinfestation from invader species is alarming.

When the total number of problem bushes for the CC and CE are compared, the difference is still highly significant.

Figures 4.5, 4.6, and 4.7 respectively illustrate the existing ranking of bush density in the different locations for (a) the height class of <0.5 m, (b) the height class of 0.5–4.0 m, and (c) total problem bushes.

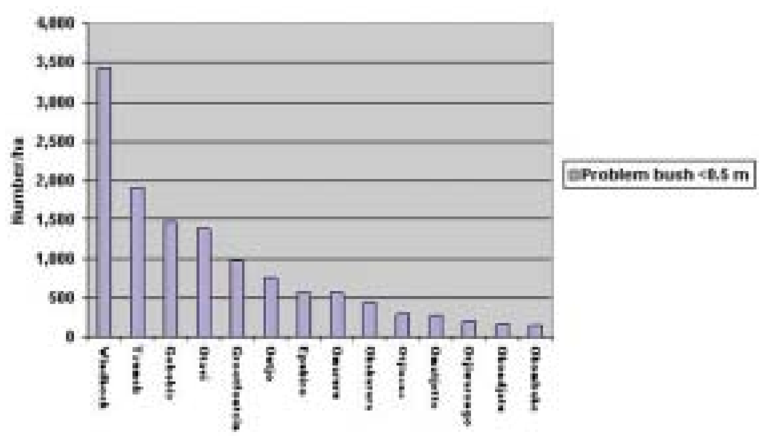


Figure 4.5: Problem bushes smaller than 0.5 m for different site locations

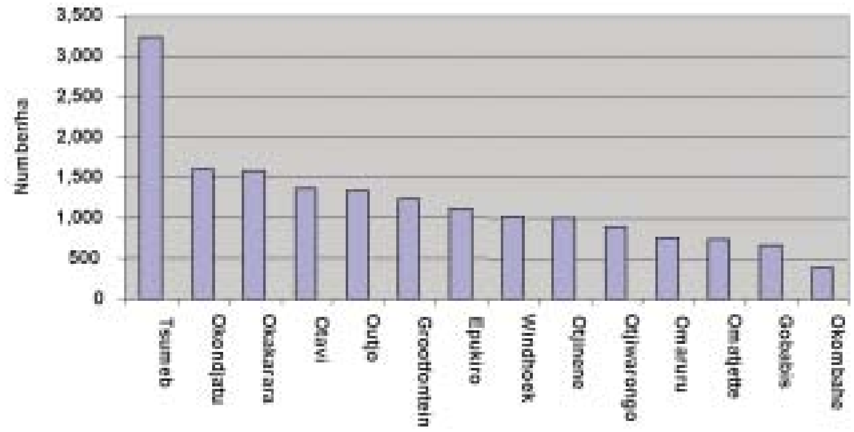


Figure 4.6: Number of problem bushes between 0.5 and 4 m for different site locations

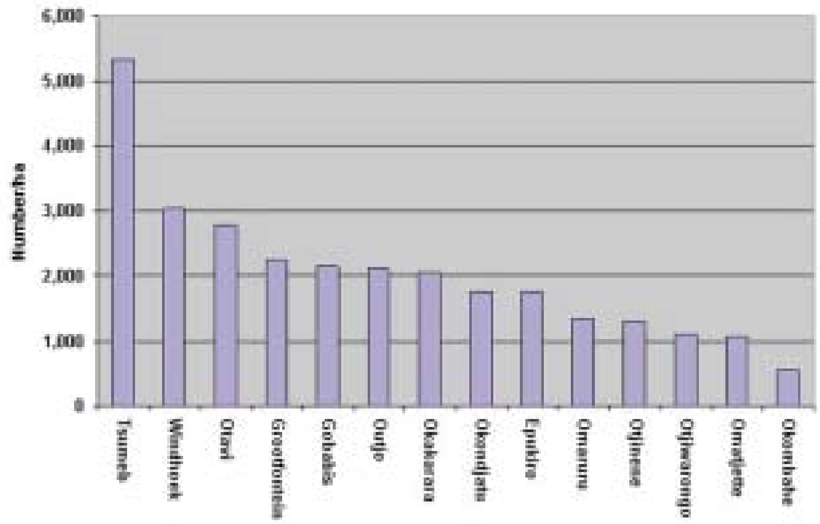


Figure 4.7: Number of total problem bushes for different site locations

4.1.1.2 Correlations

Correlations calculated for all sites (412) between problem bushes and other variables showed –

- a highly significant positive correlation between problem bushes and total trees
- a highly significant negative correlation with the percentage of perennial grasses, and
- a highly significant negative correlation with the percentage of perennial plus annual grasses.

In other words, with an increase in the number of problem bushes, the percentage of perennial grasses as well as total grass cover (perennial plus annual) declined.

The correlation between the percentage of *Aristida* grasses and problem bushes was positive for U, C and CC sites, but only significant in C sites.

In the case of the percentage of forbs, correlations with problem bushes were positive for all site locations, but highly significant only in the case of C sites and significant for CT sites.

The percentage of bare areas was positively correlated to problem bushes.

For fodder bushes as a whole, the correlation for both smaller (<1 m) and total fodder bushes was significant. For U sites, problem bushes were highly significantly and positively correlated with palatable and fodder bushes.

Tables 4.2 and 4.3 summarise the most important correlations from a practical point of view.

Problem bush	Total trees (No.)	Perennial grasses (%)	Perennial and annual grasses (%)	Forbs (%)
Total	## positive	## negative	## negative	# positive

Note: ## = highly significant (P<0.01); # = significant (P<0.05)

Table 4.2: Correlation between total problem bushes and total trees, perennial grasses, total grass cover and forbs

Category of problem bush	Palatable bush (<1 m)	Fodder bush (<1 m)	Total fodder bush (No.)	Perennial grass species (%)	Perennial plus annual grass species (%)	Forbs (%)
<0.5 m	## positive	## positive	NS	NS	NS	NS
0.5–4 m	NS	NS	NS	NS	NS	## positive
Total	**NS**	**NS**	**# positive**	**# negative**	**# negative**	**NS**

Note: ## = highly significant (P<0.01); # = significant (P<0.05); NS = not significant

Table 4.3: Correlations between problem bushes and other variables for treated sites

4.1.1.3 Problem bushes and veld condition

Higher numbers of problem bushes in U sites are associated with a substantial increase in the number of thorny trees, non-thorny trees, palatable bushes, forbs and bare areas, as opposed to decreased percentages of perennial grasses and total grasses (perennial plus annual).

Statistically there was nearly no significant difference between the CC and CT sites in respect of veld condition, based on components like the number of problem bushes, percentage of perennial grasses, percentage of annual grasses, percentage bare areas, percentage of aristidas and the number of perennial grass species. It should be noted that veld condition scoring as such was not done at the time of the surveys.

The relatively small differences between CC and CT sites in respect of the components shown above may indicate that a large number of these sites were treated a number of years ago, and that reinfestation and regrowth of problem bush has since occurred on a large scale.

Increased smaller problem bush numbers showed a less negative effect on the percentage of perennial grasses when compared with the increased numbers of larger problem bushes in CC and CE sites. This may suggest that smaller bushes are less competitive for available moisture.

4.1.2 Thorny problem bushes

4.1.2.1 Densities

Numbers of thorny problem bushes differed highly significantly between CC and C sites on the one hand, and CC and CT sites on the other.

CC sites had highly significantly more thorny problem bushes smaller than 0.5 m than the C and CT sites. Only Epukiro had more of this type of bush than the Otavi and Otjiwarongo sites.

Windhoek, Gobabis and Tsumeb sites had more than 1,000 thorny problem bushes smaller than 0.5 m per hectare.

The C sites had many more larger thorny problem bushes than smaller ones.

Of the C sites, Epukiro (836 per hectare), Okakarara (995 per hectare) and Okondjatu (1,025 per hectare) had the highest numbers of thorny problem bushes between 0.5 and 4 m.

Okombahe (507 per hectare), Omatjette (644 per hectare) and Otjinene (571 per hectare) had the lowest numbers.

CE and CW areas differed significantly in the number of thorny problem bushes smaller than 0.5 m, and highly significantly in respect of thorny problem bushes between 0.5 and 4 m and for total thorny problem bushes.

Thorny problem bushes smaller than 0.5 m differed significantly between CC and CT individual locations only in the case of Outjo (588 per hectare in CC sites against 188 per hectare for CT sites).

In the case of CC and CT sites, more than 60% of thorny problem bushes smaller than 0.5 m were found in CC sites. This percentage increased substantially in favour of CC in the case of larger thorny problem bushes. For bushes above 0.5 m the percentage was 70%, above 1 m it was 73%, and for bushes above 2 m it was nearly 80%.

It is not surprising, therefore, that in respect of thorny problem bush numbers more significant differences between CC and CT sites were found for bushes above 0.5 m. Grootfontein, Omaruru and Outjo had highly significantly more thorny problem bushes above 0.5 m for CC sites, while in the cases of Otavi and Windhoek the difference was significant.

4.1.2.2 Correlations

Correlations were done for all untreated sites (U = 316), whether commercial or communal. There were 96 untreated commercial sites and 220 untreated communal sites. Only total thorny problem bushes were used and correlated with various other components (see Figure 4.8).

For total thorny problem bushes, statistically highly significant (P<0.01) correlations were found with the percentage of perennial grasses (negative), and the percentage of forbs (positive).

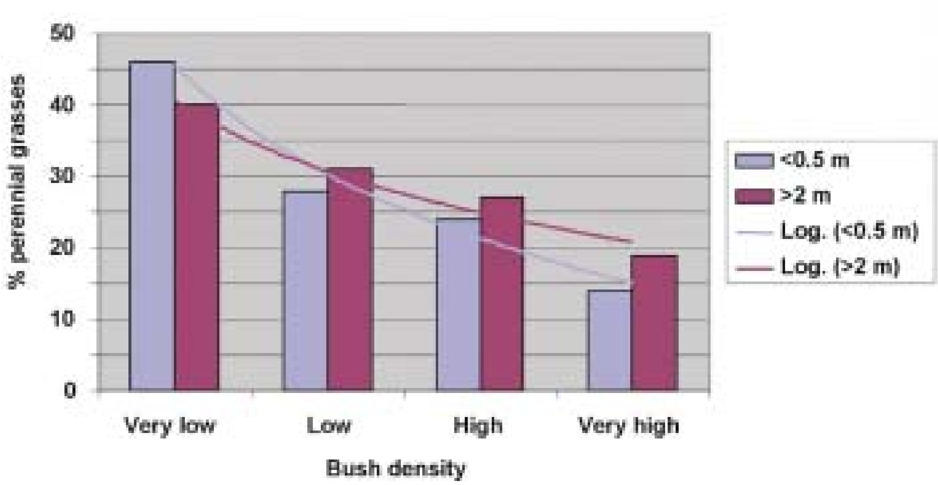


Figure 4.8: The effect of increased numbers of smaller and larger thorny problem bushes on the percentage of perennial grasses in the CW area

4.1.2.3 Thorny problem bushes and veld condition

For all height classes of thorny problem bushes in the 316 U sites there was a decrease in the percentage of perennial grasses as the number of these bushes increased. The percentage of annual grasses dropped initially when sites with no thorny problem bushes above 0.5 m were compared with sites having these bushes, but then the percentage of annual grasses increased steadily as the number of thorny problem bushes increased. The percentage of forbs, aristidas and bare areas increased in the same way, as did the number of fodder bushes and trees.

When U sites are divided into two groups, namely those with more than 600 thorny problem bushes per hectare and those with less than 600, the difference in the percentage of perennial grasses was found to be highly significant.

For the percentage of annual grasses the difference was not significant, but for the percentage of perennial plus annual grasses the difference was significant (71.8% for the low-numbered sites and 65.1% for the high-numbered sites). The percentage of forbs also differed highly significantly (10.6% for the low-numbered sites and 17.4% for the high-numbered sites).

4.1.3 Non-thorny problem bushes

4.1.3.1 Densities

CC and C sites did not differ significantly in respect of non-thorny problem bush numbers. As can be expected, CT sites had significantly less non-thorny problem bushes than the CC and C sites (see Figure 4.9). Of all the individual locations, Tsumeb had by far the highest number of non-thorny problem bushes (more than 2,000 per hectare), followed by Okakarara (864 per hectare) and Otjinene (736 per hectare). Of the two communal areas, the CE sites had highly significantly more non-thorny problem bushes per hectare than the CW sites (663 versus 234).

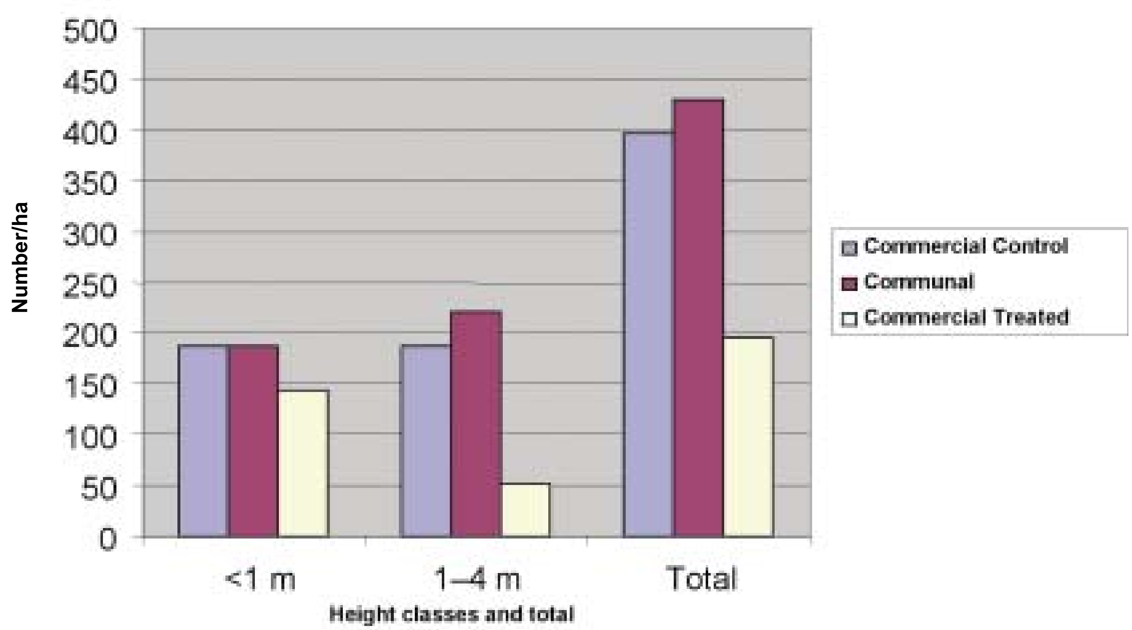


Figure 4.9: Height classes and numbers of non-thorny problem bushes for CC, CT and C sites

4.1.3.2 Correlations

The most important highly significant correlations between non-thorny problem bushes and other variables within the U sites are with total palatable bushes (positive), less-palatable bushes (positive), fodder bushes (positive) and the percentage of perennial plus annual grasses (negative).

As Figure 4.10 shows, highly significant negative correlations were found between non-thorny problem bushes in C sites and the percentage of annual grasses on the one hand, and the percentage of perennial plus annual grasses on the other. A positive and significant correlation was found between non-thorny problem bushes and the percentage of bare areas.

For the CC sites, highly significant positive correlations were found between non-thorny problem bushes and palatable bushes <1 m, total palatable bushes, less-palatable bushes <1 m, total less-palatable bushes, fodder bushes <1 m, total fodder bushes, total bushes and trees, and the percentage of annual grasses.

Significant negative correlations were obtained between non-thorny problem bushes and (a) the percentage of perennial grasses, and (b) the number of perennial grass species.

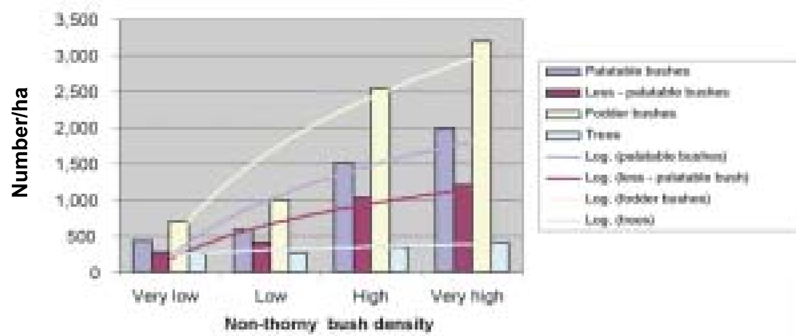


Figure 4.10: The effect of increased numbers of non-thorny problem bushes on certain indicators of veld condition for CC sites (1)

4.1.3.3 Non-thorny problem bushes and veld condition

In the case of CC sites (see Figure 4.11), increased numbers of non-thorny problem bushes led to increased numbers of palatable and less-palatable bushes, a lower percentage of perennial grasses, and higher percentages of annual grasses and bare areas.

U sites were divided into two groups, low and high, based on non-thorny problem bush numbers per hectare. The "low" group had less than 400 non-thorny problem bushes per hectare (50 per hectare on average), while the "high" group had more than 400 (1,345 per hectare). These two groups were used to illustrate the effect of increased numbers of non-thorny problem bushes on certain indicators of veld condition for the U sites.

Highly significant differences between the high and low groups were found for palatable bushes (low = 488 per hectare, high = 1,137 per hectare), less-palatable bush (low = 399 per hectare, high = 634 per hectare), the percentage of annual grasses (low = 31.8%, high = 22%), the percentage of perennial plus annual grasses (low = 70.7%, high = 61.5%), the percentage of aristidas (low = 4.17%, high = 8.52%), and the percentage of bare areas (low = 10%, high = 17%).

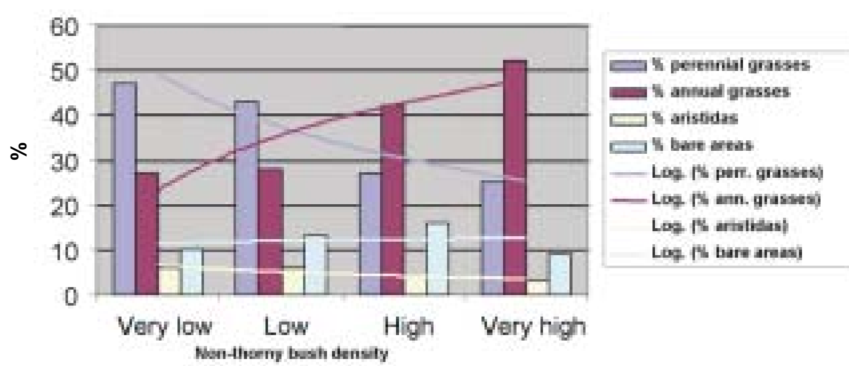


Figure 4.11: The effect of increased numbers of non-thorny problem bushes on certain indicators of veld condition for CC sites (2)

4.1.4 Fodder bushes

All plants classified as fodder bush by local farmers and technicians were included here. The most important and dominant fodder bushes include various *Grewia* spp. (Raisin shrubs/Rosyntjiebossoorte), *Bauhinia petersiana* (Coffee neat's foot/Koffiebos), *Boscia albitrunca* (Shepherd's tree/Witgat), *Catophractes alexandri* (Trumpet thorn/Gabbabos), *Combretum apiculatum* (Red bushwillow/Koedoebos), *Tarchonanthus camphorates* (Wild camphor bush/Vaalbos), and the pods of *Acacia erioloba* (Camelthorn/Kameeldoring).

4.1.4.1 Densities

The CC sites had significantly more fodder bushes (1,349 per hectare) than the CT (777 per hectare) and C sites (1,047 per hectare), but there was no significant difference between the CT and C sites (see Figure 4.12).

A statistically highly significant difference in fodder bush numbers per hectare was found between CE (1,393 per hectare) and CW areas (758 per hectare).

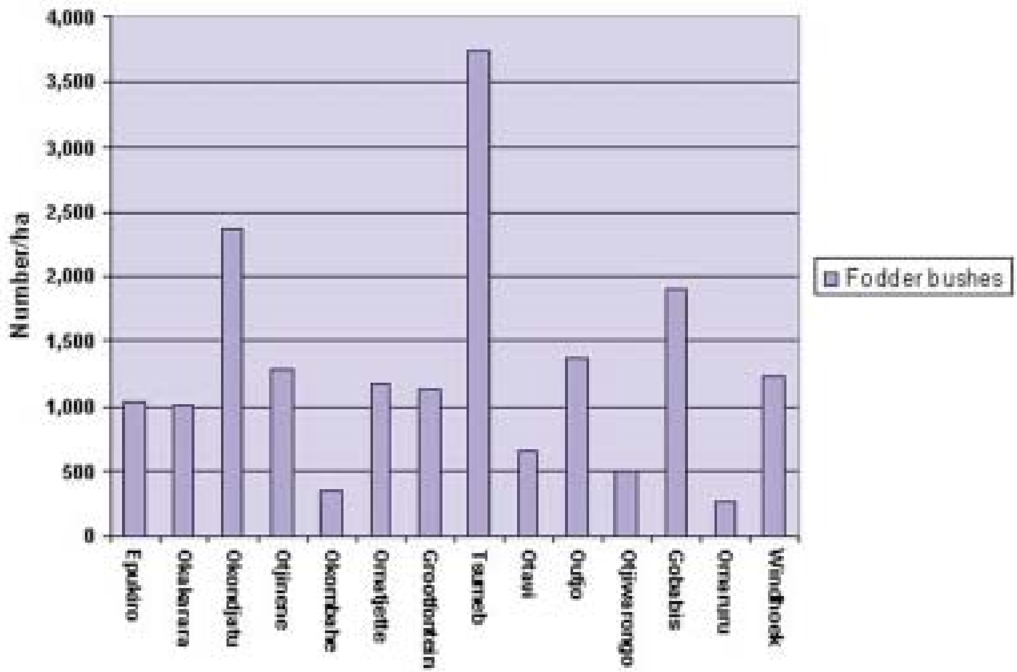


Figure 4.12: Fodder bush numbers for the different site locations: U sites

4.1.4.2 Correlations

A highly significant positive correlation was found between fodder bushes and indicators of veld condition within the CC sites in respect of non-thorny problem bushes. Significant correlations were found with problem bushes (positive), percentage of perennial grasses (negative), the number of perennial grass species (negative) and the percentage of aristidas (negative).

In the case of U sites the following highly significant correlations with fodder bushes were found: non-thorny problem bushes (positive), problem bushes (positive), the percentage of bare areas (positive), the number of perennial grass species (positive), the percentage of annual grasses (negative), and the percentage of perennial plus annual grasses (negative).

4.1.5 Total bushes and trees

All bushes and trees, whether problematic or not, are included in this group. For the purpose of this study all problem species are defined as "bushes", irrespective of height, while taller benign species are referred to as "trees".

4.1.5.1 Densities

Figure 4.13 shows clearly that the CC sites had highly significantly more bushes and trees than the C and CT sites, but between the C and CT sites there was no significant difference. If one looks at Figure 4.14, it is clear that only Okombahe can be regarded as a low density area, while locations like Epukiro, Gobabis, Grootfontein, Okakarara, Okonjatu, Otavi, Outjo, Tsumeb and, surprisingly, Windhoek fall in the very high density group. Although the Outjo and Otjiwarongo areas showed medium densities it needs to be emphasised that the sample was very small and in both cases restricted to lower-density areas. The eastern part of Outjo is well known as a very high density area, while most of Otjiwarongo will fall in the same category. Fodder bushes are and will always remain a very important component of the total livestock diet under natural conditions.

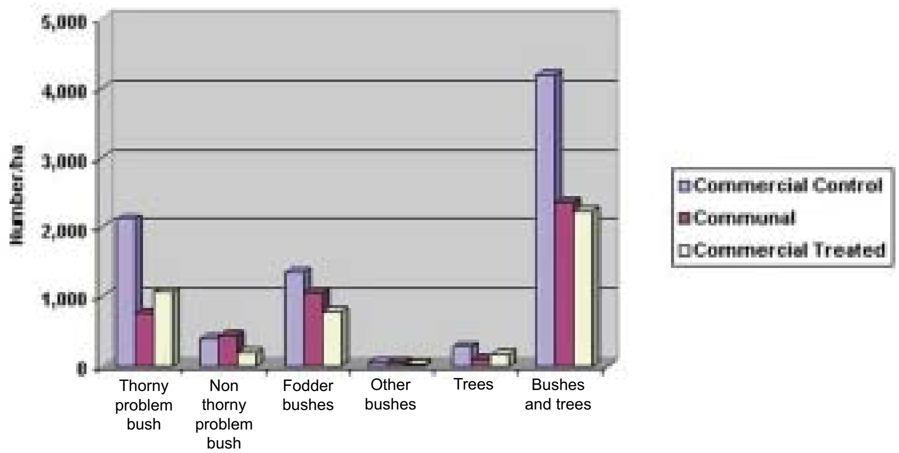


Figure 4.13: Number of bushes and trees for CC, CT and C sites

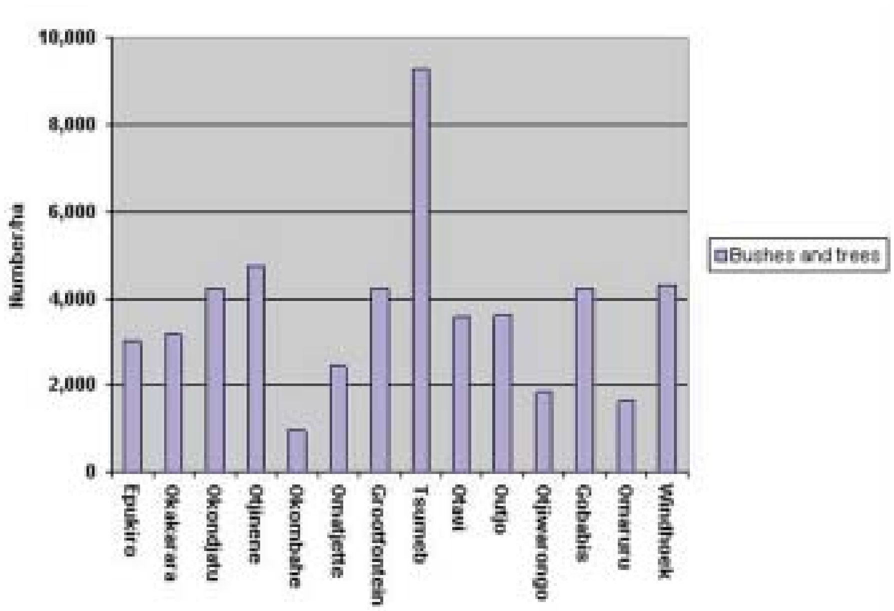


Figure 4.14: Total bush and tree densities for different site locations

A study carried out by Kruger (2001) reveals much higher total bush and tree densities for communal areas. The eastern Otjozondjupa Region (Otjituuo, Okakarara) and the Omaheke Region (Otjinene, Epukiro), as well as the western and north-western communal areas in the Erongo Region (Okombahe and Omatjette) and the southern Kunene Region (Grootberg, Kamanjab) seem to have substantially higher bush densities than were found in the current study. In the communal areas of the Otjozondjupa Region, bush densities varied between 3,933 bushes per hectare for the Okakarara area, 3,816 bushes per hectare in the Okamatapati area, 5,916 bushes per hectare in the Otjituuo area, and 5,549 bushes per hectare in the Okondjatu area. In the communal areas of the Omaheke Region, Epukiro (8,117 bushes per hectare) and Otjinene (7,735 bushes per hectare) showed the highest bush densities, with Rietfontein (2,883 bushes per hectare) and Aminuis (2,750 bushes per hectare) showing considerably lower densities. Communal areas in the west, considering the much lower annual rainfall, also recorded alarming bush densities: Otjimbingwe had 1,033 bushes per hectare; Omatjete 2,826 bushes per hectare; and Okombahe 3,020 bushes per hectare, while bush densities in the Grootberg area seem to be low (1,783 bushes per hectare).

Communal areas in Aminuis, Grootberg and Otjimbingwe do not seem to have much of a bush encroachment problem, but close monitoring of the situation is needed.

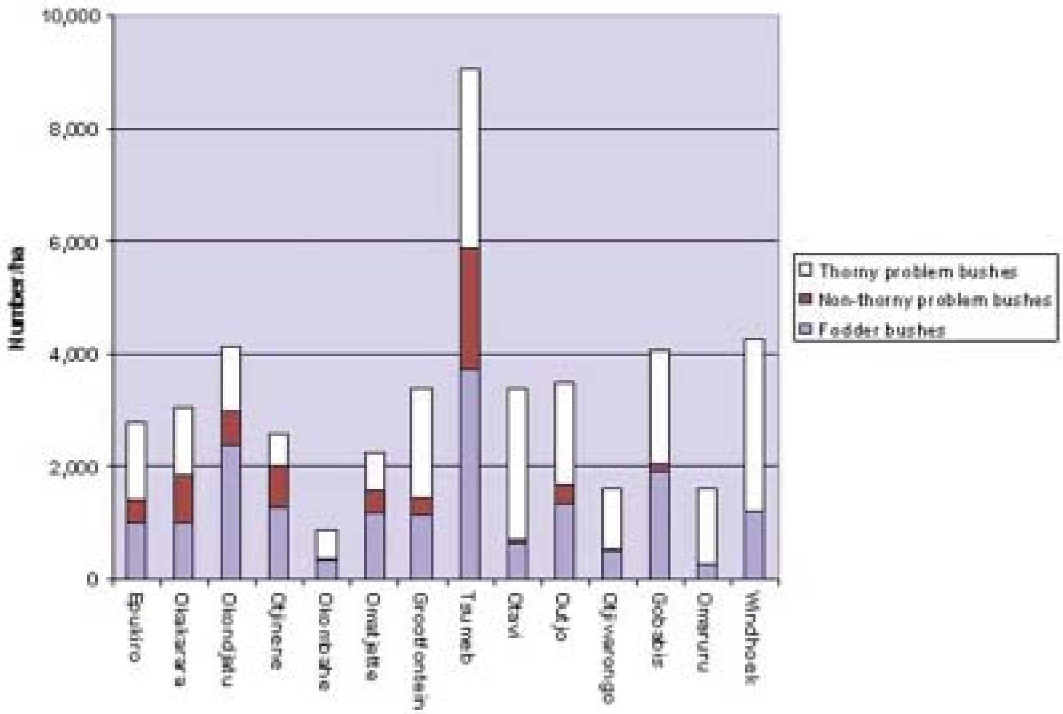


Figure 4.15: The relative contribution of problem and fodder bushes to total bush

4.1.5.2 Correlations

In the C, CC and CT sites, total bushes and trees were highly significantly and positively correlated to –

- total thorny problem bushes
- total non-thorny problem bushes
- total problem bushes, and
- total fodder bushes,

while highly significant negative correlations were found with –

- the percentage of annual grasses, and
- the percentage of perennial plus annual grasses.

4.1.6 Dead bushes and trees

4.1.6.1 Densities

As could be expected, CT sites had highly significantly more dead bushes and trees than CC and C sites. Between CC and C sites the difference was not significant (see Figure 4.16).

The percentage of dead bushes in the CC and C sites was 2.0% and 2.3%, respectively. Although the figures in this study do not reveal large mortality rates among invader bushes, it is well known that invader bushes were killed by fungi over thousands of hectares, and that the natural dying-off of bushes could be much higher in certain areas.

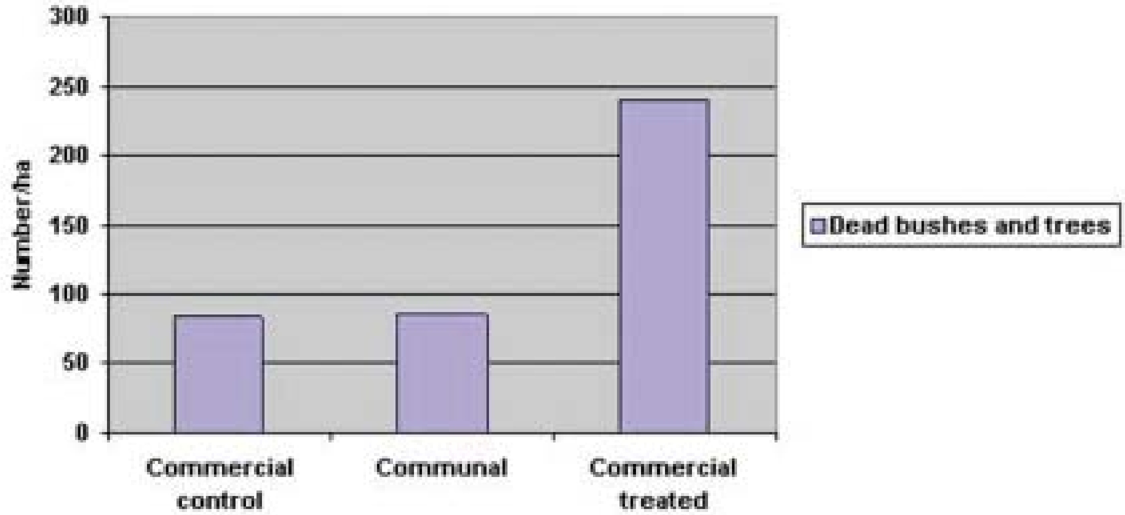


Figure 4.16: Number of dead bushes and trees in CC, CT and C sites

4.1.6.2 Correlations

For C sites, dead bushes and trees correlated in a highly significant positive way with –

- total thorny problem bushes
- total less-palatable bush
- total fodder bushes higher than 1 m
- total bushes, and
- total bushes and trees above 0.5 m.

Significant correlations were found with fodder bushes (positive), total bushes and trees (positive) and the percentage of aristidas (positive).

For CC and CT sites, not one significant correlation was found between the number of dead bushes and trees and other variables.

4.1.7 Conclusions

In the case of "Total problem bushes (all height classes)", the CC sites – with an average of 2,508 bushes per hectare – are highly significantly more encroached than the CT (1,254 per hectare), C (1,186 per hectare) and CE sites (1,639 per hectare). The fact that veld fires were suppressed and controlled for a much longer period in the commercial farming areas since the introduction of the Soil Conservation Act (which was not applicable in communal areas) seems to be one of the main reasons for this difference.

Treated areas showed an alarming increase in total problem bush numbers for the height classes <0.5 m and 0.5–4.0 m, and clearly show that single treatments are not long-lasting. This phenomenon clearly illustrates how important follow-up treatments are.

The disturbing number of invader bush species in commercial as well as communal areas in the groups smaller than 0.5 m in particular, but also those measuring 0.5–4.0 m, pose a huge threat for the future productivity of Namibian savannas. This concern is further amplified when the much higher bush-density figures derived by Kruger (2001) are taken into consideration. There is an urgent need for immediate action to prevent an ultimate collapse of the production system.

In terms of total bushes and trees, only Okombahe could be regarded as a low-density area while locations like Epukiro, Gobabis, Grootfontein, Okakarara, Okonjatu, Otavi, Outjo, Tsumeb and, again surprisingly, Windhoek fall in the "very high" density group. Fodder bushes are and will always remain a very important component of total livestock diet under natural conditions.

The sample sizes for sites in the districts of Otjiwarongo and Outjo are too small and densities presented here are not representative of those districts. Figures in this regard should, therefore, be ignored.

Except for Omaruru, all the U sites in commercial districts showed highly significantly more total problem bushes, thorny problem bushes, non-thorny problem bushes and total bushes and trees than in communal areas. Even if commercial U sites are compared with U sites in the eastern communal areas, the difference is still highly significant. This finding implies that the difference in bush densities between commercial and communal farming areas may be ascribed to the application of different land-use practices. Follow-up research to determine the reasons for this should be regarded as a priority.

With an increase in the number of total problem bushes, thorny problem bushes, non-thorny problem bushes and total bushes and trees, a highly significant decline in the percentage of perennial grasses as well as total grass cover (perennial plus annual) was found for each of these groups.

For sites with more than 600 thorny bushes per hectare, the percentage of perennial grasses was highly significantly less than for sites with lower densities of thorny bush.

The percentage of bare areas and the percentage of forbs were significantly correlated to a positive degree with problem bushes.

An interesting finding is that fodder bush densities are significantly to highly significantly correlated with thorny, non-thorny and total problem bushes in C and U sites, respectively, and that increased densities of fodder bushes also significantly suppress perennial and total grass cover.

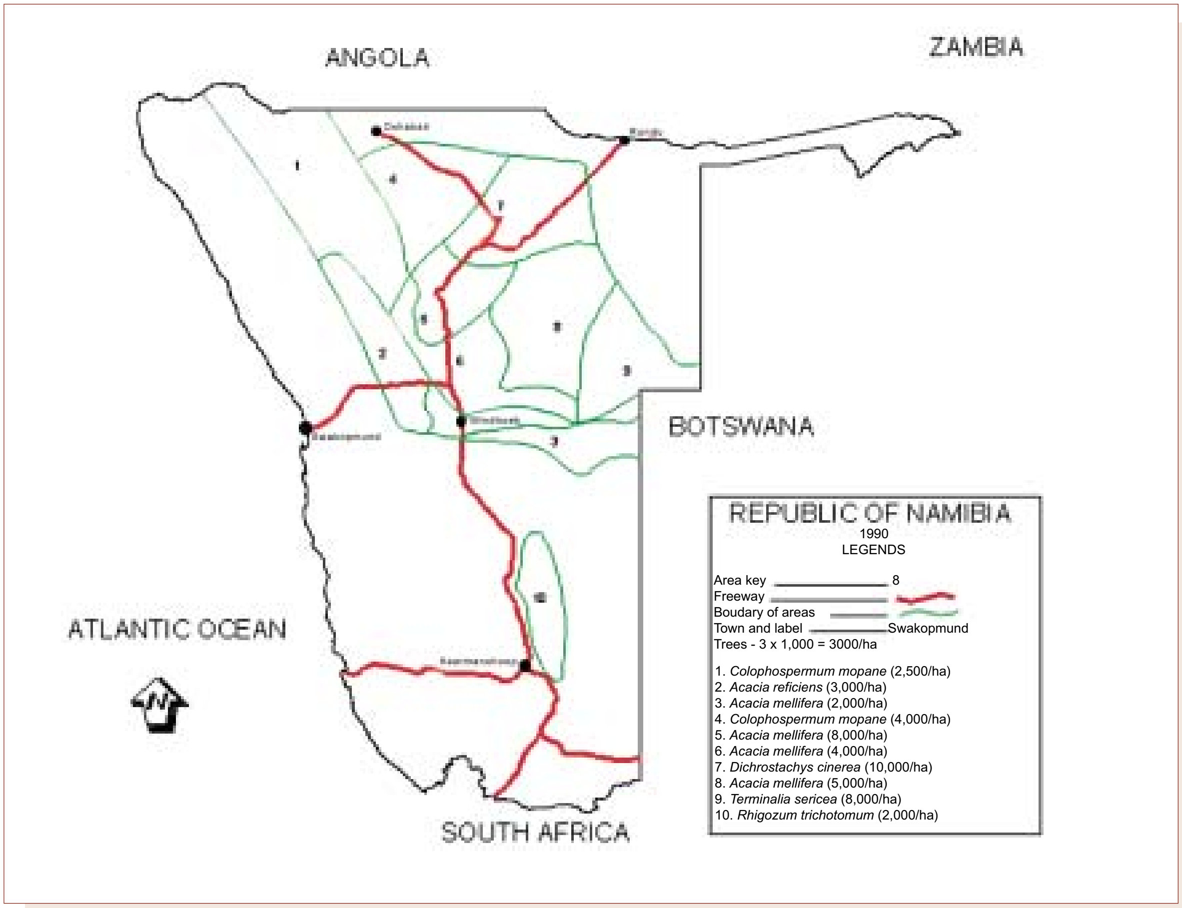
The above results clearly illustrate the adverse impact of especially problem bushes in the affected areas, and that bush thinning should be applied over the entire spectrum of bushes. In almost all the areas investigated, trees occur in small numbers. Farmers should, therefore, refrain from eradicating any non-problem trees.

The survey showed that natural mortalities of invader bush vary between 2–3% and do not seem to pose the long-term solution hoped for.

4.2 Mapping historical and present information on bush density and composition

4.2.1 Historical situation

Figure 4.17 illustrates the dominant invader bush species and bush densities in different parts of the affected commercial areas (Bester 1996). As far as the communal areas are concerned no maps whatsoever could be found to depict the situation. However, more light was shed on the magnitude of the problem in both communal and commercial areas by Bester (1999), as illustrated in Table 4.4.



Source: Bester (1996)

Figure 4.17: Dominant invader bush species and bush densities in different parts of the affected commercial areas

Category of thickened bush			**Hectares**	
No. on map (Figure 4.17)	**Main bush species**	**Bush density (No. per hecare)**	**Commercial land**	**Communal land**
1	*Colophospermum mopane*	2,500	1,451,000	2,986,000
2	*Acacia reficiens*	3,000	1,676,000	691,000
3	*Acacia mellifera* subsp. *detinens*	2,000	3,360,000	195,000
4	*Colophospermum mopane*	4,000	482,000	1,090,000
5	*Acacia mellifera* subsp. *detinens*	8,000	2,067,000	13,000
6	*Acacia mellifera subsp. detinens*	4,000	2,692,000	210,000
7	*Dichrostachys cinerea*	10,000	2,513,000	1,220,000
8	*Acacia mellifera* subsp. *detinens*	5,000	950,000	2,453,000
9	*Terminalia sericea*	8,000	586,000	1,624,000
Total			**15,777,000**	**10,482,000**

Table 4.4: Approximate area covered by the different dominant bush species in commercial and communal areas

According to the figures presented in Table 4.4 the area covered with problem bushes (26 million ha) is much larger than the 17 million ha referred to in the past. *Acacia mellifera* subsp. *detinens* is dominant in 45.5%, and *Colophospermum mopane* dominates in 22.9% of the total problem area. *Acacia reficiens* occurs mainly in the western parts and covers an area of 9.0%. *Dichrostachys cinerea*, which occurs on 14.2% of the rangelands, is the most prominent problem in the Grootfontein/Otjituuo/Tsumeb areas, while the corresponding figure for *Terminalia sericea* is 8.4% – mainly in the eastern sandy soils of the encroached areas.

In the southern parts of Namibia *Rhigozum trichotomum* invasion on approximately 2 million ha is causing substantial production losses, with densities varying between 1,000 and 2,500 plants per hectare (average 2,000 plants per hectare). No surveys have been done in these areas to verify the figures, however.

In the present study the following sources of information were used to determine the prevailing densities and dominance of specific invader bush species together with their relation to various variables:

- Approximately 2,000 data points from surveys carried out and coordinated by the Bush Encroachment Research, Monitoring and Management Project; Mr FV Bester of the Directorate of Agricultural Research and Training (MAWRD); and the National Remote Sensing Centre (NRSC) in the Directorate of Forestry (MET), which have estimated numbers of bush per hectare and/or attempted a classification of low, medium or high bush densities based on real surveys
- Total (cumulative) seasonal biomass production estimations over 17 years (1985/6–2001/2), calculated from NOAA–AVHRR[11] and SPOT VEGETATION Normalised Difference Vegetation Index (NDVI) images with a pixel size of 900 m x 900 m
- Aggregated agro-ecological zones (AEZs) and soil/terrain mapping units from the MAWRD
- Vegetation units from the *Atlas of Namibia* (Mendelsohn et al. 2002), and
- Mean annual rainfall of Namibia, as interpolated from existing rainfall data by Namibia Resource Consultants.

The methodology and information used for –

- data processing and analysis
- the display and analysis of bush density data
- species data
- bush data, and
- biomass production data

are shown in a detailed study compiled by Mendelsohn and Coetzee (2003), which is available at the libraries of the Ministry of Environment and Tourism and the Ministry of Agrculture, Water and Rural Development.

4.2.2 Present situation: Results and analysis

4.2.2.1 Bush density

A total of 1,909 plots were assigned to one of the four bush density categories (very high, high, medium or low), as follows:

Density category	Bush density per hectare	Number of plots	Percentage of plots
Very high	>3,000	493	26
High	2,000–3,000	613	32
Medium	1,000–2,000	429	22
Low	<1,000	373	20

Table 4.5: Number and percentage of plots within each of the bush density categories

[11] National Oceanographic and Atmospheric Agency (NOAA) Advanced Very High Resolution Radiometer (AVHRR)

There is no clear-cut dominance by any given category. Furthermore, the sampling was not completely randomised. However, there is a general trend of increasing density in a south-westerly to north-easterly direction: 77% of the "very high" and 52% of the "high" density sites lie north-east of the Otjiwarongo–Gobabis axis (see Figure 4.18), while 58% of the "medium" and 58% of the "low" density sites lie south-west of that axis.

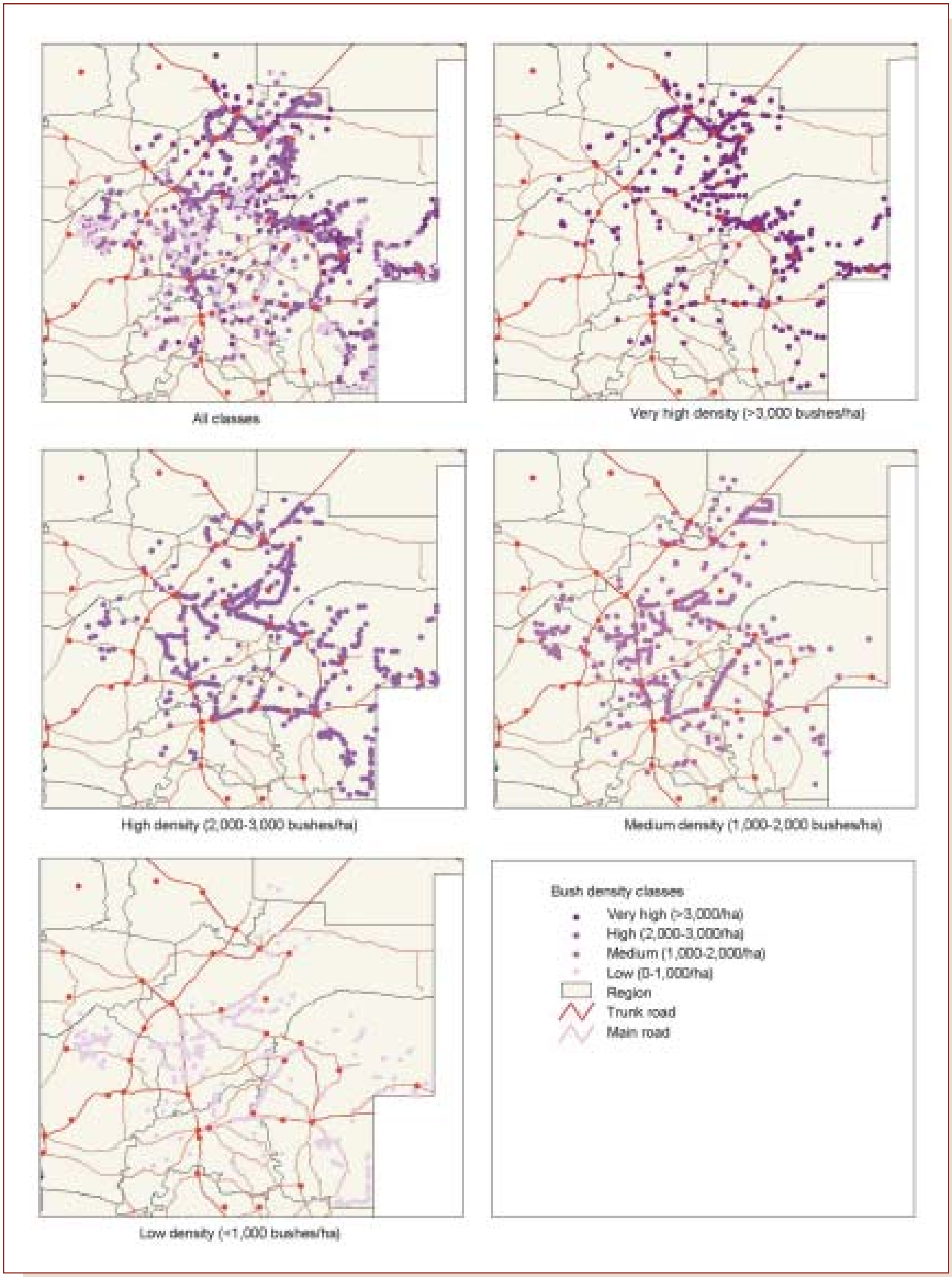


Figure 4.18: Distribution of bushes, as per "very high", "high", "medium" and "low" bush density classification

4.2.2.2 Bush density per agro-ecological zone

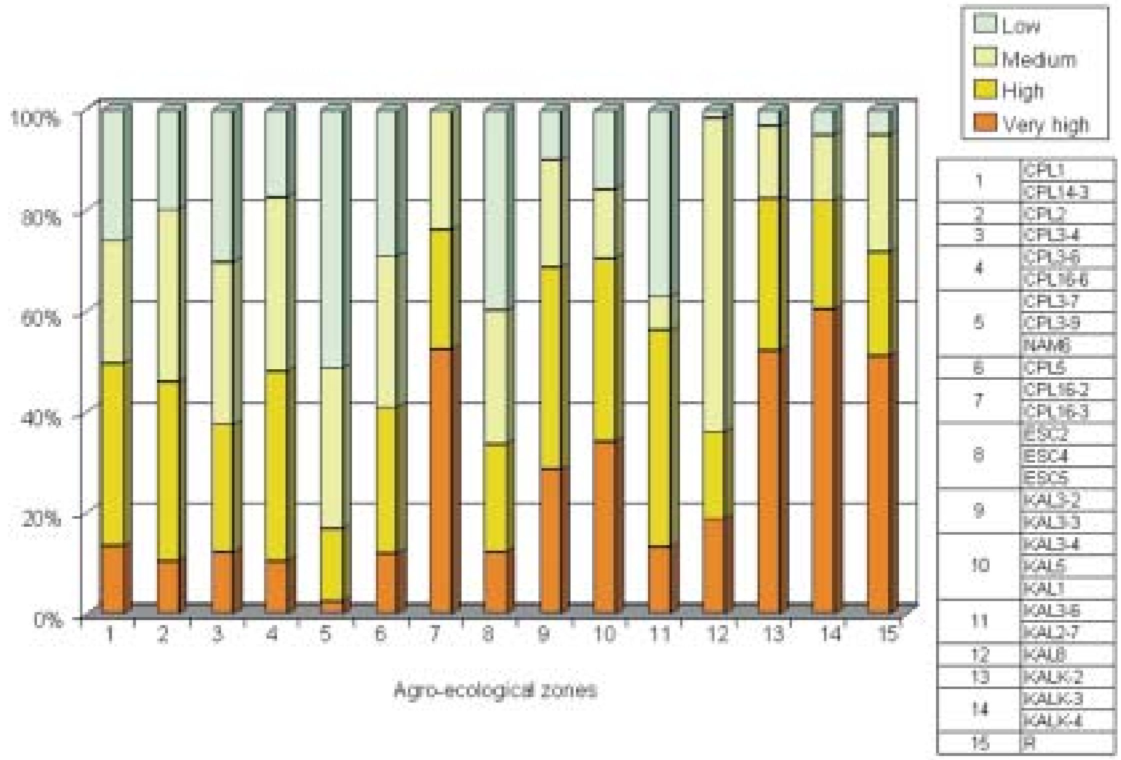


Figure 4.19: Bush density classes per agro-ecological zone

As Figure 4.19 illustrates, agro-ecological zones (AEZs) CPL16–2 and CPL16–3 (combined), zones KALK–3 and KALK–4 (combined), zone KALK–2 and zone R are highly encroached, with more than 50% of all plots falling into the "very high" density category, and more than 20% of all plots falling into the "high" density category.

Zones KAL3–3 and KAL3–2 (combined), zones KAL3–4, KAL1 and KAL5 (combined), and zones KAL3–6 and KAL2–7 (combined) are also highly encroached, with more than 50% of all sampled plots falling in either the "high" or "very high" density category.

The combined zones CPL3–7, CPL3–9 and NAM6 have the lowest incidence of encroachment, with only 3% of plots in the "very high" and 14% in the "high" bush density categories, respectively.

The remaining AEZs in the study area, namely zones CPL1 and CPL14–3 (combined), zones CPL2, CPL3–4, CPL3–6 and CPL16–6 (combined), zones CPL5, ESC2, ESC4 and ESC5 (combined) and zone KAL8 are intermediary cases, with between 30% and 50% of their sampled plots in either the "very high" or "high" bush density categories.

The relative encroachment of AEZs in the study area is shown in Table 4.6 as well as in Figures 4.19, 4.20 (plot locations) and 4.21. Caution is advised with the interpretation of the extrapolation since the sampling sites did not evenly cover the whole area of any AEZ, although they were randomly chosen (especially in communal areas).

AEZ	Plots								
	No.					%			
	VERY HIGH	HIGH	MEDIUM	LOW	TOTAL	VERY HIGH	HIGH	MEDIUM	LOW
CPL1 + CPL14–3	30	81	54	58	223	13	36	24	26
CPL2	15	50	48	28	141	11	35	34	20
CPL3–4	7	14	18	17	56	13	25	32	30
CPL3–6 + CPL16–6	14	50	46	23	133	11	38	35	17
CPL3–7 + CPL3–9 + NAM6	2	11	24	39	76	3	14	32	51
CPL5	13	31	32	31	107	12	29	30	29
CPL16–2 + CPL16–3	31	14	14	0	59	53	24	24	0
ESC2 + ESC4 + ESC5	10	17	21	32	80	13	21	26	40
KAL3–2 + KAL3–3	34	48	25	12	119	29	40	21	10
KAL1 + KAL3–4 + KAL5	159	169	63	74	465	34	36	14	16
KAL2–7 + KAL3–6	16	51	8	44	119	13	43	7	37
KAL8	11	10	36	1	58	19	17	62	2
KALK–2	47	27	13	3	90	52	30	14	3
KALK–3 + KALK–4	84	30	18	7	139	60	22	13	5
R	20	8	9	2	39	51	21	23	5

Table 4.6: Number and percentage of plots in each agro-ecological zone

CPL1	Central Plateau, Southern Omatako Plain
CPL2	Central Plateau, fringe plains
CPL3–4	Central Plateau, strongly dissected inselberg plains; average growing period 61–90 days, very short dependable growing period
CPL3–6	Central Plateau, strongly dissected inselberg plains; average growing period 41–60 days
CPL3–7	Central Plateau, strongly dissected inselberg plains; average growing period 21–40 days
CPL3–9	Central Plateau, strongly dissected inselberg plains; average growing period <10–20 days
CPL5	Central Plateau, flat plains on metamorphic rocks
CPL14–3	Central Plateau, table mountains on Karoo rocks; average growing period 61–90 days
CPL16–2	Central Plateau, red Kalkveld; average growing period 91–120 days
CPL16–3	Central Plateau, red Kalkveld; average growing period 61–90 days
CPL16–6	Central Plateau, red Kalkveld; average growing period 31–60 days
ESC2	Escarpment, high mountains on Basement Complex rocks
ESC4	Escarpment, high plateaux on Basement Complex rocks
ESC5	Escarpment, strongly dissected uplands bordering the highlands
KAL1	Kalahari Sands Plateau, stabilised W–E dunes with few pans
KAL2–7	Kalahari Sands Plateau, stabilised NW–SE dunes with common pans; average growing period 31– 40 days
KAL3–2	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 91–120 days
KAL3–3	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 61–90 days, dependable growing period 60% of average
KAL3–4	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 61–90 days, very short dependable growing period
KAL3–6	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 41–60 days, no dependable growing period
KAL5	Kalahari Sands Plateau, slightly incised river valleys
KAL8	Kalahari Sands Plateau, “omuramba” dune association
KALK–2	Kalkveld; average growing period 91–120 days; dependable growing period 80% of average
KALK–3	Kalkveld; average growing period 61–90 days; dependable growing period 60% of average
KALK–4	Kalkveld; median growing period 61–90 days; very short dependable growing period
NAM6	Namib Desert Plains, gravel and rock pavement
R	Undifferentiated rocky hills and inselberg mountains

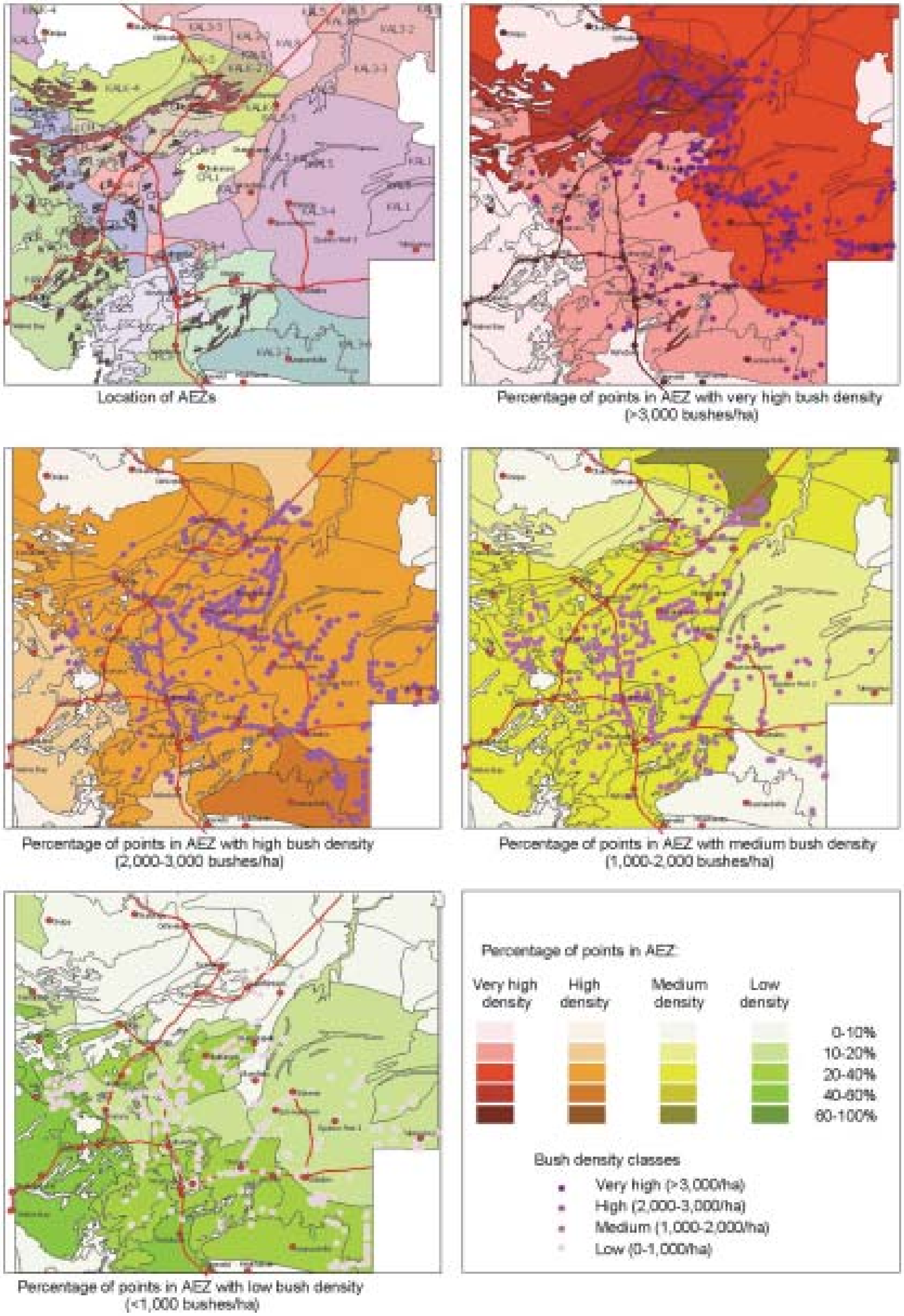


Figure 4.20: Plot locations and bush densities within each AEZ

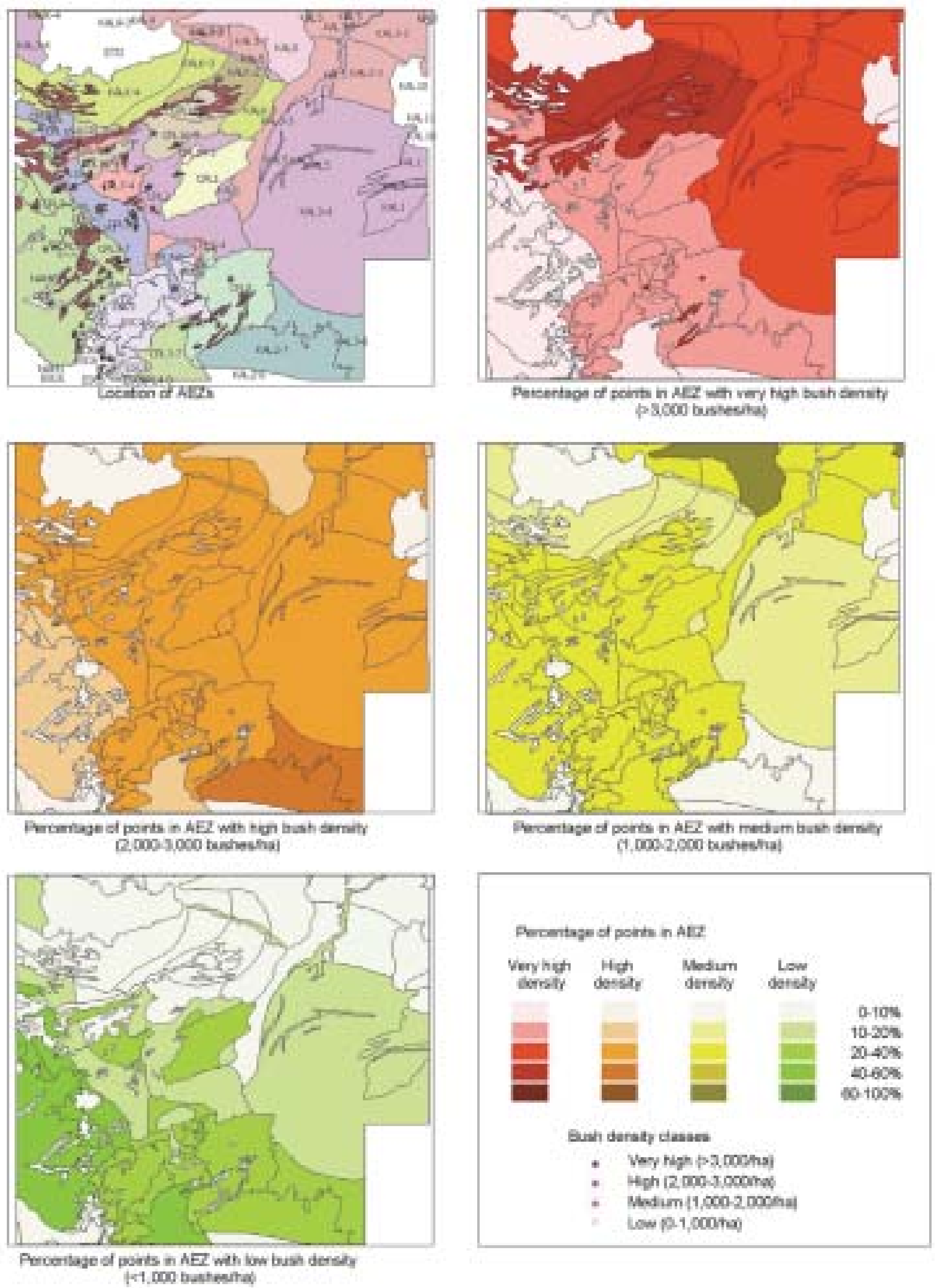


Figure 4.21: Bush densities per agro-ecological zone

4.2.2.3 Bush density per vegetation unit

The Tamboti Woodlands, though represented by only 18 sampled plots, shows the highest degree of encroachment, with 83% of plots in the "very high" bush density category and a further 11% in the "high" category.

The Loam and Turf Karstveld, the Dolomite Karstveld, and the Tree Savanna and Woodlands all show a very high degree of encroachment, with more than 75% of sampled plots in either the "very high" or "high" bush density category. The Camelthorn Savanna has 62% of plots in the two highest density categories.

The Acacia Hilly Shrubland and Inselbergs are least encroached, with only 15% of plots in either the "very high" or "high" bush density category. Low encroachment is also found in the Shrubland of the Central Escarpment (23%).

The other vegetation units, namely the Burkea–Baikiaea Woodlands, the Highland Shrubland and the Thornbush Shrubland, show intermediate levels of encroachment.

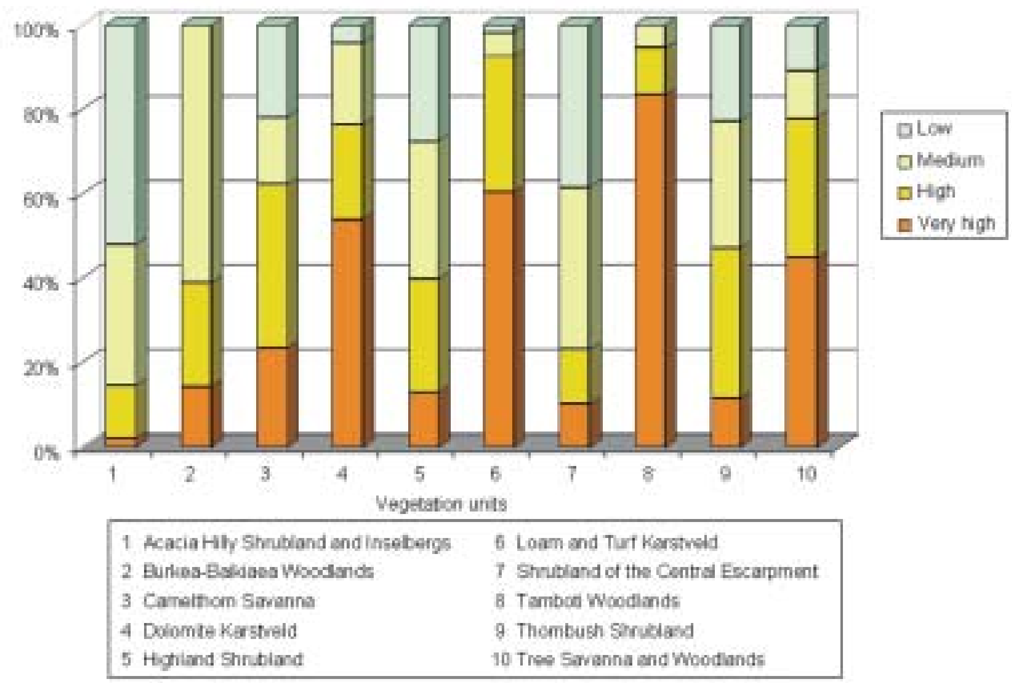


Figure 4.22: Vegetation unit locations and bush density per vegetation unit

Vegetation unit	Plots								
	No.					%			
	VERY HIGH	HIGH	MEDIUM	LOW	TOTAL	VERY HIGH	HIGH	MEDIUM	LOW
Acacia Hilly Shrubland and Inselbergs	1	6	16	25	48	2	13	33	52
Burkea–Baikiaea Woodlands	11	19	47	0	77	14	25	61	0
Camelthorn Savanna	149	248	101	140	638	23	39	16	22
Dolomite Karstveld	99	41	35	8	183	54	22	19	4
Highland Shrubland	21	44	53	45	163	13	27	33	28
Loam and Turf Karstveld	32	17	3	1	53	60	32	6	2
Shrubland of the Central Escarpment	4	5	15	15	39	10	13	38	38
Tamboti Woodlands	15	2	1	0	18	83	11	6	0
Thornbush Shrubland	45	137	116	88	386	12	35	30	23
Tree Savanna and Woodlands	107	79	27	26	239	45	33	11	11

Table 4.7: Number and percentage of plots within each vegetation unit

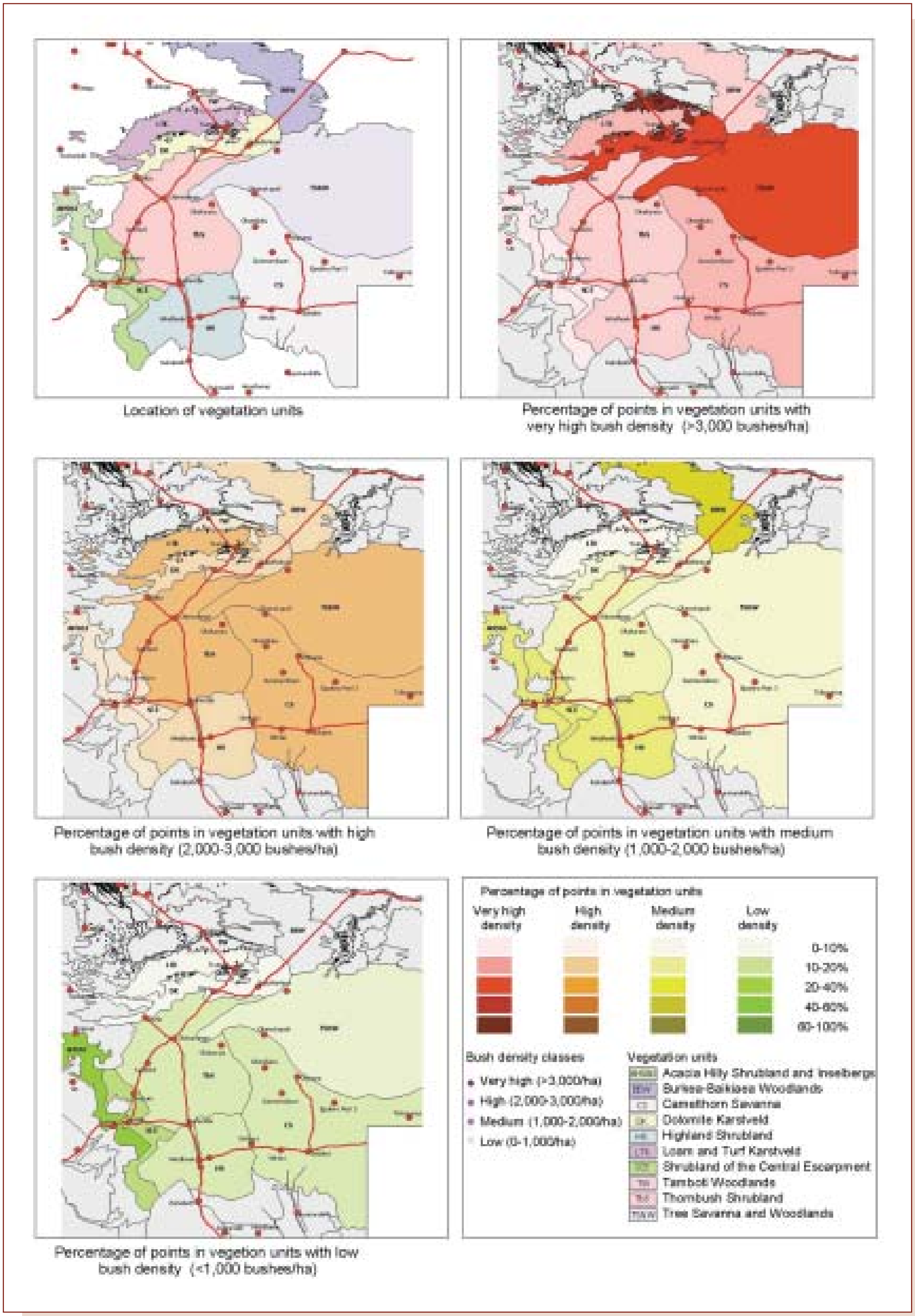


Figure 4.23: Bush density per vegetation unit

4.2.2.4 Bush density per rainfall interval

The investigation into the relationship between bush density and rainfall made use of two rainfall data sets: the isohyetal map compiled in 1994 by the Hydrology Division of the Department of Water Affairs (DWA), MAWRD; and the map compiled in 1998 by Namibia Resource Consultants (NRC). The latter is considered to be more accurate, as it made use of a larger number of rainfall stations and longer record lengths, from which extrapolations were done.

(a) Rainfall data from the DWA map

Table 4.8 and the bar graph in Figure 4.24 were compiled from the DWA rainfall map, with sampled plots assigned to the closest 50-mm isohyet. There is a strong trend of increasing bush density (in the four usual categories) with increasing rainfall.

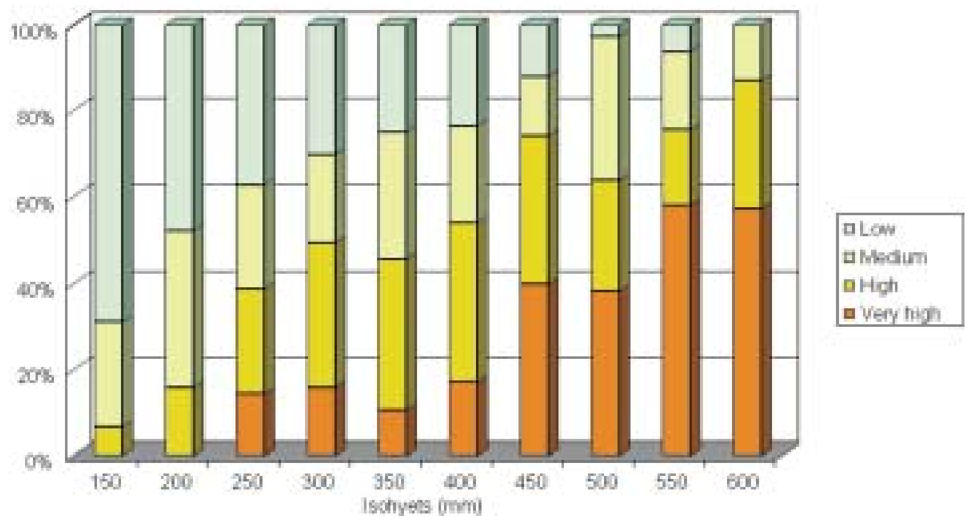


Figure 4.24: Bush density per rainfall isohyets

Rainfall (mm)	Plots								
	No.					%			
	VERY HIGH	HIGH	MEDIUM	LOW	TOTAL	VERY HIGH	HIGH	MEDIUM	LOW
150	0	2	7	20	29	0	7	24	69
200	0	7	16	21	44	0	16	36	48
250	9	15	15	23	62	15	24	24	37
300	18	38	23	34	113	16	34	20	30
350	29	96	80	68	273	11	35	29	25
400	107	231	141	146	625	17	37	23	23
450	162	140	55	49	406	40	34	14	12
500	74	50	65	5	194	38	26	34	3
550	67	20	21	7	115	58	17	18	6
600	27	14	6	0	47	57	30	13	0

Table 4.8: Number and percentage of plots within different rainfall zones

The correlation of actual (counted) densities with the 10-mm isohyets is significant, with $r^2 = \pm 0.3$, as shown in the scattergraph (see Figure 4.25). The conclusion is that rainfall has a significant effect on bush density, but is not the only contributing factor.

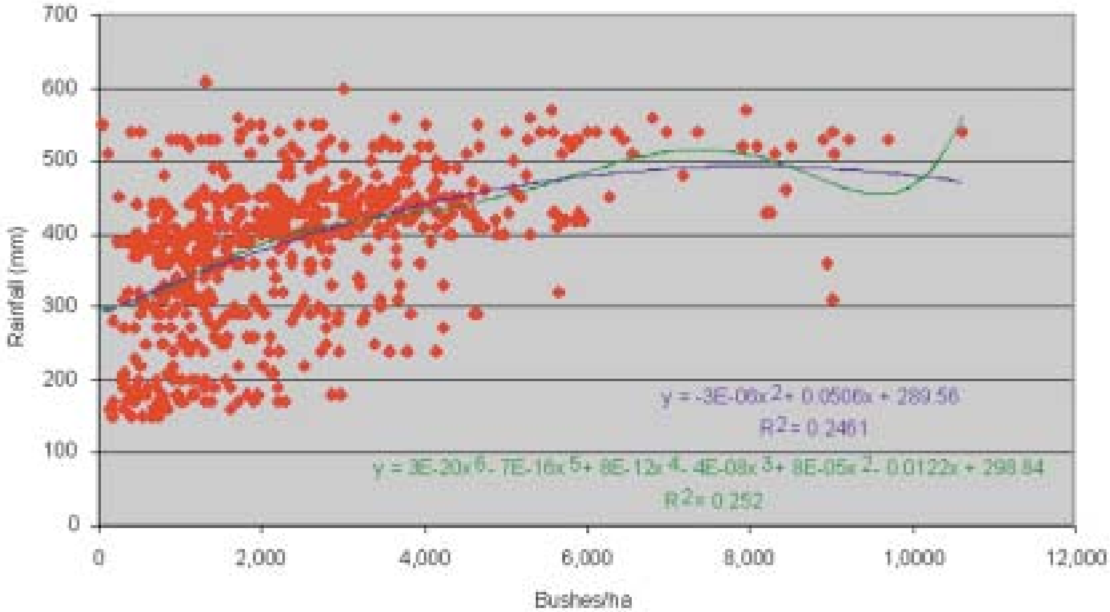


Figure 4.25: The relation between bush density and rainfall (10-mm isohyets)

(*b*) *Rainfall data from the NRC map*

The subsequent graphs and figures draw on the NRC map. The scattergraph (see Figure 4.26) once again shows a significant influence of rainfall on bush density ($r^2 = \pm 0.3$), although it is clearly not the only contributing factor.

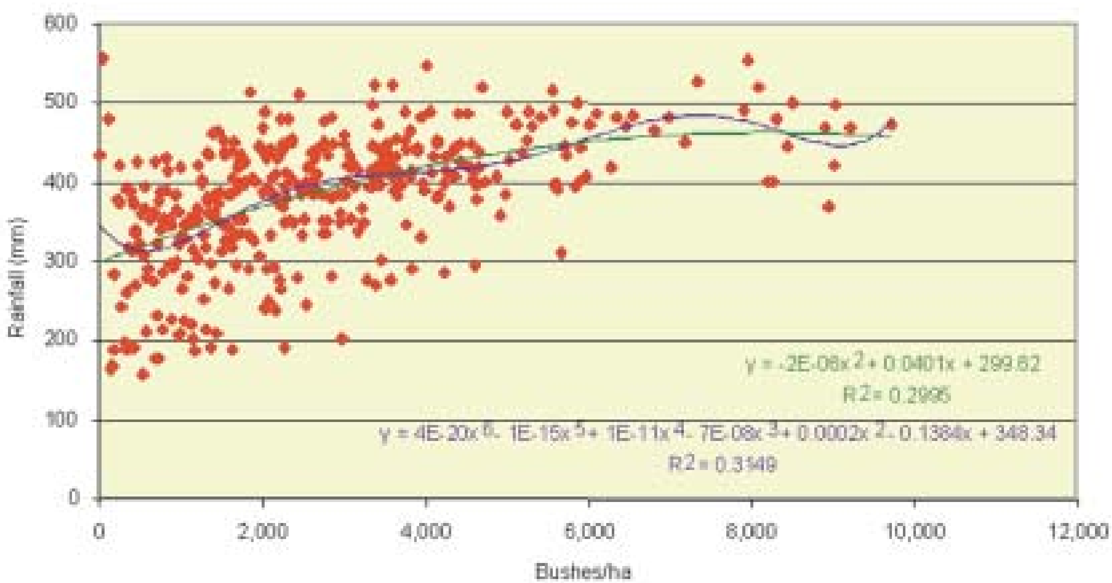


Figure 4.26: The relationship between rainfall and bush densities, using NRC data

The histograms in Figure 4.27 show that the majority of sampled plots fall within the 300–550 mm range, with the largest concentration within 350–400 mm. Among the "low", "medium" and "high" bush density classes, most plots are in the 350–400 mm rainfall interval. The "very high" density plots predominantly occur in the 400–450 mm interval, with a considerable number in the 350–400 and 450–500 mm intervals.

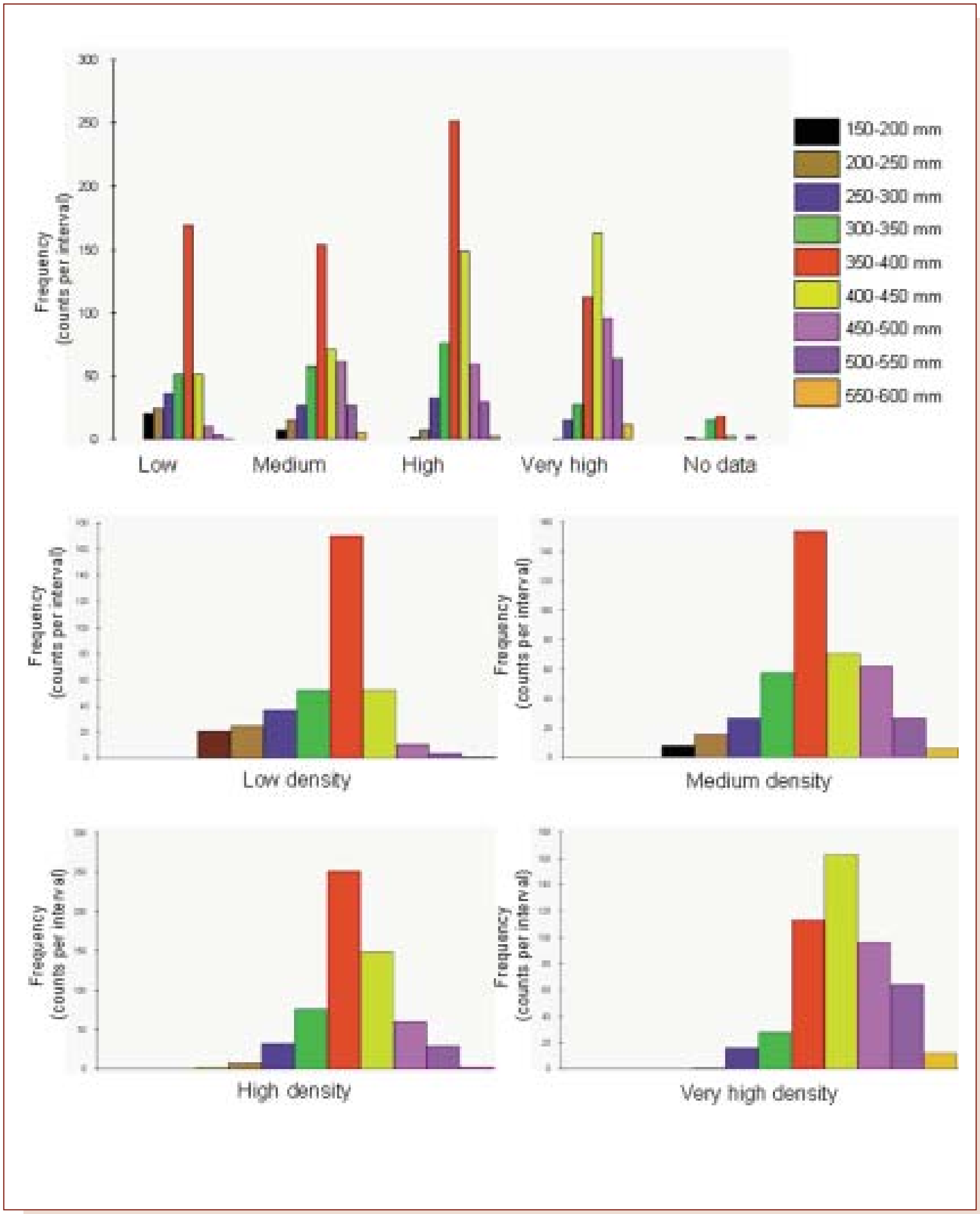


Figure 4.27: Bush density categories versus rainfall distribution, using NRC data

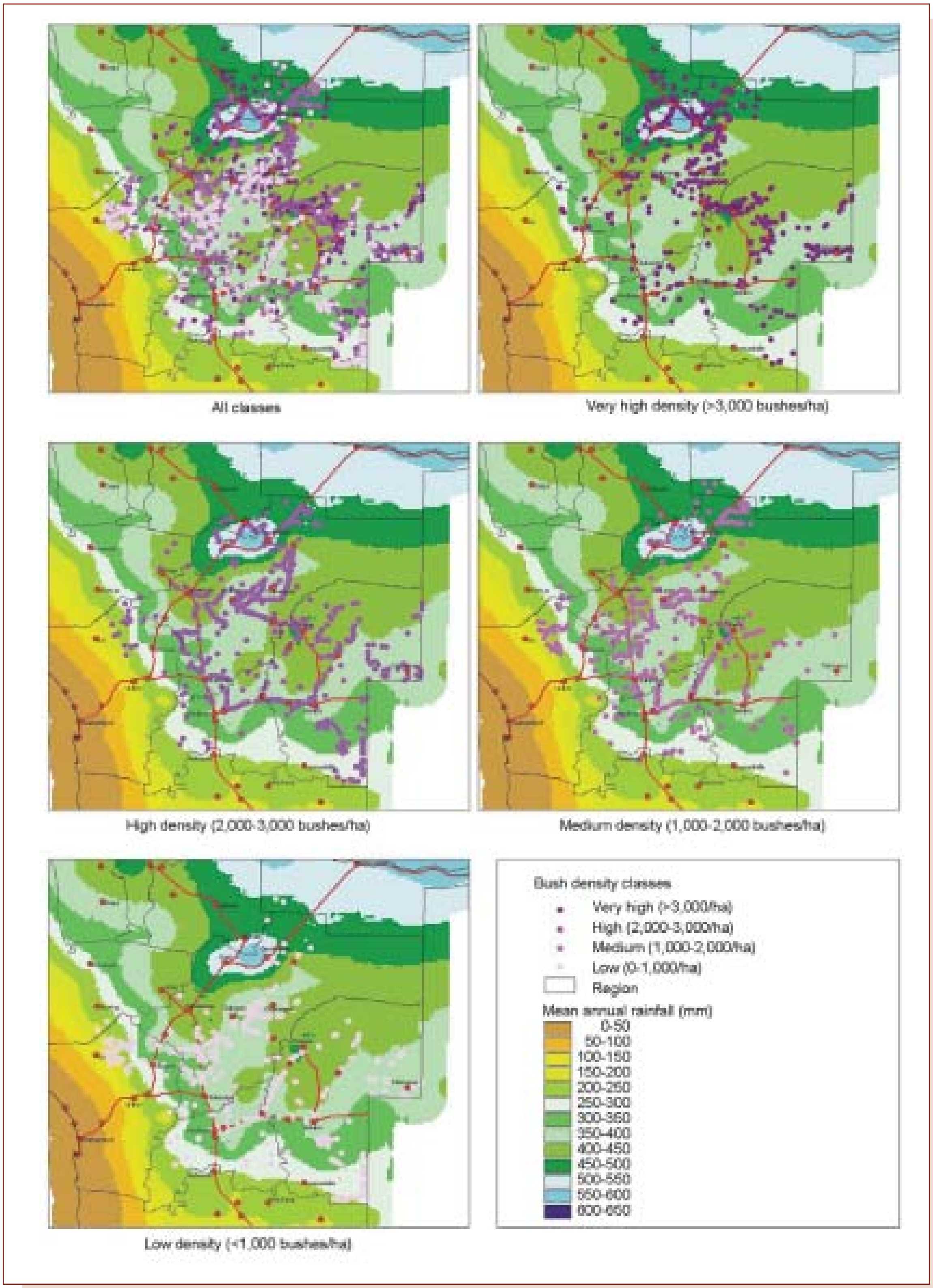


Figure 4.28: Maps illustrating the interaction between rainfall and bush density

The next graph, Figure 4.29, illustrates the minimum, maximum and mean (counted) bush densities, as simplified to the nearest 10-mm isohyet (see NRC map). A trend-line through the mean densities per 10-mm isohyet shows a very strong correlation: $r^2 = 0.85$ in the case of a sixth-order polynomial fit, and even $r^2 = 0.81$ in the case of a simpler third-order polynomial fit. The conclusion is that rainfall would contribute about 80–85% to the density distribution of bush on a macro-scale. However, the large spread between the minimum and maximum values should be noted: the spread shows not only that the situation is quite complex, but also that other factors such as management practices can play an important role at the micro-scale.

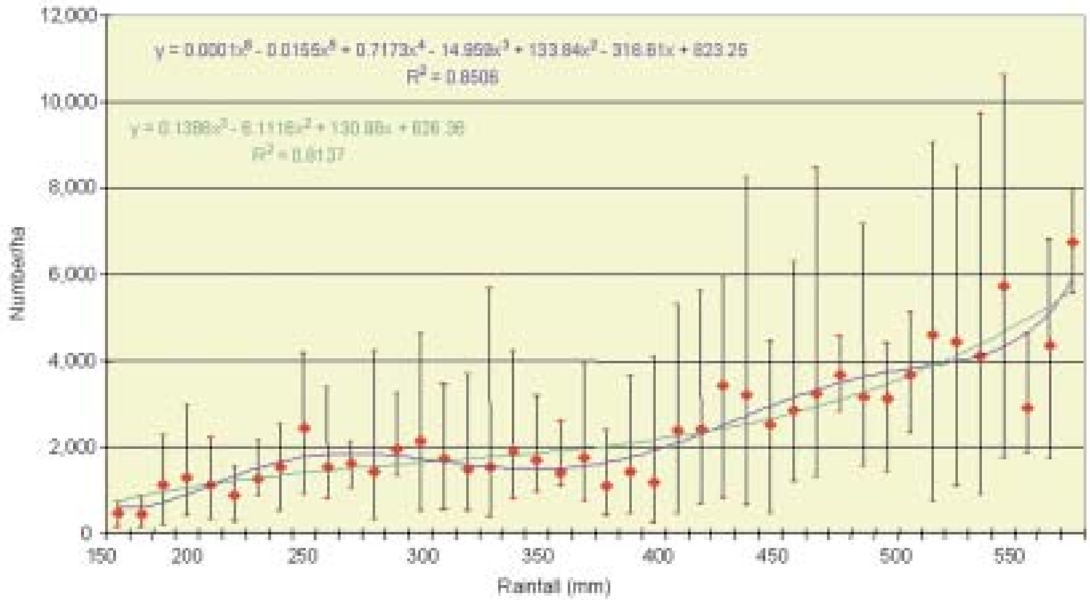


Figure 4.29: Correlation between bush density and rainfall zones using minimum and maximum bush density values

4.2.2.5 Bush density as a function of geology, terrain and soil

The underlying geology (i.e. lithology), terrain and soil type have a rather obvious influence on bush density, as can be seen in the following tables and graphs.

(a) Geology

The highest bush density is found on soils derived from sedimentary rock of organic origin, i.e. limestone and dolomite, such as that found in the Karstveld. The unconsolidated soils of aeolian (wind-borne) and fluvial (water-borne) origin, such as those of the Kalahari sand plains and dunes as well as dry river beds and adjacent river valleys, also show high levels of encroachment. Soils of acid igneous and acid metamorphic origin show lower levels of encroachment. These classifications are too broad for discerning specific relationships, however (see Figure 4.30 and Table 4.9).

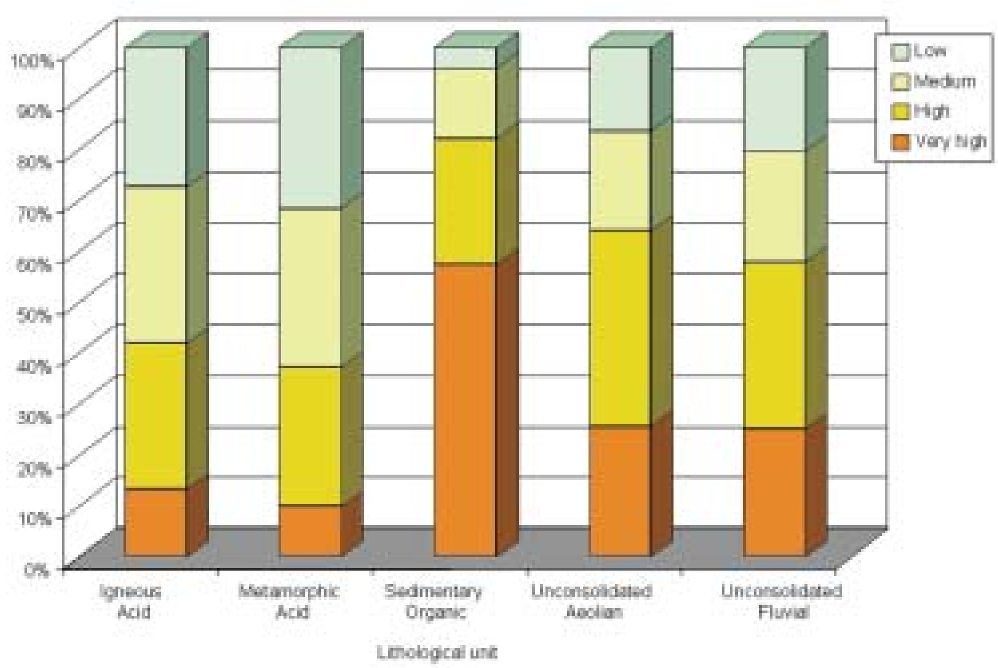


Figure 4.30: Bush density classes per lithological unit

Lithology	Plots								
	No.					%			
	VERY HIGH	HIGH	MEDIUM	LOW	TOTAL	VERY HIGH	HIGH	MEDIUM	LOW
Igneous Acid	29	63	67	60	219	13	29	31	27
Metamorphic Acid	33	94	106	108	341	10	28	31	32
Sedimentary Organic	170	73	41	12	296	57	25	14	4
Unconsolidated Aeolian	188	283	145	120	736	26	38	20	16
Unconsolidated Fluvial	67	88	58	55	268	25	33	22	21

Table 4.9: Number and percentage of plots in each lithological unit

(b) Terrain and soils

The 1:1 Million Scale Soil Map of Namibia (2000) was used as data set for this analysis. Some strong relationships were found with the soil/terrain mapping units, while the relationships with dominant soils seem to be more ambiguous: more than 80% of the sampled plots in soil/terrain mapping units CKg1, CKh1 and CKl1 are in the two highest categories. High encroachment levels are also found in units KDf1, KFv2, KFv5 and KSd1, with between 60% and 70% of points in the two highest density categories. The most notable soil/terrain mapping unit with low encroachment levels is CLl1 (see Figure 4.31).

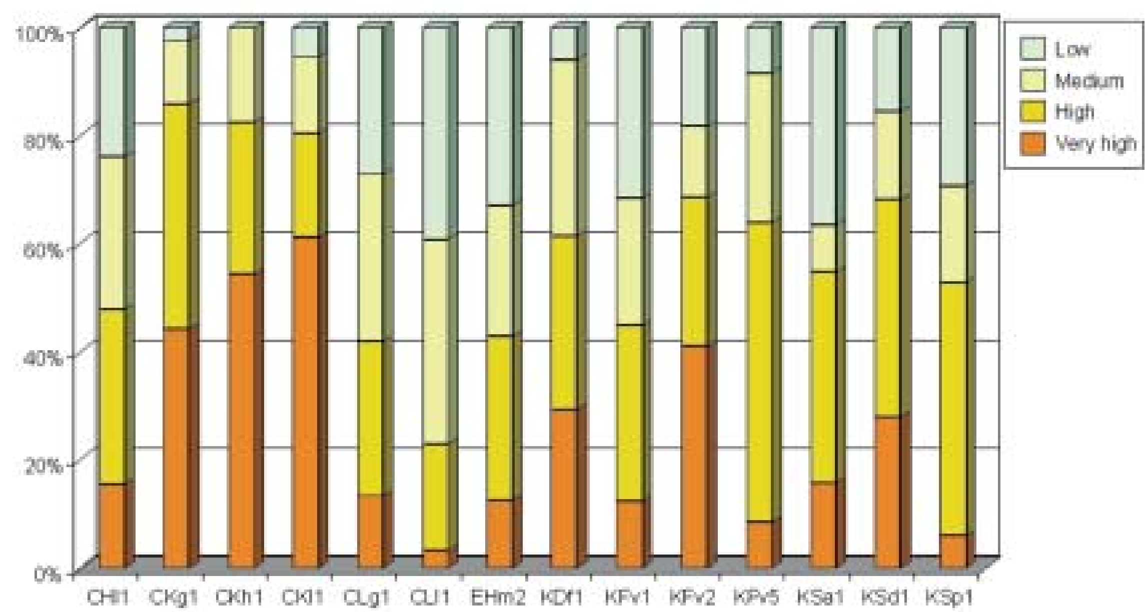


Figure 4.31: Bush density classes per soil/terrain mapping unit

Soil/terrain mapping unit	Plots								
	No.					%			
	VERY	HIGH HIGH	MEDIUM	LOW	TOTAL	VERY HIGH	HIGH	MEDIUM	LOW
CHl1	11	23	20	17	71	15	32	28	24
CKg1	19	18	5	1	43	44	42	12	2
CKh1	31	16	10	0	57	54	28	18	0
CKl1	104	33	24	9	170	61	19	14	5
CLg1	29	62	67	59	217	13	29	31	27
CLl1	4	25	48	50	127	3	20	38	39
EHm2	10	24	19	26	79	13	30	24	33
KDf1	54	59	60	11	184	29	32	33	6
KFv1	12	32	23	31	98	12	33	23	32
KFv2	47	32	15	21	115	41	28	13	18
KFv5	3	20	10	3	36	8	56	28	8
KSa1	13	32	7	30	82	16	39	9	37
KSd1	122	176	71	68	437	28	40	16	16
KSp1	2	16	6	10	34	6	47	18	29

Table 4.10: Number of plots within each soil/terrain mapping unit

CHl1	Highlands in the Central Plateaux; nearly level highlands; leptic Regosols and haplic Leptosols Association
CKg1	Plateaux with karst on hard Damara limestone; gently undulating lowlands; chromic Cambisols and leptic Regosols and petric Calcisols complex
CKh1	Plateaux with karst on hard Damara limestone; hills and ridges; rock outcrops and lithic Leptosols complex
CKl1	Plateaux with karst on hard Damara limestone; level lowlands; mollic Leptosols and petric Calcisols complex
CLg1	Lowlands in the Central Plateaux; gently undulating lowlands; leptic Regosols and haplic Regosols and petric Calcisols complex
CLl1	Lowlands in the Central Plateaux; nearly level lowlands; chromic Cambisols
EHm2	High mountains of the escarpment; rock outcrops and lithic Leptosols complex
KDf1	Kalahari aligned fossil sand dunes; ferralic Arenosols and arenic Fluvisols and haplic Calcisols association
KFv1	Flood-prone areas; "omuramba" and river valleys; arenic Fluvisols and haplic Calcisols association
KFv2	Flood-prone areas; "omuramba" and river valleys; arenic Fluvisols and ferralic Arenosols association
KFv5	Flood-prone areas; "omuramba" and river valleys; fluvic Cambisols and haplic Fluvisols and ferralic Arenosols Complex
KSa1	Kalahari sand deposits with aligned dunes; ferralic Arenosols
KSd1	Kalahari sand deposits; ferralic Arenosols
KSp1	Kalahari sand deposits with pans; ferralic Arenosols and petric Calcisols association

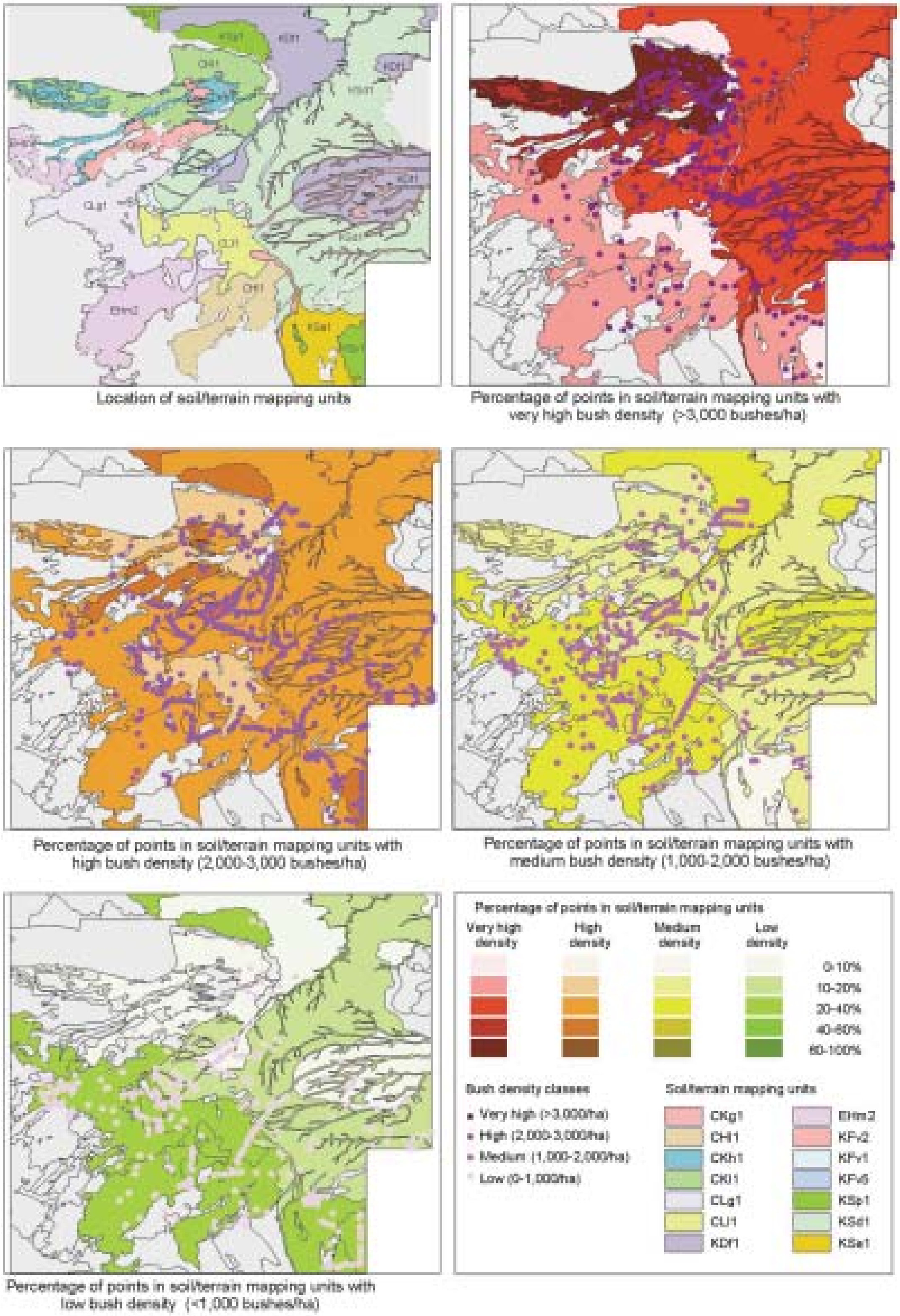


Figure 4.32: Bush density per soil/terrain mapping unit

Among the dominant soil types, only the fluvic Cambisols have 77% of points in the two highest density categories. One should note, however, that only 36 of all plots fall into this soil type. This is a relatively small sample size and can be misleading (see Table 4.11).

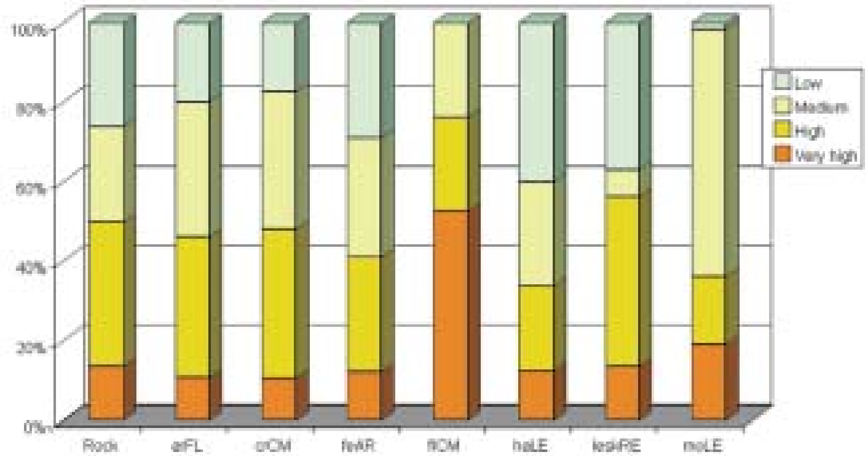


Figure 4.33: Bush density classes per dominant soil

Domin-ant soil	Plots								
	No.					%			
	VERY HIGH	HIGH	MEDIUM	LOW	TOTAL	VERY HIGH	HIGH	MEDIUM	LOW
Rock	31	21	17	11	80	13	36	24	26
arFL	59	64	38	52	213	11	35	34	20
crCM	26	45	55	51	177	11	38	35	17
feAR	188	283	145	119	735	12	29	30	29
flCM	3	20	10	3	36	53	24	24	0
haLE	15	35	28	30	108	13	21	26	40
leskRE	40	85	87	76	288	13	43	7	37
moLE	121	37	33	10	201	19	17	62	2

Table 4.11: Number and percentage of plots in each dominant soil type

Rock		Rock outcrops and mountains
arFL	arenic Fluvisols	Sandy soils developed in recent alluvial deposits, having no diagnostic subsurface horizons
crCM	chromic Cambisols	Soils in early stages of development, showing the beginning of horizon differentiation through changes in colour, texture and structure; strongly coloured in this case
feAR	ferralic Arenosols	Deep, weakly developed soils of course texture (i.e. very sandy) and low nutrient storage capacity; it has a subsurface horizon resulting from long and intense weathering
flCM	fluvic Cambisols	Soils in early stages of development, showing the beginning of horizon differentiation through changes in colour, texture and structure; developing in alluvial deposits in this case
haLE	haplic Leptosols	Weakly developed, shallow soils developing in eroding uplands with no particular distinguishing characteristics; overlying rock or hard calcretes
leskRE	leptic-skeletic Regosols	Very shallow and gravelly soils with weak or no horizon development; non- alluvial unconsolidated material with no diagnostic subsurface horizons
moLE	mollic Leptosols	Weakly developed, shallow soils developing in eroding uplands; the surface layer is well-structured, dark-coloured, with a high base saturation and a moderate to high organic matter content

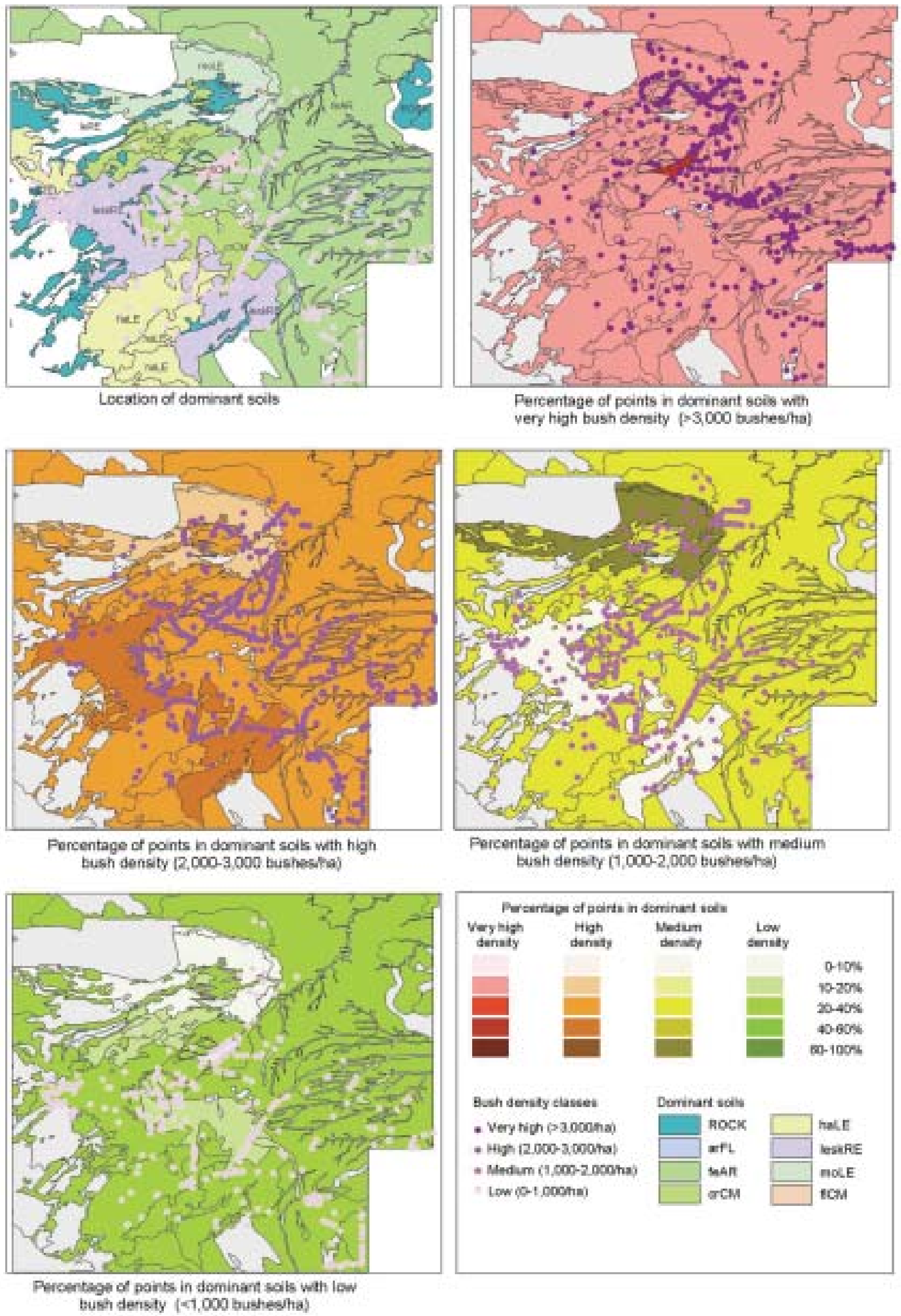


Figure 4.34: Bush density per dominant soil type

4.2.2.6 Bush density as a function of total seasonal biomass production

A model which uses NOAA-AVHRR and/or SPOT VEGETATION satellite images to calculate production of cumulative seasonal biomass has been evaluated for this purpose. The biomass includes trees, shrubs, grasses and herbaceous plants.

A number of statistical parameters from these "biomass grids" were evaluated in connection with the bush density classes and counted bush numbers. If strong enough relationships could be found, regression equations could be used to extrapolate bush densities spatially, and better maps of bush distribution and density could be compiled. The next six maps (Figures 4.35–4.40) depict some of these statistical parameters.

The first map, namely Figure 4.35, shows the mean cumulative seasonal biomass production for the 17 years from 1985/6 until 2001/2. The maximum and minimum values of each pixel over these 17 years are shown in the second and third maps (Figures 4.36 and 4.37). The map in Figure 4.38 indicates temporal variation in terms of the coefficient of variation. The fifth map (Figure 4.39) is an index of areas with the smallest range (difference between maximum and minimum values), which ought to coincide with presence of bush. The aforementioned index was calculated by subtracting the grid of minimum pixel values from the grid of maximum pixel values, dividing the result by the grid of the mean pixel values, and multiplying everything by 100, as follows: [{(MAX – MINBIO) / MEANMC} * 100]. This index is called the normalised range of biomass production. The relation between bush densities and the normalised range of seasonal biomass is illustrated in Figure 4.40.

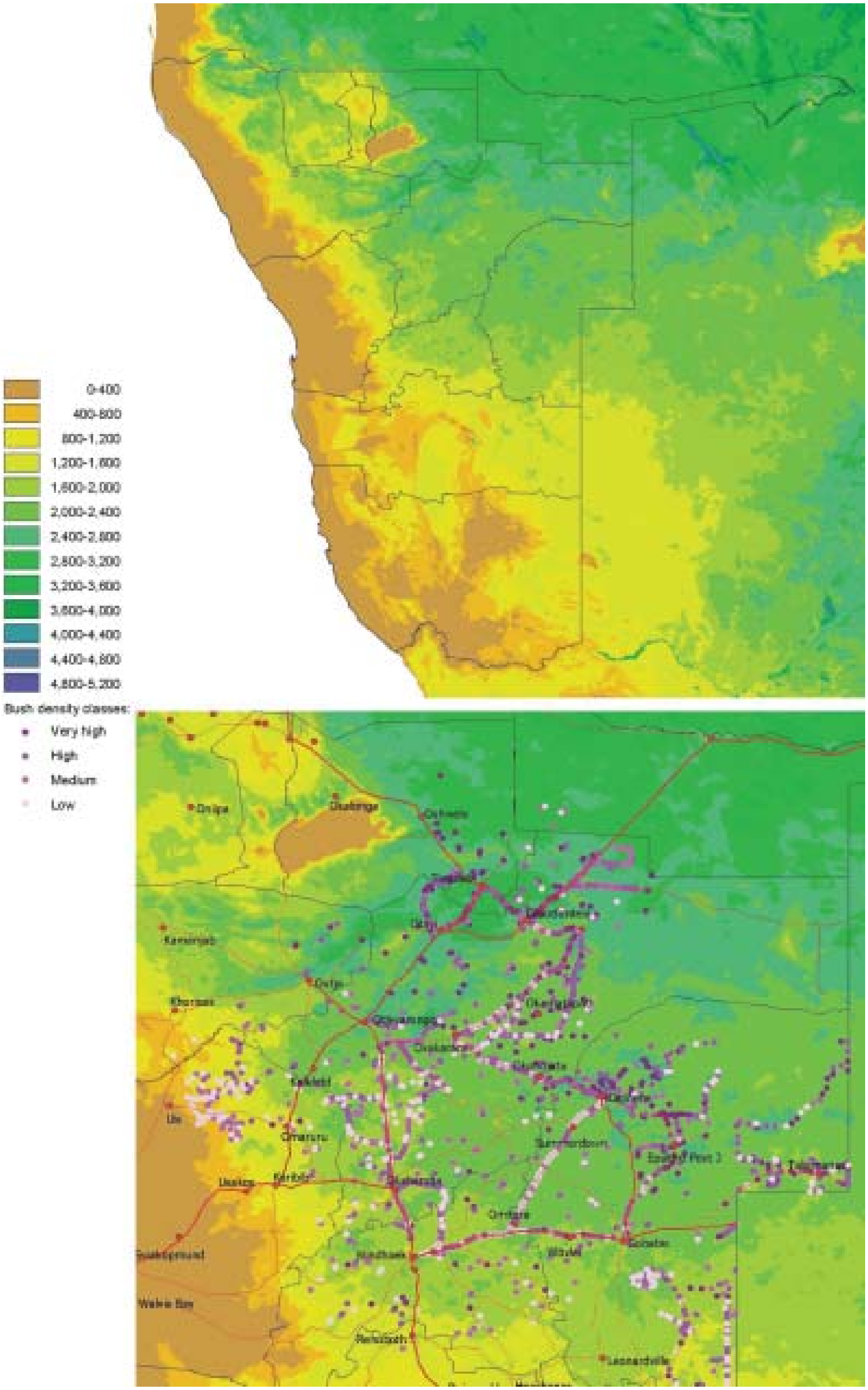


Figure 4.35: Mean total seasonal cumulative biomass production (kg per hectare)

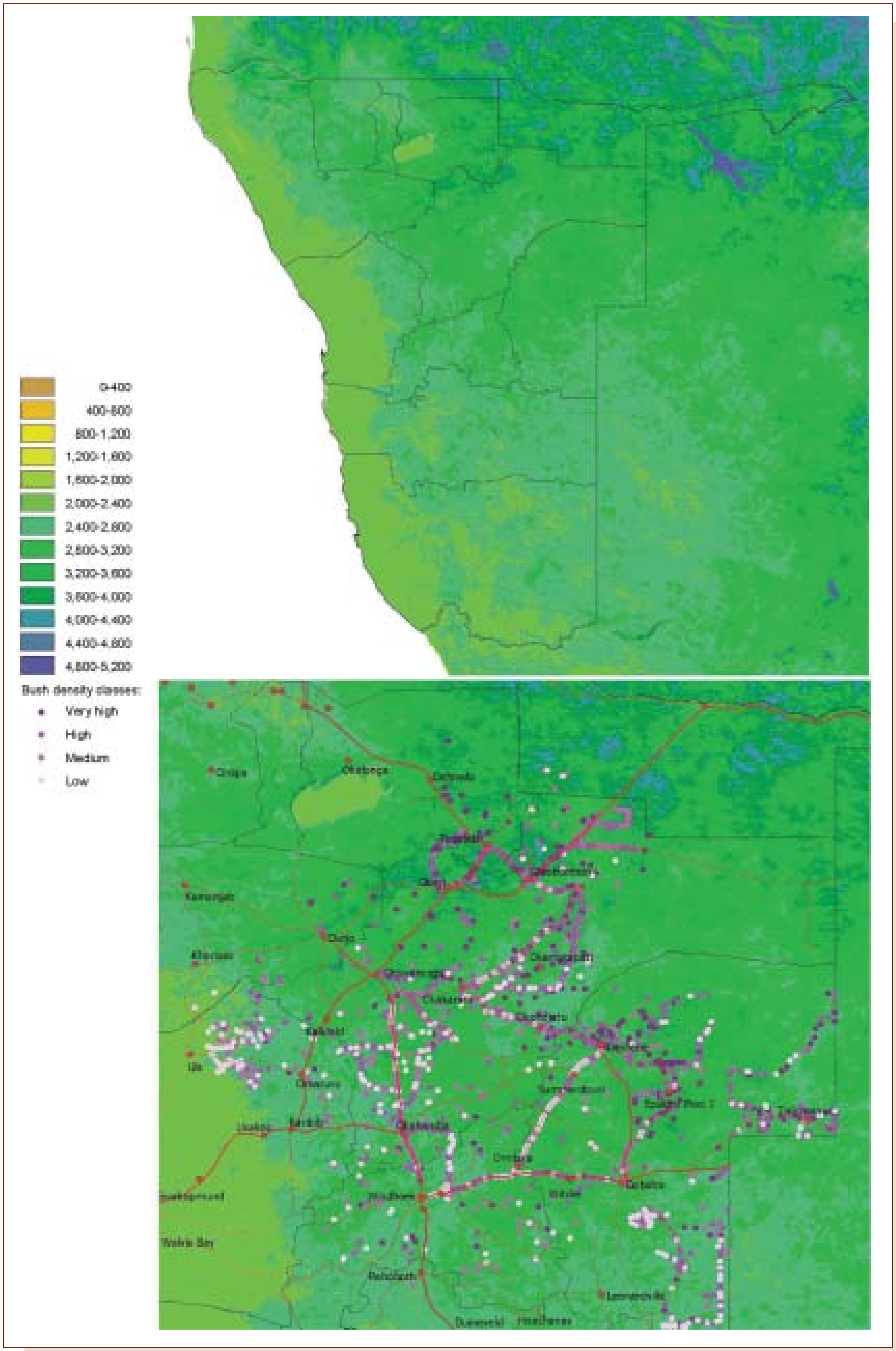


Figure 4.36: Maximum total seasonal biomass production (kg per hectare)

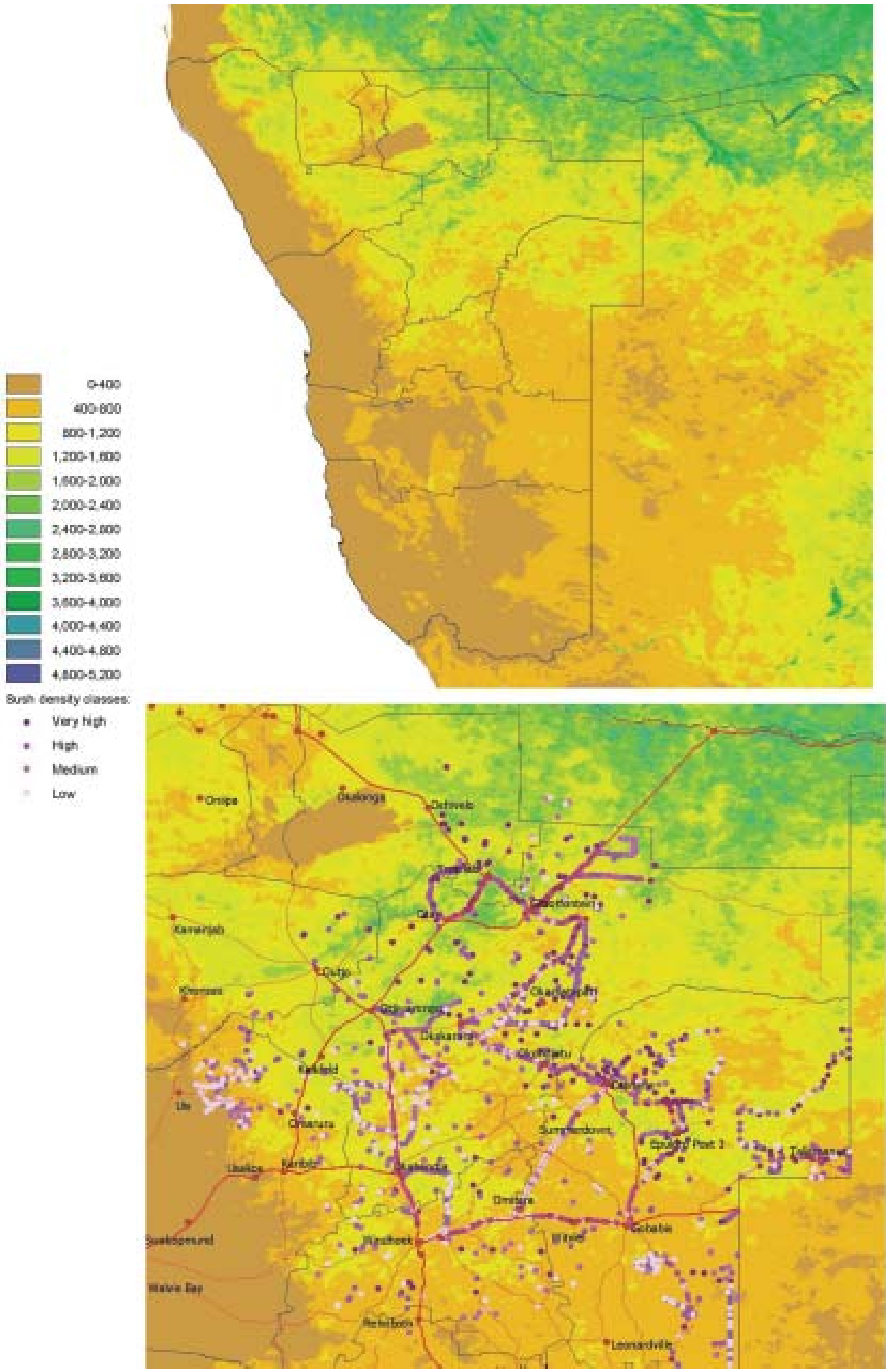


Figure 4.37: Minimum total seasonal biomass production (kg per hectare)

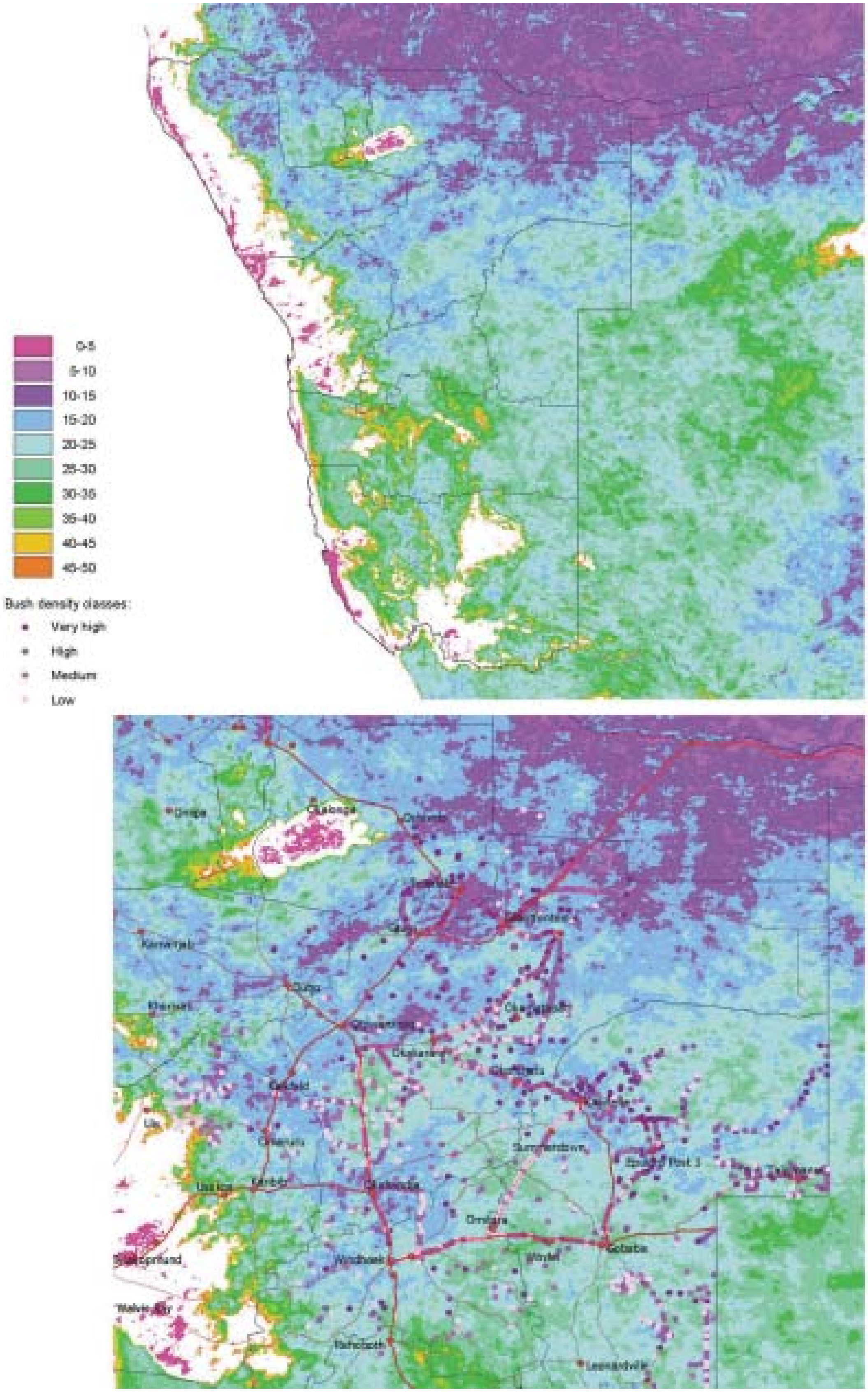


Figure 4.38: Coefficient of variation of total seasonal biomass production (kg per hectare)

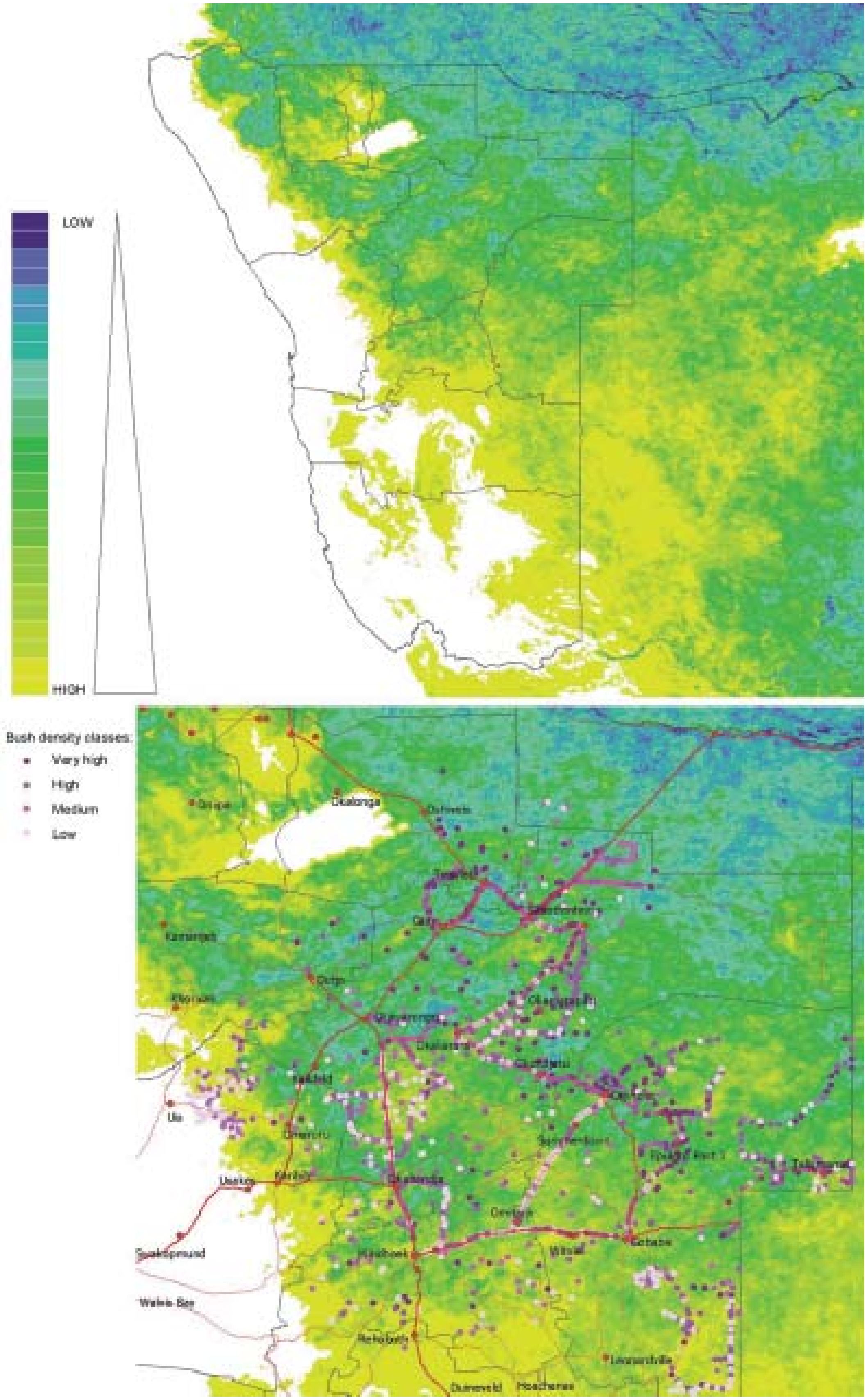


Figure 4.39: Normalised range of seasonal biomass production

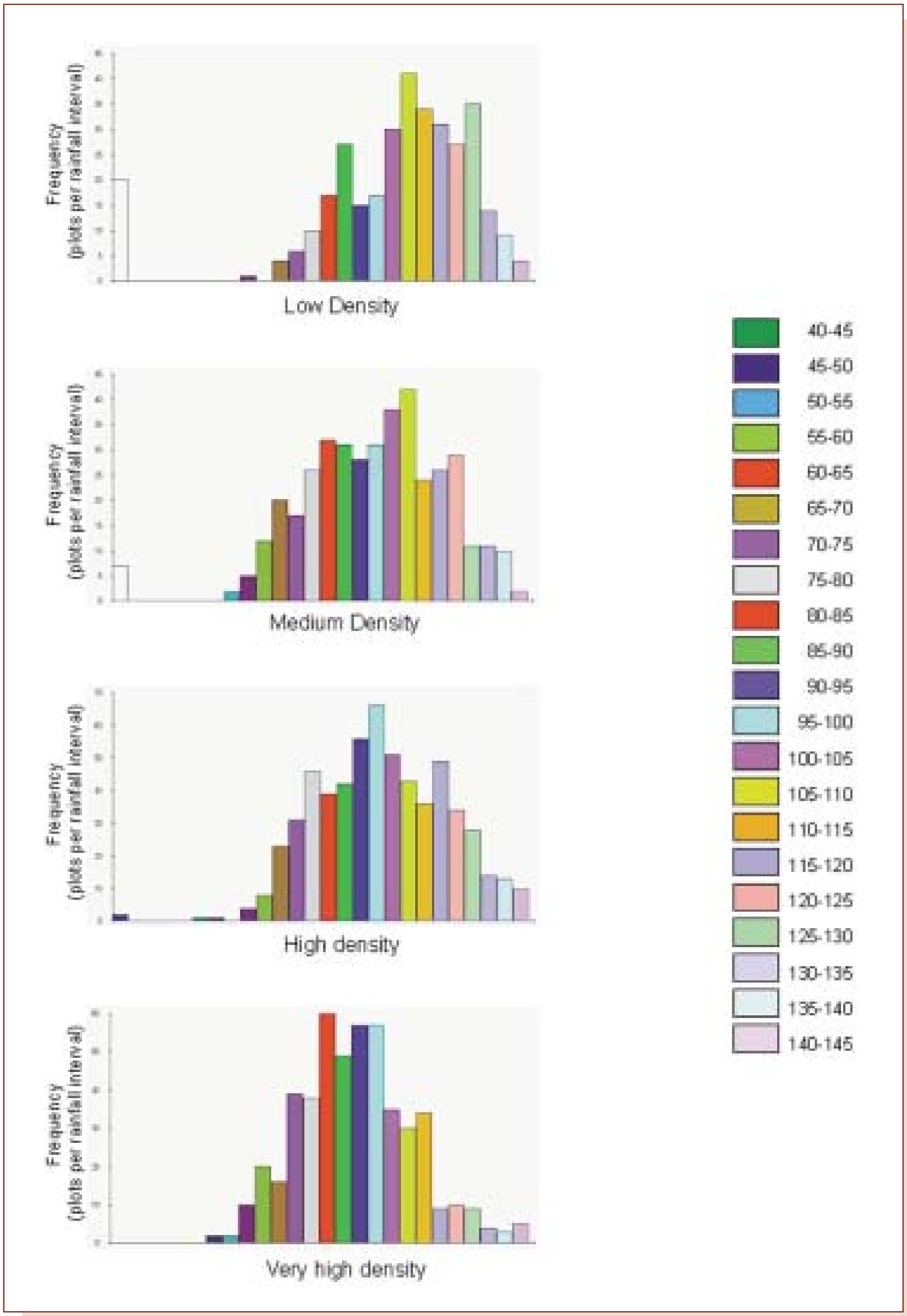


Figure 4.40: Bush density classes versus normalised range of total seasonal biomass

Unfortunately, none of these derived biomass grids (in Figures 4.35–4.40) correlated well enough with the bush densities or density classes to use them for extrapolation of point data to polygons.

Some trends were found, e.g. the mean pixel values of MXMNME (representing the normalised range of biomass production) in terms of the bush density classes were as follows: very high = 87.5, high = 97.5; medium = 101.9; low = 121.4. These results show a clear, linear trend. However, when all actual pixel values were plotted against either a bush density class or actual bush densities (in bushes per hectare), the best fit only had an r^2 of 0.18, which may be significant, but it was still too low for extrapolating point data to the polygons presented by this index.

4.2.2.7 Species distribution

A total of 1,372 of the 2,267 plots in the original data set have at least one of the six encroacher species, namely *Acacia mellifera*, *Acacia reficiens*, *Colophospermum mopane*, *Dichrostachys cinerea*, *Terminalia prunioides* or *Terminalia sericea*. Of these 1,372 "problem bush" plots, 744 (54%) have *Acacia mellifera*, 222 (16%) have *Acacia reficiens*, 18 (1%) have *Colophospermum mopane*, 537 (39%) have *Dichrostachys cinerea*, 151 (11%) have *Terminalia prunioides* and 262 (19%) have *Terminalia sericea*. Many plots have more than one type of encroacher.

Throughout this interpretation one should keep in mind that the results are only valid within the study area, that sampling was not completely random, and in some cases (e.g. mopane) the sample size was too small to have complete confidence in the spatial-statistical analysis.

Acacia mellifera is clearly the most widely distributed encroacher species, with *Dichrostachys cinerea* in a strong second place. The current survey has not really included north-west Namibia, which is dominated by *Colophospermum mopane*.

The next set of maps shows the distribution of the six encroacher species within the study area. *Colophospermum mopane* is concentrated towards the north-west, while *Terminalia prunioides* is found mainly in the Otavi–Tsumeb–Grootfontein–Mururani area. *Terminalia sericea* is found in 95% of "problem bush" plots east of an axis through Omitara and Otavi. *Dichrostachys cinerea* is widely distributed north of the Windhoek–Gobabis road (91% of "problem bush" plots). *Acacia reficiens* is distributed widely and occurs further west than any of the other encroachers. *Acacia mellifera* has the widest distribution of the six encroacher species.

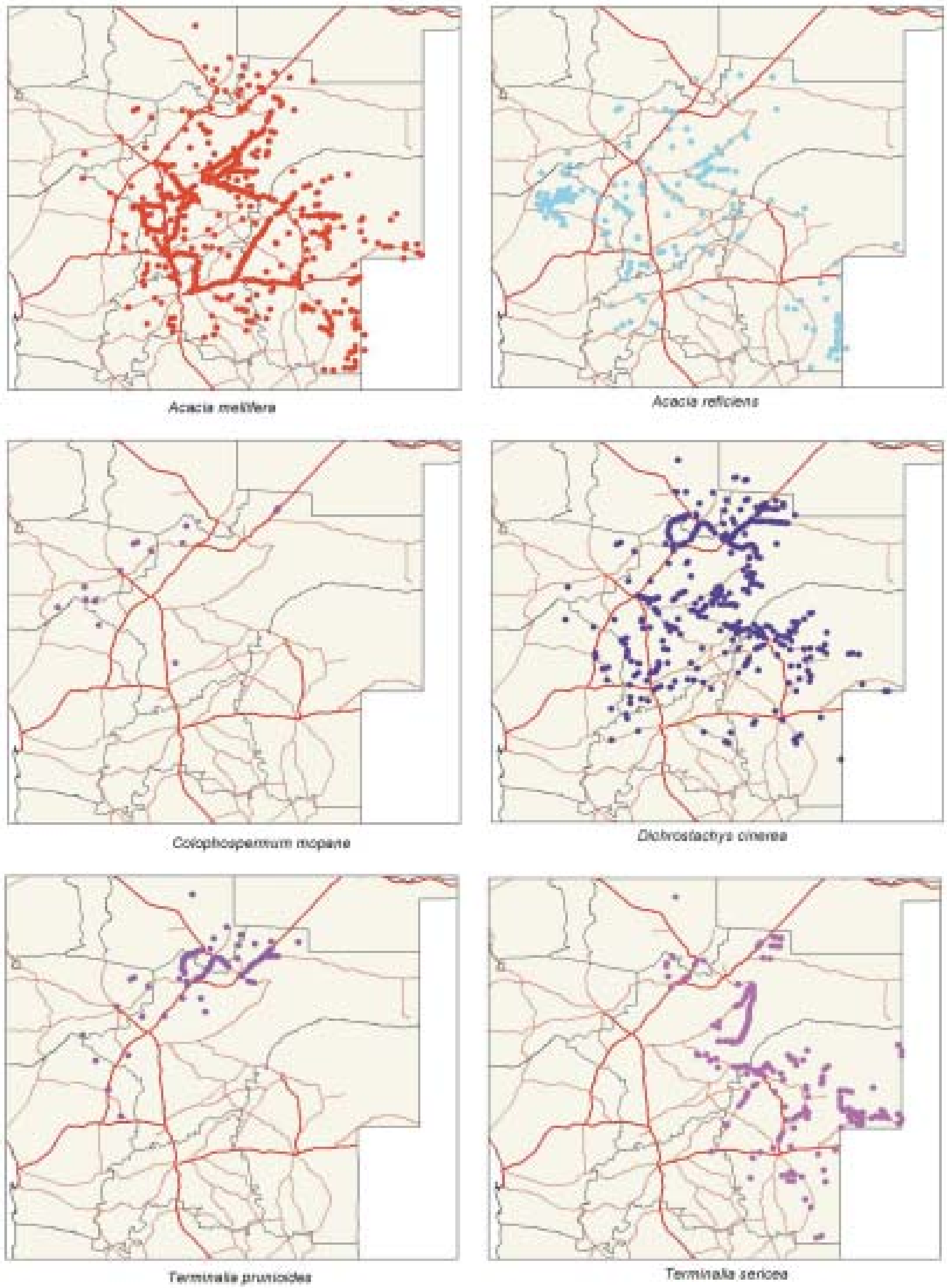


Figure 4.41: Distribution of six main encroacher bush species

4.2.2.8 Species distribution per agro-ecological zone

As figure 4.42 and table 4.12 illustrate, *Acacia mellifera* (AM) dominates in agro-ecological zones CPL5 and the combination of ESC2, ESC4 and ESC5 zones, with 82% and 72% of plots in zones with *Acacia mellifera*. It also dominates in zones CPL1 and CPL14–3 (combined), zones CPL2, CPL3–4, CPL3–6 and CPL16–6 (combined), and zones KAL2–7 and KAL3–6 (combined).

Acacia reficiens (AR) dominates completely in the combined zones CPL3–7, CPL9 and NAM6. It also forms a significant component of problem bush in zones CPL3–6 and CPL16–6 (combined), zones ESC2, ESC4 and ESC5 (combined), and zones KAL2–7 and KAL3–6 (combined).

In general, north-western Namibia is dominated by *Colophospermum mopane* (CM). However, the number of plots in the study was too small to make meaningful conclusions (see also the relevant column in Table 4.12).

Dichrostachys cinerea (DC) dominates in zone KAL8, zone KALK–2, and the combination of zones KALK–3 and KALK–4.

Terminalia prunioides (TP) shows up in slightly less than a third of plots in zone KALK–2, zone R, zones CPL16–2 and CPL16–3 (combined), and zones KALK–3 and KALK–4 (combined).

Terminalia sericea (TS) is an important component of zones KAL1, KAL3–4 and KAL5 (combined), KAL8, and the combination of zones KAL3–2 and KAL3–3.

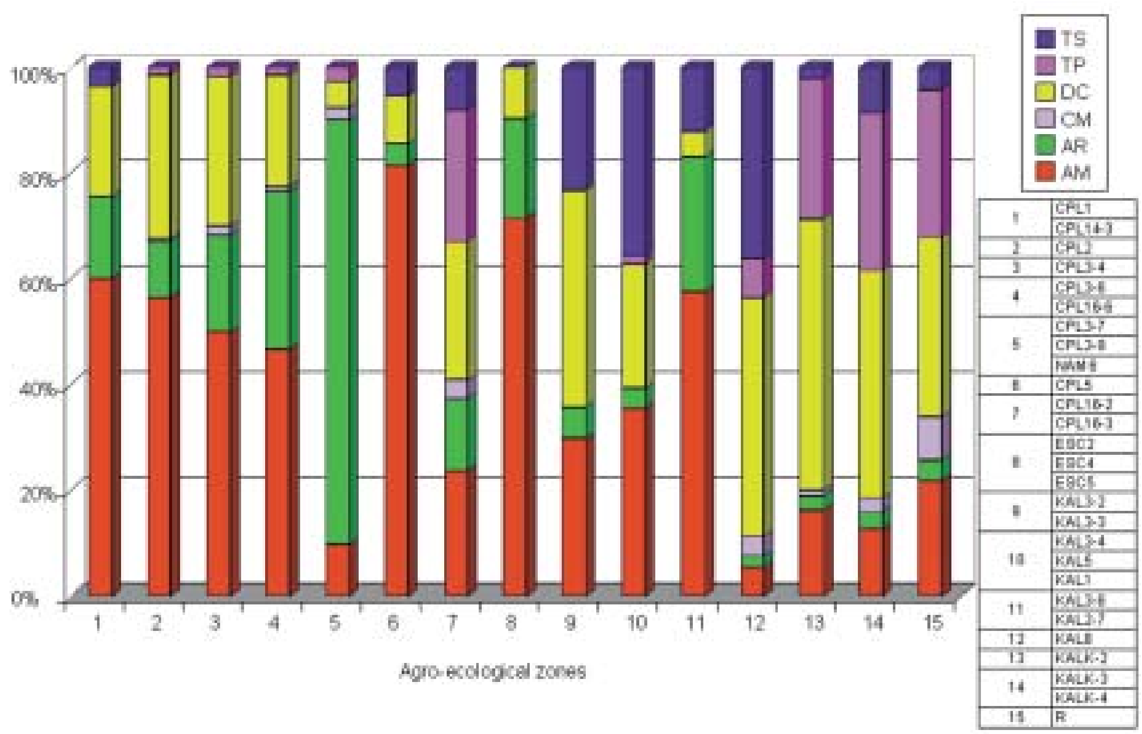


Figure 4.42: Bush encroacher species per agro-ecological zone

AEZ (or combin-ations)	Plots												
	No.							%					
	AM	AR	CM	DC	TP	TS	TOTAL	AM	AR	CM	DC	TP	TS
CPL1 + CPL14–3	144	37	0	50	0	8	239	60	15	0	21	0	3
CPL2	86	16	1	47	2	0	152	57	11	1	31	1	0
CPL3–4	30	11	1	17	1	0	60	50	18	2	28	2	0
CPL3–6 + CPL16–6	64	41	1	29	2	0	137	47	30	1	21	1	0
CPL3–7 + CPL3–9 + NAM6	4	33	1	2	1	0	41	10	80	2	5	2	0
CPL5	62	3	0	7	0	4	76	82	4	0	9	0	5
CPL16–2 + CPL16–3	21	12	3	23	22	7	88	24	14	3	26	25	8
ESC2 + ESC4 + ESC5	38	10	0	5	0	0	53	72	19	0	9	0	0
KAL3–2 + KAL3–3	40	8	0	55	0	31	134	30	6	0	41	0	23
KAL1 + KAL3–4 + KAL5	154	18	0	101	6	155	434	35	4	0	23	1	36
KAL2–7 + KAL3–6	48	21	0	4	0	10	83	58	25	0	5	0	12
KAL8	3	1	2	24	4	19	53	6	2	4	45	8	36
KALK–2	17	3	1	54	28	2	105	16	3	1	51	27	2
KALK–3 + KALK–4	20	5	4	68	47	13	157	13	3	3	43	30	8
R	11	2	4	17	14	2	50	22	4	8	34	28	4

Note: See Figure 4.21 for the specific location of each AEZ.

Table 4.12: Number and percentage of plots in each of the agro-ecological zones

CPL1	Central Plateau, Southern Omatako Plain
CPL2	Central Plateau, fringe plains
CPL3–4	Central Plateau, strongly dissected inselberg plains; average growing period 61–90 days, very short dependable growing period
CPL3–6	Central Plateau, strongly dissected inselberg plains; average growing period 41–60 days
CPL3–7	Central Plateau, strongly dissected inselberg plains; average growing period 21–40 days
CPL3–9	Central Plateau, strongly dissected inselberg plains; average growing period <10–20 days
CPL5	Central Plateau, flat plains on metamorphic rocks
CPL14–3	Central Plateau, table mountains on Karoo rocks; average growing period 61–90 days
CPL16–2	Central Plateau, red Kalkveld; average growing period 91–120 days
CPL16–3	Central Plateau, red Kalkveld; average growing period 61–90 days
CPL16–6	Central Plateau, red Kalkveld; average growing period 31–60 days
ESC2	Escarpment, high mountains on Basement Complex rocks
ESC4	Escarpment, high plateaux on Basement Complex rocks
ESC5	Escarpment, strongly dissected uplands bordering the highlands
KAL1	Kalahari Sands Plateau, stabilised W–E dunes with few pans
KAL2–7	Kalahari Sands Plateau, stabilised NW–SE dunes with common pans; average growing period 31–40 days

KAL3–2	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 91–120 days
KAL3–3	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 61–90 days, dependable growing period 60% of average
KAL3–4	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 61–90 days, very short dependable growing period
KAL3–6	Kalahari Sands Plateau, stabilised sand drift with few pans; average growing period 41–60 days, no dependable growing period
KAL5	Kalahari Sands Plateau, slightly incised river valleys
KAL8	Kalahari Sands Plateau, "omuramba" dune association
KALK–2	Kalkveld, average growing period 91–120 days; dependable growing period 80% of average
KALK–3	Kalkveld, average growing period 61–90 days; dependable growing period 60% of average
KALK–4	Kalkveld, median growing period 61–90 days; very short dependable growing period
NAM6	Namib Desert Plains, gravel and rock pavement
R	Undifferentiated rocky hills and inselberg mountains

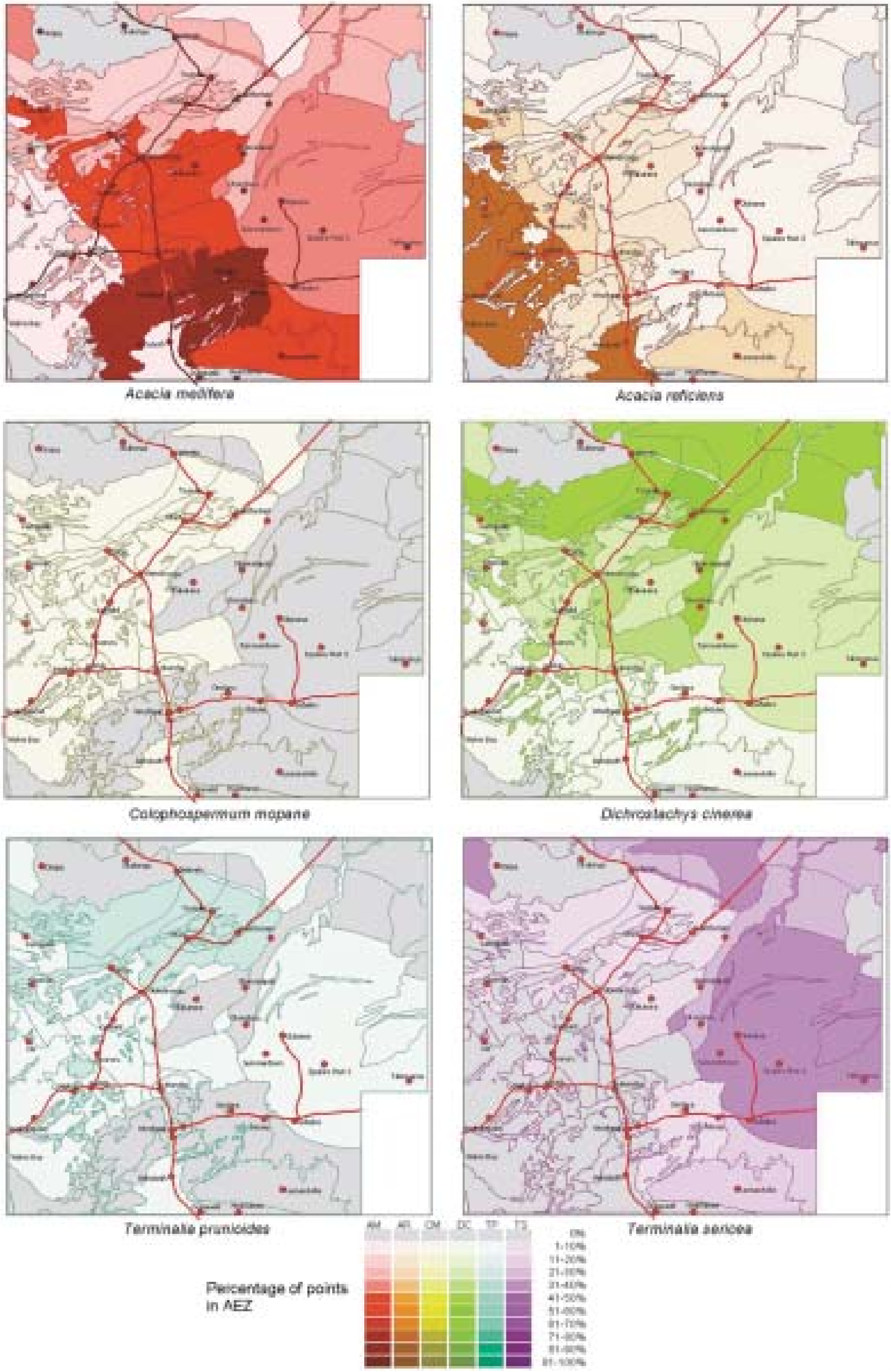


Figure 4.43: Encroacher species per agro-ecological zone

4.2.2.9 Species distribution per vegetation unit

Vegetation units are described in Table 4.13 while their names and positioning are shown in Figure 4.43. The percentage that each encroacher species contributes to such vegetation units is illustrated in Figures 4.44 and 4.45.

As Figure 4.44 and Table 4.13 show, *Acacia mellifera* dominates in the Camelthorn Savanna (Unit 3), the Highland Shrubland (Unit 5) and Thornbush Shrubland (Unit 9).

Dichrostachys cinerea dominates in the Burkea–Baikiaea Woodlands (Unit 2), Dolomite Karstveld (Unit 4) and Tamboti Woodlands (Unit 8), while showing a strong presence in the Loam and Turf Karstveld (Unit 6), Shrubland of the Central Escarpment (Unit 7), Thornbush Shrubland (Unit 9) and the Tree Savanna and Woodlands (Unit 10).

Terminalia prunioides is the dominant species in the Loam and Turf Karstveld (Unit 6), and shows a strong presence in the Dolomite Karstveld (Unit 4) and Tamboti Woodlands (Unit 8).

Terminalia sericea is significant in the Burkea–Baikiaea Woodlands (Unit 2), Camelthorn Savanna (Unit 3) and Tree Savanna and Woodlands (Unit 10).

Acacia reficiens dominates in the Acacia Hilly Shrubland and Inselbergs (Unit 1) and the Shrubland of the Central Escarpment (Unit 7).

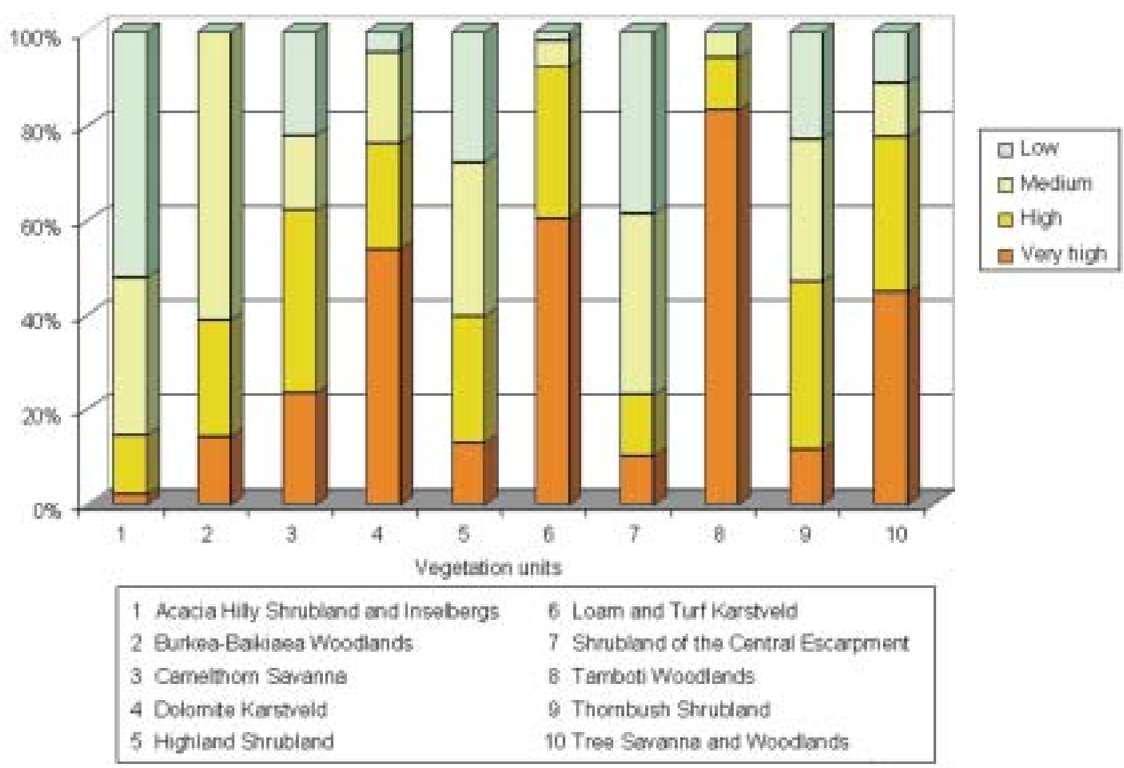


Figure 4.44: Species composition per vegetation unit

Unit Identification No.	AEZ (or combin-ations)	Plots												
		No.							%					
		AM	AR	CM	DC	TP	TS	TOTAL	AM	AR	CM	DC	TP	TS
1	Acacia Hilly Shrubland and Inselbergs	1	25	1	0	0	0	27	4	93	4	0	0	0
2	Burkea–Baikiaea Woodlands	2	1	2	38	4	20	67	3	1	3	57	6	30
3	Camelthorn Savanna	293	66	0	115	0	144	618	47	11	0	19	0	23
4	Dolomite Karstveld	30	8	5	102	66	12	223	13	4	2	46	30	5
5	Highland Shrubland	91	21	0	18	0	1	131	69	16	0	14	0	1
6	Loam and Turf Karstveld	6	5	5	28	35	3	82	7	6	6	34	43	4
7	Shrubland of the Central Escarpment	4	18	0	7	1	0	30	13	60	0	23	3	0
8	Tamboti Woodlands	2	1	0	10	6	0	19	11	5	0	53	32	0
9	Thornbush Shrubland	230	52	2	103	10	3	400	57	13	1	26	3	1
10	Tree Savanna and Woodlands	65	9	0	70	1	68	213	31	4	0	33	0	32

Table 4.13: Number and percentage of plots in each vegetation unit

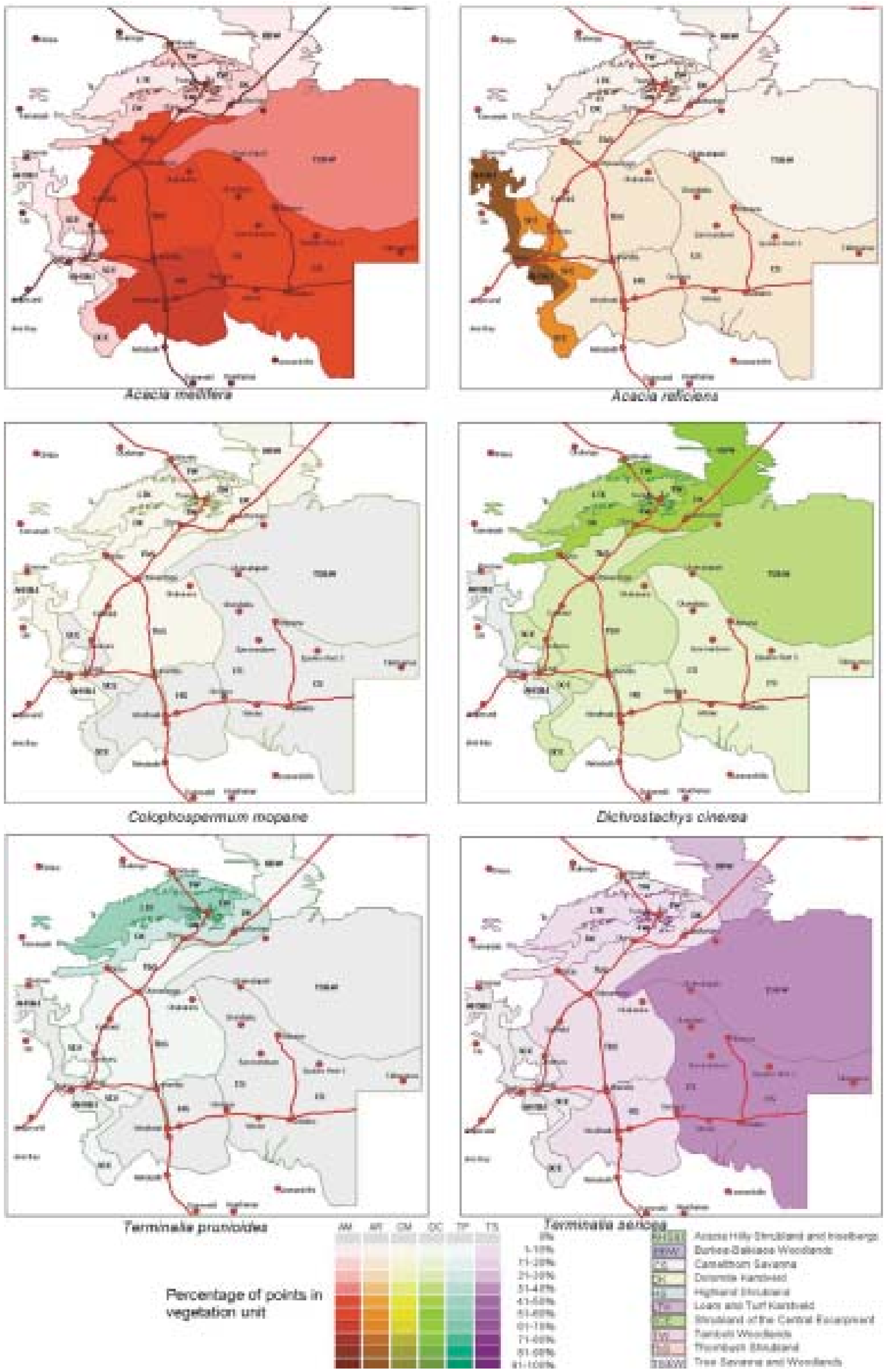


Figure 4.45: Distribution of six encroachers per vegetation unit

4.2.2.10 Species distribution per rainfall interval

The next two graphs show the distribution of species over the rainfall zones in two slighly different ways.

From the first graph (Figure 4.46) it is clear that almost 50% of all the plots with *Acacia mellifera* fall within the 350–400 mm rainfall zone, with 82% in the 300–450 mm range.

A third of plots with *Acacia reficiens* are in the 350–400 mm range. This species occurs on 6% of plots in the low (150–200 mm) range – the only species in this range, according to the present survey.

Dichrostachys cinerea seems to be evenly distributed throughout the 350–500 mm interval; 76% of plots with *Dichrostachys cinerea* occur in this interval.

Terminalia prunioides shows strong concentration in the 450–550 mm range; 86% of plots with TP occur in this interval.

Terminalia sericia is concentrated in the 350–500 mm range, with 71% of plots occurring in the 350–450 mm interval.

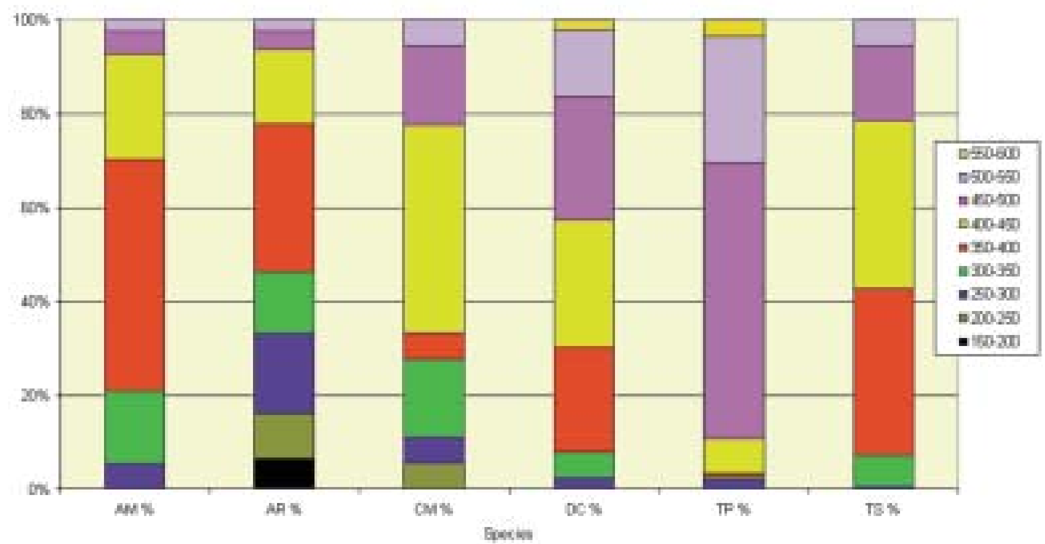


Figure 4.46: Encroacher species distribution per rainfall zone

Rainfall interval (mm)	No. of plots with specific species in each rainfall zone							Rainfall zone spread of each species (%)					
	AM	AR	CM	DC	TP	TS	TOTAL	AM	AR	CM	DC	TP	TS
150–200	0	14	0	0	0	0	14	0	6	0	0	0	0
200–250	0	22	1	0	0	0	23	0	10	6	0	0	0
250–300	40	38	1	14	3	2	98	5	17	6	3	2	1
300–350	115	29	3	29	1	17	194	16	13	17	5	1	6
350–400	365	70	1	119	1	93	649	49	32	6	22	1	35
400–450	164	35	8	145	11	94	457	22	16	44	27	7	36
450–500	37	9	3	143	89	42	323	5	4	17	27	59	16
500–550	17	5	1	75	41	14	153	2	2	6	14	27	5
550–600	0	0	0	11	5	0	16	0	0	0	2	3	0

Table 4.14: Number and percentage of plots in each rainfall zone

The next graph (see Figure 4.47) shows clearly how *Acacia reficiens* dominates the lower rainfall plots (150–250 mm) and shares dominance with *Acacia mellifera* in the 250–300 mm range. From 300–450 mm, *Acacia mellifera* takes over dominance. *Dichrostachys cinerea* appears at 250–300 mm and increases steadily in importance up to 600 mm, which is the maximum rainfall of the study area. *Terminalia sericea* peaks at around 400–450 mm, while *Terminalia prunioides* forms a constant percentage of problem bush in the 450–600 mm range. In Figure 4.48 the distribution of invader species per rainfall zone is depicted in a different way and follows exactly the same pattern.

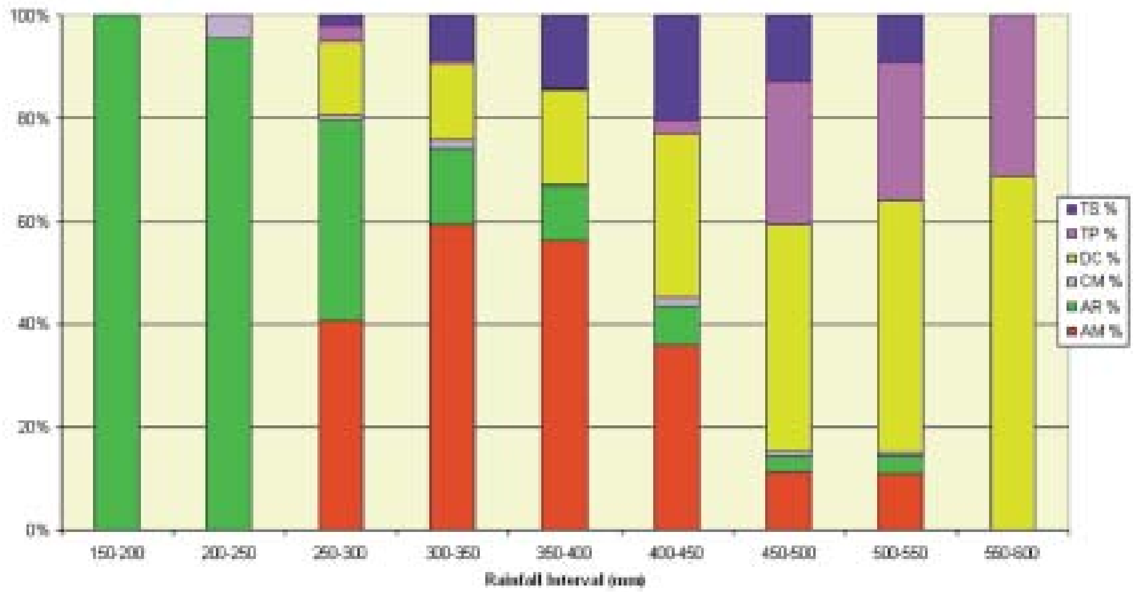


Figure 4.47: Encroacher species composition in each of the rainfall zones

Rainfall interval (mm)	Encroacher species composition of each rainfall zone (%)					
	AM	AR	CM	DC	TP	TS
150–200	0	100	0	0	0	0
200–250	0	96	4	0	0	0
250–300	41	39	1	14	3	2
300–350	59	15	2	15	1	9
350–400	56	11	0	18	0	14
400–450	36	8	2	32	2	21
450–500	11	3	1	44	28	13
500–550	11	3	1	49	27	9
550–600	0	0	0	69	31	0

Table 4.15: Percentage of encroacher species in each rainfall zone

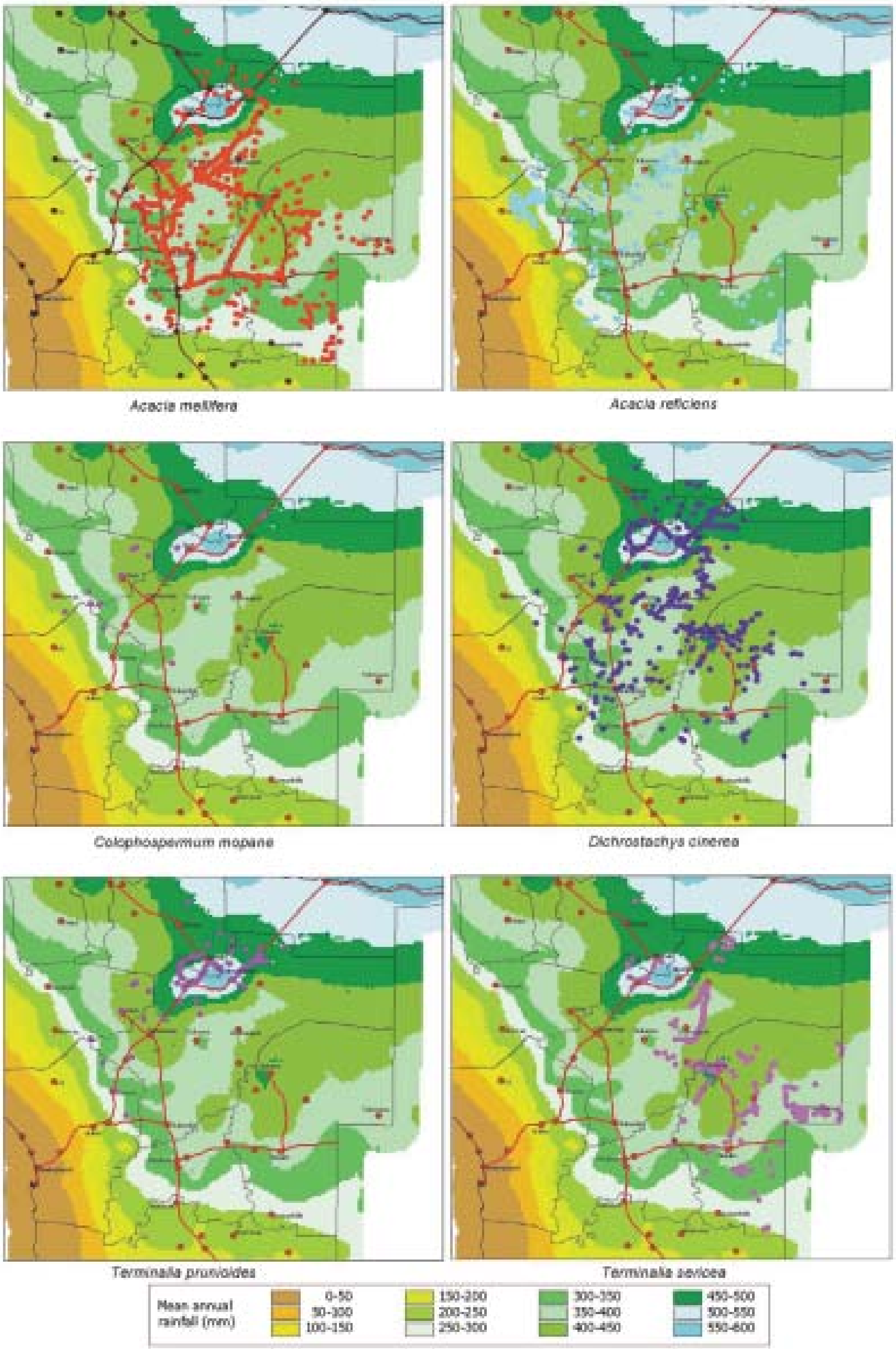


Figure 4.48: Map showing species distribution per rainfall zone

4.3 Conclusions

It needs to be borne in mind throughout this interpretation of the results that they are only valid within the study area, the sampling was not completely random, and in some cases the sample size was too small for complete confidence to be expressed in the spatial-statistical analysis.

Although an attempt was made to use information collected during surveys as a basis for ground-truthing and remote sensing to identify and describe bush-encroached areas (using satellite imagery), it did not materialise. The main reason was the continuing lack of knowledge and expertise available to master this daunting challenge. Hopefully, however, the interpretation of satellite images will finally be able to replace the expensive and exhausting surveys through which changes in vegetation are currently monitored. Further research in this field should form an indispensable part of any future research strategy.

From the aforementioned analysis the following results and conclusions are presented:

- 58% of the plots showed high to very high concentrations of invader bush (>2,000 bushes per hectare). Only 20% of the plots showed low bush densities (less than 1,000 bushes per hectare). Considering the severe impact of 500 TEs and more per hectare on grass production, the study shows clearly that approximately 80% of the study area (with more than 1,000 bushes per hectare) is subject to huge losses in land productivity.

- There is no clear pattern showing an unambiguous relationship between AEZs and bush density. Most of the AEZs are interspersed with densities varying from low to very high. The general trend, however, is that 77% of the "very high" and 52% of the "high" density sites lie north-east of the Otjiwarongo–Gobabis axis (see Figure 4.18), while 58% of the "medium" and 58% of the "low" density sites lie south-west of that axis.

- When the occurrence of invader bush is considered against the various vegetation units in the study area, it is the Acacia Hilly Shrubland and Inselbergs that are least encroached, with only 15% of plots in either the "very high" or "high" bush density category. On the other hand, the Tamboti Woodlands, although represented by only 18 sampled plots, show the highest degree of encroachment, with 83% of plots in the "very high" and 11% in the "high" bush density categories, respectively.

- The Loam and Turf Karstveld, the Dolomite Karstveld, and the Tree Savanna and Woodlands all show a very high degree of encroachment, with more than 75% of sampled the plots located within it in either the "very high" or "high" bush density category. The Camelthorn Savanna has 62% of the plots located within it in the two highest density categories. The remaining vegetation units show intermediate levels of encroachment.

- In all four of the bush density categories there is a strong trend of increasing bush density as rainfall increases. The correlation of actual (counted) densities with the 10 mm isohyets is significant, with $r^2 = \pm 0.3$. The "very high" bush density plots predominantly occur in the 400–450 mm interval, with a considerable number in the 350–400 and 450–500 mm intervals.

- One set of analyses showed that rainfall could contribute ±80–85% to the density distribution of bush on a macro-scale. However, one should take note of the large spread between the minimum and maximum values: these show that the situation is quite complex and that other factors such as management practices can play an important role on the micro-scale. The conclusion is that rainfall has a significant effect on bush density, but is not the only contributing factor.

- The present data also revealed a strong association between underlying geological formations. The highest bush density is found on soils derived from sedimentary rock of organic origin, i.e. limestone and dolomite, such as that found in the Karstveld. The unconsolidated soils of aeolian (wind-borne) and fluvial (water-borne) origin, such as the sandy Kalahari sand plains and dunes as well as dry river beds and adjacent river valleys, also show high levels of encroachment. Soils from acid igneous and acid metamorphic origin show lower levels of encroachment. However, these classifications are too broad to enable specific relationships to be discerned.

- Looking at the interaction between dominant soil/terrain types and bush densities, more than 80% of the sampled plots in soil/terrain mapping units with Karst on hard Damara limestone (Tsumeb–Grootfontein–Otavi) are in the two highest bush density categories.

- High encroachment levels are also found in units with Kalahari aligned fossil sand dunes and deposits as well as flood-prone areas like omurambas and river valleys.

- No relationship between seasonal biomass production and bush densities could be found.

- *Acacia mellifera* is clearly the most widely distributed encroacher species, with *Dichrostachys cinerea* in strong second place. The current survey has not really included north-west Namibia, which is dominated by *Colophospermum mopane*.

- *Colophospermum mopane* is concentrated towards the north-west, while *Terminalia prunioides* is found mainly in the Tsumeb–Grootfontein–Otavi–Mururani area. *Terminalia sericea* is found overwhelmingly (95% of "problem bush" plots) east of an axis through Omitara and Otavi. *Dichrostachys cinerea* is widely distributed north of the Windhoek–Gobabis road (91% of "problem bush" plots). *Acacia reficiens* is distributed widely and occurs further west than any of the other encroachers.

- It is interesting to note that each of the vegetation units is characterised by one specific encroacher which dominates the unit.

- *Acacia mellifera* dominates in the Highland Shrubland, Thornbush Shrubland and Camelthorn Savanna.

- *Dichrostachys cinerea* dominates in the Burkea–Baikiaea Woodlands, the Dolomite Karstveld and the Tamboti Woodlands, while showing a strong presence in the Loam and Turf Karstveld, the Shrubland of the Central Escarpment, the Thornbush Shrubland, and the Tree Savanna and Woodlands.

- *Terminalia prunioides* is the dominant species in the Loam and Turf Karstveld, and shows a strong presence in the Dolomite Karstveld.

- *Terminalia sericea* is significant in the Burkea–Baikiaea Woodlands, the Camelthorn Savanna and the Tree Savanna and Woodlands.

- The occurrence of the six main encroacher species shows a strong correlation with rainfall. *Acacia reficiens* dominates the lower rainfall plots (150–250 mm) and shares dominance with *Acacia mellifera* in the 250–300 mm range. From 300–450 mm *Acacia mellifera* takes over dominance. *Dichrostachys cinerea* appears at 250–300 mm and increases steadily in importance up to 600 mm, which is the maximum rainfall of the study area. *Terminalia sericea* peaks at around 400–450 mm, while *Terminalia prunioides* forms a constant percentage of problem bush in the 450–600 mm range.

- *Acacia reficiens* dominates in the Acacia Hilly Shrubland and Inselbergs and the Shrubland of the Central Escarpment.

- Although a large amount of information was used in establishing bush densities, the distribution and occurrence of different invader species, and their relationship/interaction with several variables, it was found that the number of sample plots per variable used was still inadequate. Additional surveys in the different AEZs are needed to arrive at more definite conclusions.

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Chapter 5
Overview of potential methods to combat invader bush[12]

[12] Constituted Component 1 in the original Terms of Reference

The first experimental work on combating bush by chemical means started in 1972 at the Omatjenne Research Station in response to farmers' needs to address the problem of bush encroachment. However, several methods were tested between 1972 and 2003, including chemical control by way of Tordon 225, the use of bulldozers and root ploughs, chopping bush with axes, and using goats as browsers.

The combating of bush encroachment is discussed here in relation to the following problem species:

Problem species	**English**	**Oshiwambo**	**Otjiherero**	**Khoekhoe-gowab**	**Afrikaans**
Acacia erubescens	Blue thorn	Omunkono	Omungongomui	!uri!gonis dûùbë.s	Geelhaak or Blouhaak
A. fleckii	Plate thorn	Omumang-	Omutaurambuku andjamba	!ürîgönè.s	Sandveld akasia or Bladdoring
A. luederitzii & A. reficiens	False umbrella thorn	Omutyuula	Omungondo	!gûs	Rooihaak or Baster haak-en-steek
A. mellifera	Black thorn	Omunkono	Omusaona	!noes	Swarthaak
Colophospermum mopane	Mopane	Omusati	Omutati	!oenis	Mopanie
Dichrostachys cinerea	Sickle bush	Ongete	Omutjete	|gò(w)e.s	Sekelbos
Terminalia prunioides	Purple-pod terminalia	Omuhama	Omuhama	!niob ≠kheas	Deurmekaarbos or Sterkbos
Terminalia sericea	Yellowwood/ Silver terminalia	Omugolo	Omuseasetu	|gää.b	Sandgeelhout
Catophractes alexandri	Trumpet thorn	Okalyanzi	Omukaravezi	!abba.s	Gabbabos or Trompetdoring
Prosopis spp.	*Prosopis/ Mesquite*	–	–	|ànrã.s –	Prosopis or Suidwesdoring or Muskiet
Rhigozum trichotomum	Three thorn	–	–	||häú.b/s	Driedoring

Sources: Khoekoe names, Eiseb et al. (1991); English and Afrikaans names, Van Wyk & Wyk (1997); Oshiwambo and Otjiherero names, Jeffares & Green Inc. (2000)

Table 5.1: Problem species and their local-language equivalents

Farmers who intend to execute bush control or harvesting need to familiarise themselves with the protected plant species in Namibia, namely those listed in the Forest Ordinance of 1952, the Forest Act, 1968 (No. 72 of 1968) and the Nature Conservation Ordinance of 1975 (No. 4 of 1975).

5.1 Chemical treatment

5.1.1 Results obtained with chemical treatment

According to a study by Stewart Scott Namibia Consulting Engineers (SSNCE 1999), about 10% of the farmers that formed part of the study used aerial application of chemicals to carry out debushing, while 15% did it by hand.

The time of the year when bush control is done is also of considerable importance. When carbohydrate reserves in the plants are low, the plants are more vulnerable to external interference. Many plant species are, therefore, very sensitive to defoliation at this stage (Teague 1983; Teague & Walker 1988b). From a phenological point of view, this is the best time to apply chemicals or other methods of bush control. However, root-absorbent chemicals which remain active in the soil for the entire year or even for several years could be

applied during the winter provided there is no risk of such chemicals being washed or blown away.
At Neudamm Agricultural College, between 2.5 and 3.0 kg of Graslan per hectare was applied on mispah soils. Ten years later, the results were very successful in terms of mortalities, increased grass production, and increased income. Bester and Reed (1998) found that, on average, bush density had decreased from 3,800 to 850 per hectare.

Figure 5.1: Increase in grass production: 120 kg per hectare to 852 kg per hectare

The average dry matter (grass) production in the treated camps was 852 kg per hectare, compared with 120 kg per hectare in the control. This reflected an increase of more than 700% in both grass production and net income. Another important conclusion is that lucrative livestock production is not possible in the Neudamm area, with densities of more than 3,000 bushes per hectare (Bester & Reed 1998). Lubbe (pers. comm.) mentioned that the average carrying capacity for the untreated camps during 1991–2002 was 8.23 kg live body mass per hectare, while the corresponding figure for the treated camps was 38.0 kg per hectare.

Some researchers are of the opinion that chemical control should only be applied during the initial phases of combating bush. This is mainly because of the high costs of such an exercise.

Acacia hebeclada showed a remarkable resistance against Graslan 20 P, while *Boscia albitrunca* and *Catophractes alexandri* were still present in satisfactory numbers. Species like *Acacia hereroensis*, *Grewia flava*, *Lycium* spp., *Rhus marlothi* and *Pheaoptilum spinosum* are very sensitive to Graslan 20 P, and showed a 100% mortality. (These species were, however, not present in large numbers at the onset of the trial.)

Only 24% of the original total number of bushes present were still there after ten years. No seedlings, especially of *Acacia mellifera*, were detected during the ten-year period.

Bester and Reed (1998) are convinced that correct, sound management practices are prerequisites for rangeland reclamation after chemical control. Bush control with herbicides cannot be seen as a one-off practice and, therefore, aftercare treatment (mechanical, biological or chemical) is indispensable for long-term success. The rate of reinfestation will have a profound influence on the economic viability of bush control programmes.

In this respect, Aucamp (1990) recorded that the influence of any bush eradication programme is of short duration and that its success would, therefore, be dependent on the kind of aftercare programme. In the eastern Cape in South Africa it was proved that neither resting, burning nor good veld management could prevent reinfestation.

Figure 5.2: Chemical treatment with Graslan 18 years ago, followed by an aftercare treatment (left). Same treatment in adjacent camp but with no aftercare treatment (right)

Herbicide treatment repeated every few years may be economically viable, since young stems can be manually cleared and treated at relatively low cost, and the mortality at each clearing is cumulative. Furthermore, because of the effects of inflation and rapid tree regrowth immediately after clearing, most of the benefit of bush clearing is accrued during the first few years. Complete mortality can be achieved using granular herbicides containing Tebuthiuron or Ethidimuron. In the case of the latter herbicides, it is the rate of seedling establishment that controls the regrowth rate. In reality, seedling establishment is likely to occur in pulses rather than at a slow, continuous rate (Scholes 1990).

Very effective root kills (from 80% to 100%) were obtained by spraying the lower stems of Black thorn plants with hormone types of herbicides dissolved in either diesoline or power paraffin at concentrations of approximately 1% acid equivalent and more (Donaldson 1969).

The density (and/or yield) of perennial grass species is estimated to increase by 200–400% after treatment, depending on the condition of the range before treatment. Grazing days per annum have been reported to increase by 100% over a period of seven years. This would allow production to rise to 16 kg live weight per hectare, resulting in a net financial gain of N$24 per hectare at a price of N$3 per kilogram live weight (1993 prices). At the 2002 price of more than N$7 per kilogram live weight, the financial gain would be beyond N$56 per hectare (Quan et al. 1994).

The results obtained from a few individual case studies in Namibia are summarised as follows:

- In the Okahandja district a number of farmers, participating in a study group under the auspices of the local extension officer, kept records of their production/income. After debushing their income went up from N$25 to N$70 per hectare in real terms (Swanepoel, pers. comm.).
- At the Omatjenne Research Station, grass as well as meat production doubled after bush was chemically treated with Tordon 225.
- On the Menow Farm in the Gobabis district, the owner could not keep more than 460 cattle on a farm of 8,000 ha. Bush densities on the farm varied between 3,700 and 5,500 bushes per hectare, and consisted of *Dichrostachys cinerea*, *Acacia mellifera*, *Acacia erubescens* and *Acacia luederitzii*. The first two species dominated. He started his bush control programme in 1995 and used a mixture of 1 kg of Reclaim plus 1 kg Hyvar X with 20 *l* of water. On average, 4 ml of this mixture was applied manually per bush. Apart from a large variety of palatable perennial grass species which came in, the grass yield increased by approximately 140%. His farm is now able to carry 1,050 head of cattle in a below-average rainy season without any signs of being overstocked. The long-term sustainability of such a stocking rate will have to be monitored, however.

Figure 5.3: A profusion of desired perennial grasses on the Menow Farm after application of arboricides (left) with almost no grass production in the bordering untreated camp (right)

Some very useful labour performance data came out of this study as well, as shown in Table 5.2.

Source: *CR Liebenberg, Menow Farm, Gobabis district*

Labour performance criteria	Result
Average number of workers	8
Total number of working days	67
Total area treated (manual application of chemicals)	900 ha
Total person days (8 x 67)	536
Area cleared per day per worker	1.68 ha

Table 5.2: Performance criteria for workers

5.1.2 Practical application of chemicals

Chemical control methods are normally expensive to apply and should be considered only under specific circumstances. Smit et al. (1999; Trollope et al. 1989) recommend the application of certain chemicals under the following circumstances:

- When the woody component is so dense that not enough fuel accumulates to support a fire sufficiently intense to kill the top-growth of the target woody species
- Where a majority of the trees have grown out beyond the reach of browsing animals
- Where the tree density is such that animal access is severely restricted
- Where the woody component is largely unpalatable
- Where, for a variety of reasons, it is not practical to incorporate browsers in the livestock system, and
- Where herbicides are available which will selectively affect the target woody species more severely than the palatable species.

All remedies/chemical products used in Namibia are obliged to be registered with the Registrar in accordance with the Fertilizers, Farmfeeds, Agricultural Remedies and Stock Remedies Act, 1947 (No. 36 of 1947). A number of arboricides/herbicides that have been subjected to strict criteria for registration have so far been registered in Namibia. The availability and use of herbicides for bush control purposes are well summarised and documented by Smit et al. (1999).

Herbicides available for chemical control of invader bushes are either root-absorbent or foliar and stem-absorbent (Smit et al. 1999; Lubbe 2001).

5.1.2.1 Root-absorbent herbicides

Herbicides with Tebuthiuron, Ethidimuron or Bromacil as the active ingredient are applied on the soil surface and taken up by the roots of target bushes after effective rain has occurred. Products containing these ingredients are available as granules or pellets, wettable powders or in a liquid form. The ones in granular form that are suitable for manual application are applied under the canopy next to the stem. The dosage depends on the height of the tree/bush; it is recommended that larger dosages be applied in two to four portions around the stem. Some of the granular forms are also suitable for aerial application. With these, however, it should be emphasised that they are less selective and may damage desired plants too. Wettable powders, mixed with water and herbicides in liquid form, are sprayed onto the soil adjacent to the stem (Smit et al. 1999).

The application rate of the soil-applied formulations will vary according to the clay content, the soil's organic matter content and pH, the species of tree being treated, and its size. The higher the clay content, the greater the dose should be. All materials use tree height or some other measure of size on which to base the needed dosage (Smit et al. 1999). Soil type and, more specifically, the clay content of soils play an important role in the effectiveness of herbicides. If clay makes up more than 20% of the soil, chemical treatment is perceived to be much more expensive as a result of the need for higher dosages. Below 20% clay, applications on the soil are effective (Trollope et al. 1989; Dahl & Nepembe 2001). Some of the herbicides are not effective on soils with a clay percentage above 35% (Smit et al. 1999).

Various plant species also differ as far as their resistance to herbicides is concerned (Smit 1993). *Dichrostachys cinerea*, for example, will require double the dose (Quan, Barton & Conroy 1994) applicable to *Acacia mellifera*.

After application, these herbicides remain inactive until such time as rain carries the active ingredient (Tebuthiuron, Ethidimuron or Bromacil) into the soil, when it is taken up by the tree roots. Their action in the plant is to inhibit photosynthesis. The leaves become yellow and abscise. New leaves are formed, but also abscise. This process continues until the tree no longer has reserves to initiate re-growth and so it dies. These herbicides should be applied early in the growing season. If applied in the dormant season or late in the growing season, they will remain inactive on the soil surface for lengthy periods (Smit et al. 1999).

Aerial application is usually done when the plant is in an active growth stage, i.e. the leaves and the stoma are still open and able to absorb the remedies. Several researchers (e.g. Moore 1989) also found that the carbohydrate status of plant parts at the time chemical treatment was applied had a huge influence on the application's effectiveness. Thus, the carbohydrate status of the different plant parts during chemical application will influence the minimum dosage and, consequently, the economic viability of bush control. Chemical control will be the most effective during the translocation of carbohydrates to the roots, and when they are stored in the roots.

Aerial application of root-absorbent herbicides is also regarded as an effective method to combat bush and is probably the fastest way to clear bush.

5.1.2.2 Foliar and stem-absorbent herbicides

Products in this group contain Picloram and Triclopyr as the active ingredients and are used in either an oil- or a water-base form (Smit n.d.). Herbicides are sprayed directly on the plant's above-ground growth. These chemicals will then be absorbed by the leaves.

Foliar and stem-absorbent herbicides are also applied where the stems of plants are cut off close to the soil surface. Until recently, the most common practice was to apply Picloram and Triclopyr (Tordon Super) mixed in diesel or old oil at a 1% concentration to the stem of the plant using a knapsack spray or a brush. A red oil-immiscible dye is available for adding to the mixture. Small trees with a stem diameter of less than 10 cm can be sprayed directly, while those with stem diameters of more than 10 cm need to be cut back before treatment. In the latter case, the tree should be cut off approximately 5–15 cm above the soil surface and be treated as soon as possible thereafter. The cut surface and the remaining stump as well as any exposed roots should be wet thoroughly. If only one side of the stump is treated, it will often grow out from the untreated side. Although the manufacturers advise that the product should only be used during the active growing season, good results can be achieved at other times as well (Smit n.d.).

Tables 5.3 and 5.4 provide a summary of the available herbicides and their active ingredients.

Source: *Smit (pers. comm.); Stoltsz (pers. comm.); Van Eck (pers. comm.)*

Herbicide	Type	Active ingredient
Molopo SC	Liquid	Tebuthiuron (50%)
Molopo GG	Pellet	Tebuthiuron (20%)
Spike 5GR	Pellet	Tebuthiuron (5%)
Savanna 500	Liquid	Tebuthiuron (25%), Bromacil (25%)
Bushwacker	Wettable powder	Bromacil 500 g per litre (80%)

Table 5.3: Soil-applied herbicides (non-selective)

Herbicide	Type	Active ingredient
Tordon Super (Cut stump or basal stem application)	Liquid (mixed with diesel)	Picloram 120 g per litre (12%) Triclopyr 240 g per litre (24%)
Access (Cut stump, basal stem or foliar application)	Liquid (mixed with water and Actipron)	Tebuthiuron 240 g per litre (24%)
Viroaxe (Foliar)	Liquid (mixed with diesel)	Triclopyr 480 g per litre (48%)
Touchdown Plus (Stump)	Liquid (mixed with water)	Glyphosate trimesium 480 g per litre (48%)

Source: *Smit (pers. comm.); Stoltsz (pers. comm.); Van Eck (pers. comm.)*

Table 5.4: Plant-applied herbicides (selective)

5.1.2.3 Advantages and disadvantages of using herbicides

(a) Soil-applied herbicides (Tebuthiuron, Ethidimuron and Bromacil)

(i) ADVANTAGES

- Treatment of individual trees is relatively fast (Bester 1985a; Smit et al. 1999).
- Application can be selective, particularly when applied by hand. There is little danger of untreated trees being exposed to the herbicide (Smit n.d.).
- The residual effect can suppress seedling regeneration for up to five years (Smit et al. 1999; Bester 1985a), and
- The manual application of herbicides is labour-intensive and provides ample opportunities for job creation (Van Eck, pers. comm.).

(ii) DISADVANTAGES

- Even with selective application, trees that have not been treated may die because their roots extend to the vicinity of application (Bester 1985a; Smit et al.1999; Smit n.d.).
- The active ingredient may be slow to take effect because it only becomes active once rainwater has carried it into the soil profile. This means it can take up to two years to effectively kill target species (Bester 1985a; Smit et al. 1999).
- Trees that die remain standing and show a resistance to decay and decomposition when certain of these herbicides are applied. Nutrients contained in their wood remain unavailable for use by other plants for long periods of time (Bester 1985a; Smit et al. 1999). This is especially of concern in dense stands of bushes.
- The rate of application is dependent on the soil's clay and organic matter content, making this method very expensive in soils with a high clay content (Bester 1985a).
- Trees differ in respect of their sensitivity to herbicides. Some trees require a higher rate of application. Therefore, a person applying the herbicides without the necessary knowledge of trees and correct application rates may cause failures and substantial subsequent financial losses, and
- A large number of dead standing trees makes for an unattractive landscape (Smit et al. 1999).

(b) Foliar and stem-applied herbicides

(i) ADVANTAGES

- These are selective methods, as the leaf area of a specific tree is treated. There is little danger of untreated trees being exposed to the herbicide (Bester 1985a; Smit et al.1999).
- Chopped-down trees whose stems have been treated immediately, die immediately (Bester 1985a).
- One can establish very soon whether or not the appropriate number of trees has

been retained (Smit et al. 1999).

- Dead plants can be harvested and utilised for the production of firewood or charcoal, for example. Income derived from such products can be used to retrieve some of the costs arising from bush clearing (Smit et al. 1999; International Development Agency 2003), and
- It is labour-intensive and can create job opportunities.

(ii) DISADVANTAGES

- The procedure is very time-consuming (Smit et al. 1999) and tedious (Bester 1985a), and
- With increasing bush densities, manual applications become increasingly expensive. For areas with more than 2,000 bushes per hectare, aerial application is the cheaper option.

(c) Aerial application

(i) ADVANTAGES

- Because of its uniform application, no individuals escape treatment (this can also sometimes be a disadvantage). Seedlings which are often missed in hand applications are usually killed by aerial applications (Smit et al. 1999).
- It is a cheaper method when bush densities exceed 2,000 per hectare.
- It is not time-consuming and large areas can be controlled within one season, especially where high bush densities occur (Bester 1985a).
- It is effective, with a mortality rate in the order of 70–90%. However, this still means that not all the bushes are killed (Bester, pers. comm.), and
- Very little labour is required (an advantage from a financial point of view, but less attractive from a socio-economic perspective).

(ii) DISADVANTAGES

- Valuable plants may be adversely affected by the herbicide due to the non-selective nature of aerial applications (Smit et al. 1999), and
- Landing strips for aircraft are not always available (Van Eck, pers. comm.).

5.1.3 Aftercare measures

Most bushes die within one year and the recovery of grass is good. Despite this, follow-up treatment is required because the increase of perennial grass species does not appear to suppress reinfestation. Whatever the method may be, aftercare treatment should continue indefinitely.

Van Niekerk (1990) suggests that the following aftercare measures be applied:

- Manually applied chemical treatment should be followed up with another round of chemical control or a controlled veld fire after 5 years, and a veld fire every 5–7 years thereafter.
- An effective aerial application of chemicals needs to be followed up either by manual spraying or a controlled veld fire after every 7–12 years. Aftercare treatment is needed by way of hand spraying (every 5–7 years) or a veld fire (every 5 years).

A study carried out by Dahl and Nepembe (2001) supports the view that applying chemicals manually is an effective means of aftercare for an area subjected to bush control at an earlier stage and which needs additional treatment after a few years to prevent regeneration of unwanted bush.

Other options include an occasional controlled burn, removal of bush by hand, or the introduction of goats to browse the regenerating bush. The application of controlled veld fires could be an alternative or supplementary aftercare technique in order to regain grazing areas (ibid.).

Manual stumping or removal of bush with either a saw, a mattock or an axe is a moderately slow and labour-intensive method. This seems, however, to be one of the most common techniques used by farmers. Nearly 30% of the farmers in the study by SSNCE (1999) cleared bush by chopping them out with axes.

Another type of aftercare is the introduction of goats or game to browse the regenerating bush. The use of goats in the aftercare process of debushing requires additional managerial skills, cash flow and capital investment. Few farmers take the latter option because goats are difficult to manage, herding and fencing are expensive, and there are the risks of theft and predators (see also under "Preventive techniques" below).

5.1.4 Preventive techniques

The objective of rotational grazing is to ensure that paddocks receive sufficient rest during the rainy season so that the preferable grass species are allowed to grow, occupy the upper layers of the soil with roots, and become competitive for soil moisture. A vigorous perennial grass cover tends to suppress the establishment and growth of bush seedlings and, therefore, the encroachment of bush.

Game or goat ranching is another method used to prevent unwanted bush invasion. Game help to thwart encroachment since bush growth is suppressed. Game seem to eat and suppress more bush species than cattle do, which makes them useful for slowing down the invasion of unwanted shrubs. However, the cost of establishing a game farm is formidable due to the high prices of game and fencing materials.

5.1.5 Environmental and health risks

Some concerns about the environmental impact of chemical methods do exist. For this reason, although bush encroachment can be regarded as an ecological disaster, when dealing with the problem all measures need to be taken to prevent another or even bigger disaster.

5.1.5.1 Soil-applied herbicides

Tebuthiuron (N–(5–(1,1–dimethilethyl)–1,3,4–thiadiazol–2–y1)–N, N–dimethylurea) is non - toxic to human beings and animals. Plants differ in their resistance to Tebuthiuron. For this reason, low dosages of the herbicide can be used effectively to target certain species only.

Tebuthiuron is readily absorbed through roots and translocated to other plant parts (Smit 1993). It produces its effect by inhibiting photosynthesis, the process by which plants receive light from the sun and convert it into energy (Anon. 1994).

Mammals, birds and fish metabolise and excrete Tebuthiuron effectively without any of the formulation accumulating in the body tissues (Smit 1993; Anon. 1995a; Lubbe 2001).

Experiments in this regard show that 100 ppm (7 mg per kilogram per day) does not have any influence on mammals (Smit 1993).

Tebuthiuron is practically non-toxic to birds (Anon. 1994, Kidd & James 1991). However, as Joubert (2003; citing Anon. 1995) points out, Tebuthiuron is slightly toxic to birds but not to bees, while it is slightly toxic to bees (IVI 1995).

A concentration of 9.3 ppm (50 times more than the maximum concentration monitored on treated areas) had no influence on aquatic life. Anon. (1994) and Anon. (1995b) regarded Tebuthiuron as practically non-toxic to fish and other aquatic species. In addition, Johnson (1992) found that the small quantity of Tebuthiuron or its metabolites in wood originating from treated trees poses no danger when it is used as firewood (Smit 1993).

When applying chemical control, dosages varying between 400 and 1,600 g of Tebuthiuron (as the active ingredient) per hectare are used. This means that, if applied judiciously, relatively small quantities of Tebuthiuron are needed to achieve the required result. Adsorption coefficients for Tebuthiuron vary between 0.2 mg per 100 g of (sandy) soil and 10 mg per 100 g for soils high in organic matter. The practical implication of these soil properties is to ensure that those with a higher clay content obtain a higher dosage in order for the herbicide to be effective, and that leaching of the active ingredient does not take place. If the recommended dose for a specific soil type is adhered to, the herbicide will reach deeper than 600 mm after three years (Smit 1993). Little or no lateral movement has been seen in soils with appreciable clay or organic matter content (Anon. 1994).

Consequently, such treatments do not pose any risk in respect of polluting underground water.

Tebuthiuron has an approximate half-life of 12–18 months. After 3–7 years, it will reach a level where it is practically no longer a risk to any life form. High temperatures and water promote the herbicide's breakdown. Johnson (1992) also illustrated levels of 0.5 mg per kilogram in dead trunks, 0.1 mg per kilogram in the hard wood, and 0.7 mg per kilogram in the bark of trees 3–9 years after treatment. He concluded that these levels had no detrimental effect on the environment or the consumer of wood.

On the other hand, as Joubert (2003) states in his EIA, –

> Bromacil is found to be toxic to birds at high dosages (Clayton & Clayton 1981).
>
> The median tolerance limit, or the concentration of Bromacil that will kill 50% of the exposed fish after 48 hours of exposure, varies from 40 ppm to 164 ppm, depending on the type of fish tested (Clayton & Clayton 1981). Bromacil is not toxic to either aquatic invertebrates or honeybees (Van Driesche 1985; Meister 1992).
>
> Bromacil binds, or adsorbs, only lightly to soil particles, is soluble in water, and has a relatively lengthy soil half-life (60 days). For these reasons, Bromacil is expected to move (leach) quite readily through the soil and it can contaminate groundwater. The potential for Bromacil to leach and contaminate groundwater is greatest in sandy soils (Van Driesche 1985). Bromacil should not be used near drinking water reservoirs or in well recharge areas because of its mobility in soil. Directions and precautions listed on product labels must be followed to minimize potential Bromacil movement into groundwater (Van Driesche 1985; Meister 1992; Anon. 1990). Field dissipation studies have shown that phytotoxic residues of Bromacil have persisted in both sand and clay soils for longer than 2 years (Anon. 1989).

5.1.5.2 Stem-applied herbicides

The most commonly applied remedy from this group is Tordon Super, with the esters Picloram and Triclopyr as active ingredients. This remedy penetrates the bark, moves to the plant's cambium layer, and is then translocated to the branches, leaves and roots. If a tree is cut before treatment takes place, the active ingredients are translocated to the roots; the above-ground growth will, therefore, be free of any chemicals.

However, it seems that an oil-soluble/wettable agent like diesel is a prerequisite for the remedy to penetrate the bark and, eventually, the cambium layer. Furthermore, it is believed that these esters do not move readily in the wood. This fact explains why plants only die off on the treated side while the opposite side could coppice again. In practice it means that two or more locations around the stem of the plant should be treated for the herbicide to be effective (Smit 1993).

In his EIA, Joubert (2003) also points out the following:

> Tordon Super has a low toxicity for humans as well as animals. As far as birds and fish are concerned, Triclopyr is slightly to practically nontoxic (Anon. 1984; Anon. 1994). The compound has little if any potential to accumulate in aquatic organisms (Gersich et al. 1984) and is nontoxic (Kidd & James 1991) or relatively non-hazardous (Tew 1996) to bees.
>
> In natural soil and in aquatic environments, the ester and amine salt formulations rapidly convert to the acid, which in turn is neutralized to a relatively nontoxic salt. It is effectively degraded by soil micro[-] organisms and has a moderate persistence in soil environments (Anon. 1984). The half-life in soil ranges from 30 to 90 days, depending on soil type and environmental conditions, with an average of about 46 days (Anon. 1983b). Longer half-lives may occur in cold or arid conditions. Triclopyr is not strongly adsorbed to soil particles and has the potential to be mobile (Anon. 1984).
>
> Triclopyr is not readily hydrolyzed at pH 5 to 9 (Anon. 1984). Reported half-lives in water are 2.8 to 14.1 hours, depending on season and depth of water (Anon. 1983b). The ester formulation half-life is from 12.5 to 83.4 hours (Anon. 1983b).
>
> Triclopyr is readily translocated throughout a plant after being taken up by either roots or the foliage. The estimated half-life in aboveground drying foliage as in a forest overstory is 2 to 3 hours (Anon. 1984).

The dosage per unit area will largely be determined by the total number of woody plants and whether they are single- or multi-stemmed.

5.1.5.3 Foliar-applied glyphosates

Joubert (2003) points out that –

> Glyphosate is slightly toxic to wild birds (Kidd & James 1991).
>
> Technical glyphosate acid is practically nontoxic to fish and may be slightly toxic to aquatic invertebrates (Anon. 1994). Some formulations may be more toxic to fish and aquatic species due to differences in toxicity between the salts and the parent acid or to surfactants used in the formulation (Anon. 1994; Anon. 1985). There is a very low potential for the compound to build up in the tissues of aquatic invertebrates or other aquatic organisms (Anon. 1985).
>
> Glyphosate is nontoxic (Anon 1994; Kidd & James 1991) or relatively non-hazardous (Tew 1996) to bees. Label instructions should still be followed carefully.
>
> A study conducted in Australia suggests that glyphosate used to combat an alien weed species negatively affected an endangered indigenous plant species (Matarczyk et al. 2002). The above-mentioned authors state that glyphosate may also affect biodiversity adversely.
>
> Glyphosate is moderately persistent in soil, with an estimated average half-life of 47 days (Anon. 1994; Wauchope et al. 1992). It is strongly adsorbed to most soils, even those with lower organic and clay content (Anon. 1994; Wauchope et al. 1992) and even though it is highly soluble in water, it does not leach appreciably, and has low potential for runoff (Edwards et al. 1991; Wauchope et al. 1992). One estimate indicated that less than 2% of the applied chemical is lost to runoff (Malik et al. 1989).
>
> In water, glyphosate is strongly adsorbed to suspended organic and mineral matter (Anon. 1984) and its half-life in pond water ranges from 12 days to 10 weeks (Anon. 1992).
>
> Glyphosate may be translocated throughout the plant, including to the roots. It is extensively metabolized by some plants, while remaining intact in others (Wauchope et al. 1992).

5.1.5.4 Conclusions

It can be concluded that the movement of Picloram and Triclopyr in water is very limited because they are not water-soluble formulations. From practical experience it seems that Tordon Super does not affect species other that the targeted ones (Smit 1993). Smit (ibid.) concludes that most of the herbicides available on the market are safe, provided they are applied in accordance with the manufacturers' prescriptions.

It is important to keep in mind that chemicals used for bush clearing inhibit respiration and photosynthesis as well as the formation of nucleic acids (Trollope et al. 1989), and that the chemicals have a residual effect of up to four years.

One of the main threats associated with the use of herbicides in general is the possibility that the export market will reject Namibian beef on the grounds that grazing has been polluted by the active ingredients of applied herbicides. Great care needs to be taken, therefore, to ensure no misperceptions cause a negative impact on the export of beef to the European Union (Dahl & Nepembe 2001).

It should also be emphasised that, over more than 25 years of chemical bush control in Namibia, not a single case has been identified or diagnosed where a person showed any symptoms of poisoning as a result of direct or indirect contact with these herbicides or by means of wood products or food.

Nonetheless, there is good reason to further investigate the possible detrimental effect of all these active ingredients in the soils and in products emanating from treated rangelands. People are becoming more and more sensitive to and emotional about anything posing a health risk, and it should be proved beyond doubt that there is –

- no pollution of the environment
- no health risk to humans, plants or animals, and
- no other environmental risk whatsoever

associated with the chemical treatment of bush encroachment.

5.2 Biological control

5.2.1 The use of browsers

In commercial and communal farming areas, goats are predominantly used for commercial purposes and not managed for ecological considerations. Browsing game species still occur on commercial farms. Kudu can be found on almost all farms in the bush-affected area, but their numbers are of such a nature that they will not exert any significant impact on problem bush species. Eland still occur on a few farms, but in very limited numbers. Giraffe occur naturally on a limited number of farms in the western parts of the Outjo district, and on some farms in the Tsumeb and Grootfontein districts. It can be expected with a high degree of certainty, therefore, that browsers do not play any significant role in suppressing bush encroachment in the present scenario. Thus, it is of particular importance to consider the possible role that browsers (goats and game) could play in a long-term management strategy.

5.2.1.1 Impact of goats on bush density, composition and herbaceous layer

Acacia karroo trees are very sensitive to defoliation in the early-flush phenophase when carbohydrate reserves are at their lowest, and are very tolerant of defoliation when reserves are high (Teague & Walker 1988b). The time of year, therefore, plays an important role in the application of any biological bush control methods.

Trollope (1974) obtained a 90% reduction in bush density in a matter of five years. Using a stocking rate of one goat per hectare, bush encroachment was brought down to 1,625 plants per hectare. However, this result is only possible if the woody species are within the reachable browse line.

In another study (Sweet & Mphinyane 1986), a 10-ha block of *Acacia nigrescens–Combretum apiculatum* veld which had been burned with an intense surface head fire was stocked at the rate of one goat per hectare to control woody regrowth. After one year, the block was subdivided: in one half, the stocking rate remained at the same low level, while in the other half it was increased to three goats per hectare. After two more years, there was insufficient forage to sustain the high stocking rate of three goats per hectare. At this stage, the bush density below 2 m had been reduced by 23% in the normally stocked half of the block, and by 52% in the highly stocked half. Similarly, the bush canopy below 2 m had been reduced by 70% and 95% in the areas with low and high stocking rates, respectively.

For both halves of the block, there was greater mortality of benign browse species than of spinescent species, and adverse changes in herbaceous layer composition were recorded. The species composition of the woody plants in the height class above 2 m remained constant, but there were substantial changes within the lower height class, particularly at the high stocking rate. Thus, browsing had a greater influence on those species not exceeding a height of 2 m.

As regards the benign species in both halves of the block, there was 100% elimination of the very useful browse tree *Combretum apiculatum* and a 73% reduction of *Grewia bicolor*, another useful browse species. Surprisingly, there was no reduction of *Grewia flava* despite its high acceptability to stock, so this species appears to be remarkably tolerant of browsing. Furthermore, *Boscia albitrunca* was initially present in small numbers only, but was not eliminated despite being a species preferred by goats.

Within the spinescent species in both halves of the block, commonly the encroachers, there was a 65%, 44% and 21% reduction of *Acacia erubescens, Acacia nigrescens* and *Dichrostachys cinerea*, respectively. *Acacia tortilis*, a major encroaching species in Botswana, was not controlled at all by the goats in either half of the block, and in fact increased by 25% during the trial period.

Overall, therefore, the changes in botanical composition were more adverse for range condition at the high stocking rate.

Oates (1956; cited by Sweet & Mphinyane 1986) reported that grass cover was improved a great deal by browsing of tree and shrub regrowth, and that goats caused the death of various woody species without harm to the grasses. However, adverse changes in herbaceous composition were recorded at the high stocking rate imposed in Oates's experiment. Zimmermann and Mwasi (2002) concluded in this respect that goats also grazed significantly on the regrowth from perennial grasses. The browsing pressure should not be excessive, therefore, as the goats also threaten the perennial grasses.

The effect that running steers and Boer goats separately and together would have on animal production and vegetation changes was studied in Namibia's thorn-tree savanna. All treatments had a significant ($P<0.05$) effect on the number of trees per hectare. In the cattle/goat treatment, the number of bushes decreased by 77.8%; the bush decreased by 70.1% in the treatment involving only goats, and by 62.8% in the treatment involving only cattle. The "goats-only" treatment resulted in the best veld composition in terms of species composition/basal cover of the sward. It was also the only treatment where there was an increase in the perennial grass species (1.95–3.6%). The "cattle-only" treatment led to a reduction in the basal cover of the grass component.

It is important to note, therefore, that high goat-stocking rates may not be sustainable until such time as the required bush density is achieved, because of the depletion of the total available fodder. In these circumstances, the use of goats should continue intermittently or at a lower stocking rate compatible with grass vigour, until the desired level is attained.

Predictably, the more palatable species are consumed in greatest quantity and some of the browse species considered desirable for cattle may be eliminated in the reduction of overall bush density. Further information is required on the bush densities critical to grass production and on the contribution of browse to the bovine diet, in order to be able to determine the trade-off point between grass increase and browse decrease. The problematic encroaching species such as *Acacia* spp. and *Dichrostachys cinerea*, although palatable, are more resistant morphologically to browsing than the benign browse plants. This means that, in multi-species savannas, either a higher number of benign browse plants need to be sacrificed or a higher bush density tolerated (Sweet & Mphinyane 1986).

At a high stocking rate there was a marked decline in the desirable perennial grass *Digitaria eriantha*. There was also a reduction in the useful species *Eragrostis rigidior* and an increase in the undesirable annuals *Aristida congesta* and *Tragus racemosus* (Sweet & Mphinyane 1986).

A trial performed at Neudamm (Namibia) towards the end of the 1998/9 rainy season showed that goats preferred woody plants, which constituted 51.2% of the total food in their diet. Grasses dominated the natural vegetation (51.9%), but formed only 29.4% of the goats' diet. Herbs and forbs made out 23.6% of the veld and contributed to 18.7% of the goats' diet. Only 13 of the 16 woody species present in the feeding area were utilised, compared with over 40 herbaceous species taken. The most preferred forage species were the woody plants *Phaeoptilum spinosum* (13.0% of diet), *Acacia mellifera* (10.7%) and *Catophractes alexandri* (8.0%). This trial indicates that Namibia's Highland Savanna is extremely suitable for goat farming. This trial also offers conclusive evidence that Boer goats prefer to utilise woody plants, i.e. browse, even during seasons when actively growing, nutritious green grass is available in abundance (Rothauge et al. 2001).

Teague et al. (1990) state that, after a bush-clearing exercise, it is not possible to prevent *Acacia karroo* from re-establishing itself and increasing again if the methods of burning, resting or good grazing management are applied. This view is supported by Du Toit (1968, 1972) and Trollope (1974).

5.2.1.2 Impact of goats on beef production

The control of problem bush regrowth results in an improvement of grass cover, which can be brought about by using goats (Aucamp 1990). In addition, the total meat production can be increased considerably by introducing browsers to utilise the bush component, while herbivores are concentrated on the grass component. In this respect, the Adelaide Research Station in South Africa found (ibid.) that a combination of Boer goats for browsing and cattle for beef production is almost twice as profitable as beef production alone. In this case, the objective should be to maintain a sound ratio of desirable bush and grass. In general, bush should not be regarded simply as a threat: it could also be exploited as a partner. An important principle, therefore, is not to eradicate bush unless it can be replaced by something better.

The farmer, therefore, has two options:

- Total bush clearing in order to increase grass and meat production, or
- The introduction of a browsing component in combination with cattle farming.

Thus, goats are simultaneously able to control *Acacia karroo* and increase saleable secondary meat production per unit area by browsing in these communities with a minimal adverse effect on grass production, which markedly increases profitability (Aucamp 1976; Aucamp et al. 1983; Stuart-Hill et al. 1987, cited by Teague et al. 1990).

Bester and Reed (1998) strongly support Teague et al.'s (ibid.) finding. Research at the Omatjenne Research Station in Namibia showed that goats could be effectively incorporated into bushveld areas along with cattle, with a 40% increase in beef production. As regards the effect browsing goats have on bush reduction, there was a very clear decline in the density of *Dichrostachys cinerea* (from 500 to 56 per hectare) as well as fodder bush (from 2,047 to 481 per hectare) after a grazing period of 13 years. However, the density of *Acacia mellifera* remained relatively constant over the same period, even at a high stocking rate. It also needs to be borne in mind that a high level of management is needed to keep both goats and cattle.

Goats displayed an interest in mopane trees as a source of food. Goats do not rely on sight alone for selection and possibly perceive mopane's smell as a deterrent. Goats consumed both fresh as well as senescing mopane leaves with the same frequency, although they were more accepting of the latter. Goats are highly selective of food types that have a low fibre content. The senescing mopane leaves which the goats selected most often had the lowest fibre content and also few condensed tannins. The results imply that goats seem able to differentiate between leaf quality in terms of fibre and tannin content (Styles & Skinner 1996). These results are consistent with other findings on goat feeding behaviour (Owen-Smith & Cooper 1987).

Boer goats are well suited to controlling woody plants because the intensity and frequency with which they utilise the browse can be controlled. In addition, they seem to be relatively insensitive to chemical deterrents such as the high tannin levels present in many woody species. However, Boer goats cannot be used to control dense stands of woody plants whose canopies extend above the browse line of approximately 1.5 m (Smit et al. 1999).

Since the goat is primarily a browser, it is supremely suited to the semi-arid and arid savanna rangeland found in Namibia (Rothauge et al. 2001).

5.2.1.3 Browser interaction with fire

Browsers are also found to be effective when used in tandem with fire to control bush thickening (Trollope 1974). When harvesting for charcoal purposes, the subsequent coppice becomes more accessible to most browsers, especially when below 2 m in height. This regrowth can be successfully controlled when it is utilised by browsers (Caughley 1976; Guy 1976; Pellew 1983).

The need for the addition of browsers in combination with fire to control bush encroachment in lower rainfall areas is highlighted by Du Toit (1972), who only recommends burning every 10 to 15 years.

It is concluded at this stage that, in semi-arid savannas, goats can improve the condition of the rangeland for use by cattle. However, the degree to which the bush can be controlled will be determined by the height of intruder species, proportions of the species which are acceptable or unacceptable to goats, and whether or not the species are acceptable to browsers. To use goats as a control measure is not recommended where high bush densities occur, although it is very effective as an aftercare treatment. Furthermore, total production of meat can be substantially increased.

The decision on the number and kind of browsers to be kept needs to be taken with great circumspection. Although the whole plant spectrum can be utilised with a larger variety of game species, often without direct competition to each other (Smit 2002), game species not adapted to the specific environment should be avoided.

5.2.2 Natural die-off

Figure 5.4: Fungi-related (Phoma glomerata) natural die-off on sandy/loamy soil

The natural die-back of bushes and trees had already been observed by the early 1970s. Observations in Namibia showed that bushes and trees were killed on thousands of hectares. It was only during the early 1980s that constructive efforts were made to determine the causes of these mortalities. In close cooperation with the University of Stellenbosch in South Africa, the die-back phenomenon was intensively investigated. All the findings recorded here were published by Holz and Schreuder (1989a,b,c,d,e).

It soon became evident that four organisms (fungi) act in concert to cause mortalities in *Acacia mellifera*. These are *Cytospora chrysosperma, Phoma cava, Phoma eupyrena,* and *Phoma glomerata*. *Phoma cava* and *Phoma glomerata* play a primary and decisive role in the disease complex. *Phoma cava* was aggressive even under relatively high soil-moisture conditions, while *Phoma glomerata* also caused disease symptoms in non-water-stressed plants. An interesting finding was that the organisms caused extensive discolouration in bushes growing in an area which had had normal precipitation during the previous ten years. It seems, therefore, as if die-back does not necessarily follow the die-back:decline pattern, but could continue during years with normal rainfall.

The more important symptoms of the disease include –

- leaf chlorosis
- defoliation
- wig and branch die-back, and
- canker formation.

A black-brown discolouration that might extend into the pitch occurs around and underneath some thorns from which the petioles have dropped. The most conspicuous symptom is an internal green-yellow to black-green discolouration and decay of wood at the base of the trunk and the upper tap root. The heartwood and parts of the sapwood start to decay and, in some plants, a hollow-base condition develops with only a small portion of the xylem being functional. Infection at the base of the trunk or upper tap root causes a gradual cut-off of water and nutrient supply to the crown.

During the experimental phase in Holz and Schreuder's (ibid.) research, the plants were successfully inoculated with the specific fungi mentioned above.

As a follow-up on Holz and Schreuder's (ibid.) work, the Council for Industrial and Scientific Research (CSIR) in Pretoria, South Africa, was approached to investigate the possibility of employing pathogenic fungi on *Acacia mellifera*. Based on the findings of the CSIR (1998) it was concluded that it would be difficult to develop a control method based on fungal products. The main difficulty with developing a novel herbicide based on a fungus is having to isolate and identify the active ingredient.

5.2.3 Natural enemies

Prosopis invasion already occurs over large areas of central and southern Namibia (100,000 ha), chiefly along the main drainage systems. Today, *Prosopis* trees and *Prosopis* invasion have already been observed outside the drainage systems (Smit 2002). Biological control seems to be one of the viable options to control and eradicate this alien plant.

Plants very often become invasive when they are introduced to a new region or country without any of their natural enemies. The alien plants gain a competitive advantage over the indigenous vegetation because the latter have their own natural enemies that feed on them and cause them to develop diseases. Biological control, therefore, is an attempt to introduce the alien plant's natural enemies to its new habitat, on the assumption that such natural enemies will remove the plant's competitive advantage until its vigour is reduced to that of natural vegetation.

Natural enemies that are used for biological control are called biological control (bio-control) agents. These agents attack specific plant organs such as the vegetative parts (leaves, stems or roots) or reproductive parts (flowers, fruits or seeds) (Klein 2002).

Furthermore, as Klein (ibid.) points out, –

> [t]he purpose is to eradicate the trees by means of bio-control agents that will damage the vegetative part as well as agents that reduce seed production. The pods of *Prosopis* trees are, however, utilized by farmers as a valuable fodder, resulting in a conflict of interests between those who want to eradicate them and those who are utilizing [them]. Any future strategy must bear this in mind. This conflict is usually resolved by using seed-reducing bio-agents only. Consequently the reproductive potential and the dispersal of the plant are reduced. This will allow the continued utilization of the plants. In such circumstances it is important to use a bio-agent which will not attack the flowers in order to allow for the production of seed for consumption by animals. In such cases seed-feeding agents are used that will prevent germination from animal droppings without significantly reducing the nutritional value of the pods.
>
> Two beetle species were introduced from Arizona, USA. *Algarobius prosopis* was released in South Africa in 1987 and *Neltumius arizonensis* in 1993.

Source: *Klein (2002)*

Figure 5.5: An adult specimen Algarobius prosopis

Source: *Klein (2002)*

Figure 5.6: An adult specimen Neltumius arizonensis

> *Neltumius arizonensis* was imported to supplement *Algarobius prosopis*, because it had been reported that *Neltumius arizonensis* laid its eggs on younger pods than those utilized by *Algarobius prosopis*. It was hoped that this beetle would damage most of the seeds before the pods dropped from the trees and became available to livestock. Contrary to expectations, *Neltumius arizonensis* does not lay its eggs on young pods, and it faces the same problem as *Algarobius prosopis* in that livestock normally ingest the pods before the beetle larvae have a chance to neutralize the seeds.

Source: *Klein (2002)*

Figure 5.7: Undamaged Prosopis *pods (bottom) and pods with escape holes, indicating where adult beetles have emerged (top)*

Source: *Klein (2002)*

Figure 5.8: Larvae of the seed beetles developing inside Prosopis *seeds*

The adult beetles of both species are active and readily fly, with the ability to cover long distances. Adult females live for several weeks. The females of *Algarobius prosopis* can each lay up to 300 eggs, while those of *Neltumius arizonensis* lay about 70 eggs on average. The eggs are colourless, flattened and oval, about 1 to 2 mm long, and are laid on *Prosopis* pods.

The two beetle species differ from one another concerning their oviposition (egg-laying) behaviour. Algarobius deposits its eggs in clusters in cracks on mature *Prosopis* pods or in old emergence holes of adult beetles. *Algarobius Prosopis* almost invariably only oviposits on pods that are fully ripened, and the eggs are attached in place with one or two adhesive strands. In contrast, the *Neltumius arizonensis* females are meticulous about where and how they lay their eggs. Each egg is deposited on the swollen area around a seed of a mature *Prosopis* pod, but never on a seed that is already occupied by an egg of either *Neltumius arizonensis* or *Algarobius Prosopis*, if free seeds are available. Unlike *Algarobius prosopis*, eggs are usually laid on undamaged pods and each egg is carefully cemented onto the surface of the pod.

After a few days tiny, cream-coloured grubs or larvae hatch from the eggs. Those of *Algarobius prosopis* have well-developed legs and crawl around on, or burrow through, the pod until they find an undamaged seed; they then chew their way into the seed. The grubs of *Neltumius arizonensis* have no legs and they burrow downwards through the eggshell and pod wall, directly into the underlying seed. While chewing through the plant material, the grubs of both species push the discarded material (frass) back into the empty eggshell, which then changes its appearance from almost transparent to white as it is filled up with frass. Once inside a seed, the larva feeds on the contents of the seed, including the embryo, while it matures over a period of a few weeks. The larva moults (sheds its skin) three times during its development. If more than one larva enters the same seed, one larva will kill the others, and normally only one larva develops per seed.

After several weeks, when the larva has reached maturity, it tunnels up to the surface of the pod where it leaves a circular, weakened “trapdoor”, which can be pushed out by the newly emerged adult. The larva then returns to the hollowed-out seed and pupates. After a few days, an adult beetle emerges from the pupa and escapes through the trapdoor.

The beetles continue breeding throughout the year, and complete several generations per year. The larvae of *Algarobius prosopis* develop slightly faster than those of *Neltumius arizonensis*. Growth rates of both species are dependent on ambient temperatures so the development times are most rapid in summer.

How to tell whether the prosopis seed beetles are present

Round exit holes are visible on the pods, indicating where adult beetles have emerged. It is impossible to distinguish the two beetle species by the exit holes alone. Usually, white eggshells are easily distinguishable on the surface of the pods when *Neltumius arizonensis* is active in an area, whereas the eggs of *Algarobius prosopis* are sheltered and therefore not easy to find.

5.2.3.1 Seed beetle damage to *Prosopis*

The larvae of both species destroy the seed embryos and prevent the seeds from germinating. The pods remain nutritious to livestock in spite of the beetle damage and can still be used to provide stock feed. The seed beetles will not control the standing infestations of *Prosopis*, but only reduce the number of seeds that are added to the seed bank in the soil. The seeds in the existing soil seed bank are very long-lived, however, and the effectiveness of the seed beetles will not be noticeable until this seed bank is exhausted (Klein 2002). After the initial introduction to only ten landholders during the 1980s, the spread of the beetles was rapid and almost all stands of *Prosopis* in Namibia are now affected (Smit 2002).

Despite this, levels of damage are often minimal because livestock and game ingest most seeds soon after the pods fall to the ground (in January/February) and before the larvae are able to fully colonise the pods. The larvae cannot survive in the digestive system of livestock. As a result, most seeds escape beetle damage unless infestations of *Prosopis* are fenced off to exclude livestock while the beetles are active. In fenced areas, beetles destroy up to 90% of seed embryos within eight months of the pods dropping to the ground.

Neltumius can account for more than half of the damaged seeds but usually destroys a smaller proportion of seeds than *Algarobius*. When both beetle species are present, *Algarobius* seems to compete more successfully than *Neltumius*, because the former species lays more eggs and its larvae develop faster. *Neltumius* avoids competition, however, by ensuring that its eggs are not laid near other eggs of its own species or those of *Algarobius* (Klein 2002).

Beetles that attack the flowers of *Prosopis* are also currently under investigation. If introduced successfully, it means that trees will not be able to produce seeds. In addition, if young seedlings are properly destroyed, further infestation is not possible.

The use of bio-control has certain definite advantages:

- It is environmentally friendly because it causes no pollution and affects only target (invasive) plants.
- It is self-perpetuating and, therefore, permanent.
- It is cost-effective, and
- It does not disturb the soil or create vacuums where other invaders could establish.

Beetles can only attack the seeds when the pods are ripe, which implies a waiting period of several months before the larvae are able to fully colonise the pods. When the pods are left under the trees for this purpose the many other *Prosopis* eaters and running water may be allowed to spread the seeds extensively during this period. When the pods are gathered and stored, infection by the beetles can be as high as 99%. The depressing fact is that the remaining 1% gives sufficient grounds for concern: *Prosopis* has the ability to produce between 25,000 and 30,000 seeds per kilogram of pods, which means that between 250 and 300 seeds per kilogram are unaffected by the beetles (Smit 2002).

Policies and legislation will have to be developed in this regard, in close cooperation with the stakeholders.

5.2.4 Fire

5.2.4.1 Controlled veld fires: Fire as a management tool

According to Brown and Davies (1973), Luke and McArthur (1978) and Trollope (1999), there are three different types of fire:

- **Crown fires:** They burn in the canopies of trees and are not commonly encountered.
- **Surface fires:** Here, surface fuels are burnt, including grass, small shrubs, seedlings, fallen leaves, twigs and bark. This is the most common type of fire in southern Africa.
- **Ground fires:** These fires burn below the surface of the ground in deep layers of organic material. They occur very seldom.

In grasslands and savannas, surface fires normally burn as head or back fires. Trollope (1978a) found that grass regrowth is significantly depressed by back fires in comparison with head fires. This is because back fires move much more slowly and cause longer periods during which temperatures remain above the threshold of 95°C.

Fire generally has an adverse effect on trees and shrubs, particularly those which do not coppice from the base of the stem when a top-kill of stems and branches occurs. However, there is great variation in the susceptibility of trees and shrubs to fire because it depends on various factors, as detailed below.

(a) The intensity of the fire

The hotter the fire, the more adverse its affect on trees and shrubs. Trollope (1974) has shown that bush encroachment can be controlled through the use of intense fires because they allow trees and shrubs to be maintained at an available height and in an acceptable state for browsers.

In the Eastern Thornveld, South Africa, fire intensity had no effect on the recovery of grass after a burn. Conversely, it had a marked effect on the top-kill of bushes to a height of 2 m. These results clearly show that stems and branches of bush species are very resistant to top-kill when they are taller than 2 m.

The mortality of trees and shrubs was relatively low and the majority of the bush coppiced from the base of the stem (Trollope & Tainton 1986).

Similarly, Sweet and Mphinyane (1986) indicated a complete top-kill of almost all woody plants up to 2 m in height, but 99% of these exhibited basal coppice while Bester (1996) states that fire only kills between 15% and 25% of bush and is responsible for dense coppice thereafter. Fire can, however, retard their growth rate, change the height strata, and suppress the establishment of saplings.

For this reason fire is best used as a preventative rather than curative measure against bush thickening. A minimum of 1,500 kg grass per hectare is needed to ensure an effective burn under Namibian conditions (Bester 1985b).

Data obtained by Trollope and Tainton (1986) and Trollope et al. (1990) show that the mixed bush of the Kruger National Park in South Africa is more susceptible to fires of equivalent intensity than the predominantly *Acacia karroo* savanna of the Eastern Cape. In both areas top-kill increased as fire intensity increased, and individuals became more tolerant of fire as their height increased.

(b) The ability of the plant to coppice

Coppicing species are more resistant to fire than non-coppicing species.

Figure 5.9: Regrowth from coppicing buds by Acacia mellifera *(left) and* Dichrostachys cinerea *(right) after a veld fire*

The effect of the fire on *Acacia karroo* bushes with different basal stem diameters is as follows:

- Firstly, bushes with a small basal stem diameter were more susceptible to a top-kill of stems and branches than bushes with thicker stems.
- Secondly, bushes with a basal stem diameter of up to 6 cm were very susceptible, but thereafter, as the diameter increased, resistance to the damaging effects of fire increased. This is undoubtedly because an increase in stem diameter means the outer layer of dead bark becomes thicker, thus providing a more effective layer of insulation around the vulnerable phloem, cambium and xylem cells of the inner portion of the stem.

The other clear trend is that, although only a small proportion of the *Acacia karroo* bushes were killed by the fire, they became more susceptible to total kill as the basal stem diameter increased (Trollope 1974).

(c) The age of the plant

Mature trees and shrubs are more resistant than young plants because they have better-insulated bark.

(d) The type of bark around the stem

Plants with thick, woody bark are very resistant to fire. This is because dead wood and the air spaces permeating the bark are poor conductors of heat and, therefore, provide protection to the phloem, cambium and xylem regions of the stem. Of course, the converse holds for thin, fleshy bark. Examples of trees with very fire-resistant bark are *Cussonia spicata* (umisenge, or Common cabbage tree, according to Van Wyk & Van Wyk 1997) and *Acacia sieberiana* (Paperbark thorn).

(e) The frequency of the fire

Results from experiments show that, as a general rule, frequent burning promotes the development of grassland in wooded regions, particularly in high-rainfall areas. This is because grass is very resistant to fire as a result of its tillering ability. Burning also promotes grassland by preventing the accumulation of excess litter and the resultant development of moribund conditions. This is of particular significance in the high-rainfall areas, e.g. Caprivi, where there tends to be a rapid build-up of excessive litter because the grass is generally more productive and becomes unpalatable to livestock as the plants reach maturity.

The greater the frequency of fire, the more adversely the trees and shrubs are affected. The frequency of burning depends on annual rainfall because of its influence on the accumulation of inflammable material. The greater the annual rainfall, the more rapid the accumulation of inflammable material and, therefore, the greater the frequency of burning. Consequently, fire has a greater suppressing effect on trees and shrubs in high-rainfall areas than in arid regions.

The amount of fuel available is critical, according to Trollope and Potgieter (1985), who found that a fire will not spread readily if the fuel load is less than 2,000 kg per hectare. This was confirmed by Du Plessis' (1997) field observations and measurements in Etosha.

Veld fires are not regarded as an effective means in reducing the number of woody plants (Strohbach1999b),as –

- undesired trees and shrubs do not die from fire, and often regrow strongly
- a suitably high fuel load is not always available, and
- grazing management is often in conflict with the use of fires.

High levels of moribundness and necromass in the grass layer lower the productivity of palatable grass species to grazers, and will eventually result in a decrease in the density of grass tufts (Scholes & Walker 1993; cited by Du Plessis 1997). In the Kruger National Park in South Africa, for example, Trollope et al. (1996) indicated that grass only becomes moribund at a fuel load of approximately 4,000 kg per hectare, which is the stage that veld should be considered for burning in order to maintain the vigour of the grass sward. However, in Namibia's Etosha National Park, grass – especially perennial species – may become moribund at fuel loads that are lower than 2,000 kg per hectare. In an arid environment like Etosha's, where the decomposing process is much slower than in areas with higher rainfall, annual and perennial standing dry grass becomes moribund if an area receives rain, but was not highly utilised before the rain (Du Plessis 1997).

After 22 years of annual and biennial burning, Sweet (1982) found an almost 40% reduction in bush density as compared with less frequent burning of between three and five years in the arid savanna of Botswana. Quan et al. (1994) concluded that fire destroys seedlings and saplings, but rarely kills mature trees. Therefore, the medium-term effect of burning is not to reduce the number of trees or bushes, but to suppress the establishment of young trees. Thus, fire helps to suppress bush encroachment, but it will not solve the problem once bush has become established. Veld fires may be used to modify the structure of the woody layer and it is for this purpose that they are most useful (Smit 2002). To be effective, burns need to be hot (>2,000 kJ per second per metre, a temperature which can be achieved with a fuel load of 2,000 to 4,000 kg dry matter per hectare) and occur every three to four years in wetter areas. In dry savannas, however, it is clear that farmers cannot afford to burn their veld at such intervals. In these cases, burning is recommended to be undertaken opportunistically, depending on rainfall and the presence of small woody plants that need to be controlled (Smit 2002; Trollope 1980).

The total exclusion of fire or, conversely, the frequent occurrence of fire under conditions different from the above-mentioned fire regime may benefit the establishment of woody plants (Smit et al. 1999).

An aspect, however, that needs to be investigated is the time from burning until the plant produces seed again. This information will serve as an important additional guideline for the frequency of burning, which in turn impacts on the frequency of seed production.

(f) *Season of burning*

Burning in late spring and early summer, after active growth has commenced, causes severe damage to the grass cover. The ideal burning period is through the late winter (August–September) while the grasses are still dormant. The correct time for burning, therefore, is just prior to the commencement of growth in the grass at the start of the growing season. This avoids the plants having to draw on plant reserves twice to produce new growth and, therefore, maintains the vigour of the sward (Trollope 1999).

(g) *Environmental conditions at the time of the fire*

Factors that influence the intensity of a fire are the quantity of inflammable material, relative humidity, temperature of the air, and wind velocity. The amount of inflammable material has already been discussed (see point (e) above in this section); suffice it to say, therefore, that an adequate amount needs to be present for the required fire intensity. Experience gained at the University of Fort Hare in South Africa indicates that the following values for the other variables are required to obtain a high-intensity and clean burn:

- Relative humidity must be low: <50%.
- Air temperature: above 25°C.
- Wind velocity: 10–20 km per hour; burn with the wind.

Experience has also shown that the appropriate relative humidity and temperature conditions exist between approximately 11:00 and 15:30. Burning at wind velocities of greater than 20 km per hour is dangerous and should be avoided (Trollope 1999).

A high-intensity fire of more than 2,000 kJ per second per metre can be achieved with a fuel load of 2,000–4,000 kg of dry matter per hectare (Trollope 1980).

(h) *Fire–herbivory interaction*

Trollope (1999) states that goat browsing has been used in conjunction with opportunistic fires following seasons with above-average rainfall, to convert dense stands of bush to open savanna in semi-arid regions. He (ibid.) concluded that fire and browsing can have a significant impact on the physiognomy of bush in savanna areas.

Burning cannot be used to eradicate bush but can be used to assist in bush control, especially in aftercare programmes.

Concerns are very often expressed regarding the impact of fire on soil properties. The research findings of Trollope (n.d.) are briefly reflected here:

(a) Soil organic matter

Contrary to expectations, burning has not been found to decrease the organic matter of the soil, although it reduced litter.

(b) Soil chemical content

This aspect of burning is not very clear. American workers, for example, claim that the ash deposited by a fire has more available phosphorus, calcium and magnesium, and that soil is generally improved chemically by burning. Singh et al. (1991) also established that grazing and burning increased inorganic nitrogen, bicarbonate-extractable inorganic phosphorus, and microbial carbon.

Conversely, research in South Africa has shown that after six years of burning grassland, there was no change in soil pH and amounts of soluble salts, and only a slight loss of nitrogen (West 1965). It would appear, therefore, that – in South Africa at least – burning does not have any significant effect on the chemical content of soil in grassland areas.

Soil temperatures are not greatly affected by fires. An experiment in the USA showed that soil temperature only reached 123°C at a depth of 6 mm (ibid.). This is because soil is a very poor conductor of heat. Conversely, air temperatures can be as high as 1,000°C during a fire (ibid.).

Frequent burning has little direct effect on the soil. Most effects are indirect and result from changes in the vegetation. Such effects include reduced organic matter and nitrogen, and slightly increased phosphorus. Burning may speed up the rate of nutrient cycling, but nitrogen, carbon and sulphur are lost through volatilisation as smoke and ash. The importance of these losses has not yet been determined (Teague & Smit 1992). As regards the effect of grassland fires on the soil, Cook (1939; as cited by Donaldson 1969:22) found that although the fire reached a temperature of 600°C, it caused little rise in soil temperature – even at a depth of only 0.2 inches (0.5 cm).

5.2.4.2 Fire-girdling

Fire-girdling – or *stem-burning*, as it is also known – is an effective bush control method, but the process is very labour-intensive and relatively slow. Fire-girdling also presents an alternative to the use of veld fires. In this process, a fire is made at the base of the tree, using wood, cattle dung or rubber from tubes as fuel. The burning of the stem base of a bush or tree for a sufficient time will kill it.

The technique is relatively safe if applied when grass has been removed. The cost per hectare is also perceived to be less than many of the other methods available. Nonetheless, the use of fire-girdling seems to be quite uncommon: less than 5% of the respondents in the current study appeared to apply this method to combat bush encroachment (SSNCE 1999).

Donaldson (1969) described an apparatus to fire-girdle stems with butane (liquefied petroleum gas/LPG) as fuel. He had considerable success with this apparatus, provided the stems were burned for at least three minutes.

Donaldson's (ibid.) view with the minimum burn-time of three minutes can be explained by the anatomy of the stem, and the function of the various tissues in the stem. Without such apparatus, e.g. when ordinary wood is used for this purpose, a burning period of at least 10 minutes will be needed. For bigger trees more time is needed, but the crucial issue here is that the bark needs to be properly damaged for it to kill the bush or tree (Strohbach, pers. comm.).

Very little difference was observed between the effects of the various heights of fire-girdling. The two plants which were killed were fire-girdled 5 cm (treated during October 1991) and 20 cm (treated during March 1992) above ground levels. From this evidence it can be deduced that the lower treatment heights are more effective in killing the trees (Strohbach 1999a).

A drop in the amount of coppicing was observed in all trees treated during the rainy season. The coppicing rate was reduced in shrubs treated before the start of the rainy season (around the end of November), and the effect on the amount of coppice was reduced dramatically by the middle of the rainy season (as from March) (Strohbach 1999a).

This earlier sensitivity to treatment can be attributed to the phenology of the trees. Flushing starts as early as October, whereas the other species start at the beginning of the rainy season. This flushing depletes nutrient levels in the roots, making the trees sensitive to felling or fire-girdling treatments. The nutrients seem to be replenished as early as March in a process probably similar to translocation, as described by Tainton (1981) for grasses.

In general it was shown that fire-girdling, as with felling, is most effective if done as near to ground level as possible. In addition, evidence obtained from the trial with *Terminalia sericea* suggests that the active growth period, rather than the rainy season, is the period during which trees are most susceptible to damage by fire and/or felling (Trollope & Tainton 1986).

These findings are supported by Strohbach (1999b) who investigated five encroaching species (*Acacia mellifera, Acacia nilotica, Dichrostachys cinerea, Terminalia prunioides* and T*erminalia sericea*). They were fire-girdled at various heights and during various seasons. The regrowth was lowest and the mortality rate the highest for trees fire-girdled during the rainy season, i.e. between January and April. As mentioned previously, for fire-girdling to be effective, it should be done as near to ground level as possible, and a minimum duration and intensity of fire should be achieved. Post fire-girdling treatments, especially with browsers, are suggested as well, as coppicing does occur.

Fire-girdling of *Acacia mellifera* trees at ground level is very effective. With *Dichrostachys cinerea*, however, the mortality is extremely low after treatment.

From fire-girdling of *Acacia nilotica* at various heights it was shown that burning the stem at 5 cm above the ground results in the highest percentage mortality and the least coppicing. Treatments during the rainy season also result in low amounts of coppice and high mortality. The same results were obtained for *Terminalia prunioides*.

Evidence obtained from the trial with *Terminalia sericea* suggests that the active growth period, rather than the rainy season, is the one during which trees are most susceptible to damage by fire and/or felling.

As cambial bridging was observed on several occasions, the necessity of a minimum time span of fire-girdling to effectively destroy the cambium was again demonstrated. Donaldson (1969) has already described this phenomenon, explaining the ineffectiveness of veld fires in destroying encroaching woody species. In most cases, he maintained (ibid.), the available fuel at the stem base is insufficient to support a prolonged hot fire as very little grass is available underneath a tree/shrub canopy to add to the fuel load.

Donaldson (ibid.) also found that 75% of root kills could be achieved by setting fire to packed wood around and between the stems of standing or stumped Black thorn plants.

Donaldson (1969) tested flameless smouldering fires (using fine kraal manure and sawdust) and hot-flame fires (packing dry grass, twigs and maize stalks) as a means of combating bush. The smouldering fires were obtained by spreading fine kraal manure or sawdust around the base of the plant and lighting it. The hot-flame fires were obtained by packing the dry fuel materials around the base of the plant and setting fire to them.

The data revealed that while the dung and sawdust fires produced almost 100% plant mortality, the hot-flame fires were less effective. Although the hot-flame fires produced excellent kills of the aerial parts of the shrubs, a mass of coppice shoots soon developed from the crowns of the plants. It was found that the majority of the Black thorn plants which were killed by the hot-flame fires were relatively old and mature plants. This is in agreement with the generally accepted fact that dormant coppice buds tend to degenerate with the aging of the plant.

Another important observation by Donaldson (1969) was that hot-flame fires do in fact kill the top growth of the plant. This reduces the plant to a near juvenile stage of growth, resulting in its inability to flower and produce seeds for a number of years. This provides the opportunity to prevent plants from producing seeds over the long term. Unfortunately, however, no data could be found to indicate how long it takes for different species to produce seeds after a seedling has established itself or after a plant has undergone top-kill. It is important for further research to be done in this regard.

The use of cattle manure to build a fire around the bush/tree trunk is an economical and efficient method, using slack capacity of farm labour or otherwise unemployed women living on these farms for this purpose. However, the process is very slow and cumbersome and will not make as meaningful a difference to the bush encroachment problem (Aigams Professional Services 1997a).

5.3 Mechanical control

5.3.1 Stumping/felling

The manual removal of bush is a more labour-intensive way to combat bush encroachment and, therefore, has the potential to create many employment opportunities.

Stumping, also known as *felling*, entails removing bush above-ground by using axes, mattocks, handsaws, or chainsaws, or below-ground by using mattocks and axes. However, the height at which a tree or bush is cut is crucial: most species will show regrowth when they are cut above ground level (Dahl & Nepembe 2001).

The Stewart Scott Namibia Consulting Engineers' (SSNCE 1999) survey indicates that more than 35% of the respondent farmers who performed bush clearing used manual techniques.

Where tree densities are very high, and should increased herbaceous production be desired, the first operation that may be required will be to thin the trees to some predetermined density. This should be followed by a post-thinning management programme to keep an area open. Thinning (selective clearing of trees) or clearing (total clearing of trees) by means of mechanical or chemical methods will result in immediate changes in competition between woody and herbaceous plants (Smit et al. 1999).

Stumping by means of a tractor-operated saw mounted on the rear of the tractor had to be abolished mainly because of the practical difficulties encountered in sawing Black thorn plants. The revolving saw also appeared to be highly dangerous.

As Donaldson's (1969) research in the Molopo showed, while a Holt machine succeeded in flattening the relatively large Black thorn plants, it was less successful in doing so to the thinner-stemmed plants of this and other species. Vigorous coppice shoots soon developed from the crowns of the flattened plants and from the stems and crowns of partially damaged plants – irrespective of species. The machine did, however, offer the advantage of "opening up" dense and impenetrable thickets of woody plants (at an approximate rate of approximately 0.9 hectares per hour) which subsequently could be dealt with by various follow-up treatments. These follow-up treatments, however, raised the cost of bush clearing in the ranching area of the Molopo to uneconomical levels. During the three seasons (of which the latter two were exceptionally dry) following this treatment, a very poor establishment of natural grasses took place. The "basin-listing" effect of the Holt machine was of no advantage when used on the sandy soils of the Molopo area. There were firm indications that the machine did considerable harm by destroying the established perennial grass plants, thereby exposing the area to the invasion and colonisation of pioneer plants. On the other hand, there was as much as 3 feet (900 mm) of regrowth from the woody plants. Burning as a follow-up treatment was not practical due to the sparseness of the grass cover. Efforts to establish *Cenchrus, Digitaria, Eragrostis* and *Panicum* seedlings prior to and after "holting" were a failure. At that stage (1969), very few seedlings of woody plants had been observed. The relatively dry seasons in which these trials were conducted must also have played a major role in the non-establishment of grass and woody plant seedlings.

For *Colophospermum mopane* densities of 2,500 to 3,000 bushes per hectare, a harvesting strategy of 25% by means of hand felling is proposed to ensure best sustainable yields on a five-year rotation. This means harvesting every fourth tree with a circumference greater than 13 cm every five years on a specific hectare. The best available leaf biomass per hectare was attained after harvesting between 25% and 50% of the trees. Leaf biomass and flower and seed production increased after harvesting, especially in areas with lower densities (80% harvested) because of lower inter-species competition (Cunningham 1996). He (ibid.) further concluded that the best season to harvest mopane is winter, when the palatability of mature leaves is at its lowest. Months suited to harvesting *Colophospermum mopane* are April–September, with the best months being May, June, July and August. Harvesting should be avoided during spring when the palatable new leaf flush provides a very important source of food for browsers.

The manual control of bush is twofold:

(i) Where bushes are cut above the surface for bush-clearing purposes or harvested for firewood or charcoal production

Above-ground cutting was practised on a large number of farms. Because of the coppicing ability of most problem species, regrowth occurred in at least 90% of the plants. For *Dichrostachys cinerea*, 100% regrowth can be expected. Within five to seven years, these camps are covered with bush to an even greater extent. Follow-up treatment with chemicals or burning will be indispensable – which automatically pushes up the costs considerably. From practical experience it is only those plants whose coppicing buds have already degenerated that die off. A further observation is that the time of year when bushes are cut also plays an important role. Some farmers claim that *Acacia mellifera* bushes will die in large numbers if cut during mid-winter. The effect of this treatment during autumn (before the reserves have been translocated to the roots) and after flushing during spring (when reserves have been used for flushing) needs further investigation.

Terminalia prunioides has a very poor coppicing ability. A stump which has been cut down at a height of 1 m will form some 10-cm-long sprouts with a dense leaf mass, but will never produce long, strong branches. Such a stump will eventually die. *Terminalia prunioides* shrubs were seldom seen, meaning that regeneration is low (Strohbach 2000).

Plants which use stored carbohydrates to produce new growth are most sensitive to defoliation after their first growth flush (Menke & Trlica 1981). Based on the phenological data *Acacia caffra*, *Acacia karroo, Acacia luederitzii* and *Acacia mellifera* would be most sensitive to defoliation in October, whilst the remaining species would be sensitive in November. This hypothesis has implications for management of browse species and mechanical control of bush encroachment (Milton 1987).

Chemical control of *Acacia mellifera* is most effective in March (Van Niekerk & Kotze 1977). As poisoning depends on translocation of photosynthate to the roots, the most effective season for chemical control of a species could probably be predicted from leaf-fall data (Milton 1987).

When harvested for the production of firewood or charcoal, the smaller bushes cannot be harvested in an economically viable way and they are, therefore, usually left untouched. This method poses an enormous threat because the more effective competitors for available moisture are removed and the smaller ones will fill the vacuum so created. As was mentioned previously, goats can also be introduced to utilise the regrowth; such a practice, combined with grazers, can increase production and income considerably. Where the necessary infrastructure is available and management skills are in place, game (browsers) will certainly be a good alternative to goats.

When harvesting firewood with three chainsaws, 6 workers are able to clear 80 mature trees per hectare within 2 hours, or 240 trees every 6 hours. The average amount of wood harvested from 80 trees is 3 tonnes. The longer-term average per saw (2 workers) is 22 ha per month (Honsbein, pers. comm.).

On the Stolzenfels Farm in the Windhoek district, *Acacia mellifera* twigs and branches were used to produce fodder. All the young bushes on the farm were targeted. Twigs with a diameter of less than 2.5–3 cm were cut and milled with a hammer mill, while the stems of the remaining plants were treated with Tordon 155. This exercise required 7 workers to produce 44 x 35 kg bags of fodder per day.

(ii) Where bushes are removed 10 cm or more below the soil surface

Except for *Dichrostachys cinerea*, most of the invader species will not show any regrowth if this method is used to control them. Despite its high degree of success, this method is very slow, and aftercare to address reinfestation is essential.

In the case of *Prosopis*, the coppicing buds are situated well below the surface and care needs to be taken to cut stems below this area. If they are cut above this level the wound/cut area as well as the bark around the stem needs to be wet thoroughly with a recommended chemical. Even if a small area is not treated the tree will coppice again.

Figure 5.10: An illustration of bush regrowth when wrong felling methods are applied

With this in mind a farmer has various options, depending on his final objective:

- If farmers want to make a living out of producing charcoal or firewood, they can use any of the manual harvesting methods described above. As was mentioned, the vast majority of the plants will coppice and the same area could be harvested after 10 or 15 years. In this case, the objective is sustainable harvesting and veld reclamation is not relevant.
- If the objective is to restore the rangeland to its original state, then the income derived from harvesting should be used for aftercare treatments. Looking at the present net profit from charcoal production this option seems to be viable.

Considering the large number of unemployed people in the country the two options mentioned above certainly deserve to be taken into account in any future management strategy.

5.3.2 Bulldozing

The mechanical removal of bush by means of a bulldozer is a relatively fast way to combat bush encroachment, but it can cause serious problems afterwards if the topsoil is disturbed too much. The capital cost for the equipment is very high and, therefore, was judged as not affordable for most individual farmers (NAU 2001). Although the alternatives are either to hire the equipment or to contract someone to carry out the work, the mechanical method is still too expensive for land reclamation purposes. As Stewart Scott Namibia Consulting Engineers (SSNCE 1999) indicated, less than 5% of a sample of farmers studied applied this method.

A D6 caterpillar tractor fitted with a bulldozer blade was used to clear moderately dense stands of Black thorn and other woody plants. The cleared areas were prepared for the cultivation of fodder and cash crops. The object of these initial trials was to determine whether the practice of clearing, ploughing and growing of cash or fodder crops for a number of years, before allowing it to revert to veld, would be economically viable. The average income obtained from various cash and fodder crops in these trials during two abnormally dry seasons covered the production costs of the crops, but failed to cover the cost of clearing the land (Donaldson 1969).

According to Zapke (1986) debushing by means of a bulldozer is too expensive for reclaiming veld. This method has the following additional disadvantages:

- The soil surface is disturbed to a very large extent.
- It therefore serves as a seed bed for most of the problem species in a specific area. *Dichrostachys cinerea* establishment in particular is very much favoured, and
- Within five to six years the debushed area will be reinfested, with even higher densities than before.

The only viable application for this method is to clear land for crop production, but it should be discouraged for bush control purposes. Furthermore, mechanical clearing alone results in virtually no mortality and should be followed by chemical treatment (Scholes 1990).

5.4 Conclusions

5.4.1 General

As proposed by Smit et al. (1999), the following options are available to the farmer as regards debushing:

> Before any woody plant control programme is embarked on, the two alternative approaches to the problem of increasing tree density in savanna areas need to be thoroughly assessed.
>
> One approach is to adapt the livestock system to the existing vegetation and so, where tree densities are high and the woody plants are palatable, browsers should form an important component of the livestock system.
>
> The second approach is one of modifying the vegetation to suit a particular livestock system (and particularly a system based on grazing animals). Here it is important to note that the establishment of woody plants is normally a continuing process in savanna areas and so control cannot be achieved with single thinning operations. Planning and implementation therefore needs to be ongoing.
>
> Where this option is adopted in areas of high tree density, the first operation should be the often drastic one of thinning down to some predetermined density, after which a post-thinning management programme will be needed to keep the area open
>
> In making any decision on the most appropriate procedures to use, two important conditions need to be met:
> (i) ecological responsibility, and
> (ii) economic viability.

In support of the above guidelines the following principles should be adhered to:

- No bush-clearing programme will be successful in the long run if sound rangeland management practices are not applied. The latter should be a prerequisite in any aftercare programme. Considering the average size of commercial farms in Namibia and the fact that the management of cleared areas requires constant attention, it is recommended that not more than 10% of a farm/farming area be cleared in any specific year.
- Biological methods are more suitable in aftercare than for initial clearing purposes.
- As part of a general long-term strategy, one of the objectives should be to deplete the seed content of the soil pertaining to intruder bush and to prevent further seed production.
- In the national interest, labour-intensive methods should be pursued.
- The long-term loss of soil nutrients following total bush clearing, specifically on sandy soils, should receive serious consideration. Complete clearing should, therefore, be avoided.
- Bush densities of 2,000 and more per hectare cannot be controlled by resting, burning and good range management alone: external inputs are essential.
- There is a need to do more research on biological control since most of the research results quoted here were obtained from short-term trials carried out on small areas. On-farm research offers a huge opportunity where the research results will reflect the practical value of different methods in biophysical and economic terms.

5.4.2 Chemical treatment

The use of chemicals is recommended –

- when the woody component is so dense that other methods are too expensive or impractical
- where a majority of the trees have grown out beyond the reach of browsing animals
- where the tree density is such that animal access is severely restricted
- where the woody component is largely unpalatable, and
- where, for a variety of reasons, it is not practical to incorporate browsers in the livestock system.

The following conclusions are also important:

- The cost of chemical application is very high. Supplementary income-generating activities from problem bush should be pursued to break even as soon as possible.
- Since not all herbicides are selective, care needs to be taken that desired fodder bushes and trees are not affected.
- Aftercare programmes are indispensable. If they are neglected, it could lead to even worse problems.
- According to the EIA carried out by Joubert (2003), the herbicides in themselves do not seem to pose any environmental or health risk. However, this claim should be subjected to further research.
- A sound ratio of desired trees, bushes shrubs and grass should be aimed at in order to maintain the productive state of the farm/land. The principle of thinning should be adhered to.

5.4.3 Biological

- Goats, at high stocking rates, can be successfully introduced to reduce bush density to acceptable levels. However, the viability of keeping goats at the required stocking rate on a commercial farm of several thousand hectares is doubtful. Since palatable fodder bushes and grasses are eradicated at these high stocking rates, special care needs to be taken to avoid damage to these bushes and grass species.
- Goats should rather be incorporated in aftercare programmes to control regrowth. Combining goats with cattle will result in considerably higher meat production and income.
- Fire is best used as a preventative rather than a curative measure against bush thickening. A minimum of 1,500 to 2,000 kg of grass per hectare is needed to ensure an effective burn. Where high bush densities occur, there will not be enough fuel to ensure a high-intensity burn. Controlled fires can be applied successfully in aftercare programmes.
- Regrowth and reinfestation can be controlled by using intense fires and browsers in tandem; at the same time, bushes and shrubs will be maintained at a height that is available to and in an acceptable state for browsers.
- In arid savannas, fire will result in a top-kill for most plants up to 2 m in height, but more than 90% of them will coppice again. Veld fires are not regarded as an effective means in reducing the number of woody plants, therefore.
- Stem-burning of *Acacia mellifera*, *Acacia nilotica*, *Terminalia prunioides* and *Terminalia sericea* trees at ground level is very effective. Treatments during the rainy season result in low amounts of coppice and high mortality. With *Dichrostachys cinerea*, the mortality is extremely low after treatment.
- Felling in the coppicing bud area has also proved to be effective.

5.4.4 Mechanical

Bush clearing by means of bulldozers for rangeland reclamation purposes is not recommended for the following reasons:

- The soil surface is disturbed to a very large extent
- The establishment of bush seedlings is favoured and usually results result in a bigger problem, and
- The practice is too expensive.

The use of this method is only recommended for crop production purposes.

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Chapter 6

Indicators and the monitoring system[13]

[13] Constituted Component 4 in the original Terms of Reference

6.1 Introduction and Terms of Reference

In terms of Component 4 of the Bush Encroachment Research, Monitoring and Management Project, the Polytechnic of Namibia was contracted to develop an appropriate system to monitor the increasing density of woody plants in Namibia.

The Terms of Reference constituted the following:

- Define and determine what kind of information and information management system are needed for the effective monitoring of environmental changes
- Identify indicators to monitor environmental changes, i.e. soil, water, vegetation, to support the process
- Ensure such indicators are relevant, practical, scientifically reliable and easy to measure
- Take into account the broader State of the Environment recommendations
- Compile a list of indicators which reflect pressure, state and response
- Include indicators of biodiversity[14] and ecosystem function
- Conduct interactive fieldwork to assess the practicality and viability of the selected indicators
- Develop a methodology for implementation
- Evaluate the methodology in practice
- Consult and find consensus with main stakeholders before final submission, and
- Feed data into a remote sensing and GIS database.

This report was compiled by the Polytechnic in accordance with an agreement obtaining with the MET's Directorate of Environmental Affairs. The complete report by Zimmermann et al. (2001b) is available as "Proposed monitoring of bush encroachment in Namibia".[15]

6.2 Indicators

6.2.1 Introduction

Indicators can be defined as parameters that provide information about the environment, with significance beyond that normally ascribed to, and directly associated with, a parameter value (OECD 1993). In this section, indicators are divided into three types, namely pressure (P), state (S) and response (R) indicators, as outlined by the Organization for Economic Cooperation and Development (ibid.). Within this "PSR" framework (ibid.), –

- *pressure indicators* describe pressures exerted on the environment by humans (although this includes pressure indicators such as rainfall, which are not pressures exerted by humans as such) and are seen as early warnings
- *state indicators* describe the state of the environment (in the case of Namibia, including both states and impacts of those states on other environmental elements), and
- *response indicators* describe the societal responses to environmental conditions (the state).

Klintenberg (2001) has reviewed and analysed the process of indicator development in State of the Environment Reports, and his work is used in evaluating indicators developed by Zimmermann et al. (2001b).

6.2.2 Criteria for good indicators

Based on the Organization for Economic Cooperation and Development's criteria, Klintenberg's (2001) report, workshop discussions, and the present findings regarding the context of bush encroachment in Namibia, the criteria by which indicators are evaluated have been summarised as follows (the terms in bold italics refer to the abbreviation to be used hereafter):

- **Easy to measure and time-/cost-effective (*easy-measure*)**
  The data should be easy to collect (by farmers in some cases) and should not require costs and time disproportionate to their value. This is evaluated subjectively, and based on the authors' own trial monitoring of state responses.

[14] *diversity*=amount of variation
[15] For more details the full report is available from the Directorate of Environmental Affairs library.

- **Easy to use and interpret (*easy-use*)**
  The data should be easily interpretable, and unambiguous. This is evaluated subjectively, and also based on the authors' own trial monitoring of state responses.

- **Responsive to changes (both human-induced and natural) and showing trends over time, or, in the case of pressure indicators, responsible for change (*responsive*)**
  In many cases this is difficult to prove, since the trial monitoring of state responses measured variables at one time only. In the case of pressure indicators, this criterion does not apply.

- **Have a threshold[16] or "reference" value for comparisons to be made (*threshold*)**
  There are some roughly defined thresholds for transitions from state to state, and these thresholds are used for management actions in the draft decision table and expert system (to be explained later herein). These thresholds relate mainly to the onset of bush thickening (and, thus, are used with certain specific pressure and state indicators). It is not clear how the criterion of threshold fits in with response indicators. Nonetheless, the criterion is still useful, since the fact that a threshold (even if it is unknown) exists for that indicator is important. Furthermore, a "reference" value is very important, which is why the establishment and maintenance of benchmarks[17] will enhance the Bush Encroachment Research, Monitoring and Management Project and rangeland management in general.

- **Data must be easily accessible and reliable (*accessible/reliable*)**
  Data accessibility refers to the ease with which databases can be accessed. Unreliable databases will provide false impressions of indicators and may result in erroneous management decisions. This is particularly critical for land managers, who need to apply the results of monitoring in their management practice.

- **Scientifically sound and relevant (*scientific*)**
  Here the indicator is evaluated in terms of whether it is causal (in the case of pressure indicators) or whether it truly represents the situation (in the case of state and response indicators). Statistical analyses should be able to point out where changes occur in the indicator.

The appropriateness of indicators was evaluated in relation to the above criteria. Owing to some overlap in the definitions of *pressure, state* and *response* indicators, however, cases where confusion may occur are clarified in the text.

6.2.3 Methodology

Potential indicators were identified through –

- workshops held at Hebron, a commercial farm in the Otjozondjupa Region
- discussions with the Desert Research Foundation of Namibia, the MET's Directorate of Environmental Affairs, and the MAWRD
- academic literature
- Internet searches, and
- the authors' personal current knowledge.

Some of these (some state indicators) were tested through trial monitoring at Hebron. Other (pressure, response and the remaining state indicators) were evaluated with the assistance of workshop participants and key informants. Finally, all these indicators were evaluated according to the criteria outlined above.

In most cases, it was assumed that an indicator's appropriateness was the same for all AEZs. Those that were obviously not appropriate were left out of the final evaluation. The rest were provided with a priority rating or a "No" if it was decided that too many criteria had been violated. Evaluation was subjective, but was related to the degree of positive comment in the evaluation table. Of particular importance was the *scientific* criterion, since this included statistical acceptability which, of course, depends upon the monitoring procedures. In this summary of the research undertaken, only those indicators chosen as appropriate have been listed.

[16] A level beyond which a situation becomes desirable or undesirable (Klintenberg 2001), and, in the context of the report, a management decision is reached.
[17] A section of rangeland that has been managed in a way that would achieve the optimum conditions under the current macro-climatic conditions, in order to compare with its surroundings and to show the true potential of the land.

6.2.4 Discussion

Although there is concern that measuring too many indicators would waste time, many of the parameters suggested here are already being measured. Moreover, many newly suggested indicators can be measured simultaneously during certain monitoring procedures. More indicators than some informants would have thought wise have been included. However, rangeland monitors need not measure each indicator and may prioritise according to Table 6.1 below.

6.2.4.1 Pressure indicators

All of the indicators suggested in Table 6.1 (except for the activity of *Phoma glomerata*) can be considered as early warnings of different stages. Stocking rates, grass cover and biomass are very early warnings, while fruit production, and frost and rainfall amount and distribution are later warnings of imminent bush encroachment. The thresholds are not yet determined, but could be estimated with further research.

An increase in the activity of *Phoma glomerata* suggests that the pressure of bush encroachment will be diminishing, provided that appropriate management procedures are instated to minimise the chances of encroachment recurring. Grass biomass measured by remote sensing, with ground-truthing calibrations, will be especially useful on a regional and national level. Six indicators were chosen, many of these (e.g. remote sensing measurements of grass biomass and rainfall) are already recorded and documented. Fruit production and frost could easily be recorded by farmers. Importantly, the impacts of these pressures are dependent upon the magnitude of the other indicators. Thus, the thresholds for each indicator are especially difficult to determine since they would depend upon the levels of the other pressure indicators. For example, a large amount of perennial grass cover would probably tend to inhibit seedling survival, but the threshold for this would depend upon soil moisture, which would in turn depend upon the rainfall of the current and previous seasons. Furthermore, some of the responses to these pressures may in fact not be threshold-like, e.g sales of herbicides. Thresholds for pressure indicators (indeed, for all indicators) remain a difficult and debatable topic on which further research would be valuable.

6.2.4.2 State indicators

Five ground-monitoring indicators and two remote-sensing indicators were given a priority rating of 1. Although this appears to be high, once again these are commonly measured, and the remote-sensing data is already being gathered and is readily available. The data for the ground monitoring was given a rating as "fairly" accessible and reliable. This is because it is uncertain at this stage how willing farmers would be to measure these indicators, and how accurately they would record the data. Many of these measurements can be done with little extra effort if done together. Seedling density would also be seen as an important pressure indicator since it indicates the imminent onset of bush encroachment if management actions to prevent this are not taken. The annual variation in NDVI values as a measure of bush encroachment was suggested by John Mendelsohn (pers. comm.).

(a) Biodiversity indicators

Since simplification of habitat (either through bush encroachment or excessive bush clearing) results in species diversity loss, habitat and structural heterogeneity are recommended as proxy indicators of potential biodiversity. If distance measurements in ground monitoring are already being done, this would mean that no extra effort is required in the field. Similarly, with aerial photography cover estimates, landscape-level heterogeneity could be determined with no extra sampling. Some measure of variability (to be determined) would then need to be tested. For example, results from bird point samples or walking transects (and small-mammal trapping) would first have to be correlated with these heterogeneity (or variability) measures. An appropriate diversity index could be adapted (Magurran 1987), and classification and ordination tools may be able to determine the variety of habitat types present. Alternatively, easily identifiable species indicative of certain habitats could be used as indicators (e.g. Blackshouldered Kites would become less abundant in response to bush encroachment, whereas hornbill species would respond to a decrease in woody stems large enough for nest cavities). Woody and grass species diversity is not recommended since the relationship between bush cover and plant species diversity is not clear, and is likely to be related to other factors as well. Often, disturbed areas show high species diversity. It is well known that faunal diversity is more responsive to structural diversity than to the species diversity of plants.

Measures of animal species richness are too time-consuming and dependent on expert knowledge to be incorporated as state indicators (although they could be used on occasion when experts are available). However, it is strongly recommended that the monitoring of bush encroachment indicators be integrated with the monitoring of other degradation indicators.

6.2.4.4 Response indicators

The relevance of thresholds for this section is uncertain. The appropriateness of societal responses is hardly ever linear, given the nature of bush encroachment. For example, destocking to a certain level would be appropriate if an area is overstocked, but at some level, destocking may lead to vegetation becoming moribund (which would then cause it to be an inappropriate response). There is also uncertainty as to whether destocking would achieve an improvement in management within a time frame without mechanical rehabilitation of the soil and the introduction of seeds of climax perennial grasses. Likewise, wood harvesting may be appropriate if forestry principles are adhered to, but widespread clearing would have negative effects. Records of fires may be quite easy to gather since extension workers would most likely know (or be able to find out) where and when fires were started and whether they were deliberate management fires or accidental.

Since two response indicators (i.e. destocking and wood harvesting, as explained above) are already recommended as pressure indicators, they are also recommended here. Rest, the practice of stem-burning, and the number of hectares of field cleared may be good indicators of appropriate responses, but they require additional effort to obtain and are, therefore, given a lower priority. It should also be noted that the sale of herbicides is a rather indirect indicator and, although easy to measure, does not actually measure the amount of usage.

6.2.4.5 Indicators currently in use for the National Programme to Combat Desertification

The Desert Research Foundation of Namibia is currently compiling a desertification risk map based on four pressure indicators and one state indicator. Obviously, it would be valuable to use these. However, due to the almost contradictory nature of bush encroachment as a symptom of desertification, only livestock data and NOAA images coincide with the indicators recommended here.

6.2.4.6 Indicators suggested by the State of the Environment Report

Out of the seven indicators finally suggested by the State of the Environment Report on Agriculture and Land Resources (MET 2000), there are two that relate directly to bush encroachment. These are "Rangeland condition index" and "Population changes/movement".

Rating	Type of indicator	Indicator	Monitoring procedure	Source of information
1	Pressure	Livestock type and numbers (stocking rate) or balance between browsers and grazers (including game species)	Available records	Farmers/Veterinary Services, MAWRD
1	Pressure	Frost	Climate data/farmers' record-keeping	Farmers
1	Pressure	Rainfall amount and distribution	Climate data/farmers' record-keeping	Farmers/Ministry of Works,Transport and Communication
1	Pressure	Fruit production of bush-encroaching species	Opportunistic record-keeping	Farmers/Extension services
1	Pressure	Amount of perennial grass cover		Point sampling Farmers/ Extension services

Rating	Type of indicator	Indicator	Monitoring procedure	Source of information
1	Pressure	Grass biomass	Biomass clippings/NDVI	Farmers/Extension services/Remote Sensing Unit
2	Pressure	Vigour of perennial grass	From point sampling/ index	Farmers/Remote Sensing Unit
2	Pressure	Activity of *Phoma glomerata*	Point sampling	Farmers/Extension services
1	State	Canopy cover (of different height classes) of bush-encroaching species (and changes therein)	Point sampling/Bitterlich gauge	Farmers
1	State	Seedling density (also a pressure indicator)	Plots	Farmers
1	State	Bush density of different height classes (and changes therein)	Distance measurements	Farmers
1	State	Amount of grass (density, cover and species com-position) and annual/ perennial balance (and changes therein)	Points/distance measurements	Farmers
1	State	Balance of cover between bush-encroaching (undesirable) bushes and desirable bushes (and changes therein)	Points/Bitterlich gauge	Farmers
1	State	Inter-annual variation of the NDVI (and changes therein)	Remote-sensing data	Remote Sensing Unit/ Etosha Ecological Institute
1	State	Estimates of canopy cover from aerial photography (and changes therein)	Aerial photography	Surveyor General
2	State	Amount of organic litter on ground (and changes therein); the balance between bush and grass litter	Points	Farmers
1	State (biodiversity)	Vertical heterogeneity – based on variability of height class data (and changes therein)	Points/Bitterlich gauge/ distance measurements/ belt transects	Farmers/Extension services
1	State (biodiversity)	Horizontal heterogeneity – based on variability of distance measurements to nearest bushes (and changes therein)	Distance measurements	Farmers/Extension services

Rating	Type of indicator	Indicator	Monitoring procedure	Source of information
1	State (biodiversity)	Habitat diversity from aerial photography – standard deviation of canopy cover estimates (and changes therein)	Aerial photography	Surveyor General
2	State (biodiversity)	Woody species diversity from ground monitoring (and changes therein)	Distance/belt transects	Farmers/Extension services
2	State (biodiversity)	Perennial grass species diversity (and changes therein)	Distance measurements	Farmers/Extension services
3	State (biodiversity)	Animal species richness, e.g. small-mammal counts, bird counts, insect counts (and changes therein)	Censuses, walking transects, point samples	MET
1	Response	Destocking	Available records	Farmers/Veterinary Services, MAWRD
1	Response	Browser component	Available records	Farmers/Veterinary Services, MAWRD
1	Response	Number of Forestry Permits for harvesting	Available records	Directorate of Forestry, MET
1	Response	Fire frequency	Remote-sensing data/ records	Remote Sensing Unit/ Etosha Ecological Institute/Farmers
2	Response	Rest	Available records	Farmers
2	Response	Hectares cleared with herbicide, burnt or harvested for sale	Available records	Farmers
2	Response	Stem-burning	Available records	Farmers
3	Response	Sale of herbicides	Available records	Suppliers of herbicides (e.g. Agra, Agrigro)

Table 6.1: Evaluation and priority rating of proposed indicators

6.2.5 Recommendations

It is recommended that –

- land-users, extension officers and rangeland scientists measure the indicators suggested in Table 6.1
- land-users, extension officers and rangeland scientists prioritise according to Table 6.1, as time dictates
- rangeland scientists determine thresholds for indicators
- rangeland scientists investigate the effects of combinations of indicators on threshold levels, and
- the monitoring of bush encroachment indicators be integrated into monitoring programmes for other degradation indicators.

6.3 Monitoring system

6.3.1 The context of monitoring

Monitoring is an activity that takes up time and resources. On its own it is not a productive activity. Therefore, in order to be worthy of the effort that goes into it, the results of monitoring need to be put to productive use. The main benefit of monitoring is to provide information regarding changes over time, which can be used to make wise management decisions. The latter, in turn, should lead to improved productivity or other objectives.

In the case of bush encroachment, the main beneficiaries of monitoring are the users of the land, such as farmers and agencies responsible for State land. Monitoring can provide early warning of threatening events so that land-users can take corrective measures in time, and when it is still cost-effective to do so. In addition, monitoring can provide feedback to land-users on how effective their management is, so that they can more easily develop appropriate management interventions. However, there are other stakeholders who also benefit from monitoring of bush encroachment, such as extension services who advise the land-users, and researchers who advise the extension services.

6.3.2 Who should do the monitoring?

Monitoring should ideally be performed by land-users, since they are the ones who should immediately apply the results to improve their management. As stated by Abbot and Guijt (1998:20), –

> [t]he information generated should contribute to improving learning and action, in addition to the regulatory, watch-dog function of many conventional monitoring programmes.

Hence, farmers should keep records of their natural resources, just as most of them do for their finances and their livestock. If farmers notice a change in the status of the bush on their land, they should be able to respond swiftly to achieve the desired conditions. Therefore, at the farm level, the monitoring should be performed – and the results of the monitoring applied – by the farmers themselves, with the analytical assistance of extension services where necessary.

However, farmers working in isolation will not be as effective as those who join forces with others. The results of their monitoring can be put to better use if they are shared. Hence, the different levels of organisation, such as farmers' associations, unions, extension services and researchers, can also play a useful role in coordinating the monitoring and its application. Furthermore, some forms of monitoring, such as remote sensing, can only be performed effectively at a larger scale through bigger organisations.

6.3.3 Simple vs. reliable measurements

The Terms of Reference required the consultants to develop a monitoring programme whose indicators should be "relevant, practical but also scientifically reliable, [and] easy to measure …". This is indeed a tall order, since there is usually a trade-off between simplicity and reliability: the simpler a measuring technique becomes, the less reliable its results are likely to be. Table 6.2 later herein provides a summary of indicators to be used in practice.

6.3.4 Need for statistical analysis

Most people, including farmers, shy away from statistical analysis. The big danger in this is that results may be misinterpreted. Most methods of ground monitoring require sampling, because it is impossible to measure everything on the ground. The results of sampling are usually expressed as an average value, which then provides an estimate of the true value. If the results of sampling over time show that there has been a change in average value, then this is usually interpreted as indicating an actual change in whatever was being measured. It is only through statistical analysis that one can determine the level of significance of any change in average value. Without statistical analysis, there is the danger that action will be taken on an apparent difference in average value which is not significantly different. Statistical analysis allows not only the level of significance to be determined, but also the optimum amount of measurements that should be taken in order to achieve the required level of reliability in the estimated value. If there is only a low level of reliability in the estimated values, then any suggested trend would need to be validated by other methods. If triangulation of the results from several different methods suggests the same trend, then there can be greater reliability in the results (Stuart-Hill, pers. comm.).

6.3.5 Subjective vs. objective measurements

Most farmers rely on subjective means to determine the status of their natural resources. Through experience on their own land, many farmers have developed a "good feel" for the conditions, so that they can make valuable judgments about any changes that take place. However, there are disadvantages in relying only upon such subjective means. Perceptions differ over time, especially in the case of insidious environmental changes occurring at a slow rate. Perceptions also differ from person to person. The skill of judging subjectively needs to be acquired over time, and is lost with the death of every farmer. In addition, subjective measurements are not as easy to quantify, and so are less amenable to statistical analysis, information management and dissemination.

Objective measurements, on the other hand, are easily quantifiable and can be made in the same way by different people who have been trained to make them, usually through the use of instruments. However, their main disadvantage is that they usually take considerable time and effort to measure. In addition, most measurements which are primarily objective still have some degree of subjectivity, which may lead to different results from different observers.

A monitoring programme should, therefore, try to make use of the most efficient objective measurements and be complemented by some subjective measurements, so as to gain from the advantages of each.

6.3.6 Need for benchmarks

In order to differentiate between the influences of climate and management, the results of rangeland monitoring need to be compared with those of a benchmark which experiences similar macroclimatic conditions. Ideally, a benchmark should show the best rangeland conditions possible under the current macroclimate. What is considered "best" will differ among land-users, depending upon their management objectives. However, the type of benchmark which will be most useful for general rangeland monitoring will be one that exhibits the healthiest ecological processes and is best protected from erosion under the prevailing macroclimatic conditions. If land-users can identify land which is representative of the unit to be monitored, and which is considered to be in the healthiest condition possible under the current macroclimate, such land could serve as a benchmark for comparison with the land being monitored, provided that the "benchmark" land continues to receive the same "good management" that kept it in such "best condition".

However, if the rangeland condition of the benchmark land is such that it could still be significantly improved through management, then it would be beneficial to fence off a representative area and manage it in such a way that the healthiest condition is achieved. For most of the AEZs this is likely to entail rest from grazing during the whole growing season, followed by a short period of fairly heavy grazing during the dry season. In the case of above-average rainy seasons it may also entail a short period of moderate grazing during the middle of the growing season, especially for the AEZs in the moister parts of the country, to maintain perennial grasses in a vigorous condition. If the benchmark area is in poor condition when it is first established, then the best conditions may take many years to achieve. In order to encourage land-users to establish their own benchmarks, the research stations and extension offices could set the example by establishing benchmarks to serve as a demonstration.

6.4 Trial ground monitoring

6.4.1 Introduction

As part of the first workshop held at Hebron, some trial monitoring of vegetation was performed with the farmers. The purpose was to test some methods proposed by the consultants so that appropriate modifications could be made, and to familiarise the participants with ground monitoring. Trial monitoring should ideally have been conducted over the range of AEZs influenced by bush encroachment, in order to cater for the different circumstances. However, this would not have been possible given the time available. The consultant, therefore, proposed concentrating all the efforts for the trial monitoring on only one AEZ. As a consequence of this decision, when the proposed monitoring is applied to other AEZs, some problems are expected to be encountered due to different circumstances.

The AEZ selected for the trial monitoring was CPL1 (Central Plateau, Southern Omatako Plain) (Coetzee 1999). In terms of mean annual rainfall, this AEZ falls roughly midway between the two extremes for bush-encroached areas in Namibia, in the vegetation type known as Thornbush Savanna (Giess 1971). The trial monitoring was restricted to only one out of the two main land types in the area, consisting of the slightly higher ground.

Normally, the results from monitoring only become useful when comparisons can be made with previous monitoring at the same site. Five different sites were selected, therefore, to cover a variety of rangeland conditions. In this way, the trial monitoring results could be compared with each other. This also allows for testing the statistical analyses to determine the level of significance in mean results between each of the five sites measured.

The findings and results of the monitoring trials are fully discussed in the Zimmermann et al. (2001) reports.

6.4.2 Conclusion

The trial monitoring was a useful exercise for testing the proposed methods and the statistical analyses. Although many of the measurements were made from 200 points per site, it appears that 100 points will give a sufficiently reliable estimate to show significant changes in most of the indicators. The sample number of 100 is also convenient for the processing of data, especially since percentage values can be obtained by simply summing the various categories found.

The lessons learned through some mistakes made during the trial monitoring can be applied to ensuring the methods for the proposed monitoring system are improved. The experiences gained from the trial monitoring were put to use in evaluating and proposing methods for a monitoring system.

6.4.3 Proposed monitoring

A summary of the proposed ground monitoring appears in Table 6.2.

Type of indicator	Indicator	Units of measure	Proposed method
Pressure	Livestock (per species and type)	Kilogram live weight per hectare	Records kept by farmers
	Wild herbivores (per species)	Subjective rank	Records kept by land-users
	Type of management	Descriptions and some quantities	Records kept by land-users
	Fires	Area marked on map	Analysis of records and maps kept by land-users
	Fruit production on encroacher species	Subjective rank	Records kept by land-users
	Rainfall	Millimetres per annum	Rain gauge
	Frost	Occurrence of top-kill in bushes	Records kept by land-users
	Fungus on *Acacia mellifera*	Percentage of bushes infested	Records kept by farmers
	Amount of bushes	Ranking in comparison with previous photographs	Fixed-point photographs
	Density of grass		
	Seedling density	Plants per hectare	Plot counts

Table 6.2: Summary of proposed ground monitoring

Type of indicator	Indicator	Units of measure	Proposed method
State	Woody canopy cover – all bushes (per species)	Percentage	Bitterlich gauge
	Bush height classes – all bushes (per species)	Percentage	Point sampling
	Density of bushes – all bushes (per species)	Plants per hectare	Distance measurements from points
	Perennial grass species composition	Percentage cover (and range condition score)	Distance measurements from points
	Biodiversity	Index	Measures of variation
	Soil cover	Percentage	Point sampling
Response	Control methods applied by land-users	Area marked on map	Analysis of records and maps kept by land-users
	Animal production	Kilogram live weight per hectare per annum	Analysis of records kept by farmers
	Wood production	Kilogram per hectare per annum (local and national level)	Analysis of records and maps kept by land-users

Since the main beneficiaries of monitoring are the land-users, it should be left up to them to decide how to do it, so that they can apply the results to improve their land management. This report recommends a monitoring system from which land-users can then decide what to do and what not to do. What is recommended, therefore, amounts to more than what most land-users would be willing to do, so that they can select what is appropriate for them. In each subsection that follows here, the recommended methods are described in an order of priority determined by the consultants. Naturally, however, land-users may have different priorities.

Hopefully, many farmers will apply fixed-point photography on their land. Only a small proportion are expected to be willing to take measurements by point sampling. Nonetheless, as long as the small proportion of farmers are well distributed over the bush-encroached areas of Namibia, their results will be useful to provide a national picture. If they are not well distributed, then gaps may need to be filled in by extension officers or research staff.

It is also appreciated that priorities for a national database will differ. A national database would prefer a uniform system applied by each land-user in the same way. However, because the land-users are expected to act on the results of the monitoring, their preferences should receive priority.

6.4.4 Recommendations

It is recommended that –

- a central database be established
- benchmarks be established at all agricultural research stations and in the vicinity of extension offices to set the example to encourage land-users to establish their own benchmarks
- land-users decide on their own priorities for monitoring, while considering the consultants' priority list
- land-users only monitor what they find to be efficient for their own uses
- extension officers and researchers do some monitoring in a few key areas to fill some of the gaps left by land-users
- a handbook be developed for land-users to refer to when deciding what and how to monitor, such as that for Australian farmers (Hunt & Gilkes 1992). This should deal with environmental monitoring in general, and not only bush encroachment
- extension officers receive training in ground monitoring so that they, in turn, can train land-users and provide a support service
- ground monitoring be focused on the priority land type to obtain reliable results

- land-users determine the most appropriate season for their ground monitoring
- land-users who would like a more holistic picture of the situation as regards their vegetation perform ground monitoring annually during the late growing season
- once a land-user has decided on his/her most suitable season to start ground monitoring of the vegetation, s/he adheres to that season for all subsequent measurements
- perennial grasses only be recorded in the monitoring if they are more than a year old, as evidenced by the presence of grey material from the previous season and a wide base. In this respect one needs to be wary of counting bush seedlings shorter than 10 cm: if the large percentage of the latter that will die are included in the data it will give a skewed picture. Interpretation of the data also needs to be done with great circumspection (Bester, pers. comm.)
- for those land-users who will be doing the monitoring, training be given in plant species identification, possibly offered by the National Botanical Research Institute
- farmers keep detailed records of their animals so that appropriate synthesis can be performed when required
- for land-users who do not census wild animals, they make a (subjective) qualitative judgment on the amount of wild animals they have and record these numbers for each rainy season and dry season
- a reference collection of photographs of differing rangeland condition be developed when the first fixed-point photographs are taken, so that they can immediately be scored
- ranking of photographs from the same site be applied from the second photo onwards
- plot counts be used for measuring bush seedlings
- the Bitterlich gauge be used for estimating canopy cover
- distance measurements be used for estimating bush density, height classes and distribution
- strip counts be used at a few sites, and infrequently, to provide calibration and validation for the density estimates from distance measurements
- farmers use distance measurements for long-term monitoring
- researchers construct degradation models for baseline[18] comparisons
- those farmers who are estimating grass biomass continue to do so and make the data available to a central database
- land-users keep records of the production they obtain from the land, as many are already doing, and
- institutions gathering data on commercial production make the data available to a central database once it becomes established.

6.5 Expert system development

6.5.1 Introduction

Monitoring is an essential component of any management system. The results of a monitoring programme provide a basis for making sound management decisions. The decisions to be made need to be based on a sound knowledge and understanding of what the indicators has measured. Without monitoring influencing decision-making, monitoring is a waste of time.

It was considered important in this study, therefore, to include a system that facilitated the process of decision-making. Expert systems provide a way of recording how decisions are arrived at (Starfield & Bleloch 1991). The design of such systems also helps to clarify thought processes and focus on key pathways to decision-making. Expert systems may then be a useful way to link monitoring results to management decisions. The expert system is usually a system of computer software that accesses and ueries a previously prepared knowledge base. While sophisticated software is available to carry out the querying of the knowledge base, the knowledge base itself requires most of the work.

Before an expert system is developed, a sound knowledge base and understanding of the dynamics of the situation are required. In this regard the State and Transition Model of vegetation change (Westoby et al. 1989) serves as a useful, cohesive and pragmatic way of incorporating our current understanding of bush encroachment.

[18] The initial phase of monitoring, i.e. the first readings of a monitoring programme.

6.5.2 Decision-making with the expert system

The first process to be undertaken when constructing an expert system is to list the expected decisions. Thereafter, a series of statements are made. These statements are converted to questions at a later stage. The answers to these questions form the basis of the rules to reach the various decisions. What is presented here is just the decision table (the precursor to the computer expert system), with the rules required to arrive at the decisions. The table consists of decisions (columns), and statements (rows). In the expert system, these statements become questions which, depending upon responses to them, arrive at a decision(s). The expert system has been drafted on a simple expert system shell.[19] The expert system will, at a later stage, be drafted onto a more powerful shell (the Mandarax Decision Support System) being developed at the Polytechnic of Namibia.

Source: *WINEXP Shell, © Starfield & Bleloch 1991*

No.	Statement	Decisions 1: Consider burning as an option. Burning should be done in the late dry season	2: Consider stem-burning or wood harvesting	3: Monitor bush seedlings during the coming rainy season	4: Continue monitoring, maintain current management practices	5: Rest veld if possible	6: Consider improving soil conditions mechanically and otherwise, and reseeding with good perennial grasses	7: Consider incorporating browsers into your system	8: Apply high grazing pressure
1	There has been a significant increase in bush cover, compared with the benchmark.	T	T	X	F	T	X	T	T
2	The density of bush-encroaching species has increased significantly over the past few years.	T	T	X	F	T	X	T	T
3	Bush-encroaching species have produced many seeds this (or during the previous) season.	X	X	T	X	T	X	X	T
4	There are seedlings of bush-encroaching species towards the end of the rainy season.	T	X	X	F	T	X	T	T
5	Grass biomass is currently high (there is a sufficient fuel load for a fierce fire).	T	F	X	T	X	F	X	X
6	There is a good balance of *Boscia albitrunca* and other "good" bushes with bush encroacher bushes (e.g. *omusauna*, *omatjette*) in the veld, with a cover of no more than 30%.	F	F	X	T	X	X	X	X
7	There is a good cover of climax perennials.	T	X	X	T	X	F	X	X
8	There has been a complete (or partial) absence of climax perennials in the area for more than 20 years.	X	X	X	F	X	F	X	X
9	Bush density is more than 2,500 bushes per hectare and bush cover more than 40%.	T	T	X	F	T	X	T	X
10	A significant cover of moribund grass in the form of sparse moribund tussocks is present.	T	X	X	F	F	X	X	T

[19] WINEXP Shell, © Starfield & Bleloch 1991

No.	Statement	Decisions 1	Decisions 2	Decisions 3	Decisions 4	Decisions 5	Decisions 6	Decisions 7	Decisions 8
		Consider burning as an option. Burning should be done in the late dry season	Consider sterm-burning or wood harvesting	Monitor bush seedlings during the coming rainy season	Continue monitoring, maintain current management practices	Rest veld if possible	Consider improving soil conditions mechanically and otherwise, and reseeding with good perennial grasses	Consider incorporating browsers into your system	Apply high grazing pressure
		If (1T or 2T or 4T or 9T or 10T) and 5T	If (1T or 2T or 9T and 5F	If 3T	If 1F and 2F and 4F and 5T and 6T and 7T and 9F and 10F	If (1T or 2T or 8T or 9T) and 4T and 10F	If 5F or 7F or 8F	If 1T or 2T or 4T or 9T	If (1T or 2T or 3T or 4T) and 10T

Source: *WINEXP Shell, © Starfield & Bleloch 1991*

KEY: T = "If this statement is true …"
F = "If this statement is false …"
X = not relevant to the decision

Table 6.3: Decision table, showing decisions and statements used for the crude expert decision system

In the table, if the statement is regarded as true (T), then it contributes to the decision in the corresponding column being taken; likewise, if the statement is regarded as false (F), then it contributes to the decision in the corresponding column being taken. X means the statement is not relevant to the decision. The rules for determining the decisions appear in the last row under the corresponding decisions. The detail has been left out of the decisions and statements. The detail (i.e. background and explanation) surrounding the questions and decisions will be included in the expert system.

6.5.3 Recommendations regarding the use of the expert system

It is recommended that –

- a simple expert system be set up on computer in regional extension offices and farmers' union and association offices until the Mandarax Decision Support System supersedes it
- extension officers and members of farmers' unions are trained in the use of the system, and that they facilitate the use of it by farmers, and
- the expert system is revised as knowledge and understanding of bush encroachment processes is improved.

6.6 Remote sensing

6.6.1 Satellite remote sensing

A number of projects are currently running under various ministries to develop systems for monitoring vegetation using remote sensing. While the NRSC is involved in mapping bush-encroached areas using Landsat data, the MAWRD is looking at the correlation between NDVI readings and grass biomass. In addition, the Etosha Ecological Institute (EEI) uses monitoring techniques in the Etosha National Park.

However, the MAWRD and the EEI are working with NOAA data. Unfortunately, the sensor is currently out of commission, and it is unsure if it will be recovered or replaced. Alternatives will need to be identified.

6.6.2 Aerial photography

Aerial photographs are periodically taken for most parts of the country. A time series of these will provide an indication of bush development in specific areas. In order to simplify monitoring, ortho-photo maps should be used so that sampling intensities can be calculated.

6.6.3 Recommendations

It is recommended that –

- current satellite remote-sensing projects determining correlations between NDVI and vegetation parameters be completed before a further monitoring system is developed. This is particularly important for the mapping project undertaken by the NRSC, and
- ortho-photo maps be used for periodic assessment of vegetation.

6.7 Data storage and distribution

A number of institutions have been identified as being the best qualified or suited to house certain components of the monitoring system.

While (a) the GIS and remote sensing data should be maintained by the NRSC, (b) the monitoring database by the MAWRD's unit for Information Management, and (c) the expert system by the Polytechnic of Namibia, the cooperation of all institutions is vital to the project.

However, a data access policy needs to be devised in consultation with the farmers to deal with the accessibility of all data, i.e. the data that is not the property of the individual farmers. The policy would need to make provision for access to data for research in addition to the overall monitoring activities, and include all data sets incorporated into the system, i.e. the spatial and non-spatial data, as well as the expert system.

Data access can be facilitated through a number of channels. These include the Internet and the periodic publication of CDs or printed reports. The suitability of these channels would depend on the amount of data to be published. A national database would, for instance, not be distributed in printed form – simply because of the volume of information involved – unless the report is in the form of maps.

6.7.1 Recommendations

It is recommended that –

- the unit for Information Management in the MAWRD host the monitoring database
- regional offices be provided with pre-processed data in order to reduce the computing requirements of the regional offices, and to reduce the size of the data sets. For more sophisticated requirements, queries may be referred to the central unit for action
- the GIS and remote sensing data be maintained by the NRSC
- the monitoring database be maintained by the MAWRD's unit for Information Management
- the expert system be maintained by the Polytechnic of Namibia, and
- budgetary provisions be made for financing these activities.

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Chapter 7
Socio-economic factors and incentives influencing farmers in combating bush encroachment[20]

[20] Constituted a part of Component 5 in the original Terms of Reference

7.1 Introduction

For many years we have thought that problems in the agricultural sector should and could be counteracted through the offering of scientific and technological solutions only. Today we realise that the degradation process, with bush encroachment as a prominent symptom, could largely be ascribed to policy failures, mainly in the socio-economic fields.

It therefore became crucial to develop a better understanding of the socio-economic, political and ecological environments in which farmers have to deal with problems like bush encroachment.

Thus, the socio-economic and cultural factors which may prevent or encourage farmers to address the problem of bush encroachment should form an indispensable part of any future bush control strategy. Consequently, a consultant – the Namibian Economic Policy Research Unit, NEPRU – was tasked to carry out a study with the following Terms of Reference:

- To determine the socio-economic factors influencing farmers' decisions to participate in Phase 2 of the Bush Encroachment Research, Monitoring and Management Project (both those who applied bush control measures and those who did not)
- To carry out a cost-benefit analysis and assessment of –
  - the need for assistance
  - the kinds and magnitude of assistance
  - the incentives for farmers to participate in Phase 2
  - the employment and self-employment opportunities which could emanate while implementing a bush encroachment management, monitoring and management strategy, and
- To make an assessment of problem-related training needs among agricultural extension officers, researchers and technicians, and recommend training programmes to be offered during Phase 2.

Thus, the study team (Dahl and Nepembe) looked into the socio-economic factors rather than technical issues regarding the bush encroachment phenomenon, and aimed to identify incentives that would encourage farmers to participate in a long-term strategy to combat bush encroachment. The Dahl and Nepembe (2001) report is available at the Ministry of Environment and Tourism's Directorate of Environmental Affairs.

7.2 Methodology

This study primarily centred on information collected during two focus-group workshops – one with mainly commercial farmers and one with mainly communal farmers.

In order to get some preliminary ideas about perceptions and attitudes concerning bush encroachment, a questionnaire was drafted and sent to a number of extension officers as well as 62 commercial and 20 communal farmers in close cooperation with the Namibia Agricultural Union (NAU) and the Otjozondjupa Communal Farmers' Union (OCFU). The questionnaire intended to identify key topics to be discussed at the workshops, and was based on the following key themes:

- Baseline information concerning the farm and the farmer
- Kinds of problems faced due to bush encroachment
- Magnitude of problems emanating from bush encroachment
- Earlier experience with anti-bush-encroachment techniques
- Estimated economic losses due to bush encroachment
- Assistance needed by the farmers (extension, research, etc.), and
- Ideas concerning employment and self-employment related to bush encroachment.

Unfortunately, the response rate from the commercial farmers (see Table 7.1) was rather low, but still gave us some insight into the magnitude of the bush encroachment phenomenon as well as the perceptions and attitudes in regard to bush as a problem for farmers.

Category of respondent	Sample	Number of respondents
Commercial farmers	62	23
Communal farmers	20	18
Extension officers, commercial land	5	4
Extension officers, communal land	5	4

Table 7.1: Sample size and number of respondents

A moderator guide for the workshops was compiled, based partly on results obtained through questionnaires sent to the farmers and extension officers. The agenda for the workshops was mailed to the participants beforehand. This was done in order to focus the discussions on a few important subjects instead of having general brainstorming sessions.

The investigating team made two field visits to bush-encroached areas, one in the Otjozondjupa Region (Okakarara, communal land) and another in the Khomas Region (commercial land). The intention of these visits was to obtain impressions and information from farmers concerning the bush encroachment phenomenon prior to the workshops.

The venues for the workshops were the Otjibamba Lodge near Otjiwarongo and the OCFU offices in Okakarara. During each of the one-day workshops, the discussions centred on different methods of bush control, socio-economic factors affecting the combating of bush, and sources of technical information. A sample of key informant farmers from these areas was selected with the help of the NAU and the OCFU.

This report, therefore, is based on information collected during the survey, the workshops, from key informant farmers, and other references and research findings in the field of bush encroachment. Consequently, the reliability and validity of the findings, conclusions and recommendations of the report are strengthened.

7.3 Bush clearing in Namibia

It soon became evident that socio-economic factors impacting on farmers' behaviour could not be studied in isolation from the different methods of combating invader bush. Although not part of the Terms of Reference, the consultant, given the time limit, made an attempt to illustrate the effectiveness and efficiency of the different methods of bush control as well as possible. These findings are reflected in more detail under Chapter 5, "Overview of potential methods to combat invader bush".

The application of individual techniques will always depend on individual circumstances such as bush density, bush species composition, soil profile, rainfall, landscape morphology and the capital available. The specific method and the costs associated with it, therefore, will vary between areas and between farmers. Consequently, each farmer applies the method(s) that suits his/her particular environment and economy best.

The respondents, especially the commercial farmers, seem to favour the faster bush-thinning methods, such as chemical treatments.

7.3.1 Economic viability of applying different bush-clearing methods

The economic viability of the different methods presently used to fight bush encroachment have been studied by the NAU (2000). These methods were –

- chemical bush control (by hand and by aeroplane)
- mechanical bush control (by bulldozer)
- biological management practices (decreasing the stocking rate)
- fire control
- chemical control combined with charcoal production, and
- chemical control combined with planted pasture.

This means that not all the options were considered, especially the use of browsers, nor were possible combinations of different methods investigated.

After assessing the NAU (2000) and Stewart Scott Namibia Consulting Engineers (SSNCE 1999) analyses, the consultant concluded that several techniques could be considered as economically viable under the current conditions. These techniques are the manual removal of bush, stem-burning, and chemicals applied by hand in combination with charcoal production. However, the three methods share the fact that they are all relatively slow if compared with methods such as bulldozing and the aerial application of chemicals.

In general, the introduction of income-generating activities such as charcoal production seems to turn the negative results of bush fighting into an economically viable practice for farmers. A core analysis would, therefore, suggest that by-products from bush such as charcoal should be a part of an economically sustainable process to combat unwanted bush in Namibia.

Manual removal of bush seems to be the main method used by farmers to eradicate bush in Namibia. The most expensive methods are chemical application by aeroplane and bulldozing (especially if individual farmers have to buy the equipment to perform the treatment). The most common bush-eradicating technique employed was manual mechanical treatment, especially chopping by way of axes or mattocks.

An economic viability analysis of bush thinning by the NAU (2000) indicates that few methods of debushing are feasible or economically viable over a 20-year period if they are not combined with some income-generating methods such as charcoal production. However, the NAU did not take tax deductions into consideration; this single aspect could change the outcome of the specific study substantially.

7.4 Socio-economic factors influencing farmers' participation in Phase 2 of the project

Many farmers in the commercial farming areas are already actively involved in debushing activities, while farmers in the communal farming areas are hardly involved in these activities at all.

The present study revealed that there is a great deal of awareness among commercial as well as communal farmers about the magnitude of the problem as well as the resultant production and economic losses associated with it. This finding is supported by Kruger's (2001) research in the communal areas of the Khomas, Omaheke and Otjozondjupa Regions. Although awareness is an important first step for the adoption of new practices by farmers, it does not necessarily imply that they will change their behaviour or management practices. According to Düvel (1980), a number of socio-economic factors serve as driving or restraining forces which impact on a person's perception and, therefore, the kind of decision s/he is going to take.

During the study an attempt was made to identify factors which serve to restrain farmers' participation in bush encroachment control programmes. The following were identified:

- Costs related to bush clearing
- Limited or lack of capital
- Availability of land to lease
- Markets for bush by-products
- Availability of labour
- The land tenure policy, and
- Awareness of clearing methods and economic benefits.

Each of these factors will be elaborated on below.

7.4.1 Costs related to bush clearing

Economic criteria are of great (if not decisive) importance in deciding whether or not to embark on bush control programmes. If the costs are not retrievable through increased productivity and income from the treated area, it is very unlikely that bush clearing will be adopted as a practice.

The right strategy of combating bush also needs to be identified and conveyed to the farming community (see Chapter 9). Most research as well as on-farm results support the view that the productivity of rangelands and, therefore, their carrying capacity are increased to the extent that bush clearing seems to be economically viable, especially if it is combined with income generated from intruder bush.

7.4.2 Limited or lack of capital

Another factor that needs to be taken into consideration is the level of indebtedness among commercial farmers. The total debt is claimed to be N$1.1 billion (Venter, pers. comm. to Dahl and Nepembe), which leaves an average debt per farmer of about N$367,000. This is based on the assumption that the number of commercial farmers amounts to 3,000. It is estimated that 30–35% of all commercial farmers are debt-free. In reality this means that many of the newly advanced loans to deal with bush encroachment will be in addition to an existing burden. However, when farmers invest in their properties, the capital costs can be written off in three years' time. This arrangement needs to be regarded as a strong incentive. Farmers will be very reluctant to take up new loans if their financial obligations are too high in relation to the net income from the farm.

7.4.2.1 Economies of scale

The cost factor should also be seen in relation to economies of scale. Small-scale farmers will have more difficulty in recovering the cost of applying bush management techniques when compared with large-scale farmers. The estimated minimum size of a farm today should be around 7,500 ha in order to make a living, meet one's financial obligations (interest plus running costs), and pay for a bush-clearing programme. On small farms, the cost of living together with fixed financial obligations swallow almost all one's profits – resulting in no surplus funds for combating bush.

7.4.2.2 Cost of equipment

Since all debushing methods require some kind of equipment, the next economic constraint involves the high cost of buying, operating and maintaining such equipment. In this regard, communal farmers are likely to be more vulnerable than commercial farmers.

7.4.2 Availability of land to lease

Another factor which serves to restrain farmers' participation in bush encroachment control programmes is the availability of farmland to lease or rent outside their own farms, and the costs involved of doing so. If the cost of renting additional grazing is less than applying anti-bush techniques on their own farm, the incentive to fight encroaching bush at once is simply not there. Some farmers have claimed that, in some cases, it made better economic sense for them to rent additional land than to clear their own farms of problem bush since the cost of leasing land has been relatively low. However, no consensus was established among the farmers concerning this issue. Still, this is something that should be studied more thoroughly in order to determine the magnitude of this strategy among farmers. It would without doubt have implications for the future of the bush encroachment project.

7.4.3 Markets for bush by-products

One crucial determinant of farmer participation is the extent to which bush can be used for income-generating activities. However, this aspect should not override environmental considerations or the purpose of the debushing programme.

The size and availability of markets for products are decisive. Many farmers seem to produce charcoal on a fragmented and rather small-scale basis (SSNCE 1999; Venter, pers. comm.). The market for charcoal, except for domestic use, is currently in South Africa and Europe. While the larger chunks are exported it is currently hard to find a market for fine charcoal. Thus, the development of markets for wood products from debushing will have decisive implications and a direct influence on bush thinning in the future. Consequently, a wider market needs to be exploited in order to expand charcoal production. Europe, for example, is a potential market for woodchips (Young, pers. comm.)

7.4.4 Availability of labour

In contrast to the high unemployment rate in the country as a whole, commercial farmers highlighted the problem of manpower availability and retention. Most Namibians prefer to live in urban areas, so the turnover as regards farm workers is high. Another perception was that few of the unemployed are prepared to take up a position as farm workers today. This leaves farmers in a situation where they consider it problematic to recruit additional staff for bush-clearing operations. If this holds true, the issue of employing farmworkers to combat bush will become even more problematic if more farmers are indeed going to get involved, and if more labour-intensive methods are practised for bush thinning.

7.4.5 The land tenure policy

Farmers on communal lands claim that shared rangeland is one of the reasons why they do not combat bush encroachment. Other farmers could easily harvest the benefits from any labour and financial input by those who performed bush clearing. This is the classic dilemma usually referred to as the "tragedy of the commons". This phenomenon is described by Hardin (1969) as the exploitation of communal land (the *commons*) as a result of the lack of responsibility for something that is owned simultaneously by no one in particular and by everyone in general. This predicament could be solved by giving the assurance that those who live on communal land will reap the benefits of their work by clearing bush for increased grazing yields in their respective areas.

Commercial farmers also claim that they face a land tenure problem. Theirs, however, is of a different nature – which makes them hesitant to take action against bush encroachment. The problem originates from the signals being given by some politicians pertaining to the future of commercial farms in Namibia. Negative statements concerning white farmers could give the impression that a more aggressive policy against commercial farmers is under way in Namibia, as has been the case in Zimbabwe, where some white farm-owners were forced off their land with no compensation. If Namibian farmers feel threatened in this way, they will probably hesitate to plough new capital into their farms, which undoubtedly will have an implication on bush control and, thereby, on Phase 2 of the project.

7.4.6 Awareness of clearing methods and economic benefits

Unlike the commercial farmers, the communal farmers identified as a major constraint their lack of basic knowledge about how bush encroachment occurred and how to fight it effectively. If bush clearing by farmers themselves is to be encouraged and stimulated in communal areas, the enhancement of basic knowledge among these farmers seems to be greatly needed.

Another problem which should not be underestimated is the lack of knowledge about the economic benefits that open up once the bush encroachment problem is addressed. Moreover, these benefits apply mainly to communal farmers (Bester, pers. comm.).

7.4.7 Summary

Although some commercial farmers emphasise that aesthetic considerations had steered them in their decision to fight bush thickening, social, political and economic incentives are expected to be of much more importance. For many farmers, bush clearing amounts to opening up areas for improved grazing or agriculture in order to make ends meet.

Bush encroachment is perceived as a big problem in both communal and commercial farming areas. Farmers are probably willing to participate in the implementation of Phase 2 of the bush encroachment project, provided an action-oriented national programme is introduced. Still, the financial implications and incentives should be directly linked to finding solutions for farmers. Thus, the extent to which farmers will or can participate is somewhat limited. However, if these problems are addressed, farmers are more likely to be positively influenced to take part in combating bush encroachment, intensify their efforts, participate in implementing action plans, and assist with a monitoring process.

7.5 Cost-benefit analysis and assessment

The assessment and cost-benefit analyses in this section will primarily concentrate on incentives brought forward by the farmers and revealed in section 7.4.

This section is divided into the following parts:

- The need for assistance in combating bush encroachment

- Type and magnitude of assistance required by farmers
- Incentives for farmers to participate in Phase 2
- Employment opportunities, and
- Summary of the main findings.

7.5.1 The need for assistance in combating bush encroachment

During the workshops a clear difference was identified between the commercial and communal farmers' need for assistance. It was established that the commercial farmers had a relatively good knowledge of the factors that caused bush encroachment, and many of them were also involved in combating bush encroachment on their farms. They knew practically all the techniques well, and many had tested a variety of methods. With this in mind, the commercial farmers did not express any immediate need for assistance from a knowledge point of view. However, it could be expected that a need for technical assistance still existed for a substantial proportion of these farmers, especially those who had not been involved in Phase 1 of the project.

The communal farmers, on the other hand, expressed an urgent need to obtain more information about encroacher bush, the causes of encroachment, and how to combat it. Many of these farmers lacked a basic knowledge about environmental issues, and this needs to be dealt with accordingly as well.

7.5.2 Nature and magnitude of assistance required by farmers

Financial assistance is the basis for most of the incentives that will influence both commercial and communal farmers to take part in Phase 2 of the project.

The second important factor that will influence farmers from both commercial and communal farming areas to take part in Phase 2 is the availability of markets for products derived from bush control or harvesting.

In addition to the challenge posed by the non-availability of workers, a lack of knowledge concerning what control methods to apply and the unresolved land tenure system are concerns that prevail more strongly among communal farmers.

7.5.2.1 Raising awareness

An enhancement of basic knowledge concerning bush encroachment is of particular importance among communal farmers. They are aware of the problem as such, but the implications of economic loss due to bush encroachment are probably only comprehended by a few (Bester, pers. comm.). An obvious forum for this kind of education would be through regional farmers' unions and/or local extension offices throughout communal lands. For example, as a consequence of the Directorate of Environmental Affairs' bush encroachment project, the OCFU has already expressed its willingness to mobilise their members in this regard.

Training programmes should aim at –
- creating an awareness about the economic losses suffered through declining carrying capacities and artificial droughts
- conveying appropriate technologies for combating bush, and
- establishing a profound understanding of environmental issues related to the problem.

The knowledge promotion programme is not expected to cost much money, especially when there are already people in place that could conduct such training in communal areas. Demonstration sites at research stations and commercial farms as well as specific sites in communal areas such as Post 8 at Epikuro should be utilised for this purpose.

The crucial point would be to brush up and extend these extension workers' knowledge about bush encroachment so that they, in turn, can improve the farmers' understanding of bush encroachment. Farmers who are seasoned in bush clearing can also be used to increase the knowledge level of communal and commercial farmers.

Figure 7.1: Small-scale entrepreneurs like the Omahua Youth Group were trained under the project in the techniques of combating bush encroachment

7.5.2.2 Land tenure politics

Since communal farmlands belong to the whole farming community, bush-clearing problems require a different approach from that applied in commercial farming areas. Since access to bush-cleared areas in communal areas is not just for those that cleared them, it would be important to give some kind of financial (e.g. cash) compensation to those who clear the land of problem bush. Otherwise, it might be extremely difficult to encourage people to participate in bush clearing.

One way to circumvent the communal user problem would be to take the initiative to establish clearing teams at village level. If all the members in a village give more or less the same input to bush thinning, the communal use of the newly cleared pastures would hopefully not create user-right issues. The bush encroachment problem would be owned by the community, not by one or two individuals in it. To try solving the communal problem in an individual/private way would probably prove impossible.

Farmers in the commercial farming areas expressed concern about the land policy. They felt this policy would substantially influence their decision on whether or not to invest in their farms. Negative signals might lead them to save their money rather than invest it in bush clearing or take out a loan to do so. Most of the commercial farmers, particularly those in the north, are past middle age and feel that, if they were to take such an important decision, it would need to benefit them after retirement as well.

Currently, the land tenure policy in Namibia is clear: it is based on the principle of "willing seller – willing buyer". The existing political environment does not suggest this situation is likely to change, provided that land reform takes place at a reasonable pace (this according to Hon. Hifikepunye Pohamba, Minister of Lands, Resettlement and Rehabilitation, at the occasion of the NAU Congress in 2001). However, the graveness of the uncertain future land policy should not be underestimated.

It is reasonable to conclude, therefore, that the willingness of farmers to invest in their farms corresponds with the right signals from the Government to the commercial farming community.

On the other hand, if bush clearing at a national level could enhance the productivity of land substantially, and thereby create room for increased income and more farmers, it would also contribute to the process of land reform since more productive land would be made available.

7.5.2.3 Financial assistance

As was pointed out, the major stumbling blocks preventing farmers from becoming involved in bush control programmes on a large scale are –

- a lack of capital and cash flow to bridge the period before the farm reaches a higher level of production in respect of both land and livestock, and

- the high costs of bush clearing, which include –
  - high interest rates on money borrowed from a bank
  - the high costs of chemicals and equipment, and
  - the high costs associated with labour.

Financial support to farmers will, therefore, play an indispensable role in any future management strategy. Such support could take the form of reduced interest rates on loans from the Agricultural Bank of Namibia, for example. Rates would have to be effectively less than normal in order to encourage farmers to undertake the cost of bush-thinning activities. Should there be such a concession, the amount allocated should be audited to make sure that it is really spent for the intended purpose.

The Dahl and Nepembe (2001) report is available at the MET and MAWRD libraries. A thorough breakdown of the different scenarios, against which the recommendations were made, is given. The main principles and issues to be considered are summarised below.

(a) Magnitude of the problem

At present, 26 million ha are encroached with invader bush, of which 10–12 million ha are subjected to severe production losses. Presently the annual losses directly ascribable to the bush encroachment problem amount to at least N$700 million. The livelihoods of 6,283 title-deed farmers and 65,000 households in communal farmers are affected.

It is assumed that, out of the 12 million ha severely encroached, 5 million will be targeted effectively over the next 20 years if financial support is granted.

Based on the findings of the NAU (2000) study, the carrying capacity on a severely bush-encroached area that has been debushed can double. Bester (pers. comm.) claims that it can even triple. Still, in this study a more conservative figure (N$50 per hectare) is applied in the calculations in order not to exaggerate the possible gross return per hectare.

Government interventions by means of subsidies can be justified in terms of the Constitution, the National Agricultural Policy of 1995, the National Drought Policy and Strategy of 1997, and the Soil Conservation Act. These and other policies in support of Government interventions are discussed in detail in Chapter 8 herein.

Three different ways to subsidise or give financial assistance to farmers for debushing are suggested, as described in more detail below.

(i) *Subsidising interest rates related to bank loans for bush thinning*

We assume that a 4% subsidy would be realised for loans taken for bush control, and that the loans would be repayable after 15 years. (Government will then pay 4% while the farmer will pay the balance.) In this scenario, and assuming an increased income of N$45 per hectare (according to the study's findings at Okahandja and Nina), the break-even point would occur after approximately 9 to 10 years, ceteris paribus, for each cleared area.

If one assumes that 1,000 farmers would take up loans for the bush clearing of 200 ha per annum each, the cost in subsidies would then be N$5.3 million per annum. At this pace 50% of farmland will be cleared of unwanted bush in 20 years in commercial areas, at a total cost to the State of N$180 million in subsidies (direct cost) and N$116 million in tax reduction (indirect cost, not to be budgeted for). In total, N$296 million over a period of 34 years (20-year loan period plus 14 years' interest after the last 200-ha loan is granted) or N$8.7 million a year (see Dahl & Nepembe 2001).

From a farmer's point of view, the easiest financial solution would be to subsidise loans that aim to finance a more capital-intensive method of bush control, such as the aerial application of chemicals. This could make sense if the intention was to eradicate as much bush as possible in the shortest possible time. On the other hand, the manual application of chemicals should certainly qualify for interest subsidies because of its high biophysical effectiveness and labour-intensive nature.

(ii) Subsidising wages for manual clearing on commercial farms

An alternative contribution by Government would be to subsidise the cost of labour for bush clearing. Since employment creation is a principal development aim, and the multiplier effect of new employment would be positive macroeconomically, Government's contribution could in this case be assumed to be substantially more than that granted by way of subsidies for loans incurred to finance bush clearing operations.

In this second scenario, a wage subsidy of N$50 per cleared hectare is proposed. It is assumed that the recipient of these allowances will be obliged to pay the bush clearer an additional N$100 per hectare cleared. At a clearance rate of one worker per hectare per week, and 200 ha per farm per annum, this would cost the Government N$10,000 per farm per annum in subsidies.

Furthermore, by cutting or stem-burning, the number of bush-cutters employed in the course of the 20-year bush thinning programme would be almost 4,200. Each of the 1,000 farmers participating in this scheme would then have approximately 4 workers fully occupied with bush thinning on their land.

In this scenario, incentives have been created for the farmers, the workers and the Government. The benefit for farmers is the relatively low cost of eradicating problem bush, namely N$100 per hectare (N$20,000 per 200 ha) if paid in cash, while the workers will enjoy a relatively competitive farm salary of N$600 as an incentive. The Government, in turn, will create more than 4,000 full-time jobs at a cost of N$50 per hectare. In total, the labour subsidy would be N$10 million per annum and N$200 million over a 20-year period. The tax reduction (indirect cost, not to be budgeted for) will cost the State N$3.8 million a year or N$128 million for the 34 years of payment. This example will cost the State N$328 million in total, or about N$13.8 million per annum during the first 20 years and N$3.8 million a year for the last 14 years (Dahl & Nepembe 2001).

Although Government expenses on subsidies for the thinning of bush seem to be very high, it will be extremely beneficial from a socio-economic point of view. The benefits would, in both scenarios above, lead to a much higher carrying capacity of the land and, therefore, make farmers more competitive in an increasingly aggressive international free-trade market. This would secure many on-farm jobs, which also supports Government policies.

A comparison between higher tax revenues as a result of increased carrying capacity as well as the costs for subsidies and tax reduction to farmers indicates that taxes overtake the costs of subsidies after 5, 9 and 12 years, respectively, with subsidies of 2%, 4% and 6% (ibid.). However, if the increased tax reduction as a cost of an increased demand for subsidised loans is taken into consideration, the recovery time will respectively increase to 10, 13 and 15 years. Although Government costs for tax reduction will increase dramatically with an introduction of subsidies, this outcome should not be regarded as an additional cost since it is not a part of a subsidy.

In the case of labour subsidies, Government can only recover their associated costs after 14 years, by means of earning additional income tax from farmers. When the cost for tax reduction is added to this time estimate, the recovery period increases to 16 years. Even if labour is not subsidised, the application of a 14% interest rate will mean an 8-year recovery period for Government in respect of decreased revenues (tax deductions).

In these calculations provision was made for an annual deflator of 10% per annum, which has been added to the annual cost to Government.

If the carrying capacity and, therefore, the calculated income is almost tripled (from N$25–70 per hectare), the 4 million ha to be cleared will increase the gross income for farmers by N$180 million a year, of which Government has the potential to earn N$34.6 million a year in additional tax income after 21 years.

Since farmers seem to disagree on the notion of subsidising the price of chemicals, this option was not considered.

(iii) Providing Government-paid bush-cutters/stem-burners for communal lands

How to approach the need for financial assistance on communal lands is a more complicated issue, due to common ownership and/or user rights. However, some direct financial compensation for people that clear bush should be considered. The incentives should not, as is the case with the commercial farmers, be the exclusive right to use the grazing areas, but rather be to earn a living from bush thinning and its by-products.

The same Government subsidy per cleared hectare as is guaranteed to commercial farmers should be guaranteed to communal farmers. However, it would mean that bush thinning would not pay off as well as in commercial areas, because no one pays the landowner's share of the bush-clearing costs. Thus, to balance the remuneration between bush clearing in communal and commercial farming areas, the Government, being the legal owner of the communal land, should consider increasing its input to N$150 per cleared hectare. This approach circumvents the problem of motivating all communal land-users to apply bush-thinning because of individual/communal use issues, because any labour applied to this end by individuals will be financially compensated. A rough estimation is that out of the [20] million ha severely affected by bush encroachment in Namibia, [6] million is in communal land, mostly in the east and north-west. It is anticipated that, as in the commercial areas, 50% of the lands need to be thinned (1 million ha) over a period of 20 years (50,000 ha per annum). On the assumption that each worker will clear 47 ha per annum, more than 1,000 (1,000,000 divided by 47 [ha], divided by 20 [years]) new jobs, and the possibility of small enterprise development is created in communal areas. The cost for this scenario would be approximately N$7.5 million a year, totalling N$150 million over a 20-year period (ibid.). If we assume a tripling of the carrying capacity, the income from the new grazing areas could increase from N$25 million to at least N$70 million a year. The possibility of recovering the subsidies made available by the Government by way of income taxes should, however, be considered as highly unlikely since the modest average income levels for communal farmers do not allow taxation.

Seen superficially, the huge amount of money needed for this scheme seems to be a reason for concern. The total cost for subsidies would be around N$250–420 million over a period of 34 years, and amount to N$7–N$12 million annually. If the costs for tax reduction were included, the cost would increase to around N$390–510 million, or approximately N$11–15 million annually (ibid.). However, it should be noted that the cost for tax deduction will not require additional costs on Government's budget since the opportunity for tax deduction is already in place.

It can nonetheless be concluded that the amount of N$7–12 million should be affordable to Government.

Although labour-intensive methods are more suitable for job creation, capital-intensive schemes should not be excluded from financial assistance. Not only are the latter very effective, they will also contribute to a broader and larger tax base. However, farmers will need to choose between the two types of assistance available, namely subsidised interest rates or subsidised labour costs.

In addition to the cost of eradicating bush as outlined above, it should not be overlooked that there are several methods currently available for generating income from such unwanted bush. This will be the topic for a subsection below, i.e. the marketing of by-products emanating from eradicated bush. Such income would be of particular importance as regards communal lands: because no cost-sharing occurs, as is the case on commercial farmlands, the total cost of thinning is payable by Government. Any means of recouping those costs should be encouraged, therefore.

The introduction of these schemes will certainly have implications in terms of services to be rendered. The MAWRD has a widespread extension service in place in the affected areas. It is recommended, therefore, that the vast majority of extension activities should focus on assisting farmers in executing bush control programmes.

(b) Availability of labour

The unavailability of labour, as mentioned by farmers, contradicts the country's current unemployment rate of 35%, which is exacerbated by an underemployment rate of about 25%.

Research was not conducted among farm workers to verify their perceptions and attitudes towards work. However, it is anticipated that the average income offered on farms is at a level that would not create any special incentive to the unemployed to take up farm work. Comparatively speaking, farm workers earn around N$80–N$350 a month (RoN 1997; cited by Werner 2001). On the other hand, a survey by the Agricultural Employers' Association of Namibia (AEAN 1999) indicates an average monthly cash wage for farm workers of N$695 and a total remuneration package of N$1,018 (cash, housing, workers' stock, and free transport of learners and ill persons). Corresponding figures emanating from the 2002 NAU wages survey are N$754 and N$1,211 per month.

Farmers also raised the issue of labour regulations that do not allow farmers to use Angolan workers. The opportunity costs of employing these workers will remain reflected in the unemployment rate. One of the reasons for this could be that the income earned by workers is not attractive enough, considering the kind of work involved. Giving farmers incentives to employ Namibians might benefit all three parties, i.e. farmers, farm workers, and the Government. Instead of looking for manpower beyond our national borders, the problem with the non-availability of labour ought to be solved at home. Since manual bush clearing or charcoal production is very hard labour (Bester, pers. comm.), the financial incentive is considered to be a crucial – albeit not the only – factor of importance in respect of labour availability.

Since there is no scarcity of labour in the country, the preferences of the unemployed need to be understood and analysed in the light of socio-economic factors. In addition to purely financial matters such as remuneration, other issues that may be of crucial importance to potential workers include the standard of accommodation offered, the availability of health care, and schooling for their children. These issues, which are familiar to farmers, need to be dealt with in order to create the right kind of incentives for employer and employee alike. However, in relation to bush encroachment, these socio-economic issues should be looked at from the perspective of encouraging Namibians to engage in bush thinning by offering them sufficient incentive to take up such work. This would, in turn, satisfy national development objectives such as economic growth, employment creation and poverty reduction.

7.5.3 Incentives for farmers to participate in Phase 2

Farmers are generally positive as regards participating in the bush encroachment project's monitoring and action plans, since an effective way of eradicating bush may help farmers improve their means of livelihood. However, some farmers argue that many workshops have been held and many reports written, but very little action has been taken on the basis of previous work done. This should be taken as a serious indication that practical action plans need to unfold as a matter of urgency from the research, reports, meetings, and time dedicated by farmers, researchers, civil servants and others in this matter.

Communal farmers were also very enthusiastic in their approach, which shows the potential is fairly high for the project to be received positively in the communities.

However, farmers need to be reassured that the project is not another "talk show", but is geared to action – and not primarily that of gathering more data. The specific incentives coincide with the nature and magnitude of assistance discussed under 7.5.2 herein (see also 7.7, "Conclusions").

7.5.4 Employment opportunities

Since Namibia has a high unemployment rate, employment creation is a high priority. Combating invader bush offers a specific opportunity for this, through the activities outlined below.

7.5.4.1 Cutting and stem-burning

Manual cutting by means of axes and saws as an initial way of combating bush as well as an aftercare measure is very labour-intensive and seems to be one of the more common ways among farmers to get rid of bush. In communal lands, this may be the only means of doing so.

From practical experience one worker can clear 1 ha of bush per week by means of stem-burning. At a cost of e.g. N$100 per hectare, 5 workers can clear about 200 ha per annum at a total income of $20,000 or N$4,000 per worker. It is important to realise that this performance criterion will differ from area to area depending on bush density, species composition, soil type and terrain.

A programme like this will not only result in higher land productivity, but will also have socio-economic benefits such as combating crime, generating income, and addressing the problem of food security. The multiplier effect through money thus earned should also be emphasised. For example, a secondary effect of bush cutting is that it provides opportunities for selling the by-products as firewood, poles, droppers and charcoal.

Since additional employment will help solve one of Government's fundamental national objectives, namely to create jobs, Government should seriously consider providing the financial incentives necessary to encourage both farmers and the unemployed.

7.5.4.2 Firewood, charcoal and other production

Local production of products like charcoal, firewood, poles and droppers offer the opportunity for people to become self-employed or to start their own small business enterprises.

Such a development could be instrumental in – and even fundamental to – solving the bush encroachment problem nationally. It would require the establishment of a national wood industry, in which process Government should play a major role.

In the same way as Government supported the meat industry during difficult times, which allowed it to become one of the mainstays of the country's economy, so should it support a national wood industry. A reasonable income from the by-products of bush clearing could balance the expense of bush control itself. Presently, a separate study (independent of this project) is under way to determine the kind of institutional framework such an industry would need, what viable economic products it would deliver, what its business plan would look like, and what would constitute the policy and legal framework within which the proposed industry could thrive.

Figure 7.2: Charcoal and fire wood production with the ultimate purpose to restore rangeland on denuded soil

An effective wood industry could, for example, pave the way to much larger and organised exports of charcoal and could lead to import substitution of poles and droppers. In the case of charcoal production, which has been analysed as being economically viable, 4.5 times more labour is needed in comparison with clearing land. On the assumption that 2 million and 0.5 million ha in commercial and communal areas, respectively, will be utilised for charcoal production, the analysis shows that 10,300 workers could be employed or contracted over a 20-year period. Based on very conservative yields, 187,000 tonnes of charcoal per annum are projected to be produced. This figure is about 100,000 tonnes more than the present annual production. Depending on the availability of markets, this figure could be substantially increased.

7.5.4.3 Marketing

The availability of lucrative markets will certainly serve as a strong incentive to become involved in bush harvesting and charcoal production.

A basic but decisive problem associated with the marketing of charcoal is the uncertainty of a constant yield of quality charcoal that exists among both producers and buyers. For producers, fluctuations in the charcoal price serve as a disincentive to produce, while for buyers, the uncertainty of the supply of quality charcoal poses a risk to their business. This state of affairs has caused a vicious cycle that will need external intervention to break. These are obstacles in the production–marketing chain that need special attention if the market for Namibian charcoal is to be boosted.

Figure 7.3: Workers packing charcoal for the market

An effective management corps, supported by an effective decentralised infrastructure, is crucial to ensure the somewhat precarious industry does not teeter on the brink of collapse. The remoteness of many areas and the availability of transport make it very difficult for farmers to participate in charcoal production, especially in communal areas.

The Woodland Management Council, which was established to steer and give momentum to the industry, was never formalised and is presently dormant. There is an urgent need to revive this body and grant it legal status to achieve its objectives, namely –

- to control the quality of charcoal produced
- to improve the market, and
- to ensure the environmental sustainability of the charcoal industry.

The business management and marketing function should eventually be taken over by the industry, with strong support from Government during the initial stages.

For about eight years, Jumbo Charcoal – a private company that operates a factory in Okahandja – has cut wood and bought charcoal from about 50 commercial farmers. The main activity has been the purchasing, grading and packaging of charcoal at a factory in Okahandja. The final product is primarily exported to South Africa and Europe.

7.5.5 Summary of the main findings

Farmers are in need of assistance. Communal farmers, in particular, urgently need to be made aware of bush encroachment and the way it impacts economically on their farming activities.

Both communal and commercial farmers have urged Government to address the problem of land tenure, albeit from different perspectives: firstly, because of the common use of grazing areas, and secondly, because of the mixed messages being sent by Government concerning the future of resettlement on commercial farms in Namibia.

Financial assistance is a key area of support for farmers, but the assessment suggests that the establishment of an effective wood industry and marketing of products emanating from bush thinning would be strategic ways of combating bush on farmlands in an economically and environmentally sustainable way.

Buy-in by farmers will depend largely on how action-oriented Phase 2 of the bush encroachment project is. Commercial farmers in general are becoming discouraged, and need to see practical results and decisions from policy-makers.

The more viable employment opportunities related to bush control operations currently seem to be bush-cutting, stem-burning, and charcoal and woodchip production. The labour need for manually applying chemicals to combat bush encroachment could also be considered an important way to create jobs.

7.6 Skills training programme for agricultural extension officers, researchers, technicians, and workers

Extension officers should play an important role in training farmers during Phase 2.

A definite need was identified to train extension staff, especially those placed in communal areas. Such training programmes should focus on the economic and environmental implications of bush encroachment, the causes of bush encroachment, the ecological principles of resource management, and different methods of bush control.

7.6.1 Setting priorities

Despite being identified as a national priority, bush encroachment has not been recognised as a top priority in extension officers' activity programmes for communal and commercial farmers to date.

Compared with communal farmers, commercial farmers seem to be more familiar with the different debushing methods, so their training needs are not as high in this respect. However, a substantial percentage of commercial farmers were not engaged in bush-clearing exercises, especially the younger generation, so they should not be excluded from training programmes. Since practical skills and experience might in some cases be higher among commercial farmers than among extension officers, some of the most knowledgeable commercial farmers could be involved in training extension officers to serve the commercial and communal farms.

A training scheme for extension officers should be developed. This scheme could be based on a sandwiched theory-and-practice model, offering the provision of a mix of theoretical knowledge and practical skills.

Training should focus on the different methods of clearing bush, with the emphasis on economic viability and environmental sustainability. Although many commercial farmers already seem familiar with the methods and practices to apply, there is a dire need for training in environmental principles. Communal farmers, on the other hand, need to start with basic training on all of these subjects, especially as regards raising awareness of the economic implications of bush encroachment on their livelihoods. A proper understanding of the environmental issues at stake is also imperative. A specific curriculum for this purpose should be developed, with an emphasis on the ecological, physiological and legal aspects of bush harvesting and control.

7.6.2 Summary

There is a fundamental difference between the training needs of extension officers and technicians, and that of farmers in commercial and communal areas. Communal farmers need basic knowledge about the phenomenon, the economic implications of invasive bush species, and the basic techniques employed to fight bush encroachment. Commercial farmers, on the other hand, need more details to add to their current knowledge base and skills.

Training should not focus on technological aspects alone, but should include environmental aspects, the positive role of bush and trees in nature, alternative ways to utilise bush, and the socio-economic aspects determining people's behaviour. All training should be by means of short courses.

7.7 Conclusions

- The general conclusion emanating from this study is that the socio-economic incentives for farmers in communal and commercial areas in respect of bush clearing should be addressed in their own contexts.
- Both communal and commercial farmers are greatly challenged by bush encroachment in terms of production and financial losses.
- Of the researched methods to combat bush encroachment, the slower, more labour-intensive and biologically-based methods (or combinations thereof) are the more economically viable solutions under current conditions.
- Chemicals used for the thinning of bush are not always selective and should be applied very target-specifically. Although they are effective for bush control, they are very expensive.
- From available evidence the recommended herbicides have no detrimental residual effects on the environment. This statement is supported by the EIA carried out to examine methods recommended to farmers in this report.
- Bush encroachment should be seen as a societal challenge, and not only as the problems a few individuals are responsible for – especially if losses for the national economy and environmental degradation are taken into account.
- The next crucial issue is to establish a wood industry, based on business principles, to manufacture or process as much of the products locally and to identify and maintain lucrative markets for economically viable products. The advantages of, for example, establishing a charcoal production and marketing company under the current Export Processing Zone regulations should be investigated, since most locally produced charcoal is exported to South Africa and Europe.
- A well-structured institutional framework is imperative in regard to a wood industry and Government intervention would be seen as crucial to its success.
- The fact that individual communal farmers or communities cannot reap the benefits of all their inputs in respect of cleared areas acts as a disincentive for them to take action against invader bush in a more comprehensive and organised way.

- Some commercial farmers highlighted uncertainty concerning the current land policy as a deterrent for investment in bush clearing, despite the fact that a clear "willing buyer – willing seller" policy is in place.
- Because income-generation and employment creation are of enormous importance in Namibia, any endeavours that would promote these should be prioritised, e.g. by Government subsidising bush clearing programmes and supporting the establishment of a wood industry for the by-products of bush clearing.
- The generation of income from charcoal and other by-products of bush control might pose a more sustainable solution than creating a dependency on Government subsidies for bush-control programmes. The potential of local processing or manufacturing of intruder-bush products has recently been studied and the results and recommendations of the research should receive urgent attention.
- The findings from this study also point to a need for further education and training among farmers and agricultural extension workers alike. This need is more pronounced among farmers and extension personnel residing and working in communal areas.
- If, through proper bush control, each hectare of farmland can be made more productive, profitable land would be created for redistribution and resettlement. This could materialise through a joint effort between Government and the farmers, where more room could be created vertically for resettlement of landless people.
- Addressing the problem of bush encroachment will, therefore, open new opportunities for land reform.

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Chapter 8
Review of the policy environment and proposals for policy reform[21]

[21] Constituted Component 6 of the original Terms of Reference

8.1 Scope of the study

As was emphasised in the discussion of the causes of bush encroachment (Chapter 2 herein), technical solutions to a biophysical problem often fail because of a socio-economic policy and legislative environment that is not conducive to success. The National Agricultural Policy (RoN 1995a:5) also states that –

> if macro-economic policies do not create a stable and conducive environment, then specific policies to strengthen the agricultural sector are likely to fail.

Farmers are very frequently blamed for the alarming deterioration rate in the natural resources of Namibia in terms of overstocking and mismanagement of the land. This viewpoint should be put in perspective, since farmers' actions are sometimes dictated by forces beyond their control. It became imperative, therefore, to scrutinise and analyse the policy environment in which the agricultural sector has to perform. Following an invitation to tender, the relevant study was contracted out to the Namibian Economic Policy Research Unit (NEPRU) which assigned Dr Wolfgang Werner for this purpose.

The Terms of Reference for this study called upon the consultant to review the policy environment and relevant legislation with regard to bush encroachment and its reversal. This request stemmed from an observation that previous efforts to address bush encroachment offered mainly technical solutions, and disregarded the wider policy environment.

The intention of such a review of the policy environment was to identify gaps and prepare proposals for policy reform. Full details of the findings can be found in the report by Werner (2001) entitled "Review of the policy environment and proposals for policy reform", which is available at the library of the Directorate of Environmental Affairs.

8.2 Methodology

The methodology consisted of a thorough review of appropriate policies and legislation to assess the degree to which they provided a suitable framework to address the prevention or eradication of bush encroachment. This was followed by interviews with key informants, who were selected according to their professional knowledge of the issues and their practical managerial experience in the field of intruder bush control. Due to time and budget limitations it was not possible to conduct personal interviews with farmers about their views on the policy environment or, more importantly, on what future policies should address. This meant that most key informants were Windhoek-based, although some telephonic interviews were conducted with commercial farmers in the country.

8.3 Bush encroachment in the wider context

Despite popular myths that commercial farming is immensely profitable, the sector has amassed large debts. Over the last few decades, the financial position of commercial farmers has gradually worsened. From 1990–1998, total agricultural debt increased by 103% in nominal terms (Grobler 2000). The debt burden of the sector continued to grow to reach approximately N$1.1 billion by 2001.

A major cause of the rising agricultural debt is the worsening terms of trade in the agricultural sector. For several decades, producer prices did not increase in direct proportion to increased input costs. During the 1970s, for example, input prices increased by 475%, while meat prices increased by only 240% and karakul by a mere 146% (SWA 1981:57–58). While similar figures could not be located for the intervening years, the NAU, in its "Agricultural overview and outlook" for 1999/2000, ascribed the continuing rise in debt to the fact that "real producer prices decreased more significantly while input costs rose" (NAU 2000).

Cattle numbers on commercial farms decreased from a peak of 2.6 million in the late 1950s to 1.2 million by the mid-1990s. Land degradation, notably bush encroachment, has undoubtedly played a role in this dramatic decline in livestock numbers (Lange et al. 1997). Research indicates, however, that this decline in livestock numbers did not bring about a decline in beef production per hectare of rangeland, which has remained constant over a 40-year period. This suggests that the decline in cattle numbers and resultant reduction in stocking rates might have been a deliberate strategy by commercial farmers to increase herd productivity (ibid.:12). Thus, bush encroachment needs to be acknowledged to have prevented Namibia's agriculture sector from reaching its full potential in terms of beef production. On the other hand, the eradication of bush is likely to lead to increased levels of beef production.

In practical terms, many farming units became too small to run profitable and financially sound businesses (Harrison 1983). Ten years later, 40% of commercial farms were found to be economically unviable on account of their size and carrying capacity (Rawlinson 1994; cited by Lange et al. 1997).

As many commercial farms became too small to provide acceptable returns, farmers sought to compensate for these declining outputs in several ways. One way was to increase stock numbers in order to maximise short-term returns. This reinforced a vicious circle where declining incomes led to inherent overstocking, which in turn encouraged bush encroachment, which in turn led to further losses in productivity.

The diversification of production and incomes also provided farmers with an opportunity to improve their financial and economic situation. Wildlife-based tourism, for example, has increased considerably in recent years. Since the 1970s the amount of wildlife on commercial farms has increased by 77% (Lange et al. 1997). In addition, farmers make use of off-farm investments to sustain themselves. Since the profitability of farming was so low, however, it can be assumed that only a few of the more affluent farmers could make use of these opportunities.

The purpose of this brief discussion is to focus attention on the fact that bush encroachment may have been encouraged by the declining financial well-being of many commercial farmers. Interventions to eradicate bush will have to take into account that commercial farming simply is not as profitable as popular myth would have it. Policy measures and incentives to prevent bush encroachment and eradicate problem bush will have to recognise that, for many farmers, income from agriculture forms only one component – albeit an important one – of overall income. This is supported by off-farm income derived from fixed and moveable investments. The overall financial situation of farmers with bush-encroachment problems needs to be taken into consideration in order to devise policies and incentives that are affordable, if not even profitable, to farmers.

8.4 Policies and legislation

The policy environment for addressing bush encroachment and its prevention is much wider than the biophysical aspect of the problem. Apart from the wider macroeconomic environment that shapes management decisions on farms, land rights and pasture management practices, for example, also have a bearing on bush encroachment.

The following review will assess the extent to which the current policy and legislative framework inadvertently encourages bush encroachment or facilitates its eradication.

8.4.1 The Constitution

The Constitution of the Republic of Namibia (GRN 1990) lays the foundation for all subsequent policies and legislation in Namibia. Article 95(l) stipulates that the State shall actively promote and maintain the welfare of the people by, amongst other things, adopting policies which include the –

> maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilization of living natural resources on a sustainable basis for the benefit of all Namibians....

The maintenance of ecosystems is a constitutional obligation, therefore, and not simply a matter of choice.

However, there is a concern that some provisions of the Constitution may inadvertently undermine the good intentions of Article 95(l). In the first place, the Constitution does not protect any customary rights to land and natural resources in non-freehold[22] or communal areas. Secondly, Article 21(h) states that it is a fundamental human right of all Namibians to "reside and settle in any part of Namibia", which may threaten the security of tenure which customary tenure systems may be providing. This in turn may lead to a situation where uncontrolled settlement in the non-freehold areas may increase pressures on agricultural land and lead to overstocking and subsequent bush encroachment.

[22] The characterisation of two agricultural subsectors as *freehold* and *non-freehold* areas is preferred to the common reference to *commercial* versus *communal* land because the latter juxtaposes a production system to a land tenure system. See also footnote No. 9 in Chapter 3 herein.

While secure land and resource tenure will not in and of itself improve natural resource management, it is equally true that a lack of secure tenure undermines any incentives to manage land and its resources sustainably (NAPCOD 1996).

8.4.2 National Agricultural Policy

The overall goal of the National Agricultural Policy (NAP) is to (RoN 1995a) –

> increase and sustain the levels of agricultural productivity, real farm incomes and national and household food security, within the context of Namibia's fragile ecosystem. This includes the promotion of sustainable utilisation of the country's land and other natural resources.

More specifically, the NAP commits Government to "ensure that sound agricultural and macro-economic policies and a conducive investment climate encourage efficient and sustainable resource use" (ibid.).

Thus, Government will address the serious problems of desertification and environmental degradation caused by the destruction of forest cover, soil erosion, overgrazing and bush encroachment (ibid.:32). Bush encroachment, in particular, is a matter of great concern to the MAWRD. The NAP regards the eradication of bush as an important part of its strategy to exploit the full potential in commercial and small-stock farming areas.

In terms of the NAP, Government intends to "establish mechanisms to support farmers in combating bush encroachment effectively over both the short and long term". In line with this, Government will (ibid.:25) –

> endeavour to ensure that appropriate bush control technologies and inputs are available from the private sector at the lowest possible prices. Research and advisory services to farmers on biological and technical issues relating to bush clearing and utilisation will also be strengthened. [It will also] promote labour-intensive and private sector initiatives which utilise bush products.

These strategies could involve the development of bush clearing and utilisation industries, including charcoal, fuel briquettes, and chipboard manufacture (ibid.:14).

The NAP also proposes the review of all existing legislation with the aim of bringing it in line with national policy. With regard to legislation required to reduce agricultural risks, the NAP limits itself to pests and disease, the importation of unregulated food, plant and animal products, and fertilisers and chemicals. Amongst other things, strictly implementing agricultural legislation on soil conservation and resource management will contribute towards reducing risk to the agricultural economy and ecosystem (ibid.:19).

The NAP contains a number of policy statements, which, while not dealing directly with the eradication of bush, have a bearing on options for eradicating and preventing bush encroachment. The role of the State and subsidies, for example, are important in addressing bush encroachment.

The role spelled out for the State in achieving the objectives set out in the NAP differs markedly from before Independence. This will have a direct bearing on the respective roles of farmers and the State in eradicating bush encroachment. Government will no longer be the central actor in promoting agricultural development. Instead, it will concentrate on creating a macroeconomic environment conducive to agricultural development, within which private sector initiatives undertaken by individuals, non-governmental organisations (NGOs), cooperatives and other community groups can provide essential agricultural services (ibid.:8–12).

In terms of the NAP, long-term and/or continuing subsidies will be avoided as they tend to cause distortions in the economy and contribute towards fiscal deficits.

The policy does concede, however, that subsidies can play a useful role in achieving specific short-term agricultural and socio-economic objectives.

It is conceivable that the eradication of bush could qualify for this.

The NAP envisages that tax legislation will be reviewed with the aim of maximising revenue and tax efficiency. It anticipates that levies and duties will be done away with in favour of taxes on income and land. Tax incentives will be considered as drought-coping mechanisms (ibid.:24).

Government will also encourage the use of environmentally friendly farm inputs. Supervision will be strengthened to ensure that ineffective and dangerous chemicals will not be improperly imported or used (ibid.:24):

The chemicals mentioned in the NAP refer to fertilisers and pest management in general. To the extent that bush encroachment is not commonly classified as an agricultural pest, chemicals for its eradication and control should be included in this paragraph.

With regard to land tenure, the NAP proposes permitting the subdivision of agricultural land in order to broaden access to land. However, this will only be allowed on condition "that appropriate provision is made for the maintenance of farming units to an economically viable size and the long-term sustainability of natural resources and agricultural production on the land". It envisages that a land tax will discourage "overly large and multiple agricultural holdings" (ibid.:35).

Finally, the NAP acknowledges that the country's agricultural potential can only be realised if effective drought-preparedness planning and responsive drought management are implemented (ibid.:13).

8.4.3 National Drought Policy and Strategy

To this effect, the National Drought Policy and Strategy was approved at the end of 1997 (RoN 1997b). This represents a significant shift away from pre-Independence drought relief policies. Some of these changes are summarised in Table 8.1.

Pre-Independence drought relief policy	National Drought Policy and Strategy, 1997
Inadequate definition of *drought*: ad hoc, not scientific	• *Disaster drought* will be scientifically defined • Aridity and highly variable rainfall are to be regarded as normal
Government bore the main risk of disaster management	• Managing drought risk will shift from Government to farmers • Financial assistance will shift towards support for on-farm risk management • A National Drought Fund will be set up to finance drought relief along the principle of counter-performance
Drought subsidies encouraged unsustainable farming practices (e.g. fodder subsidies, and support beyond maintaining core herds)	Livestock programmes will encourage sustainable farm and range management
Vulnerable food distribution programmes were poorly targeted and inefficient	Food vouchers are proposed to make delivery more efficient

Table 8.1: Comparison between pre- and post-Independence drought relief policies

Consistent with the NAP, the National Drought Policy and Strategy foresees a very different role for the State in addressing drought conditions in the country. Whereas Government used substantial public funds in the past to mount drought relief programmes, the new policy transfers much of on-farm drought risk management to individual farmers. Government will spend monies on assisting farmers to manage drought in the long run, rather than provide short-term drought relief (ibid.:4–5). More specifically, the role of farmers in drought management will be to –

- manage agricultural activities in an economically and ecologically responsible manner, and in a way that takes low and variable rainfall, crop and grazing production, and consequent income variation into account
- develop ways of reducing drought in the longer term, and
- contribute in normal rainfall years towards the cost of financial assistance during times of disaster drought.

Amongst other things, the State will help farmers to manage drought-induced income variability and reduce vulnerability to drought by promoting drought-mitigating practices and diversification as well as the development of post-disaster drought recovery and preparedness programmes (ibid.:10). The implementation of sustainable rangeland management practices is regarded as an important element of reducing vulnerability to drought. In this regard, "support for tackling bush encroachment also needs to be considered" (ibid.:25).

Losses of rangeland productivity induced by bush encroachment increase the financial vulnerability of affected farmers to drought. Management plans for drought preparedness should, therefore, include the prevention and/or combating of bush encroachment.

The National Drought Policy and Strategy proposes that rangeland degradation during periods of disaster drought be prevented by moving away from fodder and forage subsidies, as these encourage farmers to retain excessive numbers of livestock. Instead, incentives will be used to encourage farmers to market their livestock in times of drought (ibid.:17).

An important ingredient of the National Drought Policy and Strategy is that only those farmers who have implemented sustainable farm management practices will qualify for drought aid in future. In cases where poor pastures are the result of poor management practices such as overstocking, no drought aid will be forthcoming. In assessing management practices, the constraints imposed by insecure customary tenure systems on proper pasture management will be taken into consideration (ibid.:18).

Farm management practices should not only pertain to existing pastures, but should include an incentive to bush thinning. Farmers should be encouraged to keep proper resource and farm management accounts to monitor management practices.

The establishment of land rights in the non-freehold areas is regarded as important in giving land-users control over their natural resources and, hence, enable them to develop strategies for withstanding drought more successfully.

Legally sanctioned land rights in non-freehold areas will not, in and of themselves, solve bush encroachment in those areas. They are, however, a necessary condition for implementing pasture management systems designed to prevent and combat bush encroachment.

Finally, the National Drought Policy and Strategy regards an efficient and well-managed information system as one of the cornerstones of the proposed long-term drought management strategy. Amongst other things, reliable indicators need to be developed in order to take informed decisions (ibid.:29).

8.4.4 Subdivision of Agricultural Land Act, 1970 (No. 70 of 1970)

This Act aims to control the subdivision of agricultural land by making such subdivision subject to the relevant Minister's consent. The Act also prohibits the vesting of undivided shares in any person unless the Minister has consented to it. The Act has not been repealed.

Provisions of the National Land Policy and the Agricultural (Commercial) Land Reform Act, 1995 (No. 6 of 1995) seem to be in conflict with the intentions of this Act. This will be discussed in more detail in Sections 8.4.8 and 8.4.10, respectively.

8.4.5 Fencing Proclamation 57 of 1921

This Proclamation does not deal at all with issues related to bush encroachment or even range management. Instead, it lays down procedures for erecting fences and their maintenance. Section 29 prescribes the area of bush that may be removed for erecting a fence and provides for the removal of trees standing in the immediate line of such a fence.

8.4.6 Soil Conservation Act, 1969 (No. 76 of 1969)

The objective of this Act is –

> [t]o consolidate and amend the law relating to the combating and prevention of soil erosion, the conservation, improvement and manner of use of the soil and vegetation and the protection of the water sources … .

The definition of *soil conservation* in section 1 of the Act is very wide and includes –

- soil erosion and the stabilisation of land subject thereto
- the prevention of drift sand and stabilisation of land subject thereto
- the protection, conservation or improvement of the vegetation and the surface of the soil
- the protection, conservation or stabilisation of any natural water source, and
- the prevention of silting up of dams and the pollution of water by silt.

This Act gives the Minister wide-ranging powers with regard to the utilisation of land. These include the power to withdraw land from cultivation and grazing and to direct land-users to apply crop rotation and soil-stabilising measures. The Minister is also authorised to issue directives relating to the resting and utilisation of pastures, as well as to the number of large stock or small stock that may be kept on land. The Act further provides the Minister with powers relating to "the prevention, control and extinguishing of veld, mountain and forest fires".

The Minister may order the owner of land to construct soil conservation works. Such works would seek to achieve any of the objectives of the Act. In order to encourage farmers to erect soil conservation works, the Minister is given powers to pay subsidies or grants for the development of such works, or defray portions of costs involved.

The Act provides for the establishment of a Soil Conservation Committee, primarily to "advise the Minister, owner or occupier of land on all matters relating to soil conservation".

In addition, fire protection areas are provided for in the Act, as is the establishment of fire protection committees for each fire protection area. These committees are responsible for the preparation of fire protection schemes and for their submission to the Minister. Fire protection schemes have to describe the areas in which they would be implemented and have to contain provisions relating to "the regulation or prohibition of veld burning" as well as "the prevention, control and extinguishing of veld and forest fires".

Powers of expropriation are given in terms of the Act where land is required for "the prevention of soil erosion or the stabilising of land subject thereto", or "the protection of catchment areas or the conservation of water sources".

8.4.7 Weeds Ordinance 19 of 1957

This provides the Minister with the power to declare, by way of Proclamation, any plant to be a weed. Once this has happened, an official of the Ministry may order the owner of land on which such a weed has been declared to eradicate any such weed. The Minister may also make regulations to restrict the movement of livestock or prohibit or restrict the importation, distribution, conveyance or sale of any seeds, or any material with which the seed or any portion of any particular weed has become mixed. Corbett (1995) concludes that although weak, these provisions "could be used in the battle against noxious plants".

8.4.8 National Land Policy

The National Land Policy (RoN 1998b) was approved in 1998, three years after the Agricultural (Commercial) Land Reform Act was passed into law. As such, it does not contribute much on land policy that is not already contained in the legislation.

Referring to Article 95(l) of the Constitution, the Policy requires environmentally sustainable land and natural "resource use" (ibid.:2). Where land will not be used in an environmentally sustainable manner, proposed Land Boards will be able "to terminate or deny the award of title". In order to achieve sustainable use, Land Use and Environmental Boards, through their subordinate structures, will ensure that land use planning, land administration, land development and environmental protection are promoted at national, and regional level. Land-use planning and natural resources management will be the responsibility of such Boards (ibid.:16).

The Policy proposes the formalisation of tenure arrangements in several ways, all of which suggest more exclusive rights to land and natural resources. It stipulates that tenure rights allotted under this Policy and consequent legislation (ibid.:3) –

> will include all renewable natural resources on the land, subject to sustainable utilisation and the details of sectoral policy and legislation. These include natural resources, tourist attractions, fish, water, forest resources and vegetation for grazing.

Such rights will be exclusive rights, protected by law (ibid.:11).

The Policy also provides for the registration of lease agreements in respect of communal land where "no person or group of persons has existing rights to the land". In similar vein, holders of Permission To Occupy (PTO) certificates granted by the Ministry of Lands, Resettlement and Rehabilitation will be able "to apply to their relevant regional Land Boards for conversion to one of the new forms of tenure" (ibid.:12).

On excessive land holdings, the Policy reinforces the provisions of the Agricultural (Commercial) Land Reform Act, which will be discussed in more detail below.

In summary, several points can be made about the National Land Policy:

- It recognises the need for sustainable natural resource management and provides for an institutional framework to coordinate land-use planning and natural resource management.
- The Policy proposes the introduction of exclusive rights for individuals and communities to land and natural resources. While this is not sufficient to prevent bush encroachment and encourage its control, it is a necessary condition for introducing improved range management principles and encouraging people to invest in the land to which they have exclusive rights, particularly in non-freehold areas.
    - Poor natural resource management will be sanctioned by withdrawal of "title". Reference to "title" is slightly misleading in this context, since the Land Policy limits the powers of regional Land Boards to the registration of long-term leases on non-freehold land. In view of this, these sanctions seem to be aimed primarily at farmers in non-freehold areas. The Policy does not provide for similar sanctions against poor management on freehold land or land allocated under the redistributive land reform programme.

8.4.9 National Resettlement Policy

The stated aim of the Resettlement Policy (RoN 2001a) is to resettle eligible people in a way that is "institutionally, sociologically, economically and environmentally sustainable, and which will allow settlers to be self-supporting" (ibid.:1). The Policy's objectives include the alleviation of human and livestock pressure in communal areas by resettling farmers on land acquired for redistribution (ibid.:2).

Beneficiaries of resettlement will be granted 99-year leasehold rights (ibid.:46).

While the Resettlement Policy commits Government to implement resettlement in an environmentally sustainable manner, it provides no guidelines on how this should be achieved. It is imperative that resettlement schemes are planned in a way that facilitates the sustainable utilisation of natural resources.

8.4.10 Agricultural (Commercial) Land Reform Act, 1995 (No. 6 of 1995)

The Agricultural (Commercial) Land Reform Act provides the legal framework for redistributive land reform in Namibia. It provides for the acquisition of freehold land, and its subdivision and redistribution to specified Namibian citizens.

In terms of the Act, the Minister of Lands, Resettlement and Rehabilitation has the power to overrule the Subdivision of Agricultural Land Act, 1970 (No. 70 of 1970) for resettlement purposes.

According to the Act, apart from a right of first refusal regarding all freehold agricultural land offered on the open market, the Government can acquire land that is regarded as underutilised or in excess of two economic units (p. 13 of the Act). The size of economic units will be determined in terms of AEZs to be established by the MAWRD (ibid.:14–15). Underutilised land is conceptualised purely in terms of utilisation for agricultural purposes. Wildlife or tourism-related utilisation could, thus, be construed as "underutilised"(NAPCOD 1996):

> "Under[-]utilization" of land is not sufficiently tightly defined in the Act to be of much use. More specifically, under[-]utilization of land and multiple farm ownership may encourage more extensive range management systems in marginal areas, relieving pressures on land threatened by bush encroachment. In addition, this may lead to recovery of degraded grazing land.

The Act provides for the subdivision of freehold land acquired for redistribution for purposes of small-scale farming. Subdivision has to be done in accordance with a partition plan (pp. 37–38 of the Act). The Act does not require such a partition plan to explicitly reflect on environmental issues such as bush encroachment or its control. However, a condition of occupying an allocated farming unit is that it must be farmed beneficially. This means, amongst other things, that sound husbandry methods are to be practised. Livestock numbers will have to be in accordance with the requirements laid down by the Ministry of Lands, Resettlement and Rehabilitation on the recommendation of the Land Reform Advisory Commission (ibid.:42).

Rights to an allocation will consist of a 99-year leasehold agreement with an option to purchase the parcel of land after five years (ibid.:41,44).

The Land Reform Advisory Commission has laid down minimum land ceilings for the northern and southern parts of the country to ensure that sustainable agricultural production can be pursued. In the northern half, land allocations should not be less than 1,000 ha per household, while the size of allocations in the south should not be less than 3,000 ha.

There is a concern that allocations of this nature will not enable farmers to apply flexible range management methods. As land capabilities can vary dramatically within single regions, agro-ecological zoning and mapping should be strengthened to determine minimum farm sizes that are appropriate to specific AEZs. If resettlement is not planned in accordance with AEZs and is not monitored or controlled, it may lead to overgrazing and subsequent bush encroachment.

8.4.11 Land tax

The Agricultural (Commercial) Land Reform Act provides for the introduction of a land tax. The Agricultural (Commercial) Land Reform Second Amendment Act, 2001 (No. 2 of 2001), introduces this tax. For the purposes of levying a land tax, regulations will provide for the valuation of freehold farming land at regular intervals. The basis for valuation for a land tax in Namibia is the unimproved site value of the land. In terms of draft Land Tax Regulations, *unimproved site value* has been defined as the best price that may reasonably be obtained at the date of valuation, –

> assuming that no regard has been made to the decrease in price on account of factors such as excessive grazing, bush encroachment and other [*sic*] caused by bad farming practices and poor management of the taxable land. …

A land tax is likely to put additional strain on a sector that is already experiencing financial difficulties. This may tempt farmers to "recover" these additional costs by increasing the number of livestock on their farms – thus increasing the pressure on grazing land.

8.4.12 Communal Land Reform Act, 2002 (No. 5 of 2002)

The Communal Land Reform Act provides for the allocation of rights in non-freehold areas, the establishment of Communal Land Boards, and the powers of traditional leaders regarding non-freehold land (Act, p. 2).

Communal Land Boards will cater for an entire communal area or part of it. The functions of such Boards are restricted to land administration and land tenure issues. These Boards will receive applications for rights of leasehold, and will establish and maintain appropriate land registers (ibid.:4–5).

The Act also allows for the continued allocation of customary land rights by traditional leaders, but introduces some checks and balances such as maximum land holdings.

With regard to fencing of communally used pastures, the Act stipulates that this be prohibited. However, the Act also provides a procedure to legalise fences erected up to the point when the legislation is enacted (ibid.:15–16).

The right of Traditional Authorities to impose conditions for the utilisation of commonages will be entrenched, but their powers are extended to include the imposition of such conditions as limiting the number of livestock and enforcing the practice of rotational grazing (ibid.:17).

The Act also proposes the introduction of leasehold in communal areas. Applications to obtain leasehold in respect of a portion of communal land will have to be made to the Communal Land Boards. The latter may approve an application only after the relevant Traditional Authority, in whose area the land is situated, has consented. A right of leasehold for agricultural purposes may only be granted within an area that has been designated by the Minister of Lands, Resettlement and Rehabilitation for agricultural purposes after consultations with the Traditional Authority and Communal Land Board under whose jurisdiction the proposed designated land falls (ibid.:18–19).

It is not clear from the Act whether only individuals may apply for leasehold, or whether legal personas are included in these provisions as well. The latter would enable communities to apply for leasehold over the land they use. This would be in line with the National Land Policy, and would provide communities with the security of tenure required for improved management and investments in land. Specific attention also needs to be paid to inheritance rights.

The Act does not state clearly whether tenure rights allocated under its provisions include rights to all renewable natural resources as contemplated in the National Land Policy. Thus, the question remains as to the kind of rights, in relation to bush encroachment, that communities or users will enjoy under the new Communal Land Reform Act. This will impact on the right to harvest wood for commercial purposes, e.g. firewood and the production of charcoal.

8.4.13 Namibia Forestry Strategic Plan

The aim of the Namibia Forestry Strategic Plan (RoN 1996a:i) is –

> to specify forestry objectives and strategies that will guide efficient programming of forestry development projects, within the framework of integrated national development.

The Plan is aimed primarily at the protection and sustainable utilisation of natural forests. It maps out the various advantages of doing this (ibid.:iii):

- Conserving natural ecosystems for their biodiversity and other values
- Contributing to increased agricultural productivity through soil and water conservation
- Supporting national efforts aimed at poverty alleviation and equitable development, and
- Protection of biodiversity and preventing climate change.

The Plan proposes four programme areas to achieve these objectives. These are (ibid.:46–51) –

- institutional capacity-building, which will focus, among other things, on the development of institutional management systems, human resource development, and research and information management
- the community-based management of natural forests, which will grant communities the right of ownership to forests and involve the relevant communities in managing such forests
- a farm forestry programme, which will attempt to integrate forestry into existing farming systems and so contribute to food security and income-generation, and
- an environmental forestry programme, which will manage designated forest areas for conservation.

Following the trend set by the National Agricultural Policy and the Drought Policy and Strategy, the Namibia Forestry Strategic Plan regards the participation of communities and individuals in forestry development and management as crucial. The State will be responsible mainly for planning, monitoring and enforcement functions.

The Plan devotes a whole section to the protection of forests. Amongst other issues, it proposes the reduction of uncontrolled and accidental forest fires and changing the policy of burning off patches of woodlands to improve hunting grounds into using fire only as a controlled tool under specific circumstances (ibid.:33).

The main focus of the Namibia Forestry Strategic Plan is the conservation and sustainable utilisation of undegraded forests and woodlands. The rehabilitation of degraded woodlands or reduction of bush densities through bush eradication does not seem to fall within the ambit of the Plan.

8.4.14 Namibia Forest Development Policy

This document (RoN 2000f) represents a revised version of the Forest Policy of 1992. The revised Policy should contribute towards the achievement of Namibia's goal of strategic rural development. More specifically, the new Policy contains poverty alleviation measures that are aimed at relieving pressure on the environment. It enunciated four broad goals, namely (ibid.:iii) –

- the intensification of crop and livestock production through innovative land-use strategies that hold possibilities for increasing farm productivity and incomes
- the development of small- and medium-scale manufacturing enterprises based on wood, particularly non-forest wood
- conservation of the wildlife habitat as the base service for developing a tourism industry, and
- the development of a sustainable rural economy that the country is capable of supporting indefinitely.

The aims of the new Policy are to (ibid.:1–2) –

- reconcile rural development with biodiversity conservation by empowering farmers and local communities to manage forest resources on a sustainable basis
- increase the yield of benefits of the national woodland through research and development, application of silvicultural practices, and protection and promotion of requisite economic support projects
- create favourable conditions to attract investment in small- and medium-scale industries based on wood, particularly non-forest wood, and
- implement innovative land-use strategies including multiple-use conservation areas, protected areas, agroforestry and a variety of other approaches designed to yield global forestry benefits.

The Namibia Forest Development Policy regards the assignment of effective property rights as a precondition for sustainable management of the nation's woodlands and savannas. It is assumed that (ibid.:3) –

> current traditional communal resource management practices and range management practices in commercial areas are both unable to guarantee sustainable management of [the] nation's forest resources.

Thus, it is proposed that forest management practices in both subsectors be updated and supported by technical expertise from the Directorate of Forestry (ibid.:3). The Policy foresees that the activities of private-sector farmers will only be regulated where incentives to induce voluntary policy implementation are ineffective "and the rights and mechanisms for negotiated settlements are insufficient" (ibid.:4).

Forestry extension officers will advise private forest-owners on, amongst other things, the possible uses of and potential benefits from forest management (ibid.:4). The Directorate of Forestry will ensure that private farmers aim to manage forests in such a way as to realise the maximum use of forest products while conserving biological diversity (ibid.:5).

In commercial farming areas, the Policy encourages debushing for the purpose of charcoal production as this enhances range productivity, while agroforestry is encouraged in the communal areas. The Directorate of Forestry, together with the Ministry of Trade and Industry, is exploring ways to develop small- and medium-scale enterprises based on forest wood and non-wood raw materials (ibid.:9).

Property rights to forests are regarded as essential for the effective and sustainable use of forest resources. This is particularly critical in non-freehold (i.e. communal) areas. It is anticipated that the Namibia Forest Development Policy will be able to exploit leasehold tenure arrangements proposed by the National Land Policy (ibid.:8).

Finally, the Namibia Forest Development Policy regards the development of forest management plans as urgent. It argues that (ibid.:10) –

> poor woodland management and protection strategies coupled with poor appreciation of the need to maintain and manage forest ecosystems is the greatest challenge in sustainable forest management in Namibia.

It is not clear from the Namibia Forest Development Policy what constitutes a *forest* as opposed to woodlands. The Policy mentions bush encroachment once, and supports debushing efforts to increase range productivity. However, no mention is made of the means to eradicate bush. The possibility of using fires as a management tool for the eradication and prevention of bush is also not envisaged. Instead, the Policy regards fires as a threat that needs to be controlled. No guidelines on the use of arboricides are provided either, and the Policy is silent on how bush encroachment could be prevented.

8.4.15 Namibia Forest Policy Statement

This Policy Statement (RoN 2001c) is contained in the Namibia Forest Development Policy (RoN 2000f) discussed above. It is slightly shorter than the Policy, but does not contain any provisions that differ from it.

8.4.16 The Forest Act, 2001 (No. 12 of 2001)

The objectives of this Act, effective as from 15 August 2002, are to establish a Forestry Council and to consolidate laws relating to the management and use of forests and forest produce as well as the protection of the environment and the control and management of forest fires (Act, p. 2).

The Act provides for the establishment of a Forestry Council. Membership of the Council will include the Ministries of Environment and Tourism (MET); Agriculture, Water and Rural Development; Lands, Resettlement and Rehabilitation; and a representative of the Council of Traditional Leaders (ibid.:5). The functions of the Council are primarily to advise the Minister of Environment and Tourism on forest matters in general, including matters relating to legislation and the preparation and implementation of a national forest policy (ibid.:6).

Most of the provisions of the Act are aimed at "classified forests". These are defined as forest reserves, community forests or forest management areas (ibid.:4–5). Management plans will have to be produced for all classified forests, detailing the management objectives and management measures relating to such forests. Four classified forests are described in the Act: State forest reserves, regional forest reserves, community forests and forest management areas, and nature reserves (ibid.:10–14).

Forest management areas can be established on land that is not a classified forest, but is owned by a person or institution or can be legally used by that person or institution (ibid.:13). This suggests that ordinary savannas and dry forests that are owned by a person or institution are included in this provision. The establishment of forest management areas will involve entering into a forest management agreement with the MET. A forest management plan will have to accompany such an agreement, and may include provisions for the planting of trees, the management of natural forest, and harvesting practices that are to be followed in the management area (ibid.:14).

Section 23 of the Act provides for the control of afforestation and deforestation. Among other provisions, this Section prohibits the clearing of more than 15 ha of land which has predominantly woody vegetation, or the cutting of more than 500 m^3 of forest produce from ***any piece*** of land within one year, except with the approval of the Director of Forestry. ***The latter may require that the applicant prepares an EIA*** (ibid.:19–20; emphasis added).

The owner of commercial land or occupier of communal land may harvest forest produce from their land subject to a management plan, licence or agreement issued under the Act (ibid.:21).

The Act proposes the intoduction of fire management areas and the establishment of fire management committees for each such area. Such committees will have to develop fire management plans which will contain provisions relating to, among other things, the circumstances in which burning is allowed, as well as the prevention, control and extinguishing of veld and forest fires (ibid.:23–24). Fire management committees will have the power to order an owner or occupier of land that is a fire management area to participate in the implementation of the fire management plan (ibid.:24).

Statements on forest policy and strategy as well as the proposed legislation do not define what constitutes a *forest* as opposed to *woodlands*. Sustainable woodland management, which would address issues of bush encroachment and its control in a way that ensures biological diversity and environmental sustainability, does not seem to be covered under forestry. Thus, policy instruments for the forestry sector do not address situations where woody vegetation has impacted negatively on resource use such as agricultural production.

In order to address this issue, it is recommended that the definition of *forest management areas* be extended to include the sustainable management of bush and rangeland. This would make it possible to apply forestry policy and legislative instruments to bush encroachment and its prevention. However, as long as bush encroachment is regarded as an agricultural issue, this may create practical problems in that the law would be administered by one Ministry (Environment and Tourism) and implemented by another (Agriculture, Water and Rural Development).

It is also recommended that fires be treated both as a threat and as a management tool. The use of fires as a means to prevent or reverse bush encroachment or reinfestation in savanna areas needs to be investigated and experiences documented. The establishment of fire management areas may provide the legal and institutional framework to use fires as management tools in bush-encroached areas.

8.4.17 National Guidelines on Fires and Fire Management

The National Guidelines on Fires and Fire Management (NFFP 2001) are geared towards the prevention and control of forest fires in order to ensure and maximise the availability of forest products.

The Guidelines do not explicitly mention the use of fires as a tool to manage bush encroachment (prevention, reinfestation, and thinning of intruder bush). However, they do provide a practical framework for the management of fires that could easily include aspects of fires as a tool in bush management.

A large part of the Guidelines deals with the prevention of fires. It proposes that fire prevention be effected by developing fire management plans for forests, and by establishing regulations for the use of fires within specific areas, (ibid.:8) –

> including bush[-]encroached areas where fire is used as a tool to eradicate bush. These well-intended activities may however lead to desertification and loss of biodiversity.

The Guidelines also list some activities under the general category of "Community Participation in Forest Protection". These activities include the need (ibid.:9) –

> to inform and educate the public about adverse environmental and economic effects of bush encroachment on commercial farming communities [and to] encourage the formation of Fire Protection Associations in commercial farming areas and Fire Committees in communal areas. [It is proposed that] the Directorate of Forestry, [the] MAWRD and NGOs should be involved in establishing Fire Protection Associations in commercial farming communities and in addition provide appropriate training to commercial farming communities.

The Guidelines also propose the establishingment of a National Fire Forum. The Forest Act and the Traditional Authorities Act, 1995 (No. 17 of 1995) should accommodate increasing fire protection problems caused by sociocultural changes. "These new guidelines and approaches should form the framework for annual work plans for integrated forest fire management" (ibid.:11).

A forest fire management plan should not only be regarded as an integral part of forest management, but "should also form part of any land use plan for a certain area". Such a plan should be developed at national, regional, district and field level. Integrated forest fire management plans will consider all aspects of forest fire prevention and suppression (ibid.:13). Appropriate forest fire management plans should also be developed for commercial farming areas (ibid.:14).

The Namibia Forest Policy Statement and the National Guidelines on Fires and Fire Management regard the involvement of communities in both the freehold and non-freehold farming areas as essential. To this effect the Guidelines propose the establishment of Forest Protection Units (Fire Protection Associations in commercial farming areas and Fire Committees in communal areas) or Forest Protection Associations. Participation in the planning, monitoring and evaluation of all integrated forest-fire control activities should be encouraged through appropriate incentives (ibid.:17), and in new settlements (ibid.:24).

The Guidelines further recommend that the use of herbicides for clearing firebreaks along fences, roads and railroads be investigated, and that subsidies for this purpose be considered (ibid.:16).

The Guidelines also propose a number of research activities relating to fire management. These include fire ecology, the basic science of fire, the socio-economic and cultural implications of fires, smoke management, and fuel management. The latter category includes the development of bush management techniques by using fires and browsing (ibid.:40).

The monitoring of experiences with fires is regarded as an essential tool for the evaluation of fire management plans (ibid.:41).The National Guidelines on Fires and Fire Management provide a framework for the national management of fires. The Guidelinâes could also be applied to bush encroachment and its prevention, provided that the management of woodlands in general be brought within the ambit of forestry legislation and policy. Research needs to produce more information on the costs and benefits of using bush fires as a management tool in eradicating and preventing bush encroachment. Future policy and legislation needs to be guided by the results of this research.

8.4.18 Poverty reduction strategy for Namibia

Cabinet approved a Poverty Reduction Strategy for Namibia in 1998 (RoN 1998a). The Strategy differentiates between a long-term vision to alleviate poverty and short-term options to generate income. The Strategy asserts that the agricultural base of the country is too weak to offer a sustainable basis for prosperity in the long run. It assumes also that, in a quarter of a century from now, the large majority of the country's residents will be living in urban centres (ibid.:5). In order to meet these challenges, efforts are required to develop Namibia into a transport and manufacturing hub, invest in the education of all Namibians, and ensure health and prosperity for all.

In the short term, income should be generated through the promotion of agriculture, tourism, and small- and medium-scale enterprises, and Namibia's safety net should be strengthened in terms of, for example, pensions, food for work, seed reserves, and vulnerability to national disasters. With regard to the agricultural sector, the Strategy envisages increased production and productivity, particularly in the crop-growing areas of the country. This requires improvements in agricultural extension, new crops and new ways of using water. Diversification into rain-fed cotton production and peri-urban horticulture will be encouraged (ibid.:11). In addition, tree species which could thrive in the northern regions and have economic value should be identified.

The development of entrepreneurial and dynamic small- and medium-scale enterprises (SMEs) is regarded as having great potential to create jobs in the medium term. An ambitious programme to promote SMEs is under way under the auspices of the Ministry of Agriculture, Water and Rural Development, the Ministry of Environment and Tourism and the Ministry of Trade and Industry to address such issues as financing, marketing and technology. The Poverty Reduction Strategy draws attention to the fact that successful SMEs "are built on steady, cumulative processes of learning" (ibid.:4), which can be facilitated and supported by Government, but not bypassed. Public funding of SMEs should not deliver training programmes alone, but also support and catalyse learning between and amongst private sector bodies, i.e. learning from the experience of other private firms. Gains from SME development are only likely to manifest themselves in the medium term, therefore (ibid.).

The proposed Poverty Reduction Strategy includes the strengthening of Namibia's safety net by, *inter alia*, developing labour-intensive public works and grant-based transfers (ibid.:15). The Strategy recommends that support be given to the Ministries of Works, Transport and Communication and of Agriculture, Water and Rural Development, to identify and remove obstacles to fostering cash-based public works programmes (ibid.:16).

8.5 Findings and recommendations

The survey of the relevant policy and legal framework has revealed that none of the current policies and laws specifically addresses bush encroachment and problem bush eradication. Although these issues are seen as a serious problem, particularly in the National Agricultural Policy, neither this Policy nor others, nor in fact any available legislation, provide any guidelines on how to deal with the issues. The Soil Conservation Act and the latest Forest Policy Statements as well as the new Forest Act come closest to addressing the issue. However, as the discussion below will show, a number of gaps exist in the policies and legislation under discussion.

The most obvious gap in policy and legislation is that no incentives are provided to manage problem bush – both in terms of preventing it and in reversing its negative impact. While the Soil Conservation Act provides for the payment of subsidies and grants to erect soil conservation works, post-Independence National Agricultural Policy questions the payment of subsidies. Thus, subsidised bush eradication remains a contentious issue, and will be discussed below.

Although the management of bush is not explicitly addressed in the current policy framework, current policies – particularly in the agriculture and forestry sectors – provide important parameters within which bush management policies will have to be formulated. A number of specific issues can be mentioned in this regard:

- The role of the State: Post-Independence policies in the agricultural and natural resources sectors have changed the respective roles of the State and farmers dramatically. The National Agricultural Policy, the National Drought Policy and Strategy, and the Namibia Forest Development Policy devolve the responsibility for managing natural resources to the ones that own and use them. The role of the State will be limited to regulatory functions and providing technical support that will enable farmers to improve their capacity to manage resources more effectively. The State will only provide direct financial support in emergencies. This implies that farmers will have to bear the responsibility of managing their woodlands. More specifically, they will be responsible for the prevention of bush encroachment and its eradication where densities are too high.
- It follows from these new roles of State and farmer that the thinking on subsidies has changed as well. In terms of the National Agricultural Policy, long-term or continuing subsidies will be avoided. However, the Policy still allows for the possibility that well-targeted subsidies can play an important part in achieving short-term agricultural and socio-economic objectives.

With the above two provisos in mind, a policy framework for woodland management needs to spell out how the State can improve the capacity of individual farmers or groups of farmers to deal with bush encroachment. Thus, policy needs to create a socio-economic environment that provides incentives for farmers to improve the productivity of their pastures by eradicating intruder bush in an environmentally sustainable way. At the same time, improved pasture management practices need to be encouraged to minimise the risks of future bush encroachment.

The formulation of a policy to manage woodlands on both commercial and communal ranches needs to be regarded as a priority. However, it is not recommended that separate legislation be introduced to deal with bush encroachment and its eradication. Instead, a woodland management policy should be used to amend the provisions of the Forest Act to incorporate issues pertaining to woodlands that fall outside the definition of *forest* and *classified forest*. This will ensure that all woodlands in Namibia will be managed in a sustainable manner. In its present form, the provisions of the Forest Act apply to classified forests only.

With regard to the reversing of bush encroachment, a woodland management policy needs to facilitate and encourage the eradication of bush on an economical and profitable basis. A number of issues need to be raised in this regard:

- Existing opportunities and efforts/initiatives to exploit bush in a profitable way need to be strengthened. More specifically, the market for charcoal needs to be secured and expanded. This is crucially dependent on the quality of charcoal, and the way it is produced. Certification of charcoal in terms of the Forest Stewardship Council (FSC) is a prerequisite for this and needs to be encouraged. It deserves mention in this regard that, as far as the FSC is concerned, Namibia does not practise sustainable woodland management, but is instead clearing invader bush to reclaim rangeland (DFN 1997:56). This reinforces the importance of incorporating the management of woodlands into forestry policy instruments as part of low-intensity forest management.
- It is also recommended that policy instruments include providing the Namibia Woodland Management

Council (NWMC) with statutory powers similar to those of the Meat and Agronomic Boards. The NWMC was set up with a view to address issues pertaining to charcoal production, quality control and marketing. These are important functions as the economical eradication of invader bush depends on a reliable market to sell charcoal and other wood products. Additional uses for bush need to be investigated and encouraged.

- It is equally important for Namibia to demonstrate that proper woodland management is taking place in the country. It is therefore recommended that the NWMC should also be responsible for the development, implementation and monitoring of sustainable woodland management practices. Woodland management plans should be developed under the Forest Act. While the Forest Act provides for the establishment of forest management plans, it concerns itself only with the preservation of natural forests and their sustainable utilisation, but not the eradication of disturbed woodlands that impact negatively on agricultural productivity.
- The inspection of farms to ensure compliance with permit conditions and, thus, woodland management objectives as laid down in a woodland management plan should not be done by regular extension workers in the Ministries of Agriculture, Water and Rural Development or of Environment and Tourism. The main reason for this recommendation is that such a policing function may jeopardise their advisory roles in future. An alternative may be to invest the NWMC with powers to carry out all the necessary inspections.
- Incentives should be considered for the eradication of bush by labour-intensive means in preference to chemical or mechanical means. This would not only restore pastures, but also contribute towards addressing unemployment in the country. The policy framework should facilitate the identification of suitable small-scale operators who are able and willing to employ, train and manage small teams of people who are prepared to hire out their services to commercial farmers or Government to eradicate bush. Soft loans should be made available to establish such small-scale entrepreneurs and provide them with bridging finance.
- At the same time, the policy on woodland management and utilisation needs to provide a mechanism to ensure that small-scale contractors have access to a minimum of social services such as decent housing, potable water and ablution facilities. The provision of these services will undoubtedly contribute to the cost of bush harvesting and threaten its profitability. Thus, incentives in the form of tax rebates or subsidised interest rates on loans specifically for the development of such services need to be considered to offset any additional costs.
- The use of fires as a management tool should be incorporated into a woodland management policy. Current legislation, including the latest policy statements on forest management and utilisation, provides only for the prevention and control of veld fires in order to preserve forests and woodlands. It is recommended that the scope of these policy instruments be extended to include fire as a management tool. The deliberate and purposeful use of fires should become an integral part of woodland management plans.
- At the same time, too little is known about the impacts of fires. This may be the result of previous legislation, which regarded fires as a threat only. A woodland management policy needs to encourage research into the effects of veld fires on bush encroachment in different ecological situations. The concomitant data should form part of a national database. In addition, farmers should be encouraged to record their experiences with veld fires and make these available to the national database.
- Apart from including the use of veld fires as a management tool, woodland management plans also need to provide for aftercare. The positive effects of burning may be dissipated if a burn is not followed by an appropriate aftercare programme that will have to include appropriate pasture management techniques and periodic burning.
- In areas where bush densities are too high, the lack of undergrowth renders veld fires useless. Eradication of bush will have to happen either by using chemicals, mechanical means or labour (stem-burning, chopping bush down with axes). The use of chemicals to control bush should be discouraged as far as possible in favour of labour-based techniques.
- It has been stated that arboricides are toxic to varying degrees to insects, mammals and other organisms (Cunningham 1997:14), which also get harmed or killed in the process. However, chemical analysis of vegetation and soils that were exposed to arboricides in bush eradication found no traces of these chemicals ten years after the application. Meat produced on the same land did not show any residual chemicals either (Smit, pers. comm.).
- Despite these findings, perceptions may nonetheless develop that meat produced on pastures that were reclaimed through the use of arboricides may be unfit for human consumption. It is essential, therefore, that a woodland management policy specifies the terms and conditions under which arboricides should be used.
- An integrated information and monitoring system should be established at national and farm level. Data should be collected and monitored on the economic and financial management of a farm, on

the range management practices applied, on animal production (calving rates, animal health, etc.), and on environmental factors such as bush encroachment and grazing. Such a system will enable farmers and extension workers to see a particular problem within the overall context of the farming enterprise and provide advice accordingly. This system could also possibly be incorporated into the one proposed by the National Drought Policy and Strategy. Moreover, financial assistance for debushing or disaster drought should be made conditional on the adoption of such an integrated information and monitoring system.

- The implementation of these measures hinges on secure property rights, particularly in the non-freehold (i.e. communal) areas. Secure property rights in and of themselves are no guarantee for sustainable resources management. However, "without secure tenure, the incentive and opportunity to manage renewable natural resources (rangeland, forestry, wildlife, wetlands) in a sustainable manner is significantly reduced" (NAPCOD 1996:17). It is imperative, therefore, that property rights to land and all its resources be transferred from the State to resource users. This requires that legislation on non-freehold land provide for group tenure, and that such property rights include all renewable natural resources on the land – as contemplated in the National Land Policy.
- Care should be taken that the intentions of a woodland management policy are not jeopardised by conflicting policies and legislation. The broad aims of sustainable bush management need to be reflected in all policies that have a bearing on this topic. The recent land tax, for example, may inadvertently discourage the eradication of bush, insofar as land cleared of bush may increase in value and, hence, attract higher land tax. In addition, competencies between the MET's Directorate of Forestry and the MAWRD need to be clarified. Bush encroachment is widely regarded as an agricultural problem, since the primary objective of its prevention and eradication is seen to be the restoration of rangelands, rather than sustainable woodland management. In order to obtain international certification under the FSC, bush encroachment will have to become part of woodland management as provided for under forestry legislation in the Directorate of Forestry. The practical inspection and implementation should, however, rest with the NWMC. All pasture management aspects of bush encroachment and eradication should remain the responsibility of the MAWRD.

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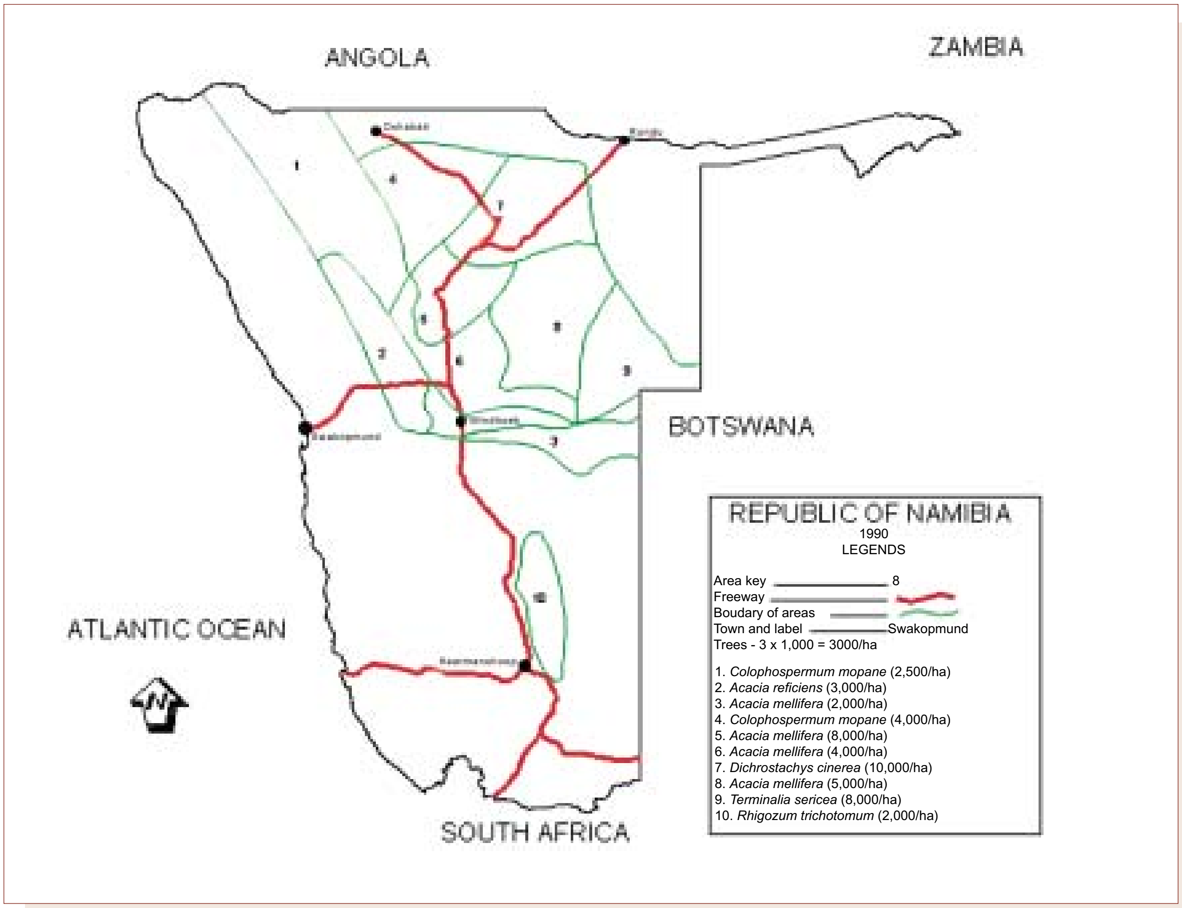
Chapter 9
Long-term strategy management for bush control[23]

[23] Constituted part of Component 5 in the original Terms of Reference

In Namibia the phenomenon of bush encroachment is regarded to be part of the process of desertification since the increase in the extent and density of woody vegetation occurs at the expense of other desirable grasses and forbs, resulting in an alarming reduction in productivity. The following definition of *bush encroachment* was accepted by a Namibian Technical Working Group consisting of rangeland specialists, ecologists, livestock specialists and farmers:

> Bush encroachment is the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, a decrease in carrying capacity and concomitant economic losses.

It has been established that an area of approximately 12 million ha is severely invaded by bush, while lower densities occur on another 8 million ha. The districts and regions affected are illustrated in Figure 9.1.



Source: Bester (1996)

Figure 9.1: Districts and regions affected by bush encroachment

If, however, the lower average rainfall figure for the lower-density areas (western parts) is taken into consideration, one may justifiably conclude that the productivity of our rangelands over an area of 26 million ha is seriously affected. Considering the large number of invader bushes below 1 m in height in both communal and commercial farming areas, the problem is predicted to intensify.

It is generally accepted that the decline in the carrying capacity of our rangelands could be as much as 100% or more (a decrease from 10 ha per LSU to, for example, 20 or 30 ha per LSU). Therefore, at a conservative production loss of only 3 kg carcass weight per hectare and at 2002 prices, Namibia is suffering a loss in income of more than N$700 million per annum. The impact of bush encroachment in terms of biodiversity and water balance is comprehensively described in Chapter 3 of this report.

The overwhelming factor determining the spatial distribution and productivity of forest savannas and grassland is soil moisture balance. This balance and, therefore, the soil water content have largely been disturbed by invader bush, resulting in very little efficiency in respect of water use on natural rangelands. Research findings in African savannas showed that rangelands in poor condition, i.e. bush-encroached, need three to four times more water to produce the same amount of grass compared with veld that is in an optimum state.

This problem is further accentuated given the erratic climatic features of Namibia, where –

- low average rainfall
- high evapotranspiration
- large fluctuations in rainfall between and within years, and
- low rainfall predictability

have a drastic impact on the stability of people's livelihoods.

Namibia and her people cannot afford these losses and the problem should be addressed as part of "Namibia Vision 2030", as envisaged by HE President Sam Nujoma in his opening speech to Parliament in 1998.

The huge potential for increased carrying capacity and productivity means that the land reform programme in Namibia cannot be seen in isolation from bush encroachment. Many of the present encroachment-related uneconomical units can provide acceptable returns again once the problem is solved. In communal areas, either more people can make a livelihood or those who are residing there will benefit in terms of increased income and quality of life.

Bush encroachment should, therefore, be regarded as a societal problem to be addressed with strong support at a national level.

The Constitution of the Republic of Namibia lays the foundation for all subsequent policies and legislation in Namibia. Article 95(*l*) stipulates that the State shall actively promote and maintain the welfare of the people by, amongst other things, adopting policies which include the –

> maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilization of living natural resources on a sustainable basis for the benefit of all Namibians … .

The maintenance of ecosystems is a constitutional obligation, therefore, and not simply a matter of choice.

The National Agricultural Policy (NAP) states that Government will address the serious problems of desertification and environmental degradation caused by the destruction of forest cover, soil erosion, overgrazing and bush encroachment. Bush encroachment, in particular, is a matter of great concern to the MAWRD. The NAP regards the eradication of bush as an important part of its strategy to exploit the full potential of commercial and small-stock farming areas.

In terms of the NAP, Government intends to "establish mechanisms to support farmers in combating bush encroachment effectively over both the short and long term". In line with this, Government will (RoN 1995a:25) –

> endeavour to ensure that appropriate bush control technologies and inputs are available from the private sector at the lowest possible prices. Research and advisory services to farmers on biological and technical issues relating to bush clearing and utilisation will also be strengthened. [It will also] promote labour-intensive and private sector initiatives which utilise bush products.

These strategies could involve the development of bush clearing and utilisation industries, including charcoal, fuel briquettes, and chipboard manufacture (ibid.:14).

Simultaneously, the objectives of the Poverty Reduction Strategy of Namibia to support the development of entrepreneurial and dynamic small and medium enterprises will be promoted.

To this effect, the National Drought Policy and Strategy also states that Government will help farmers to manage drought-induced income variability and reduce vulnerability to drought by promoting drought-mitigating practices and diversification as well as the development of post-disaster drought recovery and preparedness programmes (RoN 1997b).

The implementation of sustainable rangeland management practices is regarded as an important element of reducing vulnerability to drought. In this regard, "support for tackling bush encroachment also needs to be considered" (ibid.:25).

The Soil Conservation Act gives the Minister of Agriculture, Water and Rural Development wide-ranging powers with regard to the utilisation of land. These include the power to withdraw land from cultivation and grazing and to direct land-users to apply crop rotation and soil-stabilising measures. The Minister is also authorised to issue directives relating to the resting and utilisation of pastures, as well as to the number of large stock or small stock that may be kept on land.

The Minister may, furthermore, order the owner of land to construct soil conservation works. Such works would seek to achieve any of the objectives of the Act. In order to encourage farmers to erect soil conservation works (which may include bush control measures), the Minister is empowered to pay subsidies or grants for the development of such works, or defray portions of costs involved.

The Namibia Forest Development Policy encourages debushing for the purpose of charcoal production as this enhances range productivity, while agroforestry is encouraged in the communal areas.

Thus, Namibia avails itself of a very favourable policy environment where even Government has expressed its commitment in terms of direct involvement and support to the agricultural sector as far as the problem of bush encroachment is concerned. Against this background, a long-term strategy to combat bush encroachment is proposed with the following results and activities in mind. Table 9.1 provides a summary of the long-term goal, purpose and expected results of such a strategy:

Narrative summary of project strategy	Strategies/Activities	Indicators/Milestones
Overall goal To promote and establish appropriate systems for diverse and sustainable land management in bush-encroached areas	Strategy integrated as part of Vision 2030	Strategy accepted as a national programme
Purpose of project To implement environmentally, institutionally and socio-economically sound management and utilisation systems to tackle bush encroachment	Strategy included in the Second National Development Plan (NDP2)	Funds made available for implementation
Result 1 Environmentally sound principles of bush control are established and adhered to at local and national levels.	1.1 Develop and submit bush control policy at national level to formalise principles under which invader bush will be harvested or controlled 1.2 Adapt Forest Stewardship Council (FSC) principles to be in line with Namibian conditions 1.3 Obtain international approval for 1.2	1.1 FSC guidelines adjusted and internationally recognised 1.2 Management principles and guidelines in place
Result 2 Bush encroachment is controlled in an economically and ecologically sustainable way.	2.1 Encourage farmers to apply recommended bush control methods 2.2 Develop an economic viability model to continuously assess bush control practices 2.3 Develop rangeland restoration technologies and incorporate them into Bush Expert 2.4 Address farmers' research needs 2.5 Involve youth groups in communal areas in bush control programmes	2.1 Evaluation results following surveys 2.2 Model incorporated into the Bush Expert Decision Support System 2.3 Bush Expert linked to EcoRestore in South Africa 2.4 Research projects included in Government research activity programme
Result 3 The integrated information and monitoring system is operational at national and farm level.	3.1 Transfer Bush Expert to the NAU and the NNFU for joint management and maintenance • Build capacity to manage the database • Continue surveys to assess bush control methods	3.1 Bush Expert maintained by Namibian institution(s), operational and accessible 3.2 Geographic information system database in place at the NRSC

Table 9.1: Long-term strategy to combat bush encroachment (continued overleaf)

Narrative summary of project strategy	Strategies/Activities	Indicators/Milestones
	3.2 Continue research to do ground-truthing with satellite imagery 3.3 Recruit farmers in all AEZs to carry out monitoring in vegetation changes •Maintain the Mandarax Decision Support System 3.4 Standardise vegetation surveys for compatibility purposes	3.3 Mandarax database in place and maintained 3.4 Monitoring systems synchronised
Result 4 •An enabling institutional framework and operating policy environment for bush-based enterprises is established. •Quality control and marketing mechanisms for efficient utilisation of bush-based products are improved.	4.1 Adapt policy guidelines and legislation to create a favourable operational environment and support bush control programmes 4.2 Revive the NWMC and provide it with statutory powers 4.3 Establish formal networking. 4.4 Set up a financial support programme (e.g. socio-economic incentives) for farmers 4.5 All role players accept responsibility for bush control 4.6 Integrate bush control programmes into the land reform process and Vision 2030 4.7 Establish business plan and institutional framework as a basis for a viable wood industry 4.8 Establish the capacity to implement a long-term strategy at all levels (extension officers, researchers, key farmers, farmers in general, and the agricultural industry)	4.1 NWMC operational 4.2 Policies and legislation reformed as recommended 4.3 FSC guidelines revised, and accepted internationally 4.4 Government support rendered to industry 4.5 Communal and commercial farmers organised 4.6 Institutional framework and business plan implemented and operational
Result 5 Capacity is in place within relevant Government Ministries, and the commercial and communal sectors control manage and utilise woodland in a sustainable way.	5.1 Train extension officers and key farmers in the environmental principles of bush control 5.2 Train extension officers and farmers in the best practices of bush control 5.3 Secure direct access for extension officers and farmers to Bush Expert and other information systems 5.4 Train Government officers in law enforcement and secure adequate capacity at strategic locations 5.5 Transfer the responsibility for implementing the strategy to the MAWRD 5.6 Establish responsibility for law enforcement in the MET's Directorate of Forestry	5.1 Recommended control methods applied 5.2 Training in best methods to control bush encroachment takes place 5.3 Training in plant identification and monitoring takes place 5.4 Best practices and guidelines distributed in popular format 5.5 Farmer organisations trained in operation and maintenance of the Bush Expert database and the Mandarax Decision Support System

The action plans and activities needed to achieve the overall goal of the long-term strategy to combat bush encroachment are discussed below in relation to each of the expected results.

9.1 Result 1: Environmentally sound principles of bush control are established and adhered to at local and national levels

9.1.1 Ecological considerations/principles

Before any bush-clearing programme is introduced on a farm/farm land the landowner/user should receive basic training in ecological principles relevant to bush control programmes. A proper understanding of environmental issues together with a well-devised woodland management plan will prevent the wrong practices from being applied. The following important principles should be established among farmers and policy-makers:

- As a rule of thumb, the number of tree equivalents per hectare should not exceed twice the long-term average rainfall (mm). A *tree equivalent* (TE) is defined as a tree (shrub) of 1.5 m height. Thus, a 3-m shrub would represent 2 TE, a 4.5 m shrub 3 TE, etc. (Smit 2001).

  Example: On your farm with an average rainfall of 450 mm you have the following composition:
  100 trees over 5 m in height per hectare
  2,000 shrubs/bushes averaging 3 m in height per hectare
  2,000 shrubs below 2 m in height per hectare

  This will give you the following:

100 trees @ (6 m/1.5 =) 4 TE	400 TE per hectare
2,000 shrubs @ (3 m/1.5 =) 2 TE	4,000 TE per hectare
2,000 shrubs @ (1.5 m/1.5 =) 1 TE	2,000 TE per hectare
Total	**6,400 TE per hectare**

- As an additional guideline it is recommended that thinning should take place at the following intensity (Strohbach, pers. comm.):
  - Large trees (single-stemmed >5 m) should not be thinned more than 10%
  - Large shrubs (2–5 m) should be thinned by about 90%, leaving 10% – starting with invader species
  - Small shrubs (up to 2 m) should be thinned by about 90%, leaving 10% – starting with invader species, and
  - **In all cases, a spectrum of species and plant sizes should be left for a sound bush:tree ratio and, thus, ecosystem functioning.**

  Using the above example for a 450 mm rainfall area, thinning would result in the following densities:

90% of 100 trees left =	90 trees @ 4 TE	360 TE
10% of 2,000 large shrubs/bushes left =	200 shrubs @ 2 TE	400 TE
10% of 2,000 small shrubs left =	200 shrubs @ 1 TE	200 TE
Total		**960 TE**

  Where certain desired species need to remain, they can be marked to ensure that they are not treated. Such an approach will ensure that not all trees are killed.

  Possible scenarios to be pursued for different savannas are illustrated in Figures 9.2 to 9.8.

Figure 9.2

Figure 9.3

Figure 9.4

Figure 9.5

Figure 9.6

Figure 9.7

Figure 9.8

Smit et al. (1999) suggest the following:

> Depending on the composition of the community, one of the following three simple situations may apply:
> (i) A dense stand of shrub-type woody plants without any large trees. The objective here should be to reduce the density of the woody plants. The reduction in inter-plant competition resulting from this should stimulate the growth of the remaining individuals so that, in time, the desired open savanna comprised of large trees should develop. Thinning can be entirely random. This can be achieved by using a soil-applied herbicide at a dosage which will allow some of the plants to survive.
> (ii) A predominance of shrub-type woody plants with occasional large trees. Here the large trees should be retained at all costs. Shrubs could be cleared from a strip around the large individuals using a plant-applied herbicide. The remaining area can be treated with soil-applied herbicides.
> (iii) A predominance of large trees interspersed with shrubby individuals. Here there would be a serious risk of killing too many large trees were soil-applied herbicides to be used. Unwanted individuals would need to be removed using a selective herbicide.

- For ecological stability and long-term animal production, it is proposed that *Rhigozum trichotomum* be controlled and managed to stands of below 400 plants per hectare (Moore 1989).
- Woody plants play a very important role in the recycling of nutrients, making moisture available, preventing wind and water erosion, and maintaining biodiversity when present in desired densities and ratios. Characteristics regarding bush/grass associations and, therefore, a predetermined bush density should always be considered. Thus, land should never be completely cleared.
- Protected and benign species should not be removed. If necessary, a permit should be obtained from the MET's Directorate of Forestry before harvesting or killing any protected plants. A list of protected plant species can be obtained from the Directorate of Forestry.
- Only excessive problem individuals should be removed and then only when the prospects are good that they can be replaced by something better. The aim should be an optimum ratio between woody and grass resources in both commercial and communal rangelands.
- No bush-clearing programme should be embarked upon if there is not a long-term management plan in place for any specific farm or land.
- When bushes are cleared for the purposes of charcoal production or any other products, the principles of the Forest Stewardship Council should be adhered to.
- Twigs and branches should be left on the ground to improve soil conditions and to establish a good seedbed.
- Harvesting should be done at least 100 m away from river beds and watercourses, as the roots of bushes and trees serve to stabilise the soil and minimise erosion.
- All bush-clearing actions need to be followed up indefinitely by aftercare treatments to combat reinfestation. The intervals between treatments will be dictated through continuous monitoring by the landowner. It is necessary to establish benchmarks as reference points to assist in the monitoring programme. Fixed photo points can be of tremendous value.
- Do not compromise future generations because of ignorance.
- Do not undertake more bush clearing than what you are able to control.
- Where alien species occur they should be eradicated.
- Preference should be given to more selective herbicides where chemical treatment is inevitable.

9.1.2 Critical performance areas

Critical Performance Areas refer to vital components of a programme where work of outstanding quality needs to be performed to attain the set ultimate objectives.

In order to reclaim the original state of the savanna system in Namibia, the following aspects are of critical importance:

- Reduce/deplete seed content of invader bush in the soil over the long term
- Achieve and maintain a sound ratio of desired plant species
- Obtain a productive and more stable ecosystem to prevent re-encroachment
- Recover expenses for bush control programmes through increased income as a result of higher land productivity and incrementally higher profit and/or embark upon alternative income-generating enterprises through the sale of invader bush products, and
- Clarify the ultimate objective, namely –

- whether a land-user wants to harvest invader bush sustainably, or
- whether s/he wants to restore rangelands sustainably.

The methodology for these two strategies – sustainable harvesting and restoration of rangelands – will differ dramatically. If the objective is sustainable harvesting, i.e. the farmer has decided that his/her sole income will be from invader bush, the following guidelines – prepared as a specialist report by Jeffares & Green Inc. (2000) – should apply:

9.1.3 Guidelines for sustainable harvesting

- **Species not to be harvested (evergreens, broad-leaved species, protected species, riverine species):** These form an important part of the browse component and do not have the regenerative capacity to recover as quickly as the more dominant thickening species.
- **Avoid harvesting on sensitive soils:** Some soils, such as sodic and duplex (sand and clay) soils, are extremely erosive. Wood harvesters should determine the sensitivity of the soil in an area before harvesting. At this stage the distribution of sodic and duplex soils in the affected environment is inadequately known.
- **Avoid riverine vegetation:** Riverine vegetation forms an important habitat for fauna while the roots stabilise the soil, which would otherwise wash away in flash floods.
- **Avoid using heavy machinery:** Wood harvesters might be tempted to use bulldozers to uproot shrubs that are difficult to chop down. However, such practices increase the risk of soil erosion by disturbing the soil surface.
- **Leave the fines:** It is not recommended that twigs be compressed to make woodchips since twigs improve soil moisture and soil organic matter, and increase nutrient levels in soils after mineralisation, which improves grass production and quality.
- **Leave some dead trees:** It is suggested that charcoal producers leave one to two dead trees per hectare. This increases available cavities for cavity users, and provides perches for larger birds such as raptors.
- **Leave 90% of all mature trees** (i.e. with a diameter of >150 mm at a height of 135 cm above the ground).
- **Thin out the larger bushes** (>150 cm in height) to approximately 300 stems per hectare.
- **Multi-stemmed bushes (where applicable) should be pruned** to increase the growth of a single larger stem.
- **Thin out the small bushes:** (<150 cm in height) to approximately 300 stems per hectare.
- **Leave smaller bushes** with a stem diameter of <25 mm for a future harvest.
- **Patch harvesting should be done to maintain spatial heterogeneity:** This increases niches and, thus, species diversity. Patches act as refuges for prey species. Elongated patches can also act as corridors for shy animals to cross from one dense patch to another. Patches should be varied in shape. Elongated corridors increase the ecotonal boundary (or "edge" effect) which promotes diversity (DFN 1997). However, rounded larger patches are also important to ensure that populations of species restricted to dense bush have sufficient habitat available for minimum viable populations.
- **Leave representatives in all height classes of all species:** This increases niches and species diversity. Tall trees are more suitable for cavity users and for bird species with large nests. Tall trees also increase grass production. Smaller trees and bushes are suitable for medium-sized browsers and species of birds and other animals that require shelter.
- **Aftercare:** If reharvesting of resprouts is envisaged, resprouts need to be pruned to limit the number of stems to between one and three. This may speed up time to reharvest, but it also increases the availability of potential cavities for cavity users, increases nesting space, and increases grass production. Branches pruned can be used as browse for game or cattle or simply left on the soil surface to act as a mulch.
- **Regular monitoring:** Indicators and methodologies to track and monitor environmental change need to be put in place. Benchmarks and/or controls should be established as reference points with which to compare harvested areas.
- **Flexibility in management and a switch to alternatives if "thresholds of potential concern" are reached:** "Thresholds of potential concern" are identifiable indicators which, when a change in their number is detected to a certain predetermined level, warrants a management response to address the issue.

9.1.4 Target species

If, however, the objective is sustainable range reclamation and management, with a secondary objective being the selling of wood products, a different set of principles should apply and should be taken up with the Forest Stewardship Council and similar organisations.

Only aggressive woody species will be targeted, i.e. those that have invaded open savannas to the extent that they have caused an imbalance in the ratio of desired bushes, shrubs and grasses, a decrease in biodiversity, a decrease in carrying capacity and, ultimately, economic losses for the country.

In general, one should distinguish between three types of invaders:

- Indigenous species in normal woodland savannas (where bush thickening occurs and tree thinning should be applied)
- *Rhigozum trichotomum* plants, which occur in a different veld type and need a different approach, and
- Exotic species, e.g. *Prosopis*, which should be eradicated.

Taking the definition of *bush encroachment* as a guideline, together with the ecological principles stipulated above, the following species are targeted (Table 9.2):

Problem species	English	Oshiwambo	Otjiherero	Khoekhoe-gowab	Afrikaans
Acacia erubescens	Blue thorn	Omunkono	Omungongomui	!uri!gonis dûùbë.s	Geelhaak or Blouhaak
A. fleckii	Plate thorn	Omumang-	Omutaurambuku andjamba	!ürîgönè.s	Sandveld akasia or Bladdoring
A. luederitzii & A. reficiens	False umbrella thorn	Omutyuula	Omungondo	!gûs	Rooihaak or Baster haak-en-steek
A. mellifera	Black thorn	Omunkono	Omusaona	!noes	Swarthaak
Colophospermum mopane	Mopane	Omusati	Omutati	!oenis	Mopanie
Dichrostachys cinerea	Sickle bush	Ongete	Omutjete	|gò(w)e.s	Sekelbos
Terminalia prunioides	Purple-pod terminalia	Omuhama	Omuhama	!niob ≠kheas	Deurmekaarbos or Sterkbos
Terminalia sericea	Yellowwood/ Silver terminalia	Omugolo	Omuseasetu	|gää.b	Sandgeelhout
Catophractes alexandri	Trumpet thorn	Okalyanzi	Omukaravezi	!abba.s	Gabbabos or Trompetdoring
Prosopis spp.	*Prosopis*/ Mesquite	–	–	|ànrã.s –	*Prosopis* or Suidwesdoring or Muskiet
Rhigozum trichotomum	Three thorn	–	–	||häú.b/s	Driedoring

Sources: *Khoekoe names, Eiseb et al. (1991); English and Afrikaans names, Van Wyk & Wyk (1997); Oshiwambo and Otjiherero names, Jeffares & Green Inc. (2000)*

Table 9.2: Problem species and their local-language equivalents

Farmers who intend to execute bush control or harvesting need to familiarise themselves with the protected plant species in Namibia, namely those listed in the Forest Ordinance of 1952, the Forest Act, 1968 (No. 72 of 1968) and the Nature Conservation Ordinance of 1975 (No. 4 of 1975).

It may happen that even desired fodder species can serve as invaders following bush-clearing operations. Such problems should be addressed individually.

9.2 Result 2: Bush encroachment is controlled in an economically and ecologically sustainable way

9.2.1 Methods to control invader bush

Based on research results and on-farm experience in both humid and arid savannas of southern Africa, the methods to control or eradicate bush discussed here should be seen as guidelines only since their success cannot be guaranteed. These control methods include chemical, biological and mechanical applications. This section should be read together with Chapter 5, which is the source of some of the information here.

As proposed by Smit et al. (1999), the following options are available to the farmer as regards debushing:

> Before any woody plant control programme is embarked on, the two alternative approaches to the problem of increasing tree density in savanna areas need to be thoroughly assessed.
>
> One approach is to adapt the livestock system to the existing vegetation. Thus, where tree densities are high and the woody plants are palatable, browsers should form an important component of the livestock system.
>
> The second approach is one of modifying the vegetation to suit a particular livestock system (and particularly a system based on grazing animals). Here it is important to note that the establishment of woody plants is normally a continuing process in savanna areas and so control cannot be achieved with single thinning operations. Planning and implementation therefore needs to be ongoing.
>
> Where this option is adopted in areas of high tree density, the first operation should be the often drastic one of ***thinning*** down to some predetermined density, after which a ***post-thinning*** management programme will be needed to keep the area open. [Emphases added]

It is of utmost importance that a woodland management plan for each individual farm be devised in respect of the socio-economic environment (livelihoods, benefits and sharing, health and safety), the ecological environment (biodiversity, habitat diversity and landscape considerations), and linkages to main certification mechanisms.

For any given method, aftercare programmes are indispensable and, if they are neglected, it could lead to even worse problems.

A brief description of the methods proposed is given here.

9.2.1.1 Chemical methods

The herbicides recommended need to be applied in accordance with the quantities prescribed by the manufacturers. This in turn will mainly be influenced by the kind of problem species and the clay content of the soils. If the clay content is below 20%, the success rate of herbicides is fairly good, while higher clay contents require special attention to dosage and costs.

All remedies/chemical products used in Namibia are obliged to be registered with the Registrar of the Fertilizers, Farmfeeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act 36 of 1947).

Not all herbicides are selective and care needs to be taken that desired fodder bushes and trees are not affected.

The application of certain chemicals is recommended under circumstances where (Smit 2002) –

- the woody component is very dense (beyond 2,000 bushes per hectare)
- the majority of the trees have grown out beyond the reach of browsing animals
- animal access is severely restricted by invader bushes
- the woody component is largely unpalatable
- it is not practical to incorporate browsers in the livestock system, and
- herbicides are available which will selectively affect the target woody species more severely than the palatable species.

9.2.1.2 Root-absorbent herbicides

Herbicides with Tebuthiuron, Ethidimuron or Bromacil as the active ingredient are applied on the soil surface and taken up by the roots of target bushes after effective rain. Products containing these ingredients are available as granules or pellets, wettable powders or in a liquid form. The ones in granular form that are suitable for manual application are applied under the canopy next to the stem. The dosage depends on the height of the tree/bush; it is recommended that larger dosages be applied in two to four portions around the stem. Some of the granular forms are also suitable for aerial application. With these, however, it should be emphasised that they are less selective and may damage desired plants too. Wettable powders, mixed with water and herbicides in liquid form, are sprayed onto the soil adjacent to the stem (Smit et al. 1999).

The application rate of the soil-applied formulations will vary according to the clay content, the soil's organic matter content and pH, the species of tree being treated, and its size. The higher the clay content, the greater the dose should be. All materials use tree height or some other measure of size on which to base the needed dosage (Smit et al. 1999). Soil type and, more specifically, the clay content of soils play an important role in the effectiveness of herbicides. If clay makes up more than 20% of the soil, chemical treatment is perceived to be much more expensive as a result of the need for higher dosages. Below 20% clay, applications on the soil are effective (Trollope et al. 1989; Dahl & Nepembe 2001). Some of the herbicides are not effective on soils with a clay percentage above 35% (Smit et al. 1999).

Various plant species also differ as far as their resistance to herbicides is concerned (Smit 1993). *Dichrostachys cinerea*, for example, will require double the dose (Quan, Barton & Conroy 1994) applicable to *Acacia mellifera*.

After application, these herbicides remain inactive until such time as rain carries the active ingredient (Tebuthiuron, Ethidimuron or Bromacil) into the soil, when it is taken up by the tree roots. Their action in the plant is to inhibit photosynthesis. The leaves become yellow and abscise. New leaves are formed, but also abscise. This process continues until the tree no longer has reserves to initiate re-growth and so it dies. These herbicides should be applied early in the growing season. If applied in the dormant season or late in the growing season, they will remain inactive on the soil surface for lengthy periods (Smit et al. 1999).

Aerial application is usually done when the plant is in an active growth stage, i.e. the leaves and the stoma are still open and able to absorb the remedies. Several researchers (e.g. Moore 1989) also found that the carbohydrate status of plant parts at the time chemical treatment was applied had a huge influence on the application's effectiveness. Thus, the carbohydrate status of the different plant parts during chemical application will influence the minimum dosage and, consequently, the economic viability of bush control. Chemical control will be the most effective during the translocation of carbohydrates to the roots, and when they are stored in the roots.

Aerial application of root-absorbent herbicides is also regarded as an effective method to combat bush and is probably the fastest way to clear bush.

Rhigozum trichotomum's root distribution covers a radius around the stem base of approximately three times the plant height. The specific nature of the root system favours broadcast application of chemicals and implies a possible low application rate. In any future strategy, drastic control measures will be needed to eradicate bush where densities are higher than 1,000 bush equivalents followed by very good rangeland (Moore 1989).

9.2.1.3 Foliar and stem-absorbent herbicides

Products in this group contain Picloram and Triclopyr as the active ingredients and are used in either an oil- or a water-base form (Smit n.d.). Herbicides are sprayed directly on the plant's above-ground growth. These chemicals will then be absorbed by the leaves.

Foliar and stem-absorbent herbicides are also applied where the stems of plants are cut off close to the soil surface. Until recently, the most common practice was to apply Picloram and Triclopyr (Tordon Super) mixed in diesel or old oil at a 1% concentration to the stem of the plant using a knapsack spray or a brush. A red oil-immiscible dye is available for adding to the mixture. Small trees with a stem diameter of less than 10 cm can be sprayed directly, while those with stem diameters of more than 10 cm need to be cut back before treatment. In the latter case, the tree should be cut off approximately 5–15 cm above the soil surface and be treated as soon as possible thereafter. The cut surface and the remaining stump as well as any exposed roots should be wet thoroughly. If only one side of the stump is treated, it will often grow out from the untreated side.

Although the manufacturers advise that the product should only be used during the active growing season, good results can be achieved at other times as well (Smit n.d.).

9.2.1.4 Advantages and disadvantages of using herbicides

(a) Soil-applied herbicides (Tebuthiuron, Ethidimuron and Bromacil)

(i) ADVANTAGES

- Treatment of individual trees is relatively fast (Bester 1985a; Smit et al. 1999).
- Application can be selective, particularly when applied by hand. There is little danger of untreated trees being exposed to the herbicide (Smit n.d.).
- The residual effect can suppress seedling regeneration for up to five years (Smit et al. 1999; Bester 1985a), and
- The manual application of herbicides is labour-intensive and provides ample opportunities for job creation (Van Eck, pers. comm.).

(ii) DISADVANTAGES

- Even with selective application, trees that have not been treated may die because their roots extend to the vicinity of application (Bester 1985a; Smit et al. 1999; Smit n.d.).
- The active ingredient may be slow to take effect because it only becomes active once rainwater has carried it into the soil profile. This means it can take up to two years to effectively kill target species (Bester 1985a; Smit et al. 1999).
- Trees that die remain standing and show a resistance to decay and decomposition when certain of these herbicides are applied. Nutrients contained in their wood remain unavailable for use by other plants for long periods of time (Bester 1985a; Smit et al. 1999). This is especially of concern in dense stands of bushes.
- The rate of application is dependent on the soil's clay and organic matter content, making this method very expensive in soils with a high clay content (Bester 1985a).
- Trees differ in respect of their sensitivity to herbicides. Some trees require a higher rate of application. Therefore, a person applying the herbicides without the necessary knowledge of trees and correct application rates may cause failures and substantial subsequent financial losses, and
- A large number of dead standing trees makes for an unattractive landscape (Smit et al. 1999).

(b) Foliar and stem-applied herbicides

(i) ADVANTAGES

- These are selective methods, as the leaf area of a specific tree is treated. There is little danger of untreated trees being exposed to the herbicide (Bester 1985a; Smit et al.1999).
- Chopped-down trees whose stems have been treated immediately, die immediately (Bester 1985a).
- One can establish very soon whether or not the appropriate number of trees has been retained (Smit et al. 1999).
- Dead plants can be harvested and utilised for the production of firewood or charcoal, for example. Income derived from such products can be used to retrieve some of the costs arising from bush clearing (Smit et al. 1999; International Development Agency 2003), and
- It is labour-intensive and can create job opportunities.

(ii) DISADVANTAGES

- The procedure is very time-consuming (Smit et al. 1999) and tedious (Bester 1985a), and
- With increasing bush densities, manual applications become increasingly expensive. For areas with more than 2,000 bushes per hectare, aerial application is the cheaper option.

(c) Aerial application

(i) ADVANTAGES

- Because of its uniform application, no individuals escape treatment (this can also sometimes be a disadvantage). Seedlings which are often missed in hand applications are usually killed by aerial applications (Smit et al. 1999).
- It is a cheaper method when bush densities exceed 2,000 per hectare.
- It is not time-consuming and large areas can be controlled within one season, especially where high bush densities occur (Bester 1985a).
- It is effective, with a mortality rate in the order of 70–90%. However, this still means that not all the bushes are killed (Bester, pers. comm.), and
- Very little labour is required (an advantage from a financial point of view, but less attractive from a socio-economic perspective).

(ii) DISADVANTAGES

- Valuable plants may be adversely affected by the herbicide due to the non-selective nature of aerial applications (Smit et al. 1999), and
- Landing strips for aircraft are not always available (Van Eck, pers. comm.).

Aerial application of Graslan 20P by aeroplane is usually recommended as a first treatment, especially when there are so many bushes that it is very difficult to penetrate the thickets manually. It becomes more cost-effective with bush densities beyond 2,000 tree equivalents per hectare. As an aftercare measure, this method is regarded as too expensive; other aftercare measures should be applied before densities become too high again.

Since 1,000 *Rhigozum trichotomum* bushes per hectare can reduce carrying capacity up to 93%, it is recommended that drastic control measures be introduced to eradicate bushes where densities are higher than 500 per hectare. Because of the extensive root system, broadcasting of chemicals may be the most efficient way of combating this particular species.
Tables 9.3 and 9.4 provide a summary of the available herbicides and their active ingredients.

Herbicide	Type	Active ingredient
Molopo SC	Liquid	Tebuthiuron (50%)
Molopo GG	Pellet	Tebuthiuron (20%)
Spike 5GR	Pellet	Tebuthiuron (5%)
Savanna 500	Liquid	Tebuthiuron (25%), Bromacil (25%)
Bushwacker	Wettable powder	Bromacil (80%)

Table 9.3: Soil-applied herbicides (non-selective)

Herbicide	Type	Active ingredient
Tordon Super (Cut stump or basal stem application)	Liquid (mixed with diesel)	Picloram 120 g per litre (12%) Triclopyr 240 g per litre (24%)
Access (Cut stump, basal stem or foliar application)	Liquid (mixed with water and Actipron)	Tebuthiuron 240 g per litre (24%)
Viroaxe (Foliar)	Liquid (mixed with diesel)	Triclopyr 480 g per litre (48%)
Touchdown Plus (Stump)	Liquid (mixed with water)	Glyphosate trimesium 480 g per litre (48%)

Table 9.4: Plant-applied herbicides (selective)

Source: *Smit (pers. comm.); Stoltsz (pers. comm.); Van Eck (pers.comm.)*

9.2.1.2 Biological methods

(a) *Browsers*

With the exception of tree seedlings, which can be impacted by small browsers, the use of browsers to exercise control on woody plants largely excludes game.

Provided that target bushes are within the 1.5 m utilisation zone, goats at high stocking rates can under certain circumstances be used as a short-term measure to reduce intruder bushes.

With high densities, however, the required stocking rates are so high that many benign fodder bushes and desired perennial grasses are eradicated before invader species are reduced to the level where the problem is solved.

It is doubtful, therefore, whether it is viable and environmentally sustainable to keep goats at a required stocking rate of two to three units per hectare on a commercial farm of several thousand hectares.

As a general rule, therefore, the use of browsers is not recommended to reduce bush density if it has already reached problematic dimensions (2,000 per hectare and more).

The value of browsers (goats and game) as an aftercare or preventative measure of bush control will be discussed under 9.2.2 below.

(b) *The use of fire*

Veld fires are not regarded as an effective means of combating bush.

Even with adequate amounts of grass the number of woody plants is not substantially reduced since –

- larger trees and shrubs do not die from fire, and often regrow strongly
- bushes up to 2 m high only suffer a top-kill and have the ability to regrow
- a suitably high fuel load is not always available: A minimum of 2,000 kg of grass per hectare is needed to ensure an effective top-kill resulting in an acceptable state for browsing animals. This amount of fuel is not available where bush densities are already a problem, i.e. more than 2,000 bushes per hectare. Under such circumstances a fire will do more harm than good, and
- grazing management is often in conflict with the use of fires.

Veld fires may, however, be used to modify the structure of the woody layer and they are most useful for this purpose as well as an aftercare treatment.

The following fire regime (season and frequency of burning) is recommended:

- A high-intensity fire (>2,000 kJ per second per metre) is required. This can be achieved with a fuel load of 2,000–4,000 kg of dry matter per hectare.
- The relative humidity should be below 30%.
- Air temperature should be above 25°C.
- Burn with the wind (i.e. a head fire), but the wind speed should not exceed 20 km an hour.
- The season is also important in respect of burning. The best time is during spring, when the woody plants have already started to grow, but the grasses are still dormant – usually just before the first rains.
- The frequency of burning is not fixed. In wetter savanna areas a fire every three to four years may be possible, while in drier areas it should be undertaken opportunistically depending on the rainfall and the presence of small woody plants that need to be controlled.

Controlled fires as an aftercare measure are discussed under 9.2.2 below.

(c) *Fire-girdling/stem-burning*

Fire-girdling (also known as *stem-burning*), in which a low-intensity fire burns or smoulders for an extended period around the stem of a woody plant, can be used to selectively kill individual trees.

In general, it was shown that fire-girdling is most effective if done as near to ground level as possible. Thus, a fire is made at the base of the tree, using either wood, cattle dung or rubber from tubes as fuel.

A minimum duration (of at least 3 minutes) and intensity of the fire needs to be achieved for fire-girdling to be effective.

Regrowth was lowest and mortality the highest for trees fire-girdled during the rainy season, i.e. between January and April.

This procedure is relatively inexpensive as any available fuel may be used, but it is labour-intensive and time-consuming. It is also not well-suited to trees with small stems or to multi-stemmed woody species.

Post -fire-girdling treatments, especially with browsers, are recommended since regrowth does occur.

(d) *Use of fungi*

Based on extensive research, the Council for Industrial and Scientific Research in Pretoria, South Africa, concluded that it would be very difficult to develop a control method for *Acacia mellifera* based on fungi, e.g. *Phoma glomerata*, *Phoma cava* or any fungal products.

The main difficulty with developing a novel herbicide based on fungi is the isolation and identification of the active ingredient. The alternative approach, namely using the fungus as a selective pathogen, is also unlikely since the fungus is possibly sensitive to environmental factors which cannot be controlled.

Moreover, knowledge concerning the magnitude and extent of mortalities caused by the fungus *Phoma glomerata* is still very meagre. Prospects of solving the bush encroachment problem through natural enemies is not known and needs further investigation. This includes the extent to which regrowth takes place, the role soil types play in this regard, and the extent to which the fungi affect intruder species other than *Acacia mellifera*.

Where mortalities as a result of *Phoma* activity occur, it should be seen as a bonus at this stage. A strategy built on the hope that this fungus will eventually solve the problem may end up in great disappointment and precious time lost. Other control methods should rather supplement the bonuses that there are.

The impact of fire on the presence/activity/mortality of the fungi is unknown and should be investigated.

(e) *Use of bio-agents*

The use of bio-agents is limited to alien species.

The vast majority of the farmers who experience *Prosopis* encroachment expressed the wish to eradicate them as soon as possible. Some farmers, however, place a high value on these trees as a source of nutrition. In this case there is a clear conflict of interests. Farmers who apply expensive techniques to combat *Prosopis* find that those who utilise it serve as a source of reinfestation. Pods are spread by animals and by water movement down river courses.

The introduction of natural enemies such as *Algarobius prosopis* and *Neltumius arizonensis* beetles could solve not only the encroachment problem as such, but also the conflict of interests. The following options should be considered:

- Introduce the mentioned bio-agents that will feed on the seeds of trees.
- Once the beetles are established, the *Prosopis*-infested areas should be withdrawn from grazing for at least eight months every year. This will allow the bio-agents to destroy the vast majority of the seed embryos, curb dispersal of seeds, and reduce the amount of follow-up work after clearing. Thereafter, the pods can still be used by grazing animals without significantly losing the nutritional value. Alternatively, the pods could be thoroughly harvested and crushed through a hammer mill.
- It should, however, be realised that there are many other *Prosopis* seed eaters that can utilise the pods and spread the seeds during the period of withdrawal.
- Since the bio-agents will not affect seeds already present in the soil, seedlings will still emerge from season to season and need to be controlled/eradicated by other methods, especially on farms where the pods are utilised. Once bush densities become too high, pod/seed production will drop substantially and it will become increasingly difficult for animals or harvesters to penetrate the thickets.

A firm decision needs to be taken, therefore, in terms of a manageable number of *Prosopis* trees per hectare (a density which will allow grass production too) and one should clear accordingly. For example, –

- clear a manageable amount of land each year, either chemically or mechanically as described above, or by means of a combination of the two. Aftercare measures will be imperative.
- establish a bio-agent breeding station from which point the beetles could be distributed to farmers who are interested in using them. Such a station could be managed and maintained by the Ministry of Agriculture, Water and Rural Development.
- undertake research on bio-agents that will attack and destroy *Prosopis* flowers. The release of such an agent will require a major policy decision.
- consider utilising the wood to recover some of the costs of clearing invader species. The possibility of establishing small enterprises in this regard should be investigated.

The whole process should be supported by formal policies and legislation. Such provision does not exist in Namibia and should be incorporated under an existing Act.

Because these bio-agents are not entirely effective when used alone, they should be used in combination with other methods.

(f) *Rotational grazing and resting of veld*

Veld-resting, together with good rangeland management practices where serious bush invasion is encountered, seems to be ineffective. This method should rather be seen as an aftercare or preventative option (see 9.2.2 below).

9.2.1.3 Mechanical methods

(a) *Bulldozers*

Clearing invader bush by means of bulldozers leads to soil surface disturbance. This in turn serves as a seedbed for the establishment of a variety of woody seedlings and other pioneer species of little forage value. *Dichrostachys cinerea* in particular is favoured in the process. Over time, this may result in a woody community which is more dense than the original one. It is also a very expensive practice.

Consequently, this method is not recommended for purposes of veld reclamation.

However, where bush is cleared for crop production, bulldozing is very suitable.

(b) *Felling/stumping*

Felling bush by means of axes, saws, chain saws, mattocks, etc. is only recommended if the bush is removed in such a way that the coppicing buds are destroyed or completely removed.

This method is totally unsuccessful with *Dichrostachys cinerea*.

Where coppicing does occur, the stumps can be treated with an appropriate herbicide, e.g. Access. This treatment will be effective for *Dichrostachys cinerea*, for example. Browsers or stem-burning are also recommended.

9.2.2 Aftercare measures

Practical experience has already shown that any delay or neglect in following up treatments to control regrowth and reinfestation leads to a worsening situation.

Farmers/land-users who are not willing to commit themselves to this principle should not even attempt to control problem bush.

At the same time, sound rangeland management practices are indispensable for long-term success (Bester 1985b).

One of the most important objectives with bush control is to reduce the problem plant to a near-juvenile stage of growth. This will result in the plant's inability to flower and produce seeds for a number of years, which in turn will influence the frequency of aftercare treatments and, consequently, a reduction in the soil's seed content.

9.2.2.1 Chemical

With this treatment, most bushes die within a year and the recovery of grass is good. Despite this, follow-up treatment is required because the increase of perennial grass species does not appear to suppress reinfestation. Other options include an occasional controlled burn, the removal of bush by hand, or the introduction of goats to browse the regenerating bush. Few farmers take the latter option because it is difficult to manage, it is expensive (in respect of herding or fencing), and there is the constant risk of theft and predators.

Whatever the method may be, aftercare treatment should continue indefinitely.

Any of the manually applied herbicides mentioned under 9.2.1.2 and 9.2.1.3 can be used effectively as an aftercare treatment. The frequency of treatment will be determined by the results obtained from meticulous monitoring activities.

9.2.2.2 Biological

(a) *Browsers*

As an aftercare measure, goats can be introduced successfully to utilise and control regrowth as a follow-up to other methods like the application of herbicides, felling/stumping, and controlled or accidental fires.

A strategic approach would be to prevent problem species from producing seeds.

In other words, the grazing pressure needs to be at a level where the growth is kept low. The only significant control the browsers have on woody plants is through their effect on seedling survival. Goats can be effective in preventing the establishment of seedlings. However, if seeds from invader species like *Acacia mellifera*, *Dichrostachys cinerea* and *Prosopis* are available in abundance, goats can play a major role in the distribution of seeds and subsequent seedling establishment.

As a general rule, goats should be used in combination with cattle. The stocking rate will depend on the amount of bush and regrowth, as well as the grass yield. Unfortunately, no definite carrying-capacity guideline can be given in this regard as circumstances will differ from farm to farm (or area to area) as well as within and between years. The use of indicator species to monitor stocking rates and vegetation changes will be essential to secure success.

Browsers are also found to be effective when used in tandem with fire to control bush thickening. As an alternative to goats, browsing game can also be introduced. Species should be selected according to different tree strata and available browse. For this purpose game species like giraffe, kudu and eland can be employed successfully to utilise and control regrowth. High management skills are required for this kind of venture, however, and special attention should be paid to marketing the animals timeously in order to control stocking rates. In this respect the impact of camels on invader bush should also be investigated.

Boer goats require a high degree of management if they are to be used to control woody plants and are, therefore, not popular among farmers. If they are given free range of an area, they are likely to have little impact on the woody plants. Standard stock fences are not adequate for goat control and goat herders are generally not able to keep goats in a specified area long enough to apply the required intensity of browsing to the woody plants. Electric fences may prove more useful to restrict the movement of the goats.

(b) *Controlled fires*

The role of fire to suppress growth and the establishment of young trees in arid and humid savannas is broadly recognised. All current theories indicate that fire can be successfully introduced as an aftercare measure, but at the same time there is very little experience about the practical implementation of this tool. On the one hand, more research into the biophysical effects of veld fires on bush encroachment in different ecological situations is needed, while on the other, socio-economic considerations are as important and need further investigation. The frequency at which burning is applied can play an important role in counteracting seed production and suppressing the growth and establishment of new seedlings. Clearly, such an operation needs proper control and cooperation between neighbours.

The use of fires as a management tool should be incorporated into a national woodland management policy. At the same time, proper legislation and fire management guidelines should be in place to direct and protect landowners and land-users.

During 2001/2, more than 1 million ha of rangeland were destroyed by uncontrolled fires. All these sites can serve as excellent opportunities where the long-term effect of fire on bush densities, mortalities, evapotranspiration, productivity, survival of *Phoma glomerata*, and soil structure can be monitored and researched through follow-up burning.

(c) *Fire-girdling/stem-burning*

This practice is regarded as a very effective aftercare measure, but should be executed with caution to prevent the ignition of wild fires (see 2.2.1 for more detail).

(d) *Rotational grazing and resting of veld*

The principle of rotational grazing is based on short grazing periods followed by a long rest. Desired perennial grasses are grazed selectively to ensure and maintain a vigorous grass cover that has the advantage in respect of moisture in the upper layers of the soil. Pastures in such a condition are able to suppress the establishment and growth of bush seedlings and, therefore, the intrusion of unwanted bush species.

Once intruder bushes have established themselves in high densities, the bounds of resilience of the natural state have been exceeded. Under these conditions it is not possible for grasses to compete successfully with the extensive network of roots belonging to bushes and trees in the upper layers of the soil. External intervention such as the removal of bush is needed to restore the grass's competitive edge. Sound rangeland management practices should, therefore, be regarded as a preventative measure and, during the first 20 years or more after bush clearing, should be used in combination with other aftercare methods to prevent reinfestation.

The establishment of artificial pastures of *Cenchrus ciliaris*, for example, can be of enormous value for the reclamation of natural rangelands. In this way, camps can be withdrawn from grazing during critical phenological and/or climactic stages in order to allow the maximum rest period for desired grass seedlings to establish.

9.2.3 Restoration technologies

Many technologies and approaches have been devised and applied by land-users to restore degraded land. These technologies are often based on indigenous knowledge and skills and are adapted to address specific problems and environmental conditions, and include the mechanical and/or biological reclamation of degraded rangelands. The challenge is to optimise and exchange these experiences and to disseminate them to as many land-users as possible. An effective way to do so is to capture information from these sources into computerised "expert systems" that can be consulted and serve as a Decision Support System (DSS) for future management application.

A DSS offers the means to facilitate knowledge transfer to extension workers, researchers, conservationists, decision-makers and land-users. For this purpose, the so-called Bush Expert was created at the University of Potchefstroom in South Africa on behalf of the project.

Once established in Namibia, the Bush Expert will be linked up with EcoRestore, a DSS in South Africa, which will be interlinked with websites such as the Agricultural Geo-reference Information System of the National Department of Agriculture in South Africa, the World Overview of Conservation Approaches and Technologies and other international databases, and so offer the user a wider range of technologies and advice. In due course, the Namibian experience should have been incorporated into a DSS.

Constant interaction between the Bush Expert (Namibia) and EcoRestore (South Africa) should be promoted.

9.2.4 Addressing research needs

All research gaps identified during Phase 1 of the project should be regarded as a Government responsibility and need to be followed up by the relevant Ministries. The project should consider standardising the methodology for field surveys and seek cooperation with the NRSC/Directorate of Forestry to undertake volume calculations of sample plots, applying user-friendly technology developed for the purpose.

The experience of the Living in a Finite Environment (LIFE) Program should be utilised in respect of developing natural resources planning and monitoring systems, and practice-oriented biodiversity monitoring. Efforts to involve jobless school-leavers and graduates in bush control programmes should also be pursued.

The most pressing issues to be researched are the following:

9.2.4.1 Research of an environmental nature

- Possible residual effects of arboricides and consequences for future marketing
- The occurrence and dynamics of bushes in relation to specific habitats/AEZs
- Natural die-off of problem species: magnitude, species affected and practical implications for farmers
- Frequency of seed production by different target species
- Age determination of different generations of intruder species versus year of establishment in relation to prevailing climatic conditions
- Quantification of the impacts of different densities of various woody species in the herbaceous layer. This would help in determining the extent of thinning required, as well as the bush species that should preferably be removed

- In relation to the invasion of *Prosopis* at an alarming rate in the Nossob, Auob and Olifants Rivers over the past two decades, the following urgently need to be researched:
  - Biological control of *Prosopis*
  - Water use and water-use efficiency
  - Cost-benefit analysis, including future management challenges and utilisation
  - Implementation of a long-term strategy
  - Geo-ecological analysis of *Prosopis*-infiltrated landscapes, and
  - Business plan for community development based on the utilisation of *Prosopis* products. The utilisation of *Prosopis* products such as wood and pods as well as involvement as workers in control programmes can create considerable employment opportunities for the rural poor.

9.2.4.2 Bush control methods

- Satellite imagery as a tool to monitor changes in woody composition and vegetation in general
- Fire as a management tool
- Camels as browsers
- The development of a bush control model, with all relevant biological and socio-economic indicators. Therefore, on-farm research to evaluate the applicability and consequences of any new technology in economic terms should be done before implementation of such a model. Research in general has not aimed at relating information to the level of the individual ranch or other agriculture-based businesses.
- Developing DSSs to facilitate information appraisal and dissemination to farmers using a non-prescriptive format. This will assist in solving bush management problems by using a modelling framework, involving the incorporation of simulation models within a DSS.
- The refinement of best practices of bush control through continuous surveys and case studies, and assessing the long-term effect of bush control programmes
- On-farm experience, together with research findings, should be stored in the Bush Expert database. A programme for this purpose is planned for Phase 2. It will be of no use to have the best technologies on bush control available if suitable and sustainable aftercare and rangeland management measures are neglected or not in place, and
- Investigate the possibility of manufacturing the active ingredients of the different arboricides in southern Africa or, alternatively, to import the herbicides or active ingredients directly from the manufacturing countries.

9.2.4.3 Industrial development

- Utilisation, processing and marketing of wood originating from problem species.

9.2.4.4 Addressing political aims

- The practical implications of bush control programmes for land reform.

9.3 Result 3: The integrated information and monitoring system is operational at national and farm level

9.3.1 Maintenance of a Bush Expert Decision Support System

The effectiveness and efficiency of the aforementioned methods, both bush clearing and aftercare, will be influenced by factors such as climate, soil type and clay content, topography, species composition and height classes, the level of management, and the level of knowledge of the different bush-clearing methods.

Apart from information obtained from research data and manufacturers, there was a dire need to record the results and experience of farmers who had applied these techniques. Thus, on-farm research was carried out on a number of farms in the affected areas. These findings are being processed and stored in the Bush Expert database developed for the project by the University of Potchefstroom in South Africa.

The database is designed in such a way that the data can be accessed via the Internet (www.puk.ac.za/EcoRestore) by anyone who wants to embark on bush control programmes. For those who do not have Internet access, all the information is available on CD at the offices of the Namibia Aricultural Union, Namibia National Farmers' Union and at the library of the Ministry of Environment and Tourism.

This database should be supplemented with new information on a continuous basis. The functioning of the Bush Expert can be illustrated as follows:

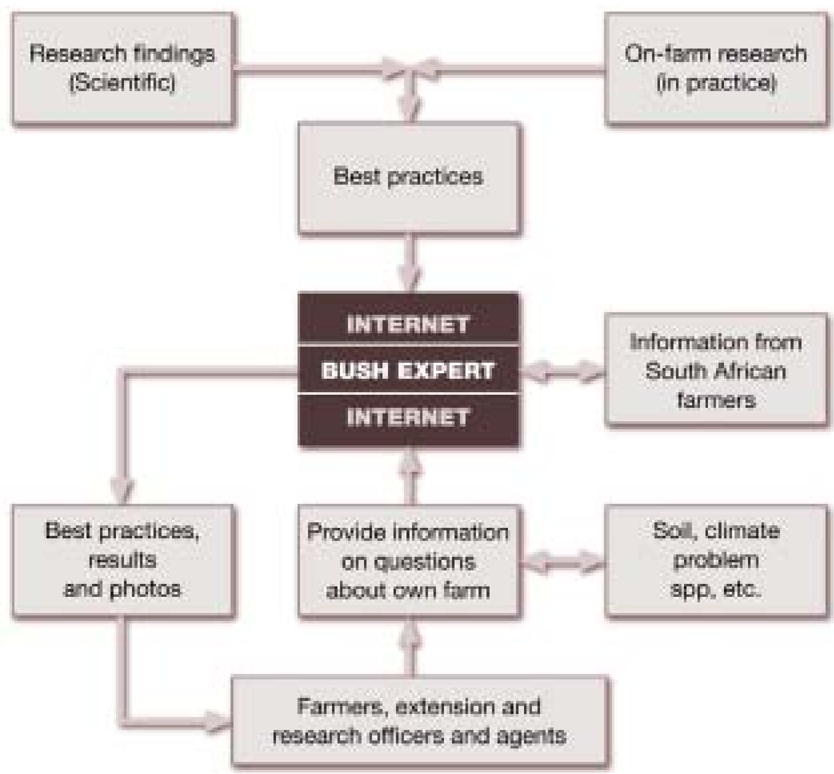


Figure 9.9: Bush Expert Decision Support System

Namibians should be trained to take over the management and maintenance of the database during Phase 2. It is proposed that the database be maintained under the auspices of the NAU and the NNFU.

A strong link with the South African database, EcoRestore, should still be maintained.

A very important outcome of this database should be that applicable extension material derived from the Bush Expert database is published in a user-friendly manner as extension packages.

9.3.2 Establishment of a monitoring system for measuring changes in woody vegetation

9.3.2.1 Using appropriate indicators

A number of indicators, presented in Table 9.5, are recommended to monitor changes in the environment with specific reference to the woody component. The indicators are classified in terms of their usefulness to reflect different forms of pressure on the environment leading to bush encroachment, the state of the rangelands and the societal response to the prevailing problem.

Type of indicator	Indicator	Units of measure	Proposed method
Pressure	Livestock (per species and type)	Kilogram live weight per hectare	Records kept by farmers
	Wild herbivores (per species)	Subjective rank	Records kept by land-users
	Type of management	Descriptions and some quantities	Records kept by land-users
	Fires	Area marked on map	Analysis of records and maps kept by land-users
	Fruit production on encroacher species	Subjective rank	Records kept by land-users
	Rainfall	Millimetres per annum	Rain gauge
	Frost	Occurrence of top-kill in bushes	Records kept by land-users
	Fungus on *Acacia mellifera*	Percentage of bushes infested	Records kept by farmers
State	Amount of bushes	Ranking in comparison with previous photographs	Fixed-point photographs
	Density of grass		
	Seedling density	Plants per hectare	Plot counts
	Woody canopy cover – all bushes (per species)	Percentage	Bitterlich gauge
	Bush height classes – all bushes (per species)	Percentage	Point sampling
	Density of bushes – all bushes (per species)	Plants per hectare	Distance measurements from points
	Perennial grass species composition	Percentage cover (and range condition score)	Distance measurements from points
	Biodiversity	Index	Measures of variation
	Soil cover	Percentage	Point sampling
Response	Control methods applied by land-users	Area marked on map	Analysis of records and maps kept by land-users
	Animal production	Kilogram live weight per hectare per annum	Analysis of records kept by farmers
	Wood production	Kilogram per hectare per annum (local and national level)	Analysis of records and maps kept by land-users

Table 9.5: Indicators of pressure, state and response and corresponding methods of monitoring

It is recommended that –

- land-users, extension officers and rangeland scientists measure and prioritise the indicators suggested; thresholds for these indicators should be determined at the same time
- rangeland scientists determine thresholds for individual or a combination of indicators; with this information, the number of indicators can be reduced, provided the purpose of the monitoring is not watered down
- the monitoring of bush encroachment indicators be integrated into monitoring programmes for other degradation indicators, and
- socio-economic and institutional indicators be developed and incorporated into the prospective monitoring system.

9.3.2.2 Implementing a monitoring system

Monitoring over the long term should form an integral part of farm management, and applies to treated as well as untreated areas on the farm.

At farm level, monitoring should ideally be performed by land-users, since they are the ones who should immediately apply the results to improve their management. Hence, farmers should keep records of their natural resources, just as most of them do for their finances and their livestock. If farmers notice a change in the status of the bush on their land, they should be able to respond swiftly to achieve the desired conditions. However, farmers working in isolation will not be as effective as those who join forces by means of farmer associations, study groups, unions, extension services, and researchers.

Furthermore, some forms of monitoring, such as remote sensing, can only be performed effectively at a larger scale through bigger organisations such as the Government. At the national level, there is a strong need to coordinate and manage information emanating from rural areas. Cooperation should be initiated with the Namibia–Finland Forestry Programme to expand the national woody resources monitoring system to include bush-encroached areas. Experiences by the Living in a Finite Environment (LIFE) Program should also be utilised for the development of natural resource planning and monitoring systems and practice-oriented biodiversity monitoring.

There is usually a trade-off between simplicity and reliability: the simpler a measuring technique becomes, the less reliable its results are likely to be. With that in mind, it is recommended that –

- a central database be established
- benchmarks be established at all agricultural research stations and in the vicinity of extension offices to set the example to encourage land-users to establish their own benchmarks
- land-users decide on their own priorities for monitoring, while considering the consultants' priority list
- land-users only monitor what they find to be efficient for their own uses
- extension officers and researchers do some monitoring in a few key areas to fill some of the gaps left by land-users
- a handbook be developed for land-users to refer to when deciding what and how to monitor, such as that for Australian farmers (Hunt & Gilkes 1992). This should deal with environmental monitoring in general, and not only bush encroachment
- extension officers receive training in ground monitoring so that they, in turn, can train land-users and provide a support service
- ground monitoring be focused on the priority land type to obtain reliable results
- land-users determine the most appropriate season for their ground monitoring
- land-users who would like a more holistic picture of the situation as regards their vegetation perform ground monitoring annually during the late growing season
- once a land-user has decided on his/her most suitable season to start ground monitoring of the vegetation, s/he adheres to that season for all subsequent measurements
- perennial grasses only be recorded in the monitoring if they are more than a year old, as evidenced by the presence of grey material from the previous season and a wide base. In this respect one needs to be wary of counting bush seedlings shorter than 10 cm: if the large percentage of the latter that will die are included in the data it will give a skewed picture. Interpretation of the data also needs to be done with great circumspection (Bester, pers. comm.)
- for those land-users who will be doing the monitoring, training be given in plant species identification, possibly offered by the National Botanical Research Institute
- farmers keep detailed records of their animals so that appropriate synthesis can be performed when required
- for land-users who do not census wild animals, they make a (subjective) qualitative judgment on the amount of wild animals they have and record these numbers for each rainy season and dry season
- a reference collection of photographs of differing rangeland condition be developed when the first fixed-point photographs are taken, so that they can immediately be scored
- ranking of photographs from the same site be applied from the second photo onwards
- plot counts be used for measuring bush seedlings
- the Bitterlich gauge be used for estimating canopy cover
- distance measurements be used for estimating bush density, height classes and distribution
- strip counts be used at a few sites, and infrequently, to provide calibration and validation for the density estimates from distance measurements
- farmers use distance measurements for long-term monitoring

- researchers construct degradation models for baseline[24] comparisons
- those farmers who are estimating grass biomass continue to do so and make the data available to a central database
- land-users keep records of the production they obtain from the land, as many are already doing
- institutions gathering data on commercial production make the data available to a central database once it becomes established, and
- an analysis of the existing monitoring systems in Namibia be undertaken and issues related to bush encroachment incorporated into existing systems, if feasible. If a separate system is needed, a definite action plan should be formulated and agreed upon between identified land-users and institution(s) committed to operating such a system.

9.3.2.3 Implementation of an expert system

It is recommended that –

- a simple expert system be set up on computer in regional extension offices and farmers' union and association offices until the Mandarax Decision Support System supersedes it
- extension officers and members of farmers' unions are trained in the use of the system, and that they facilitate the use of it by farmers, and
- the expert system is revised as knowledge and understanding of bush encroachment processes is improved.

9.3.2.4 Remote sensing

It is recommended that –

- current satellite remote-sensing projects determining correlations between NDVI and vegetation parameters be completed before a further monitoring system is developed. This is particularly important for the mapping project undertaken by the NRSC, and
- ortho-photo maps be used for periodic assessment of vegetation.

9.3.2.5 Data storage and distribution

It is recommended that –

- the unit for Information Management in the MAWRD host the monitoring database
- regional offices be provided with pre-processed data in order to reduce the computing requirements of the regional offices, and to reduce the size of the data sets. For more sophisticated requirements, queries may be referred to the central unit for action
- the GIS and remote sensing data be maintained by the NRSC
- the monitoring database be maintained by the MAWRD's unit for Information Management
- the expert system be maintained by the Polytechnic of Namibia, and
- budgetary provisions be made for financing these activities.

9.3.3 Capacity-building to manage and maintain the expert systems

As a first step the management and maintenance of the Bush Expert system needs to be transferred to the NAU and the NNFU for joint-ownership management. Given the established expertise in the NAU it is proposed that the database be housed in the NAU Headquarters. Continuous surveys and case studies for maintenance purposes will form an integral part of management. Training courses for this purpose will be indispensable.

As far as the Mandarax Decision Support System database is concerned, management thereof should be transferred to the Polytechnic of Namibia, where it can be utilised as a research instrument.

No compensation for maintenance and management of the Mandarax will, therefore, be needed. However, it is recommended that the two databases be linked to enable secure cooperation and access to both DSSs by all the users.

[24] The initial phase of monitoring, i.e. the first set of readings of a monitoring programme.

9.4 Result 4: An enabling institutional framework and operating policy environment for bush-based enterprises is established, and quality control and marketing mechanisms for efficient utilisation of bush-based products are improved

9.4.1 The present policy environment

Bush encroachment is recognised as a serious problem, particularly in the National Agricultural Policy. This policy and others focus on what should be done about bush encroachment, and therefore provide a sound foundation on which a future strategy can be built. However, they do not prescribe how problem bush should be addressed.

As previous chapters have shown, a number of gaps exist in the policy and legislative framework.

The most obvious gap is that no incentives are provided to manage bush encroachment, whether in terms of preventing it or in reversing its negative impact.

Current policies, particularly in the agriculture and forestry sectors, provide important parameters within which bush management policies will have to be formulated. A number of specific issues can be mentioned in this regard:

- The role of the State: Post-Independence policies in the agricultural and natural resources sectors have changed the respective roles of the State and farmers dramatically. The National Agricultural Policy, the National Drought Policy and Strategy, and the Namibia Forest Development Policy devolve the responsibility for managing natural resources to the ones that own and use them. The role of the State will be limited to regulatory functions and providing technical support that will enable farmers to improve their capacity to manage resources more effectively. The State will only provide direct financial support in emergencies. This implies that farmers will have to bear the responsibility of managing their woodlands. More specifically, they will be responsible for the prevention of bush encroachment and its eradication where densities are too high.
- It follows from these new roles of State and farmer that the thinking on subsidies has changed as well. In terms of the National Agricultural Policy, long-term or continuing subsidies will be avoided. However, the Policy still allows for the possibility that well-targeted subsidies can play an important part in achieving short-term agricultural and socio-economic objectives. Provision is made in the Soil Conservation Act for the payment of subsidies and grants to erect soil conservation works.

The control of invader bushes is not explicitly defined in the Soil Conservation Act as a soil conservation work and should, therefore, be included in the range of such works mentioned in the Act.

Although subsidised bush control remains a contentious issue, it could serve as an important measure to encourage farmers to tackle the problem.

9.4.2 Creating a favourable policy environment

With these principles in mind, a policy framework for woodland management needs to spell out how the State can improve the capacity of individual farmers or groups of farmers to deal with bush encroachment.

9.4.2.1 Policy and legislation

In its present form, the provisions of the Forest Act apply to classified forests only.

The formulation of a policy to manage woodlands on both commercial and communal ranches needs to be regarded as a priority.

- However, it is not recommended that separate legislation be introduced to deal with bush encroachment and its eradication. Instead, a woodland management policy should be used to amend the provisions of the Forest Act to incorporate issues pertaining to woodlands that fall outside the definition of *forest* and *classified forest*. This will ensure that all woodlands in Namibia will be managed in a sustainable manner. In its present form, the provisions of the Forest Act apply to classified forests only.

Existing opportunities and efforts/initiatives to exploit bush in a profitable way need to be strengthened.

- More specifically, the market for charcoal needs to be secured and expanded. This is crucially dependent on the quality of charcoal, and the way it is produced. Certification of charcoal in terms of the Forest Stewardship Council (FSC) is a prerequisite for this and needs to be encouraged. It deserves mention in this regard that, as far as the FSC is concerned, Namibia does not practise sustainable woodland management, but is instead clearing invader bush to reclaim rangeland (DFN 1997:56). This reinforces the importance of incorporating the management of woodlands into forestry policy instruments as part of low-intensity forest management.

Specific guidelines for woodland management need to be developed.

It is also recommended that policy instruments include providing the NWMC with statutory powers similar to those of the Meat and Agronomic Boards.

The NWMC was set up with a view to address issues pertaining to charcoal production, quality control and marketing. These are important functions as the economical eradication of invader bush depends on a reliable market to sell charcoal and other wood products. Additional uses for bush need to be investigated and encouraged.

Woodland management plans should be developed under the Forest Act.

While the Forest Act provides for the establishment of forest management plans, the Act concerns itself only with the preservation of natural forests and their sustainable utilisation, but not the eradication of disturbed woodlands that are impacting negatively on agricultural productivity.

- It is equally important that Namibia can demonstrate that proper woodland management is taking place in the country.

It is recommended, therefore, that the NWMC function under the MET, and be responsible mainly for legal aspects and law enforcement pertaining to harvesting and bush control programmes, while extension, research and implementation of sustainable management practices and monitoring should fall under the MAWRD.

In addition, competencies between the MET's Directorate of Forestry and the MAWRD need to be clarified. Bush encroachment is widely regarded as an agricultural problem, since the primary objective of its prevention and eradication is seen to be the restoration of rangelands, rather than sustainable woodland management. In order to obtain international certification under the FSC, bush encroachment will have to become part of woodland management as provided for under forestry legislation in the Directorate of Forestry. The practical inspection and implementation should, however, rest with the NWMC. All pasture management aspects of bush encroachment and eradication should remain the responsibility of the MAWRD.

- There is an urgent need for proper coordination of all strategies and activities regarding natural resource management at a very senior level.

For this purpose it is recommended that a Forum for Integrated Resource Management be established at a national level.

This Forum should be representative of key Ministries responsible for any aspect of the management of natural resources in Namibia. Clear directives and instructions on priorities should come from this body.

- The inspection of farms to ensure compliance with permit conditions and, thus, woodland management objectives as laid down in a woodland management plan should not be done by regular extension workers in the Ministries of Agriculture, Water and Rural Development or of Environment and Tourism. The main reason for this recommendation is that such a policing function may jeopardise their advisory roles in future. An alternative may be to invest the NWMC with powers to carry out all the necessary inspections.

- Incentives should be considered for the control of bushes by labour-intensive means in preference to aerial spraying or mechanical means.

This would not only restore pastures, but also contribute towards addressing unemployment in the country. The policy framework should facilitate the identification of suitable small-scale operators who are able and willing to employ, train and manage small teams of people who are prepared to hire out their services to commercial farmers or Government to eradicate bush. Soft loans should be made available to establish such small-scale entrepreneurs and provide them with bridging finance. (Also emphasised under "socio-economic incentives".)

- At the same time, the policy on woodland management and utilisation should provide a mechanism to ensure that small-scale contractors have access to a minimum of social services such as decent housing, potable water and ablution facilities.

The provision of these services will undoubtedly contribute to the cost of bush harvesting and threaten its profitability. Thus, incentives in the form of tax rebates or subsidised interest rates on loans specifically for the development of such services need to be considered to offset any additional costs.

- The Labour Act, 1992 (No. 6 of 1992) does not make provision for the appointment of contractors as a source of labour. As this is a grey area causing unnecessary confusion and friction, the Act should be revised to include contractors as an independent category of workers.

- The use of fires as a management tool should be incorporated into a woodland management policy.

Current legislation, including the latest policy statements on forest management and utilisation, provides only for the prevention and control of veld fires in order to preserve forests and woodlands. It is recommended that the scope of these policy instruments be extended to include fire as a management tool. The deliberate and purposeful use of fires should become an integral part of woodland management plans.

9.4.2.2 Research needs

- At the same time, too little is known about the impacts of fires. This may be the result of previous legislation, which regarded fires as a threat only. A woodland management policy needs to encourage research into the effects of veld fires on bush encroachment in different ecological situations. The concomitant data should form part of a national database. In addition, farmers should be encouraged to record their experiences with veld fires and make these available to the national database.
- Appropriate fire management plans should be developed for commercial and communal farming areas. The Guidelines on National Forest Fire Management provide a national framework for fire management.
- Apart from including the use of veld fires as a management tool, woodland management plans also need to provide for aftercare. The positive effects of burning may be dissipated if a burn is not followed by an appropriate aftercare programme that will have to include appropriate pasture management techniques like the use of browsers and periodic burning.
- It has been stated that arboricides are toxic to varying degrees to insects, mammals and other organisms. However, chemical analysis of vegetation and soils that were exposed to arboricides in bush eradication found no traces of these chemicals ten years after the application. Meat produced on the same land did not show any residual chemicals either. A comprehensive environmental assessment (Joubert 2003) was carried out on all aspects of chemical, biological and mechanical treatments.[25]
- Despite these findings, perceptions may nonetheless develop that meat produced on pastures that were reclaimed through the use of arboricides may be unfit for human consumption. It is essential, therefore, that a woodland management policy specifies the terms and conditions under which arboricides should be used.
- An integrated information and monitoring system should be established at national and farm level.

[25] See also the report entitled "An environmental impact assessment on bush control methods proposed under the Bush Encroachment Research, Monitoring and Management Project", which can be obtained as an independent document from the Ministry of Environment and Tourism and Ministry of Agriculture, Water and Rural Development libraries.

Data should be collected and monitored on the economic and financial management of a farm, on the range management practices applied, on animal production (calving rates, animal health, etc.), and on environmental factors such as bush encroachment and grazing. Such a system will enable farmers and extension workers to see a particular problem within the overall context of the farming enterprise and provide advice accordingly. This system could also possibly be incorporated into the one proposed by the National Drought Policy and Strategy. Moreover, financial assistance for debushing or disaster drought should be made conditional on the adoption of such an integrated information and monitoring system.

There will be an urgent need to oversee and drive the implementation of all these recommendations in the form of technical advice. In particular, assistance to guide the wood industry through its infant stages will require high-level expertise.

9.4.3 Introduction of socio-economic incentives

Bush encroachment should explicitly be regarded as a community and societal problem and not only as the farmer's or land-user's personal problem. This means that it should be approached as a problem owned by Government, farmers, the public and the private sector, and they should join forces in the struggle to regain millions of hectares of grazing areas in Namibia, without jeopardising the environment and biodiversity.

The economic viability of supporting farmers in respect of debushing through subsidies or any other financial assistance should be seen in a wider context, where alternative economic support to other business sectors should also be evaluated. This is of particular value if the aim is employment creation. However, if the main aim is to help farmers to increase their carrying capacity, the returns through additional taxes should, in the medium term (±10–12 years), compensate Government for any financial support granted to farmers.

Following the conclusions based on the results of the study, the following recommendations are made for consideration:

9.4.3.1 Establishing an institutional framework

In order to prevent the project from becoming a cost burden for the farmer or the Government, the project's key aim should be to strengthen the vertical integration of bush products and to develop and broaden the marketing of those products. A crucial achievement, therefore, would be to establish an institutional set-up such as a cooperative, parastatal or a private company, responsible for buying problem bush by-products nationally, and marketing them at home and abroad.

It is strongly recommended that Government supports such a process with all the means at its disposal.

9.4.3.2 Utilisation of wood from problem species

Almost all the practices recommended for the control of bush are very expensive. The vast majority of farmers and, more specifically, communal farmers cannot afford to launch bush-clearing programmes on a significant scale. It is of paramount importance, therefore, to find ways and means through which the capital inputs can be retrieved.

One way would be through increased productivity and income from livestock. The financial difficulties with loans, unaffordable interest rates and capital repayments in relation to a much slower response on the income side have been explained in detail earlier.

The other option is to generate income from all possible products which could be manufactured from harvested bush. Experience has shown it is possible to cover all the input costs by way of charcoal production and sales, for example. The economic viability of charcoal and several other products is currently being investigated in a study financed by the Namibian Government, and falls outside the scope of this project.

Strong support for the stabilisation and growth of such an industry should receive the highest priority for future support by Government or donor countries. This option offers the best potential for a long-term sustainable solution to the problem of bush encroachment. At the same time, such an industry would create job opportunities for thousands of people over the long term.

9.4.3.3 Subsidisation of labour-intensive bush control measures

Studies have confirmed the economic viability of various bush-thinning methods in combination with charcoal production. Government should, therefore, consider subsidising the clearing of bush by labour-intensive methods. Such an intervention will provide substantial opportunities for employment and thereby comply with two of Government's chief objectives, namely employment creation and poverty alleviation.

Farmers should be able to qualify for loans to pay workers while the work is ongoing. However, if they make use of a labour subsidy they cannot simultaneously qualify for any subsidies on loans (see also 9.4.3.4).

The financial implications will be as follows:

- **Communal land** (thinning of 1 million ha in 20 years)
  N$150 subsidy per hectare for labour-intensive thinning of bush
  1 year: N$ 7.5 million
  20 years: N$ 150.0 million
- **Commercial land** (thinning of 4 million ha in 20 years)
  N$50 subsidy per hectare for labour-intensive thinning of bush
  1 year: N$ 10.0 million
  20 years: N$ 200.0 million

9.4.3.4 Subsidising interest rates on loans from Agribank

The use of chemicals to combat bush and the application of aftercare to areas already cleared is relatively common despite the high cost (more than N$200) per hectare to do so. However, since the manual application of chemicals is one of the labour-intensive methods mentioned, a subsidised interest rate on loans is only recommended for aerial application. Farmers will, therefore, have to choose whether to make use of subsidised interest rates or subsidies for labour: they cannot qualify for both.

As regards the loan interest rate subsidy, a 4% subsidy is recommended. In other words, if the loan interest rate is 14%, the farmer will pay 10% while the Government foots the bill for the remaining 4%. This should serve as an incentive for farmers and Government alike: farmers will experience a substantial decrease in the cost of bush control, while Government can expect to retrieve the cost of subsidies through increased tax revenues.

The financial implications of this recommendation are as follows:

- **Commercial land** (thinning of 4 million ha in 20 years)
  1 year: N$ 5.3 million

  34 years: N$180.0 million
  (It will take 14 years to repay loans after the last loan in the 20-year cycle has been allocated. Therefore the subsidy on interest rates needs to be provided fora total period of 34 years.)

The possibility of tax-free imports of active ingredients for the chemicals used for bush thinning should also be evaluated as a way to reduce the input cost for debushing.

9.4.3.5 Loans for small-scale entrepreneurs

The production of poles and droppers would be a viable industry for entrepreneurs, especially in communal farmlands. The prevailing lack of capital input for this kind of business should be solved by means of soft loans for those that can provide a well-developed business plan. The provision of credit to support entrepreneurs (excluding commercial farmers and employed people) in this field, e.g. small-scale charcoal production, or by way of launching transport and harvesting services, will provide an incentive to promote debushing activities. One important aspect to investigate is the potential and viability of establishing a transport and marketing network to promote the production of poles and droppers.

9.4.3.6 Food/cash for work

A valuable way of integrating bush control programmes into existing job-creation programmes by Government is to include them as part of the Food-for-work/Cash-for-work Project. Namibia is currently facing an immensely high unemployment rate, which means Government needs to intervene to ensure jobs are created. The Food-for-work/Cash-for-work Project should, therefore, be taken into consideration as one of the possible conduits for creating jobs in bush-thinning exercises. The budgetary implications of this recommendation have already been taken into account earlier herein (see 9.4.3.3).

9.4.3.7 Property rights and political assurances

The implementation of the bush-control measures suggested in this report hinges on secure property rights, particularly in communal areas. Secure property rights in and of themselves are no guarantee for sustainable resource management. However, without secure tenure, the incentive and opportunity to manage renewable natural resources (rangeland, forestry, wildlife, wetlands) in a sustainable manner is significantly reduced. It is imperative, therefore, that property rights to land and all its resources be transferred from the State to resource users. This requires that legislation on communal land should provide for group tenure, and that such property rights include all renewable natural resources on the land as contemplated in the National Land Policy.

Care should be taken that the intentions of a woodland management policy are not jeopardised by conflicting policies and legislation. The broad aims of sustainable bush management need to be reflected in all policies that have a bearing on this topic. The recent land tax, for example, may inadvertently discourage the eradication of bush, insofar as land cleared of bush may increase in value, and hence attract higher land tax.

If commercial farming is acceptable to Government as a sustainable and viable way to produce farm products, commercial farmers' perceived uncertainty concerning the future policy of resettlement on commercial farms should be addressed. This would in all likelihood create confidence among those commercial farmers who presently harbour ideas that the Government will embark upon a land policy in the near future that will develop into a conflict-oriented one, like the situation in Zimbabwe.

In the case of communal farmers, the present land tenure system in communal lands should be evaluated in regard to the incentive for farmers to increase the carrying capacity of the bush-encroached areas.

9.4.3.8 Capacity-building and training programmes

Bush encroachment control programmes, as part of a long-term sustainable natural resource management strategy, should be prioritised as a key performance area in extension officers' duties in the affected areas. Thus, a training programme is proposed in order to improve these officers' theoretical and practical skills to address the problem. A comprehensive extension programme with intermittent short courses should be launched for the farming community. In this regard provision should be made for identifying key personnel responsible for carrying out the training programmes. Farmers with a wealth of experience should also be used as trainers.

9.4.3.9 Combating bush as a drought-mitigating strategy

The National Drought Policy and Strategy is currently operational. One of the most important principles of this Policy and Strategy is to assist farmers to become less vulnerable to droughts and develop their self-reliance. This will require the restoration of the natural rangelands to a state of high productivity and resilience. The above recommendations, therefore, should be integrated into the long-term action plans of the National Drought Policy and Strategy, the Land Reform Policy, and Vision 2030.

The tentative calculations applied in this report on the outcome of subsidies on loans and labour-intensive methods show that there is a win-win situation, for both farmers and the Government, over an intermediate term (±10–12 years) to recover the cost for subsidising bush-thinning in commercial farmland (even if tax reduction is regarded as a Government cost). As a second-best option, after a market solution, subsidies on loan interest rates should be considered. This should especially apply to loans used for labour-intensive bush-thinning.

9.4.3.10 Disseminating information, raising awareness, sharing experience and networking

An awareness of the objectives of the project and the problem of bush encroachment in Namibia has been created amongst all relevant stakeholders, role-players and the public. Although no formal networking arrangement has been established to date, firm cooperation has been established with key stakeholders such as the following:

- the NAU
- the NNFU
- certain NGOs such as the Desert Research Foundation of Namibia, the Namibia Nature Foundation, and the Namibian Economic Policy Research Unit
- Government institutions like the MAWRD's Directorate of Research and Training; Directorate of Extension and Engineering Services, Directorate of Forestry and the NRSC, and the Ministry of Trade and Industry, and
- tertiary institutions like the Polytechnic of Namibia and the University of Potchefstroom.

The Agronomic and Meat Boards of Namibia have also been cooperative. In addition, projects like Northern Livestock Development and Sustainable Animal and Range Development have actively contributed in terms of inputs during Technical Working Group meetings.

Because certain gaps have been identified, the project should share the experiences of others, e.g. the Namibia–Finland Forestry Programme and the Living in a Finite Environment (LIFE) Program.

Formal networking arrangements and active cooperation should be established with organisations with long-standing experience on participatory integrated management of natural resources on communal lands.

9.5 Result 5: Capacity is in place within relevant Government Ministries, and the commercial and communal sectors manage and utilise woodland in a sustainable way

- The project should apply integrated management and development strategies to address communal and commercial lands separately and organise intensive capacity-building and training programmes for both extension staff and land-users during Phase 2.
- The project should advocate and apply institutionally, socio-economically and environmentally sustainable and integrated natural resource management (the Forum for Integrated Resource Management/FIRM approach) in addressing bush encroachment in communal land.
- The NWMC should assume a major role in the formulation of the project document and institutional arrangements for Phase 2. The project should take an intersectoral approach and should include strategies to address bush management in both communal and commercial farming areas.
- The objectives for an implementing phase could include –
    - the creation of institutionally, socio-economically and environmentally sound management and utilisation systems to tackle bush encroachment
    - the development of an integrated information and monitoring system at national and farm level
    - building the capacity of the staff of relevant Government Ministries as well as that of commercial and communal farmers to manage and utilise woodland suffering from bush encroachment, and
    - creating an enabling institutional framework and operating environment for bush-based enterprises, and improving quality control and marketing mechanisms for the efficient utilisation of bush-based products.

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Bush Encroachment in Namibia

REPORT ON PHASE 1 OF THE BUSH ENCROACHMENT
RESEARCH, MONITORING AND MANAGEMENT PROJECT

DV8 SAATCHI & SAATCHI