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THE USE AND VALUATION OF NATURAL FUELWOOD RESOURCES IN PAULSHOEK, NAMAQUALAND AND THE ECOLOGICAL IMPACTS ON RANGELAND DYNAMICS

BY

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Abstract

This study was undertaken in Paulshoek, a rural village in Namaqualand, to identify how important natural fuelwood resources are for the daily survival of the inhabitants. Household interviews, household surveys and PRA (Participatory Rural Appraisal) exercises were used to identify the plant species used, the purpose of use and quantities used per household on a daily and annual basis. Twelve species were identified as important and most frequently used fuelwood species. Inhabitants select fuelwood species on the basis of quality, use and availability. Fuelwood is used for a variety of purposes such as cooking, heating, ironing and baking. Good quality species (e.g. *Rhus undulata*) are used for in-house activities such as cooking, heating and ironing, while low quality fuelwood (*Galenia africana*) is used for baking and kindling. Households use on average 8.7 kg of fuelwood per day which totals to 2.18 tonnes/hh/yr taking seasonal differences into account. Wood collectors walk approximately 7.2 km to collect wood and make at least 152 trips per year. The net total value of fuelwood used in Paulshoek is about R 366 272 /yr.

Rhus undulata is the most preferred and heavily used fuelwood species in Paulshoek. Five different harvesting treatments, line transects, aerial photography, matched ground photography, radiocarbon dating and modeling experiments were used to investigate the regrowth and survival ability of *R. undulata*. Results from harvesting treatments indicate that growth of *R. undulata* is stimulated by the intensity of harvesting (100% as to 25% harvesting). Growth and survival is negatively impacted when below-ground material (stumps) are removed. The number of *R. undulata* individuals has not been reduced over the last approximately 60 years. Even though the number of individuals has not changed, modelled results indicate that the availability of dead wood has been reduced. The fuelwood harvesting at present consumption level is unsustainable and will be depleted within the next 25 years.

The impacts which fuelwood harvesting have on shrub and seedling dynamics were investigated in two separate studies. Firstly, the vegetation composition was determined by randomly selecting 12 (2 x 10 m^2) plots in both commercial (lightly grazed) and communal (heavily grazed) farming areas along a fenceline. Species composition, abundance of adult shrubs and the distribution of seedlings in relation to (a) live shrubs, (b) dead shrubs and (c) open areas were assessed. There were more palatable adult shrubs on the commercial area and more unpalatable adult shrubs on the communal area. Significantly more seedlings were present in the commercial area than the communal area. More palatable species recruited in the commercial area while more unpalatable (*G. africana*) species recruited in the heavily grazed communal area. Seedlings recruited more in the open on the commercial area and under shrubs on the communal area due to different grazing and trampling impacts.

In the second study shrub skeleton removal experiments were used to determine the growth and survival ability of seedlings, which recruit under exposed and protected conditions. Results indicate that the removal of shrub skeletons resulted in reduced height and increased mortality rates of seedlings, especially in the heavily grazed communal area. Shrub skeletons protect seedlings from grazing, trampling, uprooting and desiccation. Removal of shrub skeletons for fuelwood exposes seedlings to these dangers and contributes to vegetation changes by changing soil nutrients status, causing erosion and promoting the establishment of unpalatable species.

In response to the present fuelwood dilemma in Paulshoek, alternative sources of energy and more practical resource management guideline are suggested. Refraining from the removal of green wood and removal of live stumps is important. Low cost electricity or non-grid energy as a last option is suggested. This information can be incorporated into relevant policy making processes.

Keywords: Paulshoek, Communal rangelands, fuelwood resource use, economic valuation, fuelwood harvesting, rangeland dynamics, *Rhus undulata, Galenia africana*, seedling survival, energy alternatives

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DISCLAIMER

I hereby declare that the work presented in this thesis is my own. Where applicable, the work of others is acknowledged. I also declare that this thesis has not been submitted to any other university.

Signed by candidate

A.M. SOLOMON January 2000

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CHAPTER 1

INTRODUCTION TO THE USE AND VALUATION OF FUELWOOD RESPOURCES AND THE ECOLOGICAL IMPACT OF FUELWOOD HARVESTING ON RANGELAND DYNAMICS

1.1 General introduction

Woodfuels, in global terms represent about 7% of the world's total primary energy consumption (Trossero *et al.* 1998). Seventy six percent of this energy consumption is used in developing countries, while only 2% of the total woodfuel energy consumption is used in developed countries. In developing countries, woodfuel energy represents 15% of the total primary energy consumed (Trossero *et al.* 1998). In most countries of Sub-Saharan Africa, woodfuels still constitute the major source of energy (Leach & Mearns 1988, Trossero *et al.* 1998)

Conditions in the underdeveloped areas of South Africa are representative of many of those common to Third World countries. According to Eberhard (1986) little attention has been given to the energy problems of underdeveloped areas in South Africa. This neglect has been identified by the present national government and policy has been drafted to address the energy imbalances. The Energy White Paper (1998) drafted in December 1998, proposes energy supplies that would provide for the basic energy needs of rural inhabitants.

In the underdeveloped areas of South Africa, fuelwood is utilized for basic household needs like cooking, lighting and heating. The energy derived from burning fuelwood is needed to provide an adequate service such as clean water in rural areas, while in urban areas electricity is used. Availability of energy in urban areas is relatively easy while in rural areas it is a problem. This may disrupt social and economic development (Smil & Knowland 1980, Gandar & Udit 1989).

Namaqualand is a magisterial district of the Northern Cape Province of South Africa (Figure 1.1). The total land area comprises approximately 47 700 km^2 and is divided primarily into commercial farmland and communal land shared between 7 "Coloured" reserves. The seven reserves constitute 25% of the land area. Although the study area is discussed in considerable detail later, the focus of this study is on Paulshoek, a communally-managed rural settlement, in the Leliefontein Coloured reserve.

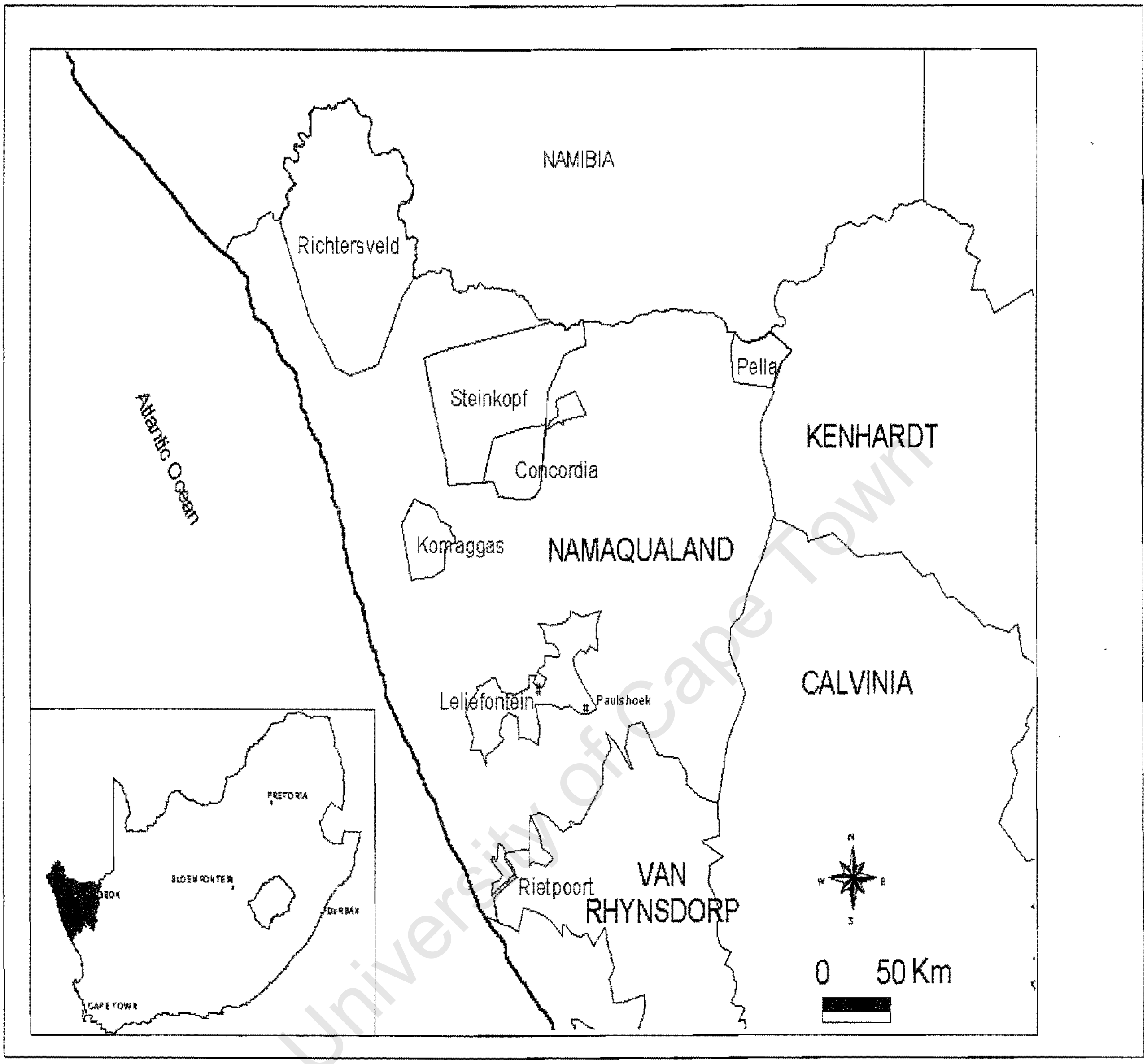


Figure 1.1: Map displaying the location of the magisterial district of Namaqualand in relation to the rest of South Africa. The location of Leliefontein communal area and the villages of Leliefontein and Paulshoek are also marked on the map. The boundaries of other communal areas in Namaqualand are also shown.

Within the context of Namaqualand's rural poverty, fuelwood is crucial for day to day living and serves many purposes (Archer 1994). The use of fuelwood impacts directly on the livelihoods of the communal farmers and other village inhabitants who, in turn, directly affect the environment through their harvesting practices. In many areas of Namaqualand the removal of firewood has contributed to both increased economic hardship and environmental degradation, as is the case in other areas of South Africa (Bembridge & Tarlton 1990, Williams *et al.* 1996). This situation is reflected in the fact that people have to pay more for wood, walk longer distances to collect wood and increasingly settle for less preferred wood species. For example, Shackleton (1993b) found in the Lowveld of Mpumalanga, that although people preferred dry wood if available, increasing demand has outstripped supply, resulting in the harvesting of live wood. Oral evidence suggests that regulations to prevent resource degradation in communal rangelands of Namaqualand and elsewhere are no longer enforced and rendered redundant, because harvesting of live wood is a reality. Similar to the rest of South Africa (Gandar 1983) and indeed the Sahelian zone of west Africa (Falloux & Mukendi 1990), fuelwood in Namaqualand used to be easily available. However, an increasing demand has depleted fuelwood resources and encouraged livewood cutting.

Woody biomass resources are scarce in Namaqualand, limited not only by the aridity and harsh climatic conditions, but also by human activities. Despite the limited woody yield in the region, utilization of fuelwood appears high. Wood is used by more than 80% of households in Namaqualand's rural settlements and is used as the main cooking fuel by approximately 70% of these households (Williams *et al.* 1996). Most inhabitants of rural Namaqualand have an understanding of the types of wood used for different purposes because they gather wood from young ages (Archer 1994). In the past women and children collected wood, but more recently men have started to gather wood for household and commercial purposes (selling for cash income). The perception amongst local users in Namaqualand is that this has resulted in a decrease of various wood types.

The high percentage of wood dependency and declining resource base in the rural areas of Namaqualand, is the result of increased unemployment (due to mines closing down), relatively high settlement density and an increase in population numbers (May *et al.* 1997).

Subsistence agriculture remains the main activity in Namaqualand's rural settlements. The impact of livestock grazing and cultivation on the general ecology of the region also has important implications for the fuelwood resources. Overgrazing caused by too many animals grazing and trampling within the relatively small and confined areas of the communal areas over several decades, has resulted in several significant changes in the vegetation of these areas. For example, in Paulshoek heavy grazing has resulted in a dramatic shift from perennial plant cover to annual plant cover (Todd 1997). Such changes are thought to have important implications for long-term carrying capacity potentials and for the fertility of the soil (Allsopp 1999, Todd & Hoffman 1999). The direct effect of grazing and trampling on the fuelwood resources are not known but are probably important determinants of key population processes (e.g. flower and seed production, germination, recruitment and survival) of important fuelwood species. A complex matrix of factors has thus contributed to the current relatively degraded state of Namaqualand's communal reserves.

1.2 Rationale and objectives of the study

With the South African government's land redistribution and integrated rural development programmes, the importance of the environment and the sustainable exploitation of its productive capacity will play an increasingly important role in focusing planners and policy makers' attention on socio-economic problems. However, the predicted reduction in state welfare allowances, the closure of mines and Namaqualand's limited opportunities for economic development will mean that the natural environment and its resources will play an increasingly important role as the region's most valuable asset in the development of rural livelihoods. Ecotourism is one potentially important source of income for local communities but its success is dependent on ecologically "healthy" ecosystems.

While the general impact of fuelwood collection in Namaqualand and elsewhere, is perceived to have had a negative impact on the proper functioning of the natural vegetation (Milton 1988) few details are available. For example, in Paulshoek, little is known of the value of the firewood resource and details of its usage. Also, the impact of fuelwood collection on ecosystem functioning is not known, although general perceptions are that it is negative.

The study done by May *et al.* (1997) has encouraged a more detailed quantitative and qualitative research programme with respect to the use and valuation of natural resources in Paulshoek. The research described in this thesis quantifies the use and dependence of households on rangeland fuelwood products and provides an economic valuation for these plants based services. It also investigates and compares the use and dependency of natural fuelwood resources between two different groupings or household types: village households and stockposts.

The quantities of fuelwood which households in Paulshoek use are differentiated on a wealth rank basis of relatively "rich" and "poor". The purpose is to describe the use, evaluate its economic importance and assess the impact that fuelwood usage has on the environment and people's livelihoods. In so doing the study may also compliment the ecological research programme currently underway at Paulshoek (Wyn Jones *et al.* 1998), which addresses the impact of communal farming on the rangeland itself and aims to develop restoration strategies to rehabilitate degraded veld. Paulshoek is due to receive electricity in the near future and perceptions are that this will reduce the pressures placed on the vegetation. However, this aspect needs to be researched. Adequate management strategies and policies also need to be developed for the area.

The general objective of this thesis is to describe, quantify and value the direct use of fuelwood resources in Paulshoek and to assess the impact of fuelwood collection on the resource itself as well as on key ecological processes in the rangeland. Relevant management strategies, policies and energy alternatives are also suggested, which could serve as a guide for policy makers and other practitioners.

The specific objectives of the study are:

1. To develop a descriptive inventory of fuelwood species used by people in Paulshoek for their various energy needs;
2. To quantify the extent of use and provide an economic value for the direct use of fuelwood-based resources;
3. To evaluate the impact of fuelwood utilization on rangeland degradation and its consequent effects on rural livelihoods;
4. To make management and alternative energy supply suggestions that could inform and assist policy makers.

1.3 Literature review

1.3.1 Background

The first step to evaluate trends in wood energy demand is to show the evolution of woodfuel consumption. There has been a notable increase in woodfuel demand in the developing world (Bembridge & Tarlton 1990) and a decline in demand in developed countries. However, this variance in woodfuel demand, results from a 22% reduction in direct fuelwood consumption and an increased use in other types of woodfuels in the last six years (Trossero *et al.* 1998). The generation of energy from recovered black liquors is high on Oceania, North America and Europe where large pulp and paper industries generate heat and fuel power plants with these biofuels. In these areas most of their energy needs are met and if any remains, it is sold to the public grid. However, wood still provides for more than 60% of the total primary energy consumption in developed countries, while it could account for 95% to 100% of the energy needs of developing areas (Gandar 1983, Trossero *et al.* 1998).

Wood removals from forest and non-forest lands for energy purposes, are estimated to make up 60% of the world's total use. It is not likely that this situation will change, because many of these countries are still greatly underdeveloped. Woodfuels will continue to be a key energy source for cooking and heating in homes (Bembridge & Tarlton 1990, Falloux & Mukendi 1990, Shackleton 1993a, Trossero *et al.* 1998).

The 1970's oil crisis encouraged widespread interest in renewable fuel (Penner & Icerman 1976, Gandar 1983, Eberhard 1986, Bembridge 1990). In 1971 woodfuel was estimated to provide 75% of energy in sub-Saharan countries. Approximately 40% of South Africa's primary energy was identified as wood, with most of it being non-commercial firewood (Gandar 1983). Research carried out during the 1980's found that about 14% of energy used globally were received from renewable organic matter. Wood is the most widely used renewable energy source and provides most of this 14%. In the European Union, most forest energy is still used by households where woodfuel represent approximately 60% of the total wood energy consumed (Trossero *et al.* 1998).

Until a few decades ago, woodfuel represented the most important source of energy in the world and even today it continues to be used by most people (Anderson & Fishwick 1984, Eberhard 1990, Campbell *et al.* 1991, Shackleton 1993a, Trossero *et al.* 1998). Developing countries (where about 77% of the world's population live) utilize approximately three-quarters of the total woodfuel consumption. Approximately 44% of the total amount of woodfuel consumed in the world is used in Asian countries. Here wood for fuel represents 81% of the total wood removed for energy and non-energy use. Trees and forest meet the basic energy needs in these countries (Lenssen 1992). In global terms, woodfuels produced either directly or indirectly from forest resources comprise more than half of the total forest removals (Trossero *et al.* 1998).

It has been apparent since the 1980's that the rate of exploitation of renewable sources in rural communities is outstripping the rate of renewal (Smil & Knowland 1980, Eberhard 1986, 1990, Shackleton 1993a). South Africa has a dual identity mainly because it consists of both the developed and less developed areas. A large industrial sector and well-developed commercial agriculture and forestry industry exist alongside very poor rural communities numbering millions of people. According to Gandar (1983) the per capita consumption of fuelwood depends primarily on the availability of wood and to a lesser extent on climate and social parameters. However, detailed analysis requires monitoring of a large sample of households over at least one year and reliable information for South Africa is scarce (Gandar 1983). Part of the problem has been the lack of local data on energy consumption and demand (Eberhard 1986).

1.3.2 Fuelwood crisis

In South Africa, approximately 11 million tons /yr of fuelwood are used at national level (Williams *et al.* 1996). From this total 6,6 million tons is used by rural households in the former homelands, 3,5 million tons by farmworker households and only 0.7 million tons in urban areas (Williams *et al.* 1996).

There is an ongoing debate in Africa around the so-called fuelwood-crisis (Williams *et al.* 1996). This debate surfaced during the mid 1970's when the world was concerned with the modern energy fuel crisis which followed the first oil price shocks of 1973-4. The woodfuel problem appeared to be a classic case of rising energy demand outstripping supply (Eckholm 1980, Gandar 1983, Leach & Mearns 1988, Williams *et al.* 1996).

Many described the fuelwood crisis as complicated and with no single solution, partly because the solutions suggested perceived the fuelwood crisis as simply a supply-and demand problem (Eckholm 1980, Williams *et al.* 1996). Conventional analyses unfortunately still consider the harvesting of trees for fuelwood as the major cause of deforestation, and have used the so-called gap theory supply–and-demand model to determine future scenarios, usually on a national, aggregated basis (Leach & Mearns 1988, Williams *et al.* 1996). The World Bank study (Williams *et al.* 1996), which helped to legitimize the woodfuel gap theory, estimated that tree planting in sub-Saharan Africa would have to increase fifteen-fold in order to close the projected gaps by the year 2000. Criticism against the gap theory is that it greatly over-estimated the need for planned interventions (Leach & Mearns 1988). It has also resulted in energy departments investing all effort into only the supply side interventions. Unfortunately these supply enhanced and demand limiting approaches seldom deal with the complexities of the problems. These complexities include price availability, abundance or scarcity of woodfuels, access to fuels by different groups, household income, household size, temperature, precipitation and cultural factors (Trossero *et al.* 1998). The gap theory neglects the reality that people have their own management strategies and may use alternative methods of fuelwood utilization or harvest more of less preferred species which are more abundant.

Recent developments have resulted in a shift away from the idea of woodfuel harvesting and collection as the major cause of deforestation in developing countries (Leach & Mearns 1988). The increasing scarcity of wood resources in many rural areas is now considered in a broader context, which acknowledges the more complex issues of land and labour availability, resource ownership, and access to political and economic power. The fuelwood problem and potential solutions are therefore no longer perceived in narrow energy terms (Williams *et al.* 1996).

It is important to develop a new intellectual and analytical framework to help with solutions to the so-called fuelwood crisis. It is necessary to understand the real nature of the problem, and not to treat it simply as a resource shortage requiring narrow supply-or demand solutions. The fuelwood crisis must be placed in the wider context of rural poverty, and of the coping mechanisms and livelihood strategies of rural people (Williams *et al.* 1996). The fuelwood situation is complex and has both macro-and microeconomic dimensions (Armitage & Schramm 1991).

1.3.3 Economic valuation of firewood

The economy is not separate from the environment in which we live. There is a co-dependency, because the way we manage the economy impacts on the environment, and environmental quality influences the performance of the economy (Pearce *et al.* 1992). Economic valuation seeks to provide quantitative values to the goods and services provided by environmental resources, irrespective of the availability of market prices (Barbier *et al.* 1997). Attempting to answer questions of use and value to different role-players requires a multi-disciplinary approach using methods from sociology, ecology and economics. One should identify relationships between inputs (variables such as plant growth rate that enter into the system) and outputs (benefits received) that are keys in affecting the ecosystem and also the economy over time (Hotsprings working group 1997). The purpose of economic valuation is to try and find the area, which points to the difference between benefit and cost. However, people use other valuation methods that can be much more complicated then an economic valuation exercise.

Economic value comes from the goods and services obtained from the veld that contribute to human needs (Hotsprings working group 1997). The economic value of any good or service is valued in terms of what one is willing to pay for the resource, minus the cost to supply it. Economic valuation provides a monetary measure by identifying what people would be willing to pay extra for a product. A problem with placing proper values on the services provided by natural environments is that many of these services are provided free. They have no formal price because no market place exists in which their true values can be obtained through buying and selling (Pearce *et al.* 1992). However, the need to value these resources has become increasingly important and therefore various valuation techniques and methods have been proposed.

Valuation methods distinguish between market and non-market valuation approaches. If there are no markets for a raw product derived from the resource, then indirect and derived demand approaches can be used for valuing the resource. When the resource is not traded in markets, non-market valuation techniques e.g. contingent valuation, can be used to estimate the economic value of the resource (Hotsprings working group 1997).

Resources may have value when the benefits derived from them are greater than the costs to produce the resource (Dosman & Luckert 1997). Campers or hikers, for example, use the environment and derive benefit from it. The approach to the economic measurement of environmental benefits can broadly be classified as direct and indirect techniques.

Direct techniques consider environmental gains (e.g. better water quality) and attempt to directly measure the monetary value of those gains. Indirect techniques calculate the combined effect of, for example land degradation on the people in the area. They estimate the relationship between degradation and the non-monetary effect (e.g. poverty). According to Pearce *et al.* (1990) three categories of values can be identified. These are (i) direct use values (e.g. for consumption or sale); (ii) indirect use values (e.g. trees providing shade) and (iii) nonuse values (e.g. spiritual values). Depending on the perceived importance of the resource one would value the resource accordingly (Campbell *et al.* 1991).

Perma *et al.* (1996) classified the value system as: (i) current use value, considers the satisfaction received from consumption of a good or service; (ii) option value is based on a willingness to pay to ensure a right to a resource for which future demand is uncertain, (iii) quasi-option values, which refer to satisfaction expected by not taking irreversible decisions, with the hope that new knowledge or technology can increase use options. These three classes are then referred to as total economic value (Kepe 1997). However, Kiepel & Quinlan (1997) preferred to explain their data in terms of absolute and relative value. They suggest that conventional economic argument analyses of value in terms of cultural attributes, are often obscure and cannot be included. Planning can only continue once financial and/or market values have been attributed to resources, even if local people do not value resources in the same way.

The quantity used is also important in the valuing process. Godoy *et al.* (1993) identified two types of quantities that should be considered for valuation purposes. One type of quantity is the stock available in a specific environment. Another quantity is the actual use by the people or resource flow. The general preference in the literature to use resource flow valuation methods rather than inventory methods, is based on the fact that the difference between the value of what is actually collected is usually much lower than the value of what exists in the ecological sites (Godoy *et al.* 1993). Resource flow is perceived as less complicated then inventory valuation.

In seeking to understand key ecological relationships and their importance to the economic process, economics has become influenced by ecology. Environmental degradation, which often results from economic activity places costs on the environment. In a market economy, relatively scarce resources are valued primarily by means of the price mechanism. The increasing relative scarcity of a resource suggests a greater demand for it and therefore a higher price relative to other resources (Barbier 1989). Many environmental resources are complex and multifunctional, and it is not obvious how the goods and services provided by these resources affect human welfare. Loss of environmental resources is an economic problem because important values are lost, some perhaps irreversibly, when these resources are degraded or lost (Barbier *et al.* 1997).

1.3.4 Tenure systems

Traditional community laws used to control the harvesting of natural resources. This indicated an inherent respect for and understanding of the natural resource which people use (Shackleton 1993a). Unfortunately in many parts of rural South Africa, both traditional authority and government legislation no longer control resource exploitation.

Analysis of the optimal rate of harvesting of renewable natural-resources must consider both the natural growth rate of environmental resources as well as land tenure system governing the resources. There is a common perception that the communal ownership of natural resources is the major cause of over-exploitation. The users of the communally owned resource may use as much as needed, with the possibility of reducing availability of the resource. This perception however, is not necessarily true. Most local communities generally have regulations in place to encourage sustainable utilization. It is in the absence of rules, interventions, agreements or traditional management rights that users may tend to over-exploit the resources. A system where rules and regulations have broken down would revert to an "open-access" situation, which leads to over-exploitation of resources.

1.3.5 Ecological impact

Unfortunately, however, it is usually the poorest people of a particular location who usually experience the consequences of firewood scarcity most severely. The increased degradation of the environment throughout Africa, Asia and Latin America, caused in part by fuelwood gathering, is a major danger to environmental stability and land productivity (Echholm 1980). This environmental degradation occurs in the form of accelerated soil erosion, increasingly severe flooding, creeping deserts, and desertification (Eckholm 1980, Dean *et al.* 1995, 1996). Development experts may no longer consider fuelwood collection to be the cause of deforestation, but removal of fuelwood places increased pressures on the land and people (Lenssen 1992). According to Armitage & Schramm (1991) rapid population growth, which accelerates land clearing for agricultural purposes and increases the consumption of woodfuels, is causing drastic reductions of forest cover. In Kenya, for example, the fuelwood sources for Nairobi have moved more than 200km away to the slopes. A fragile ecosystem exploited beyond its carrying capacity will eventually break down.

In many semi-arid areas of Africa, overgrazing by cattle, goats, and sheep is the main course of environmental impacts (Dean *et al.* 1995, 1996, Bond *et al.* 1994, Wiegand & Milton 1996). However, gathering of fuelwood and wood products is also an important contributor to the destruction of vegetation in these regions (Cunningham 1988, Armitage & Schramm 1991 and Geldenhuys 1997). Agriculture is the backbone of most African economies, and therefore this ecological deterioration severely endangers Africa's economic future (Falloux & Mukendi 1990). In the Indian subcontinent, the most obvious result of firewood scarcity is not necessarily the destruction of tree cover itself, but the alternative use of dung which robs farmland of crucial nutrients and organic matter. Even more important than the loss to agricultural nutrients is the damage done to soil structure and quality through the failure to return manure to the fields (Anderson & Fishwick 1984, Eckholm 1980). Also, organic materials- humus and soil organisms, play an essential role in preserving the soil structure and fertility needed for productive farming (Milton 1991, Versfeld & Donald 1991). Organic matter assists in the absorption and storage of water, which plants can utilize for growth. Degradation starts when the rate of fuelwood harvested exceeds the average annual rate of production (Anderson & Fishwick 1984).

Fuelwood exploitation in South Korea during the 1960's resulted in the removal of live tree branches, shrubs, seedlings and grasses. All leaves, litter, and burnable materials were also removed from the hillsides, which reduced the protective cover of the soil (Eckholm 1980). As argued by UN experts, fuelwood harvesting is one of the main causes of soil erosion in Korea (Eckholm 1980). In Eastern Nigeria circumstances force people to uproot crop residues after harvesting for fuelwood purposes. In previous years these dead stalks and leaves were left to enrich the soil and prevent erosion. In Nepal, farmers have started using cow dung as a result of fuelwood scarcity. Traditionally the dung was utilized in the fields, but with wood scarcity farmers were forced to burn more dung for fuel, and to apply less to their fields. Firewood scarcity can be linked in two ways to the food problem facing many countries. Deforestation and the diversion of manure to use as fuel are reducing the land's ability to produce food (Eckholm 1980).

The solution to resource scarcity can be viewed either through the reduced demand or increased supply angle. For poor rural communities no simplistic solution is visible. The use and need for fuelwood is basically determined by the number of people using it. Unfortunately with the increased population growth rate, dependency will not change soon (Eckholm 1980, Shackleton 1993a). Semi-arid and arid regions do not have adequate vegetation cover to provide this ever-increasing demand. It is also these regions such as Namaqualand that have too many cattle, sheep, and goats (Dean *et al.* 1995, 1996, Todd 1997).

1.3.6 Time taken to collect wood

The demands of an increasing population and the effects of localized overgrazing on the regeneration of woody vegetation mean that people must walk increasing distances, often several kilometers into the veld to gather fuelwood (Kerridge 1997). The time taken to collect firewood has also been used as an indicator of deforestation (Fleuret & Fleuret 1978, Du Toit *et al.* 1984). The length of time clearly represents a major economic cost of firewood to the consumer. It is also evident that the fuelwood scarcity affects the poor most severely (Borchers *et al.* 1990). Du Toit *et al.* (1983) in their study found that majority of inhabitants in communal lands in Zimbabwe took two hours to complete a firewood collection trip. Fleuret & Flueret (1978) in their Tanzania study found the duration of an average firewood collecting trip to be 2-4 hours. Arnold (1978) stated that countries with severe woodfuel shortages, could have people walking over 4 hours and up to half a day can be spent on firewood collection for each household.

In studies done in South Africa it was found that over 90% of households in Venda (94%), KwaNdebele (97%), Transkei (99%) and Ciskei (99%) collected small amounts of fuelwood at weekly or shorter intervals (Williams *et al.* 1996). With the exception of KwaNdebele (44%) and Lebowa (35%), more than 55% of households also collected large headloads of fuelwood at intervals of a week or less, with this figure rising to 78% and 94% in the cases of the Transkei and Ciskei respectively (Williams *et al.* 1996). According to a study done by

Kerridge (1997), in Klipfontein Namaqualand, most firewood takes the form of twigs and thin sticks from dead bushy shrubs. More preferred thicker branches are only found much further away and take much longer to find and collect. Demand for firewood is highly seasonal and increases substantially during the winter when cooking fires are also used as a source of heat.

Total times spent collecting fuelwood in the Ciskei and Transkei were higher than most areas with figures ranging between 10,9 hours and 8,1 hours per week, while total collection times dropped to as low as 2,6 hours per week in KwaNdebele. Households in Bophuthatswana and Lebowa spent on average about 6 hours per week collecting fuelwood. In Kwazulu 6,9 hours per week were spent collecting wood (Williams *et al.* 1996). The travel times amounted to 5.2 hours in Lebowa, between 4 and 4,5 hours in Gazankulu, Ciskei and KaNgwane and between 3,3 and 4 hours in Venda, KwaNdebele, Transkei and Bophuthatswana. In Namaqualand the average time spent collecting fuelwood was 8,8 hours per week with an average journey time of 4 hours per trip (Borchers *et al.* 1990). The time taken to collect wood has generally increased with increasing wood scarcity.

1.4 Study area

1.4.1 Location

Namaqualand is one of the largest magisterial districts in South Africa (Figure 1.1). It falls within the Northern Cape Province and is comprised of fourteen small urban settlements. Six of the settlements are within the "Coloured Rural Reserves" (May *et al.* 1997) and are managed under a communal land tenure system. Namaqualand's communal areas contain more than 70% of Namaqualand's rural population. Reserves range from being primarily rural in character (e.g. Leliefontein, Richtersveld) to urban & semi-urban, with the population concentrated in small towns (e.g. Steinkopf, Concordia, Pella). The Leliefontein Rural Reserve is 192 000 ha in extent and is comprised of 9 small settlements or villages. Paulshoek (Figure 1.2), located at 30;24 S; 18;08 E; is one of the villages in Leliefontein (Figure 1.1) and covers about 22 000 ha. Like many other villages, Paulshoek is characterised by high unemployment rates, relatively high settlement density, overgrazing and a skewed demographic structure, with many very young and older village inhabitants.

1.4.2 Topography and climate

The Leliefontein Rural Reserve straddles the Kamiesberg and is divided into three main topographic regions: Sandveld (coastal lowlands in the west), Hardeveld (mountainous escarpment) and the eastern plateau of Bushmanland (Acocks 1988). Paulshoek is situated on the eastern slopes of the Kamiesberg and is comprised largely of the foothills of the Kamiesberg escarpment as it grades to Bushmanland in the east.

The Leliefontein Rural Reserve receives relatively unpredictable and sporadic rainfall. The western part of the Reserve receives mainly winter rain (May – August), while the eastern areas receive more summer rainfall (Todd & Hoffman 1999) derived from convective thunderstorms. The Paulshoek area itself receives rain from both sources. The area receives between 150 and 250mm of rain annually (Todd & Hoffman 1999), although gradients may vary from 300 mm in the western, higher lying regions to less than 100 mm in the eastern lower lying regions. The mean annual temperature for Paulshoek is 16°C, while the mean-maximum temperature for the hottest summer month (January) is 30°C and the mean-minimum temperature for the coldest winter month (July) is 3°C (Schulze 1997). Water is obtained from boreholes and dugwells as there are no perennial rivers in the area (Allsopp *et al.* 1999).

1.4.3 Vegetation

Two main veld types (Acocks 1988) dominate the Paulshoek vegetation. Mountain Renosterveld, comprising woody shrubs, especially *Elytropappus rhinocerotis* and *Pteronia incana*, occupies the wetter, higher lying areas. Namaqualand Broken Veld comprised of dwarf succulent shrubs, dominates the lower lying, arid areas (Acocks 1988). Low growing leaf succulent shrubs, such as *Ruschia robusta* and dwarf evergreen shrubs such as *Hirpicium alienatum* dominate the lowlands. *Galenia africana* is also dominant in this area. The relatively steep climatic gradients in Paulshoek are mainly responsible for the rapid transition between these two distinct vegetation types. This gradient results in Mountain Renosterveld (described locally as "*suurveld*" - sourveld) plants, on the one end and mostly dwarf karroid shrubs and leaf succulent shrubs ("*soetveld*" - sweetveld) on the other (Todd & Hoffman 1999). Sustainable yield of fuelwood from this arid environment is uniformly low.

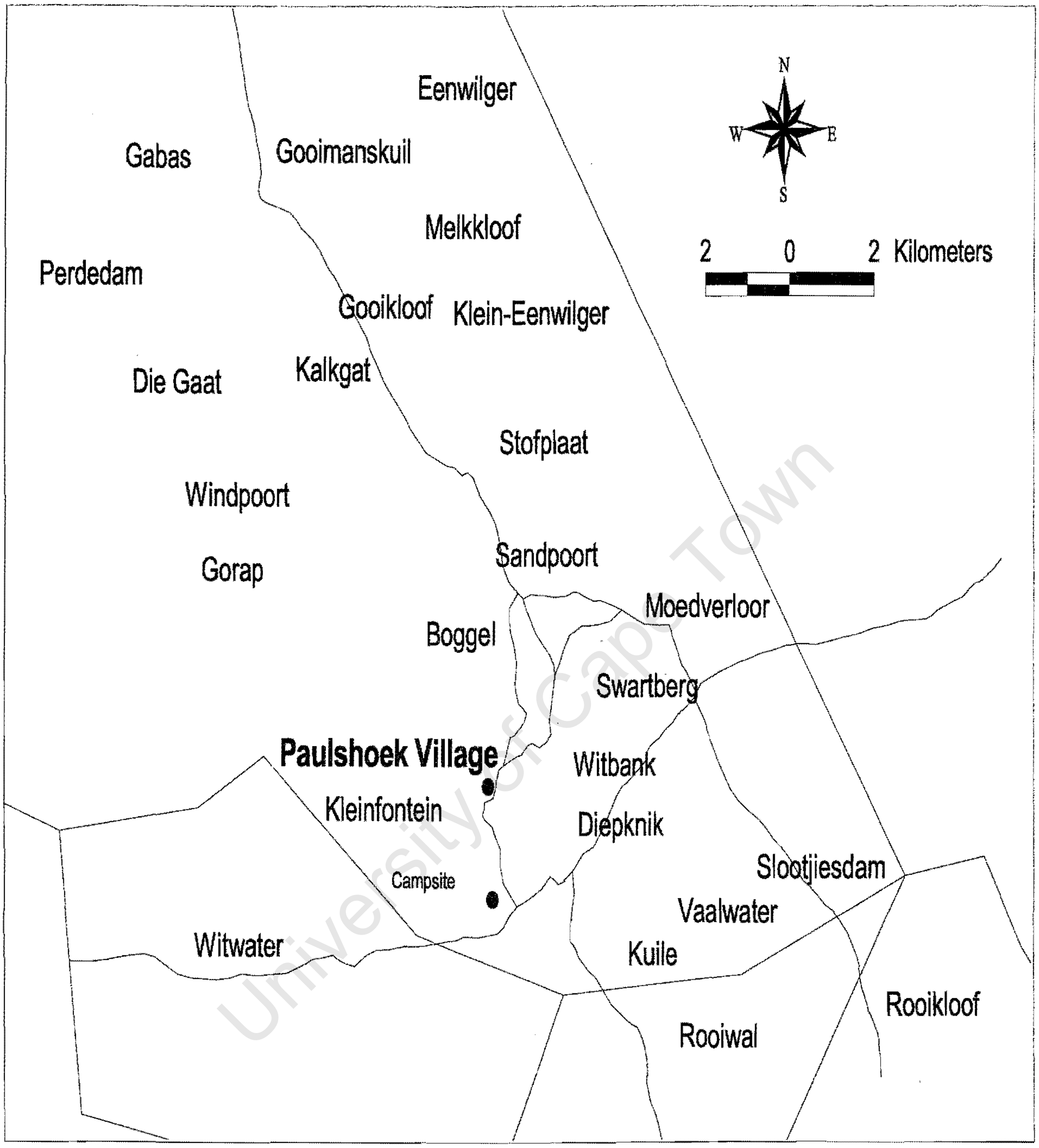


Figure 1.2: A map of the Paulshoek communal area which covers about 22 000 ha. The location of the village (30;24 S; 18;08 E), the recently established campsite as well as common place names are shown. The commercial farms of Witwater, Rooiwal and Rooikloof occur south of the commual area, while several commercial farms borders on the eastern boundary.

1.4.4 Paulshoek village: socio-economic conditions

Paulshoek is one of the smallest of the 9 villages administered by the Leliefontein Transitional Council. A local Forum (The Paulshoek Development Forum) was formed in 1995. It is comprised of several sub-committees (e.g. policing, agriculture, welfare) and allows Paulshoek community members a democratic voice. Many of the sub-committees are, however still weak. The isolated location of the area from large centres has resulted in a general lack of adequate infrastructure (e.g. telephones, electricity, sanitation) and essential services (e.g. medical facilities and transport).

Paulshoek has 140 village households and about 37 stockpost households with approximately 800 people (Figure 1.3), most of which are unemployed and depend on welfare. Forty eight percent of Paulshoek inhabitants are younger than 18 years of age while many of remaining the fifty two percent inhabitants are older than 65 years of age. Sixty four percent of the household heads are male and 36% female (May *et al.* 1997).

People use various forms of shelter including brick houses, zinc houses or traditional *maatjieshuts* (Figure 1.4). Although many (97.8%) of the people have outside taps supplying water, water based sanitation and ablution facilities are still absent (Allsopp *et al.* 1999). Consequently Paulshoek villagers rely on the veld or the bucket system as a means of ablution. Similar to many other rural villages, Paulshoek has no electricity and households rely mainly on fuelwood energy.

Paulshoek village has a pre-primary and primary school, creche and sportsground. The distance (60 km) from the nearest town (Garies) contributes to the fact that health care can only be provided once every two weeks via a mobile clinic. Transport costs to Garies are approximately R120 per trip. This is expensive when taking into consideration that most households rely on a low income base (May *et al.* 1997).

Figure 1.3: Photo displaying the village of Paulshoek. The locations of the houses and the roads are shown on the photo.

Figure 1.4: Photo of Paulshoek village taken in the town. Inhabitants live in brick, zink and maatjies houses. Traditional transport such as donkey carts are still used by the people.

Paulshoek reflects many of the common characteristics of the Namaqualand Rural Reserves, particularly in terms of poverty, lack of resources and dependence on pensions and migrant labour remittances. Incomes within households receiving remittances from migrant workers exceeded those of other households by 50-80% (May *et al.* 1997). Mines appear to contribute increasingly less to household income. Recent research (Rodkin & Rhode 2000), indicates that agriculture (livestock farming) only contributes approximately two percent to household incomes. The importance of farming as a source of income for Paulshoek inhabitants may therefore, not be a major contributor to household income, but may serve social needs. Traditional pastoral livelihoods have been consistently eroded over the last two centuries as accessible land has diminished and as populations have grown. This has resulted in a decline of agricultural income over time (Kerridge 1997).

1.4.5 The use of natural resources in Paulshoek

Paulshoek possesses a rich semi-arid plant resource base and it is used for a variety of purposes (e.g. medicines, fuelwood, livestock grazing). However, woody biomass resources are very scarce in Namaqualand and are limited by the harsh climatic conditions. The supply of fuelwood from these arid environments is uniformly low (Mander & Quinn 1995).

The right to utilize resources communally is dictated by "birthright". This is an internal institution where every community member has the right to use the resources from the land. For example, birthright rules and regulations state that a young person (age 18-21) has the right to acquire livestock and to make use of the communal resources. The tenure system in Paulshoek is based on a communal property system (May *et al.* 1997). This means that all Paulshoek inhabitants have the right to utilize the Paulshoek area and its resources. This tenure system consists of rules and regulations and mutual arrangements between the livestock holders of the village when using the land. However, there are no controls with respect to stock numbers (May *et al.* 1997). Vorster & Roux (1983) found that the over-utilization of Karoo vegetation as a result of grazing by domestic livestock, resulted in vegetation change from palatable to more unpalatable plants.

Although Paulshoek has a stocking rate of 36 ha/LSU as determined by the Department of Agriculture, Paulshoek farmers have stocked at twice this density for several decades (May *et al.* 1997). Approximately 30 stock posts are situated around the Paulshoek village. They are found predominately in the southeastern and central parts. Stockposts are normally located close to waterpoints. Some of the stockpost have been in the same area for more than 50 years while others move every few months years (May *et al.* 1997).

In previous years movement of livestock was strongly influenced by the cropping season (i.e. the time when crops are planted or harvested). This changed however, in the 1960's and now the movement is largely determined by water supply and available grazing.

1.5 General approach and thesis outline

Each chapter provides a detailed account of the method used in specific studies. What follows is a description of the general approach taken. Community surveys and ecological experiments were undertaken.

1.5.1 Community survey

The involvement of the local community in the development and sustainability of their environment is crucial. Successful conservation is ensured if links between the communities and the environment are reinforced. One method of involving local people with research is to conduct community surveys (interviews) with the user groups (Borchers *et al.* 1990). This is a way of tapping into the knowledge base of local people. According to Van Eck *et al.* (1997) one of the best ways of learning from local people is to sit down, ask questions and listen. This approach was employed to gain an understanding of the use and value of the firewood resources in Paulshoek. It was also used to develop some understanding of existing systems of harvesting so that more sustainable harvesting practices could be recommended (e.g. limiting the cutting of green wood). Plant species were ranked according to their use and importance and according to their perceived change in abundance through time. The quantitative results from the surveys were analysed using various economic methods and approaches.

1.5.2 Ecological approach

Two key ecological experiments were undertaken.

1.5.2.1 Harvesting treatments of *Rhus undulata* trees at different intensities

All necessary measures should be taken to ensure that species can continue to produce new vegetative growth or seeds after being harvested (Martin 1995). The harvesting experiments investigated the regrowth ability of the most preferred fuelwood species *Rhus undulata* growing under contrasting management practices (protected vs unprotected). Several different intensity levels (high, low and medium) of cutting treatments were employed (Milton 1983), and the resultant regrowth measured every three months for a year.

1.5.2.2 Dead shrub removal

The over-utilization of plants can result in a change in physiognomy (biomass) or a change in composition of the vegetation. It is necessary to understand the impact of the disturbances and regeneration of the target species. For example, resprouters can tolerate forms of utilization which reseeders cannot. Sustainable use of the resources remains a common issue for both resource users and management.

A fenceline contrast comparison (commercial vs communal) of seedling recruitment patterns and survival responses was investigated (Milton 1984). The first experiment identified whether shrubs influenced seedling establishment patterns. Secondly, a shrub skeleton removal experiment investigated the role of shrub skeletons in seedling survival.

1.6 Thesis outline

This thesis is divided into five chapters, each covering different aspects of the objectives. The first chapter provides a description of the thesis topic. It deals with a general introduction, rationale and objectives of the study, as well as its significance. The second section provides a literature review, which gives some background information to the fuelwood resource utilization situation globally and specifically in the South African context. The discussions cover the debate and trends in fuelwood resource utilization, socio-economic conditions, resource valuation and policies on utilization of the environment. The third section describes the study area in which the research is taking place.

Chapter two focuses on the socio-economic context of fuelwood utilization in Paulshoek. Firstly, it investigates the use of fuelwood resources in Paulshoek. The second part addresses the value of the fuelwood resources in Paulshoek. A broad socio-economic survey was conducted and results presented. The methodology in this section included conventional household survey methods (i.e. questionnaires, observations) and PRA methods to quantify/qualify resource use. Standard and economic valuation approaches considered market analysis, matrix scoring & ranking and production cost (e.g. travel & labour cost).

The objective of chapter three is to gain insights into the complex interaction of ecological processes. This chapter investigates the growth and survival ability of *Rhus undulata* (the main fuelwood species) under different harvesting conditions. Harvesting experiments were done in an area protected from grazing and in an area exposed to grazing. In order to understand the dynamic processes of the ecological environment more holistically, various additional ecological methods were used. The harvesting treatments assesses the regrowth and survival of *Rhus undulata*, line transects assessed the change in size and abundance of trees away from the village and aerial and ground matched photography investigated the utilisation of *R. undulata* over time and space.

Chapter four investigates the impacts of dead shrub removal on the growth and survival of seedlings that recruit under it. Removal of dead shrubs for fuelwood is believed to have a negative impact on the recruitment of key species. This chapter sets out to test this hypothesis. Dead shrubs (shrub skeletons) were removed from commercial and communal farming areas to monitor the responses of the seedlings. The seedling growth responses were monitored every three months for a period of twelve months.

Chapter five contains conclusions, management strategies & policy implications, suggestions of alternative energy sources and recommendations. This chapter attempts to provide a holistic view of the thesis findings. The discussions aim to provide relevant information to policy-makers and other practitioners. More importantly, this section attempts to provide answers and possible solutions that could improve the fuelwood situation in the Paulshoek community.

CHAPTER 2

THE USE AND VALUE OF FUELWOOD RESOURCES IN PAULSHOEK, NAMAQUALAND

2.1 Introduction

Fuelwood is the primary source of energy for rural areas in South Africa (Eberhard 1986). Within the context of Namaqualand's rural poverty, fuelwood is crucial for day to day living and serves many purposes. More than 80% of inhabitants in the reserves of Namaqualand still depend on fuelwood as a primary source of energy (Borchers *et al.* 1990). The increased use pressure on the resource has caused a rapid decline in the availability of fuelwood (Eberhard 1986). Despite the scarcity, it appears as if fuelwood is still important in Namaqualand reserves, judging from the fact that fuelwood use in e.g. Klipfontein (a similar reserve to Paulshoek) still accounts for three quarters of the net energy consumed (Kerridge 1997). The collection of wood is still an inherent part of subsistence life in the Namaqualand reserves (Archer 1994), because most of the inhabitants are too poor to afford alternative energy even if they wanted it (Borchers *et al.* 1990).

Many woody plants are used for fuelwood, but households are generally selective in their choice of fuelwood species. A distinction is made between good and poor firewood and kindling. Good firewood usually comes from hard wood, which forms coals and burns for long periods e.g. *Rhus undulata, Ruschia spp., Lebeckia sericea* and *Acacia karoo*. Poor firewood, on other hand, does not usually form coals, burns for short periods or releases foul-smelling odours e.g. *Ozoroa dispar* or *Galenia africana* (Archer 1994, Borchers *et al.* 1990). Certain fuelwood species are used for specific fuelwood activities e.g. for cooking but not for baking, while others are used more generally. The selection of the fuelwood is also influenced by factors such as ease of collection, distance to collection and seasonality. The decline in the availability of preferred fuelwood species has caused a change in use patterns resulting in an increased cutting of green wood (Borchers *et al.* 1990).

Fuelwood in Namaqualand is utilised for basic household needs like cooking, heating, boiling water, ironing and baking. The cooking and boiling of water takes place on an open fire either in a cooking shelter or in the open. The coals formed by species such as *R. undulata* are normally removed and used for ironing while baking takes place in an outside oven which is filled with twigs and poor quality fuelwood (Archer 1994, Borchers *et al.* 1990, Kerridge 1997). In Kleinfontein, baking accounts for as much as half of the fuelwood used by the village (Kerridge 1997) which is similar to the situation in neighbouring reserves.

A great deal of intensive quantitative and qualitative fuelwood research has been done in many other rural areas of the South Africa (Eberhard 1986, Bembridge & Tarlton 1990, James 1993, Gandar & Grossman 1994 and Campbell *et al.* 1997). Similar fuelwood studies have also been conducted in Namaqualand (Archer 1990, Borchers *et al.* 1990, Ward 1994, Eberhard 1990, Mander & Quinn 1995, Kerridge 1997), even though most only concentrate on the energy and soci-economic situation on a broader scale. The qualitative research that has been done, focuses more on alternative energy supplies for some of the Namaqualand reserves (Eberhard 1990, Kerridge 1997), while very few researchers have conducted any quantitative research (Archer 1994). The information available consists of generalisations and does not necessarily capture the situation of individual reserves. Both qualitative and quantitative fuelwood use research is lacking in Namaqualand.

In the Namaqualand reserves there is an obvious interrelationship between human economic systems and the environment. Rural livelihood practices impacts on the environment and in turn environmental quality influences the performance of the economy (Pearce *et al.* 1992). The fundamental economic problem is how to meet the demands placed on the environment for natural resources and income from a scarce resource base.

It is important to understand the value of the natural resource base in terms of its contribution to economic wellbeing. If this value is high, then the opportunity costs of using up natural capital through overharvesting are potentially high. In other words, overharvesting by present generations may incur substantial costs on future generations, or indeed, on themselves in future years. This is particularly important in cases where there is little responsibility of substitution. If, for example, cheap electrification was imminent in Paulshoek within the next few years, then an unsustainably high harvest is economically justifiable. This may only be possible provided that the same level of benefits can be sustained until the alternative energy supply is in place, and if there are no other externalities associated with the depletion of fuelwood stocks. Such externalities might be incurred due to the disruption of ecological systems and could be measured in terms of loss of productivity in other sectors, such as goat farming.

Economic valuation is a way of providing monetary value to the goods and services provided by environmental resources. The economic valuation process therefore, tries to identify the difference between benefits (e.g. fuelwood) and cost (e.g. labour) (Campbell *et al.* 1997).

Many resources are complex and multifunctional and it is not always clear how to value and quantify the goods and services provided by these resources. However, the need to value the fuelwood resources of the community has become increasingly important, because of the increased use of the resource. Perceptions are that increasing demand will outstrip supply, resulting in increased environmental degradation (Eberhard 1986, Mander & Quinn 1995). For reasons such as this, various valuation techniques and methods have been developed. This study will concentrate on the direct consumptive use values of fuelwood as defined by Pearce *et al.* (1989) and Campbell *et al.* (1997). The direct use values are estimated from biomass of fuelwood consumed, distances travelled to collect fuelwood and time spent collecting. The valuation of direct use values takes into account the benefits from domestic consumption, sales and costs (labour) (Guijt *et al.* 1995, Campbell *et al.* 1997). Placing monetary value on the fuelwood resource is important for the people who use it and for the environment of Paulshoek. The inhabitants would then be able to compare the cost of the present resource utilization with the cost of alternative sources that could be implemented. Economic valuation of fuelwood use has been researched in a few areas of Namaqualand

(Eberhard 1990, Mander & Quinn 1995). This type of information is, however, lacking for Paulshoek, which is one of the rural reserves where people still rely heavily on fuelwood.

This study thus aims to determine the extent and value of fuelwood use and in conjunction with the assessment of ecological sustainability, will attempt to predict how this value might change over time. Recommendations will be made as to how to maximize the net present value that can be realized from utilization of the resource.

The main objectives of this chapter are as follows:

i) to develop an inventory of the main species used for fuelwood, the parts used and the purposes for which these plant parts were used;
ii) to determine the relationships between scarcity, quality and demand;
iii) to quantify daily household consumption of fuelwood, describe seasonal variation in use and estimate total annual consumption. The consumption levels were related to household size and wealth;
iv) to ascertain the price (on the basis of cash or barter transactions) of fuelwood and the cost of collection (in terms of labour time) and hence the net benefit to households (use value);
v) to estimate likely changes in the abundance of fuelwood species over time from 1940 to 2010, using a timeline matrix.

2.2 Methods

2.2.1 General approach

The research approach used in this chapter incorporates both household survey and PRA methodologies. The data was collected over a two-year period. The first household survey was undertaken for one week in June 1997. A formal questionnaire in Afrikaans was used in the survey (Appendix 1). The objective of this questionnaire was to gather preliminary information on the use and value of the fuelwood resources used by inhabitants of Paulshoek and to assess the possible impact of fuelwood collection on the environment. The household survey was administered at both village and stockpost levels. In keeping with the objectives of the study, a wealth typology from a previous study (May *et al.* 1997) was modified and used in placing respondents into different wealth ranks. The wealth ranks were divided into relatively wealthy and less wealthy groups. The household's monthly income, household size and livestock holdings were used as indicators of wealth status. The respondents were placed into different wealth groups to determine if economic status influenced their collection and consumption patterns. In June 1998, a second study was undertaken to gather more detailed qualitative and quantitative information. The first phase of the study was a household survey to obtain detailed quantitative information concerning daily energy consumption patterns. The second phase comprised a participatory rural appraisal (PRA) exercise (Versveld & Cousins 1994, Pretty *et al.* 1995), based on information received from the first household survey. The objective of the PRA exercise was to gather more quantitative and qualitative information on the use, value and potential environmental impact of fuelwood collection in the area. Fifteen people, divided into three groups of five people each took part in the PRA exercise. Participants were representative of different age and social status groups.

2.2.2 Description and quantification of fuelwood use

The use of different fuelwood species was determined through interviews with respondents from the village and stockposts in June 1997. The respondents were randomly selected. A representative sample of 40 households and 10 stockpost respondents were formally interviewed by means of a questionnaire (Appendix 1). The interviews took approximately 45 minutes each. Each interview was structured so as to obtain information on what species were used, which parts (branches, stumps, roots) were used, how they were used and for what purposes (cooking, heating, boiling water, ironing, baking) and at what time of the year. Matrix- ranking and scoring methods (Pretty *et al.* 1995, Versveld & Cousins 1994) were used in the analysis of the questionnaire. These methods were used to identify, rank and categorize the main fuelwood species. In order to gain first hand experience of the fuelwood use habits, I accompanied some of the wood collectors on their "wood making" trips. The fuelwood species collected and harvesting methods were observed and recorded during these trips. Specimens were collected and identified in the Compton Herbarium. The taxonomy follows Arnold & de Wet (1993). For the purpose of analysis the respondents were stratified according to the wealth groups in an attempt to determine if economic status influenced use behaviour. Additional PRA exercises were conducted during June 1998. More information was obtained on the main species preferred and used. The plant parts utilized and their purpose of use and seasonal use changes were also recorded. Again matrix- ranking and scoring methods were used in the analysis of the PRA data. Non-parametric statistical methods (e.g. rank correlations, Kruskal-Wallis & Mann-Whitney U test), were used to test for significant differences between two or more groups of interest.

A second household survey was conducted with the focus on gathering more quantitative data on the value of fuelwood resources. This household survey was conducted using 10 previously interviewed households. The selection of the households was subjectively determined by their individual wealth statuses. The aim of the exercise was to obtain the exact amount (kg) of fuelwood used by each of the ten households over a five day period in early winter for the period 6-10 June 1998. The dead wood used by each household was weighed on a daily basis for a period of 5 days using a 10kg spring balance. The size of the bundle of fuelwood, as determined by the individual households, was weighed and put aside every day for the day's use. If a bundle of wood contained *Rhus undulata* (taaibos)- the most preferred and most used species in the region then it was weighed separately from the rest of the wood in the bundle. If not all the wood was used from the previous day's allotment, then it was weighed every morning and included in the new bundle of fuelwood to be used for the day. In most cases recordings of the fuelwood weights were made early in the morning to ensure consistent results.

2.2.3 Fuelwood value

The information from the household surveys conducted in July 1997 was also used to assess the value of the fuelwood resources to Paulshoek inhabitants (Appendix 1). In the initial interviews, an attempt was also made to gain baseline information on how much fuelwood cost the user, the amount of time spent collecting wood and the distances walked. The questionnaire information was used as a guide for developing the PRA exercises. The objective of the PRA exercises was to explore the value of the fuelwood resources as perceived by the villagers themselves. The villagers were divided into three groups representative of age, gender and social status and were asked to rank the cost of specific fuelwood species as they change over the different seasons and to value different sizes of fuelwood loads. These values were obtained in terms of cash payment in kind, and the latter were converted to estimates of cash value. General estimates provided by respondents were made and measured quantities relating to purchases were undertaken. Consumption levels were derived from the household surveys and PRA exercise. The data were tested for significant differences using parametric and non-parametric statistical approaches.

A monetary valuation of fuelwood, used by households was undertaken using a derived demand approach (Pearce *et al.* 1990). The gross unit value of firewood was taken to be the mean price per kilogram. The net value of firewood was then taken as gross value less the production cost, which was based on labour cost, or value of time employed in travel and collection of the resource. Travel and collection times for resource extraction were established in the household survey and verified in the field. The cost of fuelwood collection was estimated as follows: The rate of travel multiplied by the distance to the resource collected multiplied by the number of trips yielded total travel time per year. The quantity of resource collection multiplied by the collection time per unit of resource yielded the total collection time per year. The sum of distance and collection times yielded the total labour time. Cost is measured as labour time multiplied by opportunity cost of time. The opportunity cost is taken as the minimum wage rate. Total value of fuelwood used in Paulshoek was calculated as follows:

$$Vt = Q \times P \times H$$

where:

........Vt is the total monetary value (Rands) of the fuelwood for the whole village
Q is total quantity (kg) of wood used in each season
P is total price (Rands/kg) of wood used in each season
H is total number of households

2.2.4 The impact of fuelwood collection and use

The questionnaire and PRA exercises, which were used to assess fuelwood utilization amongst a range of households, were also used to identify the possible degree and awareness of impact on the veld. The questions asked in the interviews and PRA exercises tried to assess the sustainability of fuelwood resource use in Paulshoek. Long term changes in the abundance of specific fuelwood species were assessed primarily through a matrix ranking exercise (Pretty *et al.* 1995). For the matrix ranking, different groups of respondents were asked to provide relative abundance information for the main products at approximately 20 year time intervals from 1940-2010, and at different distances away from the village. Reasons for the decline in fuelwood resource abundance were discussed with the villagers. In addition, time taken to collect the resource and how this has changed over the years was also used as a proxy measure for the sustainability of local household harvesting practices. Descriptive statistical analyses were employed to interpret the matrix ranks and scores.

2.3 Results and Discussion

2.3.1 The use of fuelwood

Twelve species were identified as important fuelwood species in Paulshoek (Table 2.1). Fuelwood species are selected on the basis of quality, use and availability. The ability of the plant species to burn for long periods and exhibit sustained heat determines its quality as either "good", "intermediate" or "weak" wood. Plant species, which produce coals that burn for extended periods are usually utilized for the main in-house activities like cooking, heating and ironing. These are generally also the species, that will not be utilized for baking as it would be considered a waste of good quality fuelwood. However, even though the respondents in Paulshoek have a good knowledge of the local fuelwood species preferred, their use patterns have changed. They now collect more low quality fuelwood than good quality fuelwood, because of its availability. If good quality wood is not available then they settle for whatever they can find.

Good fuelwood is described as wood that forms coals and burns for long periods and is highly preferred e.g. *Rhus undulata, Ruschia robusta, Dodonaea viscosa, Lebeckia sericea, Elytropappus rhinocerotis* and *Euryops multifidus* (Table 2.1). A brief description of each fuelwood species follows.

Rhus undulata Jacq. (Anacardiaceae) can vary from a low growing shrub to a tree of about 5 m in height. It occurs in a wide range of habitats from dry arid areas to evergreen forests. It is available in Namaqualand on rocky slopes. *R. undulata* is considered the most preferred fuelwood species, because the coals can burn for as long as twelve hours or longer (Archer 1994). The durability of the coals formed makes it a fuelwood of high quality.

Ruschia robusta L. Bol. (Mesembryanthemaceae) is an erect, stiff, robust shrub, which can grow up to 1 m high. There are about 370 species of *Ruschia* in South Africa with a large percentage occurring in Namaqualand. *R. robusta* is normally found in sandy areas in Namaqualand and Bushmanland (le Roux & Schelpe 1988). *R. robusta* is considered the shrub equivalent of *Rhus undulata* because it makes good long-lasting coals.

The remaining good quality fuelwood species were seldom used mainly because they are located in habitats far away from the village. *Dodenaea viscosa* Jacq. (Sapindaceae) can take the form of a shrub or small tree varying between 3 to 10 m in height. It is located in rocky hillocks, forests or open woodlands.

Lebeckia sericea Thunb. (Fabaceae) is a densely branched shrub, which grows up to 1.5 m high. It occurs in rocky places in Namaqualand and other drier parts of the Western Cape (le Roux & Schelpe 1988).

Elytropappus rhinocerotis (L. f.) Less. (Asteraceae) is a much branched shrub, which varies in height from 60 cm to 2.5 m in height.

Euryops multifidus (Thunb.) DC. (Asteraceae) is an erect, much branched shrub, which grows up to 80 cm high. It occurs throughout Namaqualand in rocky hills (le Roux & Schelpe 1988).

Intermediate fuelwood species can form coals but burn for short periods and form ash (e.g. *Eriocephalus microcephalus*, *Lycium ferocissimum* and *Polymita albiflora)* (Table 2.1). *Eriocephalus microcephalus* DC. (Asteraceae) is a small much branched shrub, which grows up to 1 m high. It is found throughout Namaqualand and also in other drier areas of the Western Cape (le Roux & Schelpe 1988). *E. microcephalus* is used more regularly than preferred as it is more abundant and has the ability to establish quickly and in a wide range of habitats. It is better suited for baking, because of its intermediate wood quality.

Lycium ferocissimum Miers. (Solanaceae) is a spreading shrub that grows between 1-1.5 m high. It is a palatable plant, defended by spines and occurs in Namaqualand in sandy places. It also extends southwards to the Cape Peninsula and eastwards to the Free State, Eastern Cape and Lesotho (le Roux & Schelpe 1988). The wood is used more than it is preferred, because of its availability.

Polymita albiflora L. Bol. (Mesembryanthemaceae) is a low succulent shrub. The whole plant is used, but only for baking. It grows to a height of about 50 cm and occurs along the border of the winter rainfall areas in Namaqualand. *P. albiflora,* is a specialist fuelwood species which is not used for open fires because it releases a foul smell and a lot of smoke. It is however highly suitable for baking as it releases adequate heat energy, which warms the outside baking ovens. The villagers in Paulshoek thus mainly use *P. albiflora* for baking purposes, which normally takes place once a week.

Weak fuelwood does not form coals, burns for very short periods, produces a lot of ash and releases toxic smells or gases (e.g. *Euphorbia mauritanica,* Krakratjie and *Galenia africana*) (Table 2.1). Although *E. mauritanica* occurs close to the village it is least preferred and also used very little. *Euphorbia mauritanica* E. Mey. ex Boiss. (Euphorbiaceae) is a stem succulent shrub that varies between 60 cm and 1 m in height. It is generally found in the hilly areas of Namaqualand and also in Namibia (le Roux & Schelpe 1988). It is mainly used for baking and not as an open fire fuelwood, because it releases a bad smell and forms ash rapidly.

The species that comprise Krakratjie burn to ash quickly and only release limited amounts of heat and are used mostly as kindling. *Asteraceae* (Compositeae) is a general term used to describe several small shrub species, varying between 20 cm to 1 m high. Some examples are *Hirpicuim alienatum*, *Chrysocoma ciliata* and *Pteronia incana.* They are widespread in Namaqualand, Clanwilliam and other dry parts of the Western Cape. Their preferred habitats vary between sandy places to rocky slopes (le Roux & Schelpe 1988).

While villagers would prefer not to use *G. africana,* many use it to a great extent because of its availability. *Galenia africana* L. var. (Aizoaceae) is an erect woody shrublet varying between 0.5 to 1.5 m high. It is found in the western and southern margins of the Karoo. It is also widespread in the drier winter rainfall areas of the Western Cape and Namibia. It occurs in disturbed vegetation on plains and rocky areas (le Roux & Schelpe 1988). *G. africana* which is poisonous to livestock, is a pioneer species that establishes easily in over-grazed rangelands. Many households utilize *G. africana* as kindling, while poorer households who cannot always afford good quality fuelwood, use this poor quality wood as a main fuelwood source.

Table 2.1: Fuelwood species used in Paulshoek, the parts used and their purpose. The data are mean results (rounded off to the nearest whole number) obtained from PRA scoring exercises on 5 June 1998. Three separate groups of 5 people each (N=3), representative of different age and wealth status took part in the exercise. Ranks ranged from 0 (not used) to 3 (most used).

Species	**Common Name**	**Parts used**			**Purpose of use**		
		Branches	**Stump**	**Roots**	**Cooking, Heating, Boiling Water**	**Ironing**	**Baking**
Rhus undulata	*Taaibos*	3	3	3	3	3	0
Ruschia robusta	*T'nouroe*	3	3	3	3	1	3
Dodonaea viscosa	*Ysterhout*	3	3	2	3	3	1
Lebeckia sericea	*Fluitjiesbos*	3	3	3	3	1	2
Elytropappus rhinocerotis	*Renosterbos*	3	3	2	3	2	1
Euryops multifidus	*Repuis*	3	3	0	3	1	2
Eriocephalus microcephalus	*T'gibbie*	3	2	1	2	0	3
Lycium ferocissimum	*Kriedoring*	3	2	0	3	1	2
Polymita albiflora	*Muisoor*	3	3	3	0	0	3
Euphorbia mauritanica	*Melkbos*	2	0	1	1	0	2
Asteraceae[1]	*Krakratjie*	3	1	1	2	0	1
Galenia africana	*Kraalbos*	2	2	1	2	1	3

[1] Indicate a collection of woody shrubs which are part of the Asteraceae family all named "krakratjie" because they make a crackling sound when burning.

Table 2.2: The use of different fuelwood species during different months of the year. The data are mean results (rounded off to the nearest whole number) obtained from a PRA ranking exercise involving three separate groups of 5 people each (N = 3) from Paulshoek on 5 June 1998. Ranks range from 1 (least used) to 5 (most used). The shaded area indicates the coldest 6 months of the year in Paulshoek (Schulze 1986).

Species	**Common names**	Months											
						Winter period							
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rhus undulata	*Taaibos*	2	1	2	2	3	4	4	4	5	1	1	1
Ruschia robusta	*T'nouroe*	3	3	4	4	4	5	4	4	4	4	3	3
Dodonaea viscosa	*Ysterhout*	3	3	3	3	3	3	3	3	3	4	4	3
Lebeckia sericea	*Fluitjiesbos*	2	2	2	2	2	3	3	3	3	3	3	3
Elytroppus rhinocerotis	*Renosterbos*	4	3	4	4	4	4	5	5	4	4	4	3
Euryops multifidus	*Repuis*	3	3	3	3	3	3	4	4	4	3	3	2
Eriocephalus microcephalus	*T'gibbie*	3	2	3	3	3	5	5	5	3	3	2	2
Lycium ferocissimum	*Kriedoring*	2	2	2	2	2	3	4	4	4	4	3	2
Polymita albiflora	*Muisoor*	2	2	2	2	2	2	4	4	5	5	3	2
Euphorbia mauritanica	*Melkbos*	3	3	3	3	3	3	3	3	4	4	4	2
Krakratjie	*Krakratjie*	2	2	2	2	3	4	4	4	4	4	3	3
Galenia africana	*Kraalbos*	4	4	5	5	5	5	4	5	5	5	4	5
Mean for all species		**2.8**	**2.5**	**2.9**	**2.9**	**3.1**	**3.7**	**3.9**	**4.0**	**4.0**	**3.7**	**3.1**	**2.6**

Although the twelve fuelwood species are collected throughout the year, seasonal patterns are evident (Table 2.2). Not surprisingly, people use fuelwood more during the colder, wet winter months (May – Oct) than during the warmer, dry summer months (Nov – Apr). Household fires burn throughout the day in these cold months thus encouraging increased fuelwood use. Any wood that can burn is used for fuelwood during this season. Although good quality fuelwood like *R. undulata* is heavily used, other fuelwood species are also used heavily during winter. *Galenia africana*, a weak, generally least preferred fuelwood species is also used heavily during the colder months, mainly because of its availability. When *R. undulata* is wet, it is easier to use low quality species, which catch alight more quickly and are more readily available. In households that can afford gas, less gas is utilized during the colder months leading to increased use of fuelwood. The gas does not provide heat for keeping warms and therefore people prefer to use fuelwood, which warm up the shelters and at the same time, provide energy for household activities during the cold months. The least variation in use between households was observed in July, which is the coldest month in Paulshoek. Little variation in use between species was observed during the winter period, mainly because all fuelwood species are used regularly and intensively. The largest variation in use was recorded for April and October. These are periods when the seasons change and people's need for fuelwood varies according to weather conditions. The warm, dry months allow for more diversity in choosing what fuelwood is used. *R. undulata* for example, is used less during summer because it is stored away for use in the colder seasons when it is difficult to find dry and good quality fuelwood. Households can afford to do this because less time is spent making fires. During summer fires are only made for main meal times and not kept going the whole day, as is the custom in winter. Seasonal variations in fuelwood use is not only determined by weather conditions but also by social customs (Bembrigde & Tarlton 1990 and Campbell *et al.* 1997). Liengme (1983) found that use of fuelwood increased during months of initiation and traditional ceremonies. However, the variation in seasonal use in Paulshoek seems to be influenced more by climatic conditions than social customs. December, which is the Christmas season celebrated by the community, does not seem to encourage a marked increase in the use of fuelwood, probably because it is hot and some households use gas.

2.3.2 Quantity of fuelwood used

The mean estimated weight of fuelwood used per day was 7.1 kg (Table 2.3). This weight is significantly lower than the weight of 15 kg per day found by Archer (1994) for other villages in Namaqualand. Household size can obviously influence levels of consumption. Results from a Kruskal-Wallis test indicated significant differences between household size and the mean weight of fuelwood used per day ($n = 50$; $K = 9.99$; $df = 3.00$; $p < 0.05$). The households with smaller family sizes used significantly less fuelwood than large households. The results also indicate that the largest households used as much fuelwood per day as stockpost dwellers. This is not surprising, as stockpost dwellers have better access to fuelwood resources in the area and depend solely on it as an energy source. They are generally also more wasteful than villagers. The villagers are less wasteful of their fuelwood resources because of the added cost and difficulty in collecting fuelwood. These findings differ with those of Bembridge & Tarlton (1990) in the Amatola Basin, where small sized families used more fuelwood than larger households. Bembridge & Tarlton (1990) suggests that smaller family sized households used more fuelwood because they have more time for "extra" activities e.g. beer-brewing, resulting in more fuelwood being used.

Inhabitants of Paulshoek, however, do not brew beer, but just utilize the amount of fuelwood required to meet their daily needs. It is only on special occasions like weddings, funerals etc. that increased amounts would be used in the household. For this reason it is also important that care should be taken when comparing household sizes and quantities used, as cultural and socio-economic factors may differ substantially between different areas. Under normal circumstances it can be expected that the larger households would use more fuelwood than the smaller households. Larger households utilized more fuelwood because they have to cater for more people. Larger cooking pots with greater quantities of food, which has to be prepared, require more fuelwood. More people in the household also means that more people have to use hot water for coffee and tea drinking. Household chores like house cleaning and laundry in larger families usually require more hot water than in smaller households. All these activities obviously mean that more fuelwood is required.

Table 2.3: The estimated mean weights of daily fuelwood use (kg/day) per household relative to family size (no. of people in a family). The results were attained from a questionnaire (Appendix 1) used in a household survey in June 1997 in Paulshoek. The survey information was gathered from respondents living in the village and at the stockposts (N=50). Results from a Kruskal-Wallis analysis of variance test is also shown. Similar superscript letters indicates no significant differences.

No. of people in household	Location of Household	No of households N = 50	Estimated mean weight of daily fuelwood use (kg/day) for individual areas
Between 1-2	Village	7	6.0^{a}
Between 3-5	Village	21	6.2^{a}
More than 5	Village	12	8.1^{b}
From 1 to more than 5	Stockpost	10	8.8^{b}
			Mean 7.1

Table 2.4: Measured quantities (kg) of *Rhus undulata* =(Rhus) and a mixture =(Mixed) of other fuelwood species used by 10 individual households in the village on a daily basis during the period of 6-10 June 1998. The data were obtained from a survey involving wealthy and poor households in Paulshoek. The first five households were representative of relatively poor households, while numbers 6 to 10 were relatively wealthy.

Household no.	Day											
	1		2		3		4		5			
Poor household	Rhus kg	Mixed Kg	Rhus Kg	Mixed kg	Rhus kg	Mixed kg	Rhus kg	Mixed kg	Rhus kg	Mixed kg	Mean ± std. dev. for Rhus (kg)	Mean ± std. dev. for Mixed (kg)
1	2.0	3.5	0.0	5.0	0.0	7.0	0.0	11.5	0.0	7.0	0.4 ± 0.8	5.8 ± 3.8
2	4.0	8.0	0.0	5.0	3.0	3.5	7.0	6.0	4.0	10.5	3.6 ± 2.2	7.4 ± 2.2
3	0.0	9.5	0.0	6.0	0.0	9.0	0.0	8.5	0.0	8.5	0.0 ± 0.0	13.4 ± 2.1
4	5.5	3.5	0.0	6.5	0.0	3.0	6.5	0.0	5.0	0.0	3.4 ± 2.8	3.8 ± 2.3
5	10.0	0.0	2.0	5.0	4.0	3.5	0.0	6.5	0.0	7.5	3.2 ± 3.7	3.0 ± 2.5
Mean for poor hh	**4.3**	**4.9**	**0.4**	**5.5**	**1.4**	**5.2**	**2.7**	**6.5**	**1.8**	**6.7**	**2.1 ± 1.5**	**6.7 ± 0.7**
std. dev.	**3.4**	**3.4**	**0.8**	**0.6**	**1.7**	**2.4**	**3.3**	**3.8**	**2.2**	**3.6**		
6	12.0	0.0	5.5	0.0	6.5	4.5	0.0	5.0	5.0	10.0	6.8 ± 2.7	3.9 ± 3.7
7	6.0	0.0	11.5	0.0	7.5	0.0	5.0	0.0	7.0	0.0	6.6 ± 2.4	0.0 ± 0.0
8	16.0	0.0	15.0	0.0	10.0	0.0	13.5	0.0	12.5	0.0	8.3 ± 1.2	0.0 ± 0.0
9	6.5	0.0	0.0	0.0	3.5	3.0	6.0	3.0	3.0	7.0	2.6 ± 2.4	2.6 ± 2.6
10	0.0	5.5	0.0	9.0	5.0	9.5	4.5	4.5	5.5	5.5	4.5 ± 2.6	6.8 ± 2.6
Mean for wealthy hh.	**8.1**	**1.1**	**6.4**	**1.8**	**6.5**	**3.4**	**5.8**	**2.5**	**6.6**	**4.5**	**5.8 ± 0.6**	**2.7 ± 1.6**
std. dev.	**5.5**	**2.2**	**6.0**	**3.6**	**2.2**	**3.5**	**4.4**	**2.1**	**3.2**	**3.9**		
Total quantity (kg) Used per day by all hh.												**8.7**

How accurate are the estimates derived from the PRA workshops and questionnaire survey? The measured quantity of 8.7 kg of fuelwood used in 10 households in June (Table 2.4), differs from the reported value of 7.1 kg (Table 2.3). The difference can probably be ascribed to the unpredictable weather conditions experienced during the measuring period. While some days were warm other days were cold and rainy. These factors ultimately affect the way inhabitants use their fuelwood. Archer (1994), Borchers *et al.* (1990) and Mander & Quinn (1995) suggest that the inhabitants of some Namaqualand reserves (Leliefontein, Komaggas, Pella and Richtersveld) who relied solely on fuelwood for their energy needs used about 15 kg of fuelwood per day. This value is nearly twice as much as the 8.7 kg used in Paulshoek. Differences in these quantities could be explained in terms of the fact that some of the Paulshoek respondents may have used gas as an energy supplement. The warmer days during this study meant that less fuelwood was used. The large variations in the data substantiate this claim.

Inhabitants in Paulshoek appear to use as much poor quality wood as high quality fuelwood. The ideal should have been for all households to use more high quality wood. The fuelwood situation serves as an indication that fuelwood collection is determined more by availability (Gandar 1983, Bembridge 1986) then any other factor. Bembridge & Tarlton (1990) state however, that the main criterion for fuelwood use in Ciskei is based on a combination of quality and availability. Others (Tinker 1987, Leach & Mearns 1988, Campbell *et al.* 1997) conclude that the availability of labour is the determining factor and not fuelwood availability.

Results from a Mann-Whitney U test indicated significant differences ($n = 10$, $Z = -3.84$; $p < 0.05$) between wealth status groups and the amount of fuelwood used on a daily basis (Table 2.4). In most of Namaqualand's communal areas the higher income groups show a decrease in the use of fuelwood, while lower income groups generally use more wood (Borchers *et al.* 1990, Mander & Quinn 1995). This is because many of the poorer households cannot afford to pay for alternative energy sources such as gas or paraffin (Borchers *et al.* 1990). In Paulshoek, however higher income groups appear to use more fuelwood than lower income groups. This fuelwood utilization pattern also differs from the Komaggas situation where wealth status does not necessarily determine fuelwood use patterns (Borchers *et al.* 1990). Compared to other villages in Namaqualand's communal areas, Paulshoek inhabitants still maintain a rural lifestyle and even though gas might be available people prefer to use fuelwood, especially during colder months. Higher income groups in Paulshoek use more fuelwood than lower income groups because they can afford to buy fuelwood and thus always have adequate stock available in the house. Wealthier groups usually used more good quality fuelwood (e.g. *R. undulata*) then the poorer quality fuelwood, because they could afford to buy it. The poorer households use more mixed wood, while the wealthier households use *R.*

undulata (Table 2.4). The poorer groups utilized more of the lower quality fuelwood species than good quality fuelwood, because they normally have to collect it themselves. It is more time consuming and difficult to collect *R. undulata* as it grows in the rocky areas. *G. africana* on the other hand, is widespread in the area.

Table 2.5: The estimated number of days in which different fuelwood types would last in a household during different seasons (January to December). The mean results (rounded off to the nearest whole number) were extracted from a PRA scoring exercise conducted on 5 June 1998. The fifteen participants who were representative of wealthy and poor income groups, were divided into three groups of five people each for the exercise (N = 3).

Fuelwood Types	Spring (Sep-Nov)	kg / day	Summer (Dec-Feb)	kg / day	Autumn (Mar-May)	kg/ day	Winter (June-Aug	kg/ day
Bundle of *Rhus undulata* (14kg)	2	7	5	2.8	1.5	9.3	1	14
Mixed fuelwood species (14kg)	2	7	2	7	1	14	1	14
Mean	**1.9**	**7**	**3.8**	**5**	**1.4**	**11.6**	**1.0**	**14**

Fuelwood loads last longer in the warmer months than in winter (Table 2.5). A load of 14 kg lasts nearly four times longer in summer than in winter, when it is very cold and wet. The stumps of *R. undulata* are generally not used during warmer seasons but are stored for the winter season. A load of *R. undulata* would last 5 days in summer, while the same quantity of mixed wood would only last for 2 days in winter. The different periods of utilization provide an indication of the difference in quality of the fuelwood. Good quality fuelwood is also used sparingly during summer months, thus giving an indication of the community's awareness of scarcity and cost.

Table 2.6: Estimated daily and total consumption of fuelwood used by households in Paulshoek. Estimates are based on PRA and household consumption survey data collected.

	Estimated fuelwood quantities (kg) used per day based on PRA	**Annual total kg**	**Measured fuelwood quantities (kg) used per day based on consumption survey**	**Annual total kg**
Winter	14	1274	8.7	792
Spring	11.6	1056	7.2	655
Summer	5	455	3.1	282
Autumn	7	637	4.4	400
Tons used /year		**3.42**		**2.13**

Table 2.7: Estimated fuelwood consumption patterns per household per year for the 140 village and 10 stockpost households in Paulshoek. Estimates are based on a household survey conducted over a five day period during 6-10 June 1998 involving 10 households.

Total annual consumption patterns	Total values hh/yr
Total quantities (tons used /hh/yr)	2.18 tons
Rate of travel (km/hr)	1.6 km /hr
Labour time (days/hh/yr)	151.9 days

Rural households largely obtain their fuelwood requirements directly from the environment. The quantity of fuelwood used per household per year was 261 kg/hh/month or 2.18 t/hh/yr (Table 2.7). The total of 2.18 t/hh/yr (Table 2.6) as it was a more quantitative measure than the PRA estimates. The estimates from the survey may also be more a conservative estimate as people may have used wood sparingly when they knew that they were being observed. The total quantities consumed by each household compare well with consumption figures from other studies (Bembridge 1990, Eberhard 1990, Shackleton 1993a, Campbell *et al.* 1997) (Table 2.8).

Care should however be taken when comparing consumption figures as these vary with household size and ecological environment.

Table 2.8: Comparative values for fuelwood consumption rates (tons/hh/yr) in several African studies.

Country of location	Fuelwood consumption rate (tons/hh/yr)	Source
Namaqualand (Paulshoek)	2.2	This study 1999
Namaqualand (several areas)	2.6	Mander & Quinn 1995
Namaqualand (Pella)	4.1	Ward 1994
Namaqualand (Komaggas)	1.3	Ward 1994
Tanzania	1.8	Bembridge & Tarlton 1990
Gambia	1.2	Bembridge & Tarlton 1990
Sudan	0.3	Bembridge & Tarlton 1990
Transkei	1.8	Borchers *et al.* 1990
Lesotho	1.2	Borchers *et al.* 1990
Lesotho	1-1.5	Borchers *et al.* 1990
Ciskei (Peddie)	0.63	Bembridge & Tarlton 1990

2.3.3: The value of fuelwood

Seasonality plays a definite role in the price of fuelwood. The mean price of fuelwood is 3.2% higher in winter than in summer (Table 2.9). Fuelwood is cheaper in the summer months when less is used for household activities. In winter, on the other hand, the dependency on fuelwood is generally very high and wood sellers are able to demand higher prices. The inter-seasonal price of a bundle of wood varies most when bought in a bundle (R17.8 ± 5.5) and donkey cart (R72.5 ± 5.5) form and least when a bakkie load is bought (R82.8 ± 1.3). The mean price of fuelwood per (kg) bought in bakkie loads is about half the price per kilogram as a donkey cart load. Fuelwood was once a totally free resource, but scarcity and an emerging cash economy has encouraged small scale commercialization. Although, fuelwood selling now forms a small informal business for three individuals in the village, signs point to increased commercialization of fuelwood selling unless alternative energy is implemented. Some villagers, especially the elderly, can no longer walk the increased distances to collect wood and are therefore compelled to buy from the wood sellers. Similar trends are observed in other studies done in South Africa (Gandar 1983, Liengme 1983, Moller 1985, Bembridge 1987). The payment for fuelwood is based on a combination of money, barter and reciprocal exchange of services (i.e. sugar, flour or tobacco for fuelwood), similar to the services used by rural communities in Zimbabwe (Campbell *et al.* 1997). It is generally the wealthier households who buy the wood because they can afford it. The poorer groups are not able to pay for fuelwood and they are also most affected by the scarcity of fuelwood sources in Paulshoek (Borchers *et al.* 1990)

Table 2.9: The mean cost in (Rands) of approximate weights in (kg) of different *Rhus undulata* fuelwood loads during different seasons (January to December). The mean results (rounded off to the nearest whole number) were derived from a PRA scoring exercise conducted on 5 June 1998. The fifteen participants who were representative of wealthy and poor income groups, were divided into three groups of five people each for the exercise (N = 3).

Rhus undulata load and approximate weight (kg)	Spring (Sep-Nov) (Rands)	Summer (Dec-Feb) (Rands)	Autumn (Mar-May) (Rands)	Winter (June-Aug) (Rands)	Mean price ± std dev. (Rands)	Mean price/kg (Rands)
Bundle (14kg)	13	13	22	23	17.8 ± 4.8	1.78
Donkey car (70kg)	77	63	75	75	72.5 ± 5.5	1.04
Bakkie (112kg)	85	82	82	82	82.8 ± 1.3	0.74
Mean cost (Rands)	58.3	52.7	59.7	60		

Table 2.10: Approximate daily number of fuelwood collection trips and the estimated distance traveled from the village to the collection area by 10 individual households. The results were obtained from a questionnaire (Appendix 1) used in a household survey over a 5 day period (6 to 10) June 1998. The distances were calculated using a 1:50 000 topographic map of Paulshoek (3328 CC).

Household no.	Distances travelled (km) to collect fuelwood (round trip)	No. trips in five days
1	5.0	5
2	5.0	2
3	8.0	3
4	10.6	2
5	15.0	1
6	5.0	2
7	5.0	3
8	5.0	3
9	5.0	3
10	8.0	3
Mean	**7.2**	**2.7**
std dev.	**3.2**	**1.0**

The average round trip distance travelled (km) to collect fuelwood is 7.2 ± 3.2 (Table 2.10). This distance is travelled on average 2.7 ± 1.0 times in five days. According to oral testimony, people did not have to walk so far or so frequently to collect wood in the past. The long distances also mean that larger loads of fuelwood are conveyed back to the house. People currently collect as much wood as possible on a collecting trip, thus ensuring that they do not have to walk such far distances every day. The average rate of 2.3 trips per week observed by Gander (1983) in Mahlabatini (Kwazulu) is similar to the number of trips calculated in Paulshoek (2.7).

Oral testimony suggest that fuelwood resources were more readily available in previous years, but increased use has seen their decline in abundance. The perceived decline of fuelwood has caused an increase in time spent collecting fuelwood. Fuelwood collectors travel on average for 31.1 days in a year to collect fuelwood. On average, collectors walk 1.6 km per hour to collect fuelwood. This time includes walking and collecting of fuelwood.

Labour time has also increased encouraging higher labour costs. The total time spent on labour thus amounts to 151.9 days per household in a year. The sale of fuelwood is mainly done by livestock herders in Paulshoek. The collection and sale of fuelwood is seen as a means to sustain a daily living for those with little or no alternative income.

Labour is considered the only input in harvesting fuelwood, because the cost of the cutting tools used is negligible. The total net value of fuelwood used in Paulshoek is about R 366 291.75 per year. If the consumption rate is more or less similar to the annual production rate, it will mean that the resource is being used sustainably. If consumption levels increase (as is expected) above the replacement production levels of the resource, then a reduction will occur in the standing crop.

2.3.4 The impact of fuelwood use and collection

As in many other areas, local perceptions are that the availability of fuelwood species has decreased over time (Shackleton 1993a; b, Bembridge & Tarlton 1990, Campbell *et al.* 1997) (Table 2.11 & Figure. 2.1). Respondents perceived a decline in species abundance since 1940 with the exception of *G.africana*. All species have declined markedly except for *E. microcephalus,* which is able to re-establish easily and is widespread. Population increases and human dependency on the natural resource can be attributed as the main cause for decline. In previous years the fuelwood species were readily available but increased population pressure on the land has caused the decrease in fuelwood abundance. During the PRA exercise, respondents suggested that human and climatic factors (e.g. unpredictable rainfall and droughts) are reasons for change in resource availability. The general perceptions are that resources will continue to decrease in the future. One measure of fuelwood resource decline is the longer distances which people now have to walk to collect fuelwood.

Table 2.11: The change in abundance of 12 different fuelwood species over a period of time (1940-2010). The data are mean results (rounded off to the nearest whole number) obtained from a PRA matrix ranking exercise (5 June 1998), involving three separate groups of 5 people each (N = 3) from Paulshoek. Ranks range from 0 (not available) to 5 (most abundant).

Species	Common Name	1940	1960	1980	Present	2010
Rhus undulata	*Taaibos*	5	4	3	2	1
Ruschia robusta	*T'nouroe*	5	4	3	2	1
Eriocephalus microcephalus	*T'gibbie*	5	5	5	4	4
Euryops multifidus	*Repuis*	5	5	3	2	0
Euphorbia mauritanica	*Melkbos*	5	5	4	2	1
Polymita albiflora	*Muisoor*	5	4	3	2	1
Lebeckia sericea	*Fluitjiesbos*	5	4	3	2	0
Lycium ferocissimum	*Kriedoring*	5	4	3	2	1
Asteraceae	*Krakratjie*	5	4	3	2	0
Dodonaea viscosa	*Ysterhout*	5	5	3	2	1
Elytropappus rhinocerotis	*Renosterbos*	5	5	4	3	2
Galenia africana	*Kraalbos*	1	2	4	5	5

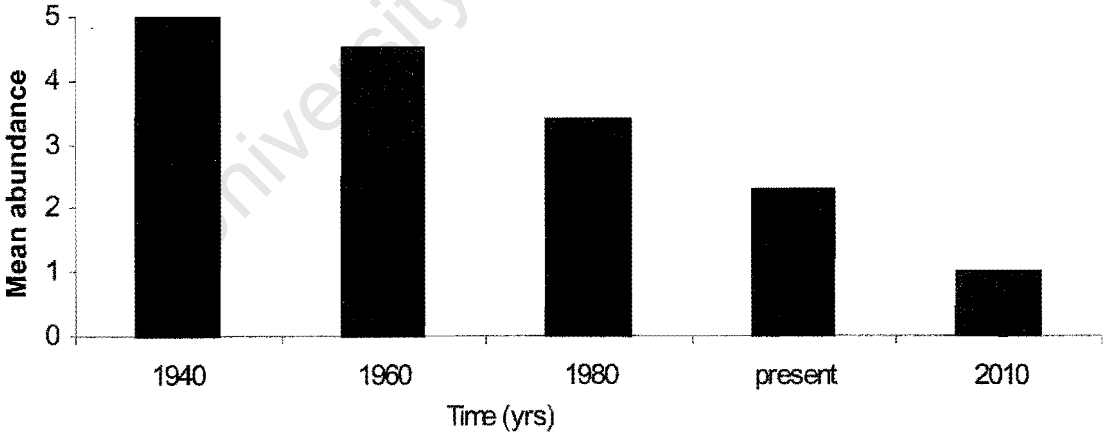


Figure 2.1: The change in abundance of 11 different fuelwood species over a period of time (1940-2010). The data were obtained from a PRA matrix ranking exercise (5 June 1998), involving three separate groups of 5 people each (N = 3) from Paulshoek. Ranks range from 0 (not available) to 5 (most abundant). *Galenia africana* (kraalbos) shows an inverse relationship to the other fuelwood species and has been omitted from this analysis.

2.4 Conclusions

Paulshoek inhabitants use at least twelve plant species for a variety of fuelwood purposes. The species are selected for fuelwood activities on the basis of the heat release ability and availability. Good fuelwood form coals which burn for long periods, while weak fuelwood form ash quickly. *Rhus undulata* is the most preferred fuelwood and it is mainly used for cooking, heating and ironing. A wide variety of shrubs are also used as fuelwood. These include good, intermediate and weak quality fuelwood. *Ruschia robusta* is considered a good quality fuelwood while *Galenia africana* and Krakratjie are considered weak fuelwood.

It is estimates that an average of 8.7 kg of fuelwood is used per household per day, which amounts to a total of 2.18 tons/hh/yr, taking seasonal differences in consumption into account. The change in seasons also has an impact on the amount of fuelwood consumed by the inhabitants. During winter months more fuelwood is consumed than in summer. The amount of fuelwood consumed by households during winter was estimated at 792 kg/hh/yr while in summer this value was estimated to be approximately 400 kg/hh/yr. Inhabitants used about twice as much fuelwood during winter than during summer. The wood collectors walk on average about 7.2 km to collect fuelwood. This distance is travel on average 2.7 times in five days, which amounts to a total of at least 152 trips per year. The cost of fuelwood varies seasonally but an average price of R0.88 /kg was estimated. The total net value of fuelwood used in Paulshoek is approximately R 366 291.75 per year.

The above information indicates the importance of fuelwood to the community of Paulshoek. People utilize it for their daily household activities and can obviously not do without it in the absence of alternative energy. Perceptions are that fuelwood has decreased and now people have to walk long distances to collect fuelwood. Solutions to the fuelwood scarcity should thus include alternative energy sources, which would help relieve the burden placed on the inhabitants and at the same time ensure the sustainable use of the natural resource.

CHAPTER 3

THE ECOLOGICAL IMPACT OF *RHUS UNDULATA* HARVESTING IN PAULSHOEK

3.1 Introduction

Despite increased electrification of some rural towns in Namaqualand, many households still prefer wood as a primary energy source, mainly because of its affordability. Close to 9% of all households in Namaqualand reserves have the luxury of electricity (Eberhard 1990) although the situation is likely to have changed since 1994. Daily consumption in the Namaqualand reserves is estimated to be about 15 kg of fuelwood per household per day, which amounts to approximately 450 kg per household per month (Archer 1994; Mander & Quinn 1995). Fuelwood consumption in Paulshoek has been estimated at approximately 8.7 kg/hh/day (see chapter 2).

In the past fuelwood was relatively freely available, but increasing demand has led to a general scarcity and the cutting of live trees in Namaqualand reserves (Borchers *et al.* 1990, Archer 1994). Fuelwood availability is especially low around settlements in the district. Fuelwood availability is not only influenced by harvesting (e.g. fuelwood collection, grazing), but very strongly by the climatic and topographic characteristics of the region. Namaqualand is an extremely arid region with most of its areas (60%) receiving less than 100 mm of rainfall per year. Frequent droughts further contribute to the environmental stress. These general climatic patterns are also very unpredictable. According to Mander & Quinn (1995) climatic and topographic conditions strongly influence the production of woody biomass. Satellite images of the area indicate a restricted woody vegetation cover comprised of less than 1% of the landscape. The reality is thus that the sustainable yield of fuelwood from these arid environments is generally low. Despite the low fuelwood yield, more than 80% of households in Namaqualand still utilize fuelwood.

The Paulshoek villagers rely on a relatively small group of species for fuelwood purposes as mentioned in chapter two. A distinction is however made between highly preferred and less preferred fuelwood species. Similar to other reserves in Leliefontein (Archer 1994), villagers in Paulshoek also identified *Rhus undulata* as the most important and most preferred fuelwood species. *R. undulata* is still the most sought after fuelwood species because of its ability to form good quality coals, which burn for long periods and which can be utilised for multiple functions. Villagers utilize the stem, branches and stumps of these multi-stemmed trees. The stump is considered the most valuable part of the tree as it produces good quality coals that can be re-used for a few days.

Although *R. undulata* trees have been harvested for many years in Paulshoek, perceptions of villagers suggest that the abundance and availability of this important fuelwood species has declined rapidly over the last few years. This is a cause of great concern to the villagers as *R. undulata* is considered their fuelwood lifeline.

Except for the knowledge of the importance of *R. undulata* as a fuelwood, very little is known about the growth, reproduction, aging and survival functions of the species. To date, no known studies have assessed the growth and survival abilities of *R. undulata* under fuelwood harvesting and grazing conditions. Studies investigating woody plant utilization report a great variation between species tolerances to harvesting (du Toit 1972, Shackleton 1983b, Ericsson *et al.* 1985, Milton 1988, Chen *et al.* 1998). Some studies have found that frequent or continuous harvesting stimulated growth (Binne *et al.* 1974, Shackleton 1983b), or had no obvious effect on growth (Hodgson *et al.* 1981) or affected growth by reducing and/or inhibiting growth processes (du Toit 1972, Ericsson *et al.* 1985, Chen *et al.* 1998). The occasional pruning of *Acacia tortilis* had a growth stimulatory effect, while continuous harvesting decreased shoot production and basal increments (Milton 1988). The harvesting of *A. tortilis* in the growing season (summer) also decreased the growth rate more than during the winter harvesting (Milton 1988). Similarly, in China with its 897 million rural population depending on tree biomass, the over-exploitation of biomass also resulted in the decrease and disruption of natural vegetation processes. The frequent harvesting for fuelwood in areas of China reduced the above ground biomass of woody species and increased the recovery time (Chen *et al.* 1998).

In many cases livewood cutting and over-harvesting prevents natural regrowth (Cunningham 1988, Milton 1991) once an area has been denuded. This causes soil erosion and degradation, which in turn adversely impacts on soil fertility important for agricultural production (Falloux &

Mukendi 1990, Shackleton 1983b, Milton 1988). Long-term harvesting may also result in changes in species composition (Shackleton 1983a, Du Plessis 1995). The removal of timber can result in functional changes in the water quality, biochemistry and soil processes, which may lead to increases in soil temperature and decomposition rates. The reduction of litter through harvesting of livewood cutting in turn also affects the nutrient release, microbial activity and nutrient cycling (Perison *et al.* 1997, Mafongoya *et al.* 1998, Yanai 1998, Miles 1981). The continuous harvesting of fuelwood has adversely impacted on herpetofaunal populations in south Carolina (Perison *et al.* 1997), various cavity-using birds species in the rivering forests of southern Africa (Du Plessis 1995) and wildlife in China (Chen *et al.* 1998).

However, it is not only the fuelwood harvesting practices that impact on wood processes and availability, but also the presence of browsing by animals. The interaction between herbivores and woody vegetation can either be mutually beneficial or disruptive. The responses of most woody plants to browsing appear to be determined by the type of plant species, intensity of browsing and seasonality (Clarke *et al.* 1995, Duncan *et al.* 1998). The indehiscent seedpods of *Acacia* species for example, which serve as an important dietary part of many herbivores, benefit through improved dispersal and germination conditions (Hoffman *et al.* 1989). Dung on the other hand also improves the growing conditions for seedlings (Miles 1981). McNaughton *et al.* (1998) found that below ground productivity of the Serengeti grasslands were not affected by intense herbivory. Clarke *et al.* (1995) similarly found that grazing by sheep on heather moorland in Scotland, increased the proportions of shoots. Unfortunately this beneficial relationship does not hold true for all herbivore and vegetation interactions. High intensities of herbivory can also easily damage the woody vegetation by trampling, repeated grazing of new shoots, breaking off and uprooting shoots (Du Toit 1972, Ericsson *et al.* 1985). Duncan *et al.* (1998) found that intensive browsing influenced the plant's susceptibility to browsing damage. Aucamp *et al.* (1983), thus suggest that use of vegetation cover can only remain sustainable if the appropriate stocking rates are maintained. Browsing can then be manipulated to attain a desired effect on vegetation composition (Milton 1983, Ericsson *et al.* 1985, O'Connor & Pickett 1992).

What is apparent though, is that harvesting of fuelwood must not exceed the regenerative capabilities of the woody species. Ecological processes are not static and differ in time and space. Computer simulation models are increasingly being used to understand and predict changes and outcomes in landscapes. A process- based model using Stella (Costanza *et al.* 1990) was developed to assist in understanding whether harvesting of *R. undulata* for fuelwood purposes is sustainable or not. If the predicted harvestable fuelwood yield is greater than the amounts consumed by the households than it can be assumed that the fuelwood is being utilized sustainably. However, if this is not the case than fuelwood is being utilized unsustainably.

The main aim of this chapter is to investigate how harvesting patterns influence the growth and survival of *R. undulata* and to identify the sustainability of *R. undulata* harvesting for fuelwood. The objectives have been divided into three main sections.

(a) Harvesting treatments:

1. to determine the effect of harvesting at different intensities on the growth responses of *R. undulata*;
2. to determine the growth response of trees in a protected and unprotected (i.e. grazed) environment;
3. to relate regrowth of shoots to annual rainfall;
4. to determine the effect of tree size on shoot production.

(b) Harvesting impact over time

1. to determine the relationship between distance and abundance and size of *R. undulata* away from the village;
2. to investigate whether the abundance of *R. undulata* has changed over time through using aerial photographs;
3. to compare the abundance and size changes of *R. undulata* from matched ground photos.

(c) Sustainability of *R. undulata* harvesting

1. to develop a predictive model of *R. undulata* annual fuelwood production;
2. to assess whether harvesting of *R. undulata* is sustainable or not.

3.2 Methods

3.2.1 Harvesting Treatments

A total of 60 randomly selected *R. undulata* trees were sampled in the harvesting experiment. Thirty of the 60 *R. undulata* trees were harvested in a protected (fenced) area of approximately 4 ha and 30 in an adjacent unprotected area. Six trees of varying sizes were used for each of the four harvesting treatments and controls. Five trees were removed during the experiment by villagers for fuelwood and thus had to be excluded from the analysis.

Table 3.1: Number of *R. undulata* individuals subjected to different harvesting treatments in a protected and unprotected area during November 1997

	Tree heights (m)					
Treatment	Small (0.5– 1.0 m)		Medium (1.0 – 1.8 m)		Large (> 1.8 m)	
	Protected	Unprotected	Protected	Unprotected	Protected	Unprotected
Control (no harvesting)	2	2	2	2	2	2
25 % cut	2	2	2	2	2	2
50 % cut	2	2	2	2	2	2
100 % cut	2	2	2	2	2	2
50 % + stump	2	2	2	2	2	2

Initial values for control and harvested trees were measured in November 1997, before the application of treatments. Each tree was marked and several variables recorded that would serve as good predictors of aboveground biomass. The *R. undulata* trees are multi-stemmed and extend from an underground rootbase structure called the stump. The stumps generally take on the form of a large bulblike from. The multiple stems grow from this stump which makes it possible to remove 50% of the canopy plus 50% of the stump without destroying the whole canopy. The measurements included: (i) size of the tree (height, length and breadth). This was used to calculate volume (m^3) as an oblate spheroid (Philips & MacMahon 1981):

$$V = (\Pi a^2 b)/6$$

where:

a is the minor axis either height or average diameter, whichever is smaller and

b is the major axis either height of average diameter whichever is greater.

(ii) length of stems cut (m); (iii) diameter of stems cut (cm). A meter stick was used to measure the size of the trees and Vernier callipers (cm) to measure the stem diameters of cut stems and new shoot regrowth. The stem diameters were measured at the soil level. The recording of original stem wet mass of the initial 48 trees harvested was not done in the first set of measurements and therefore, an additional six trees had to be felled. Six trees with relatively similar sizes and stem diameters to the previously 48 measured trees were selected, measured and cut and wet weight determined. These data were used to develop stem diameter-mass regression relationships (see later). The weight of the stems cut was recorded in the field using a Salter Abbey precision spring balance calibrated in (kg) and results were than converted into (g) for calculation purposes.

3.2.1.1 New growth measurements

New shoot growth of control and harvested trees, were measured every three months (Jan'98 to Nov'98). The length (cm) of shoots was measured from the cut stem to the tip of the shoot every three months. Diameter measurements (cm) of new shoots were taken above the basal thickening of the regrown shoot. All new shoots were measured, counted and clipped at the end of the last measurement period (Nov'98) and weighed in the field. All shoots were then bagged and oven dried at 70^0C for 30 days in the laboratory. To minimize absorption of moisture after removal from the oven, the bagged shoots were placed in large black plastic bags before weighing. The dry mass was weighed and recorded.

The advantage of destructive sampling is that it provides an accurate measure of biomass of a particular sampling point (Catchpole & Wheeler 1992). Halpern *et al.* (1996) also suggest that woody biomass is best determined by stem diameter and/or length of stems. The mass & diameters from felled tree measurements were used to develop a diameter-mass regression equation to determine biomass production.

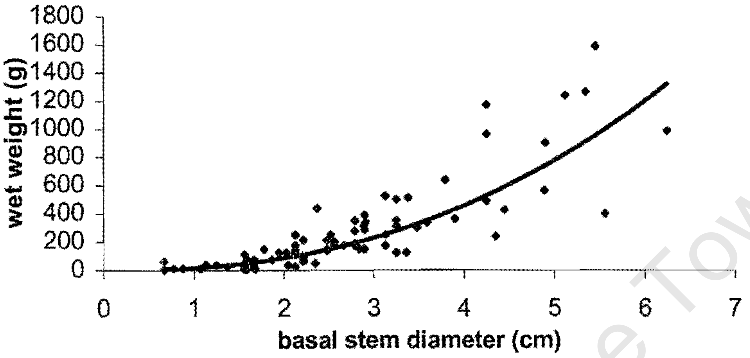


Figure 3.1: The relationship between basal stem diameter (cm) and branch (wet) weight (g) of 92 *R. undulata* branches. Results indicate a regression equation: $y = 16.743x^{2.3842}$; $R^2 = 0.7318$, where (x) = diameter of individual cut branches of *R. undulata* and y = wet weight of cut branches.

The total estimated weight of the original biomass removed from each of the 48 trees harvested was calculated from the results of the regression equation. The total weights of new growth were obtained from weighing the shoots of each of the 48 harvested trees. The % regrowth was calculated using the following equation:

$$\% \text{ regrowth} = A/B * 100$$

where:

(A) = total wet weight (g) of new shoots regrown for individual trees

(B) = total wet weight (g) of original biomass removed for individual trees

3.2.2 Harvesting impact over time

Three different methods were used to assess the impact of harvesting on *Rhus undulata* over time: (i) Line transect (ii) Aerial photographs (iii) Ground photographs.

3.2.2.1 Line transects

The impact of harvesting over time was assessed by determining the relationship between (i) distance and abundance (ii) distance and size change of *R. undulata* away from the village.

The first 50m line transect measurement was started 1000 m away from the village and continued for 3750 m along a relatively straight line. Two 20m distances were then measured perpendicular to the 50m line on either side. A total of 75 (50m) transects were sampled. Measurements of all tree individuals included abundance, size (height, length, breadth), number of dead stems, number of alive stems and number of broken stems. Trees occurring on old croplands and in rivers were not sampled. The size of the trees was measured using a meter stick. A total of 325 individuals were measured along the 3750 m transect. The area measured was chosen because wood collectors frequented it.

3.2.2.2 Aerial photographs

Two aerial photographs, taken in 1960 and 1997 respectively (see Appendix 3), were used to compare the impact of harvesting on *R. undulata* trees away from the village over time. Ten matched plots, five on each of the two aerial photographs, were mapped and data recorded. The areas of the five plots on the 1960 aerial photograph and the five matched plots of the 1997 aerial photograph were each equivalent to 4.5 ha. The matched plots were placed randomly in different directions and at different distances from the village. The numbers *of R. undulata* trees were counted in each matched plot to establish if there was any change in abundance over time.

3.2.2.3 Matched ground photos

Two black & white pictures photographed in 1937 and 1997 respectively, were used to compare the size (m) differences of individual *R. undulata* trees. The 1937 ground photo was taken by Mr. Andrews from the Paulshoek village, while Dr. Rick Rohde took the matched photo in 1997. Ten trees present in both matched photos were numbered. In order to assess the harvesting impact on *R. undulata* over time, size measurements (individual heights & widths) were recorded on the photographs. Measurement units were standardised against the size measurements of a rock present in both photos. The cover of individual trees was determined by calculating the circumference (Beyer 1976) of the numbered trees as follows:

$$C = 2\sqrt{\frac{a2 + b2}{2}}$$

where, a = height or width of tree
b = height or width of tree

3.2.2.4 Radiocarbon dating of *R. undulata* trees

Samples of *R. undulata* stump material were carbon dated at the CSIR laboratory in Pretoria. Samples of stump material from about six *R. undulata* trees were removed and tested to determine the age of the individual trees. A standard carbon dating method was used to date the material. Results are included in Appendix 2. The species name of *R. burchelli* appears on the report while herbaruim identification confirmed the species to be *R. undulata.*

3.2.3 Sustainable harvesting

Sustainable harvesting is ensured when the amount of fuelwood consumed annually by households in Paulshoek is less than the annual harvestable fuelwood yield. Information regarding the amount of fuelwood consumed by households in Paulshoek was taken from chapter two. The calculations only included *R. undulata* and not shrubs. Amount consumed was calculated as the amount (t) of *R. undulata* used per household per year multiplied by the number of households. Harvestable fuelwood yield was identified as a combination of standing crop and annual contribution of live mass to the dead wood pool. Approximately 16 000 ha in Paulshoek is covered by *R. undulata.*

Standing crop was calculated as follows:

$$S = T \times D \times W$$

where, T = total no. of trees in the area
D = mean no. of dead stems
W = mean weight of dead branches

Annual contribution of live mass to the "dead wood" pool was calculated as the percentage of live mass that becomes dead. Live mass was calculated as follows:

$$LM = T \times L \times W$$

where, LM = total amount of living tree material available in the area
T = total no. of trees in the area
L = mean no. of live stems
W = mean weight of live branches

The percentage contribution which live trees make to the dead wood pool could however not be estimated as this information was not available. As a possible solution to this gap in information a range of percentages between (1 and 5) was used (Shackleton 1994). This information was fed into a modelling package called STELLA (Costanza *et al.* 1990, Higgins *et al.* 1997) to predict the most realistic scenario for sustainable harvestable fuelwood yield in Paulshoek.

3.2.4 Statistical analysis

A paired Wilcoxon signed-rank test was used to test for significant differences between the total number of shoots on the protected and unprotected areas. Significant differences of harvesting treatments for (a) mean diameters of new shoots; (b) mean lengths of new shoots (c) % regrowth of original biomass were compared using a Kruskal-Wallis one way analysis of variance with Dunn's multiple comparisons, which tested for individual treatment differences. Differences between mean number of shoots with different treatments were compared using an analysis of variance with Tukey's multiple comparisons of slopes. Linear regression equations were used to identify significant relationships between distance and (a) abundance (b) volume of trees. A paired Wilcoxon signed-rank test was used to test for significant differences in the number of *R. undulata* trees occurring in matched plots on the two aerial photographs. The paired Wilcoxon signed-rank test was also used to test if, on the two matched ground photos, *R. undulata* showed any significant differences in size of individual trees.

3.3 Results & Discussion

3.3.1: Harvesting experiment

The different intensities of harvesting used in the experiments did not kill any *R. undulata* individuals. Treatment effects on the various variables measured are given in Table 3.2. Regrowth appeared highest for individuals where 100% above ground biomass was cut. Trees treated with 100% harvesting had the highest total number of new shoots, while 25% harvesting produced fewer new shoots. Trees not harvested (controls) had very little shoot regrowth compared to harvested trees. The total number of new shoots was significantly higher in the protected area than in the unprotected area ($N = 10$; $Z = 1.89$; $df = 4$; $p = 0.05$). The mean diameter of shoots in the protected area showed significant differences between the different harvesting treatments ($N = 2735$; $Z = 114.94$; $df = 4$; $p < 0.05$). Similarly significant differences were also found between mean diameters of shoots in the unprotected area under different cutting treatments ($N = 1821$; $Z = 90.23$; $df = 4$; $p < 0.05$). Results for the mean lengths of new shoots also indicate significant differences between different harvesting treatments in the protected area ($N = 2735$; $Z = 91.07$; $df = 4$; $p < 0.05$) and unprotected area ($N = 1821$; $Z = 203.09$; $df = 4$; $p < 0.05$) respectively.

The mean wet mass in the protected area was significantly different amongst different harvesting treatments ($N = 2735$; $Z = 16.69$; $df = 4$; $p < 0.05$). No significant differences were found between the mean wet mass of harvesting treatments in the unprotected area ($N = 1821$; $Z = 8.58$; $df = 4$; $p > 0.05$). Similar results were also found for the mean dry mass of different harvesting treatments. The results for the protected area indicated significant differences ($N = 2735$; $Z = 16.62$; $df = 4$; $p < 0.05$), while the unprotected area showed no significant differences ($N = 1821$; $Z = 9.13$; $df = 4$; $p > 0.05$).

Regrowth appeared to be related to intensity of harvesting. The total shoot mass of control treatments was less than for harvested trees. Results showed significant differences in the percentage regrowth of original biomass removed under different harvesting treatments in the protected area (N = 24; Z = 15.35; df = 3; $p < 0.05$) and the unprotected area (N = 22; Z = 5.50; df = 3; $p < 0.05$) respectively. The total regrowth of shoots as a percentage of original biomass removed was highest for the 100% harvested trees. The 25% above ground and 50% above & below ground harvesting treatments had very little regrowth. Results suggest a marked difference in the percentage of biomass regrowth between 50% above ground and 50% above & below ground harvesting. Removing 50% below ground biomass has a disastrous effect on the regrowth potential of the trees. Heavily (100%) harvested trees in the protected area yielded 35.6% and lightly (25%) harvested trees 2.74 % of the original harvest mass. Results suggest a higher percentage of original biomass regrowth for individuals growing in the protected area than individuals in the unprotected area.

Variable growth responses of trees harvested at different intensities have been reported (Aucamp 1972, Ericsson *et al.* 1985, Milton 1988, Chen *et al.* 1998). The results found in this study suggest that the different intensities of harvesting stimulated the growth of shoots. Bassman & Dickmann (1985) and Milton (1988) attribute this to the mobilization of stored carbohydrates that cause compensatory growth. After harvesting, carbohydrate flow decreases to the roots and increases to shoots. The mobilization of stored carbohydrates may also result in compensatory growth (Milton 1988).

Harvesting stimulated *R. undulata* shoot growth. Harvesting also stimulated growth of longer shoots with greater diameters in *Acacia tortilis* (Milton 1983) while it reduced the basal increments in the Scots pine (*Pinus sylvestris* L.) (Ericsson *et al.* 1985). Results of the *R. undulata* study differ, however, in that no clear pattern could be noticed with shoot diameter and shoots length increases or decreases, as variances were large.

Table 3.2: The regrowth results (mean ± std. dev.) of *Rhus undulata* after four different cutting treatments. Growth was monitored every three months for twelve months (Nov'97 to Nov'98) in both a protected area and an unprotected area (i.e. grazed). Six trees of varying sizes were cut for each of the four treatments (N=48), while 6 trees on each side were used as controls. During the course of the study, 5 trees were harvested by inhabitants for firewood and therefore lost to the experiment. Dissimilar superscripts denote significant differences in treatment effects.

	Control Protected N=6	25% above ground only Protected N=5	50% above ground only Protected N=6	100% above ground only Protected N=6	50% above & below ground Protected N=6	Control Unprotected N=6	25% above ground only Unprotected N=5	50% above ground only Unprotected N=5	100% above ground only Unprotected N=5	50% above & below ground Unprotected N=5
Total no. of new shoots	9	223	428	1814	261	2	218	229	1114	258
Mean diameter of shoots (cm)	0.31 ± 0.13^{c}	0.26 ± 0.13^{a}	0.26 ± 0.13^{a}	0.32 ± 0.18^{b}	0.23 ± 0.12^{a}	0.25 ± 0.11^{b}	0.25 ± 0.11^{b}	0.23 ± 0.10^{ab}	0.29 ± 0.15^{b}	0.21 ± 0.10^{a}
Mean length of new growth (cm)	19.00 ± 16.76^{ab}	17.37 ± 18.76^{a}	23.01 ± 23.12^{b}	25.95 ± 24.52^{b}	14.15 ± 13.15^{a}	25.00 ± 8.00^{a}	15.25 ± 14.17^{a}	9.07 ± 7.90^{b}	19.02 ± 21.99^{a}	11.38 ± 14.89^{b}
Mean wet mass (g)	8.04 ± 2.93^{a}	18.21 ± 17.25^{a}	147.14 ± 181.13^{ab}	664.58 ± 722.31^{b}	19.95 ± 26.94^{a}	1.38 ± 0.51^{a}	22.78 ± 20.22^{a}	10.05 ± 4.98^{a}	256.46 ± 289.01^{a}	20.34 ± 14.58^{a}
Mean dry mass (g)	7.75 ± 4.04^{ab}	11.42 ± 9.38^{ab}	106.77 ± 101.07^{ab}	410.50 ± 453.69^{b}	12.47 ± 16.10^{a}	0.90 ± 0.30^{a}	13.02 ± 11.41^{a}	5.64 ± 2.53^{a}	151.94 ± 168.62^{a}	12.90 ± 8.81^{a}
Total wet mass (g)	16.07 ± 4.87	91.05 ± 34.38	882.81 ± 331.85	3987.49 ± 1448.84	119.68 ± 46.34	2.75 ± 0.94	113.90 ± 42.34	50.26 ± 17.15	1282.34 ± 508.85	101.72 ± 36.28
Total dry mass (g)	15.50 ± 6.04	57.10 ± 20.87	640.61 ± 225.67	2463.01 ± 898.70	74.80 ± 28.54	1.80 ± 0.60	65.10 ± 24.13	28.20 ± 9.55	759.70 ± 299.99	64.50 ± 22.83
Total regrowth as % of original biomass removed	—	2.74 ± 1.47^{a}	17.87 ± 12.76^{ab}	35.60 ± 10.34^{b}	3.99 ± 5.59^{a}	—	5.34 ± 4.24^{a}	7.59 ± 9.94^{a}	17.51 ± 12.80^{a}	2.54 ± 1.17^{a}

The shoots indicate a steady regrowth response over the 12 month period related to intensity of harvesting and growth (Figure 3.2a) & (Figure 3.2b). Regrowth was greater in the protected area than the unprotected area. The results from a heterogeneity regression test indicate significant differences between the number of shoots within the different treatments in the protected area ($F_{(4,15)} = 105.28$; $p < 0.001$) and in the unprotected area ($F_{(4,15)} = 68.88$; $p < 0.001$).

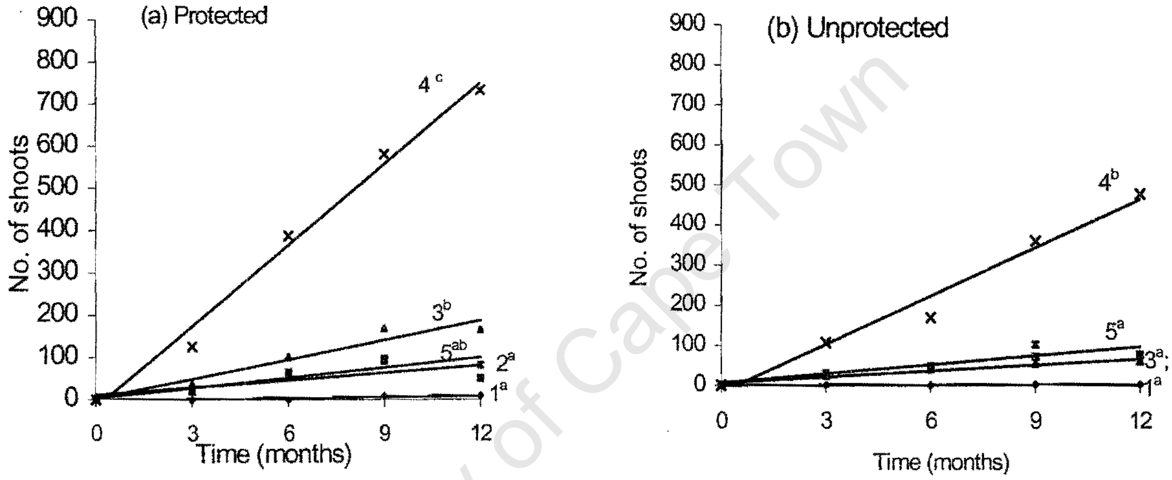


Figure 3.2: The total number of *Rhus undulata* shoots that were produced over 12 months after four different cutting treatments (a) protected and (b) unprotected areas. Growth was monitored over every three months for twelve months (Nov'97 to Nov'98). Cutting treatments were done on 24 trees of varying sizes, while 6 trees were used as controls. Treatments are represented as (1) – control; (2) – 25% cut; (3) - 50% cut; (4) – 100% cut; (5) – 50% + stump. Treatments with the same superscript were not significantly different.

Various studies suggest that continuous browsing reduces shoot production (Du Toit 1972, Aucamp *et al.* 1984, Milton 1988, Chen *et al.* 1998). Heavy browsing during the early growing season may also disrupt the productive ability of the trees more than during other growth cycles (Milton 1983). Similarly to *Acacia* species the regrowth of *R. undulata* was tolerant of most disturbances. Even though reduced growth in the unprotected area was recorded, *R. undulata* nevertheless survived. The production of new leaves on old nodes could contribute to the resilience of *R. undulata* (Milton 1988). The tampering with below ground materials seemed however, to have a disastrous effect on growth (see also Table 3.2). The removal of the stump robs the tree of valuable stored nutrients and structural material necessary for growth and survival. Although the trees with removed stumps did not die, field observations suggest that they are in danger of doing so. Unsustainable utilization will reduce or inhibit the regenerative ability of the trees.

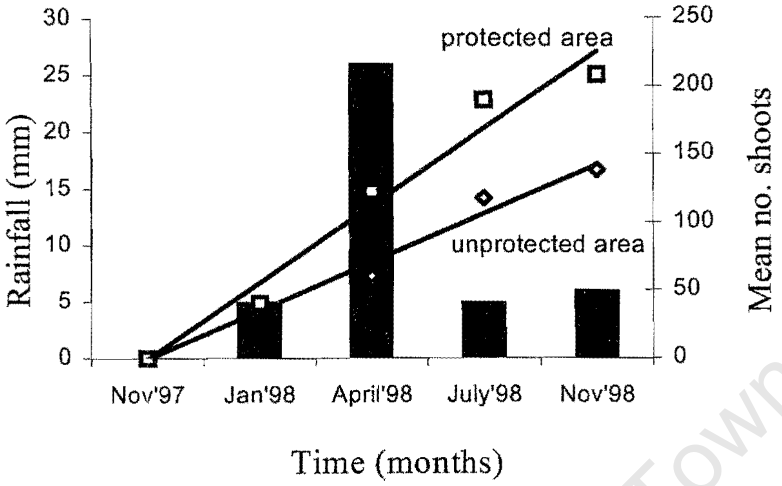


Figure 3.3: The relationship between annual rainfall (mm) in (bars) for 1998 in Paulshoek and mean no of shoots measured every three months for 12 months (Nov'97 to Nov'98). Results from both the protected and unprotected sampling area are included.

The general regrowth pattern is summarised in (Figure 3.3). The results suggest that regrowth was uncoupled from rainfall and season. Regrowth of shoots was higher in the protected area than in unprotected area.

The rainfall had no measurable effect on the number of shoot produced over 12 months. Shoots of *R. undulata* grew irrespective of the drought experienced during November 1997 to November 1998. The growth of *R. undulata* shoots are not necessarily influenced by rainfall, but by other factors i.e. topography and grazing. *R. undulata* trees are found growing in rocky, mountainous areas and very rarely on flat areas. The presence of deep rooting systems ensures the absorption of water from deep lying ground water sources. Droughts may therefore not be the main factor endangering the survival of *R. undulata,* even though Teague (1983) found that water stress inhibited growth of *Acacia karoo* trees. The results found in this study contrasts with results found by (Rutherford & Panagos 1982, Milton 1988) who found that shoot production in broadleaved trees was related to the previous season's rainfall. Milton (1988) obtained a positive correlation between rainfall, shoot production and growth. This present study did however not find any relationship between rainfall and growth of shoots over a one year period.

R. undulata trees seem to be adapted to the semi-arid conditions of the area. The total number of shoots increased irrespective of seasonal changes. The shoot growth initiation of *Ochna pulchra* & *Burkea africana* however, corresponded to high temperatures (Rutherford & Panagos 1982). It is, however, not clear whether high environmental temperatures during the harvesting period (November 1997) also contributed to the initiation of shoot growth. What is clearer though, is that the seasonal temperature changes did not have a measurable effect on the continuous growth of the shoots. The continuous growth of shoots could be as a result of the mobilization of stored carbohydrate reserves (Rutherford & Panagos 1982, Milton 1988) provided by the large below ground stump. Rutherford & Panagos (1982) also mention the importance of the below ground material in contributing to the production of shoots.

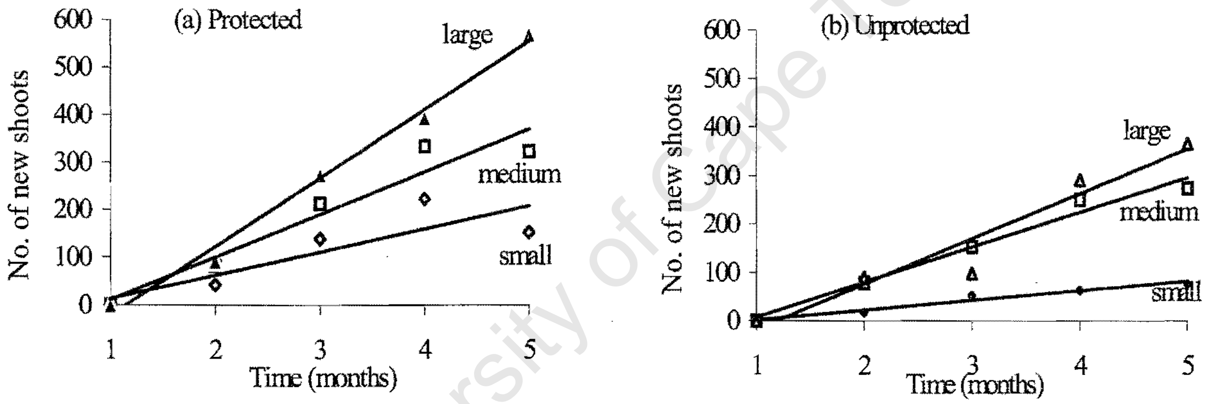


Figure 3.4: The total number of *Rhus undulata* shoots that grew after four different cutting treatments of trees in varying size classes in (a) protected and (b) unprotected areas. The size classes are small (0.5-1 m); medium (1-1.8 m); large (> 1.8 m). Growth was monitored every three months for a period of twelve months (Nov'97 to Nov'98). Cutting treatments were done on 24 trees of varying sizes, while 6 trees were used as controls.

Larger sized trees produced more new shoots than medium and smaller harvested trees (Figure 3.4a) & (Figure 3.4b). Regrowth was greater in the protected area (Figure 3.4a) than the unprotected area (Figure 3.4b). The number of new shoots from large *R. undulata* trees in the protected area were more than the number of shoots produced in the unprotected area. Both medium and small sized trees in the protected area had more new shoot growth than the trees in the unprotected area.

The number of shoots corresponded directly to the increase in size of *R. undulata* trees. The ability of larger trees to produce more shoots may be as a result of larger and more effective morphological growth structures (e.g. well developed rooting systems) (Mohammed *et al.*

1998). As found in *Burkea africana* (Rutherford & Panagos 1982), larger *R. undulata* trees are also able to control the loss and lack of water more efficiently than medium and smaller sized trees. Larger *R. undulata* have larger below-ground material (stump) with presumably deep rooting systems compared to the smaller sized trees. The below-ground material provides sufficient ground water and stored food, which in turn the tree can depend on, for growth purposes. Smaller trees however, have less effective root systems and less below-ground material that provides limited ground water and stored nutrients. Younger trees usually channel more energy into producing a more efficient root system before investing a lot of energy into shoot production (Rutherford & Panagos 1982).

3.3.2 Line transect

Results indicate no significant relationship between distance (m) away from the village and abundance of *R. undulata* (Figure 3.5). Trees are as abundant closer to the village as 4.75 km away from the village.

Abundance was not influenced by human activity but rather by climatic and topographic factors. This does not necessarily mean that villager's use of the trees does not impact on the trees. The trees closer to the village may appear similar in numbers but not necessarily in structure (Figure 3.6). On condition that fuelwood collectors do not remove the stumps of live *R. undulata* trees, it appears as if this fuelwood species will be able to survive and continue growing in the area of Paulshoek.

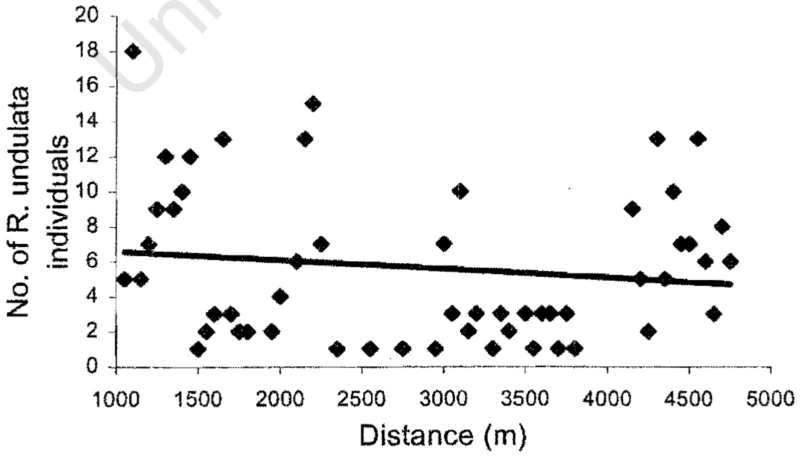


Figure 3.5: The distance (m) and total abundance of measured *Rhus undulata* trees 1 - 3.75 km away from Paulshoek village within a fuelwood collection area. The data are mean results obtained from 75 transects of 50m each in a direction away from the village. The equation for the line is $y = -0.0005x + 7.0735$; $R^2 = 0.0192$; $p > 0.05$.

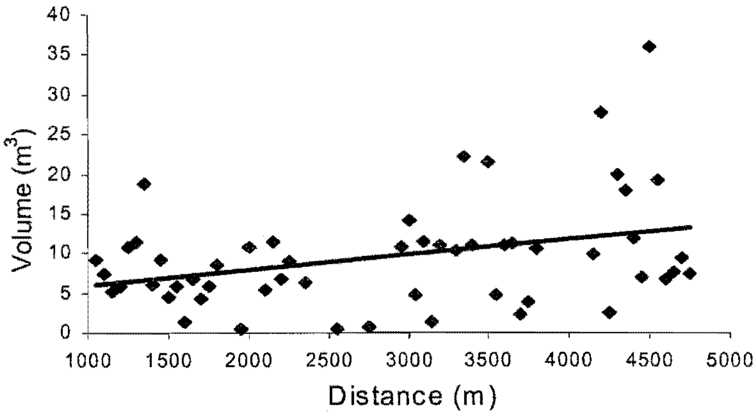


Figure 3.6: The relationship between distance (m) and mean volume (m^3) of measured *Rhus undulata* trees 3.75 km away from Paulshoek village along a fuelwood collection area. The data are mean results obtained from 75 transects of 50m each in a direction away from the village. The equation for the line is $y = 0.002x + 3.9615$; $R^2 = 0.1164$; $p < 0.05$.

The results indicate a weak but significant relationship between distance (m) away from the village and the mean volume (m^3) of *R. undulata* trees (Figure 3.6). The mean volume (m^3) of *R. undulata* trees increase with an increase in distance.

The *R. undulata* trees closer to the village are smaller than the trees further away from the village. This pattern is however not uncommon or unexpected. Villagers preferred to utilize the available fuelwood closest to the village first before they would walk far distances to collect fuelwood. The removal of branches and other structural material has thus had an impact on the growth and structure of the trees. The smaller tree sizes closer to the village and larger trees further away describes a utilization pattern followed in many other rural areas (Shackleton 1983b). The relationship between distance and volume and abundance (Figure 3.5) are good indicators of use impact, as it confirms *R. undulata's* resilience and strong survival ability under intense harvesting. One could also assume that the larger trees normally have more branches on them that can be utilized for fuelwood. Smaller sized trees are generally the younger generation trees that have not grown to their full potential and reached senescence.

3.3.3 Aerial photography

Results from the matched aerial photograph study showed no significant difference (n = 5 matched pairs; Z = 0.82; P > 0.05) between the mean abundance of *R. undulata* trees in 1960 and mean abundance during 1997 (Table 3.3).

Utilization as a result of harvesting and browsing has had no visible impact on the abundance of *R. undulata* individuals away from the village. The evidence from the aerial photos suggests that both long-term and shorter-term responses to fuelwood harvesting are not dynamic. This does not at all imply that if utilization of *R. undulata* were practiced in an exploitative manner that it would have no impact on *R. undulata*. One of the few signs of severe impact on *R. undulata* is noticed in the Paulshoek village itself, where a piosphere of disturbance-related shrubs have established as a result of complete removal of *R. undulata* trees and other preferred vegetation. As an isolated incident one could easily take this as proof of unsustainable utilization of vegetation. However, possible explaination is that land had to be cleared for the building of houses for people in the village.

Table 3.3: The mean (± std. dev.) abundance of *R. undulata* trees identified in matched plots on two aerial photographs taken in 1960 and 1997 respectively. A set of five matched plots in different directions and distances away from the village were identified and compared using the two aerial photographs.

	No. of trees in matched photographs.	
Matched plot number	**1960**	**1997**
1	17	16
2	24	25
3	29	30
4	53	49
5	31	29
Mean	**30.8**	**29.8**
Std. dev.	**12.1**	**10.8**

3.3.4: Matched ground photographs

Results from analysis of matched ground photographs indicate a significant difference in the size of trees visible in the matched photos ($n = 10; Z = 1.94; p = 0.05$) (Figure 3.7).

Irrespective of the heavy utilization pressure exerted on the area, *R. undulata* individuals measured in the ground photographs showed an increase in size during the last 62 years. All individuals except (no. 1) have increased in size since 1937. This result supports the notion that *R. undulata* trees are resilient and are able to tolerate severe utilization pressures. The resilience of *R. undulata* becomes more apparent if one considers the history of the Kleinfontein area. Prior to the 1940's, the Kleinfontein area was occupied by Nama families who settled there. A local school situated a few 100 m from the photo station, further ensured the presence of a large number of local people in the area. A few years later (during the 1940's) however, the people moved to a new location a few km away. Paulshoek as it is known, became the permanent settlement location. The human and livestock pressures in the Kleinfontein area were reduced as a result, although not completely eliminated. Today still sees the presence of at least two stock posts in the area. The difference now compared to the 1930's is that the utilization pressures exerted on the *R. undulata* trees are less. The evidence suggests that traditional fuelwood harvesting practices which discourage the removal of live wood and whole below ground material (stumps) have consciously been adhered to in the region, thus ensuring the continuous growth of *R. undulata* individuals present on the matched photos. The relocation of inhabitants at that time further ensured the survival of *R. undulata* by reducing the potential for unsustainable fuelwood harvesting and providing trees with the time to regenerate.

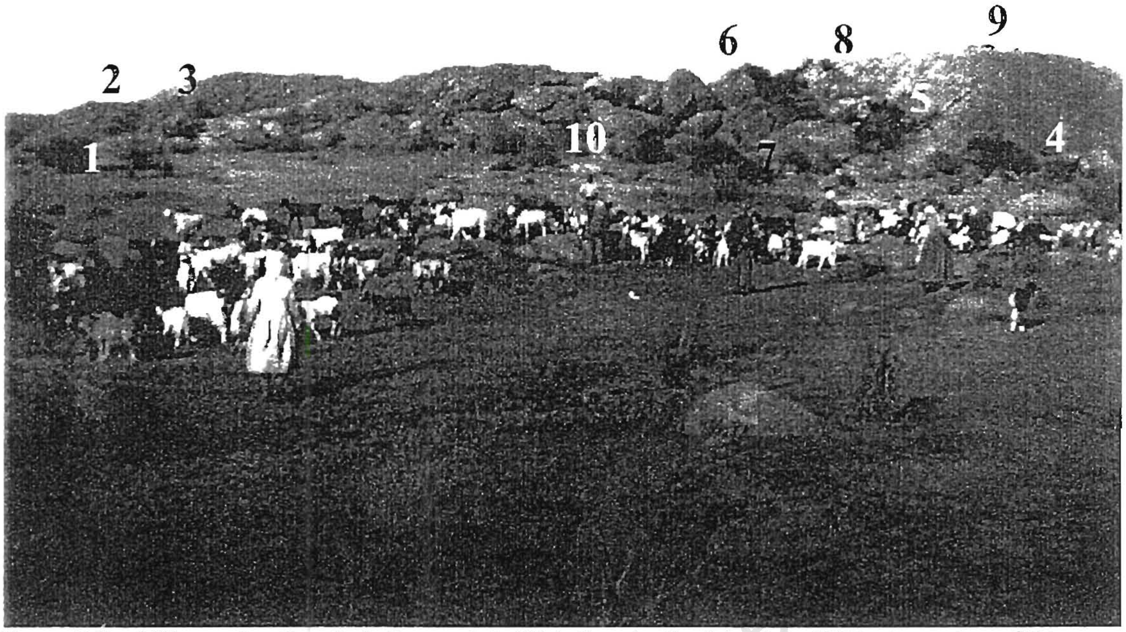


Figure 3.7a: Villagers herding their livestock in Kleinfontein, Paulshoek in 1937. A number of *Rhus undulata* trees are present in the background between the rocks, while the foreground has sparse cover of disturbanc-related shrubs species (e.g. *Galenia africana & Lycium ferocissimum*). (Photo taken by Mr. Andrews)

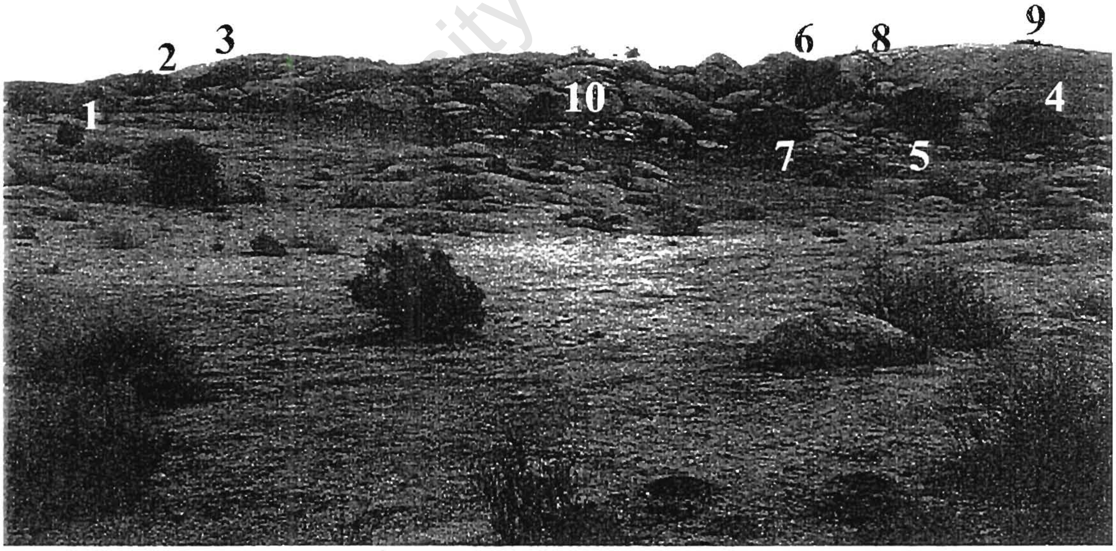


Figure 3.7b: Matched photo of Kleinfontein taken in 1997. Detail indicates a general increase in tree size in the background and vegetation cover on the plains. The size of *R. undulata* appears to have increased, irrespective of the fact that the area is still used as a stockpost location. The presence of the same individuals confirms the resilience of *R. undulata*. The increase in abundance and cover of disturbance-related shrubs (e.g. *Galenia africana & Lycium ferocissimum*) in the foreground, indicate the degree of land degradation in the area. (Matched photo taken by Dr. Rick Rohde).

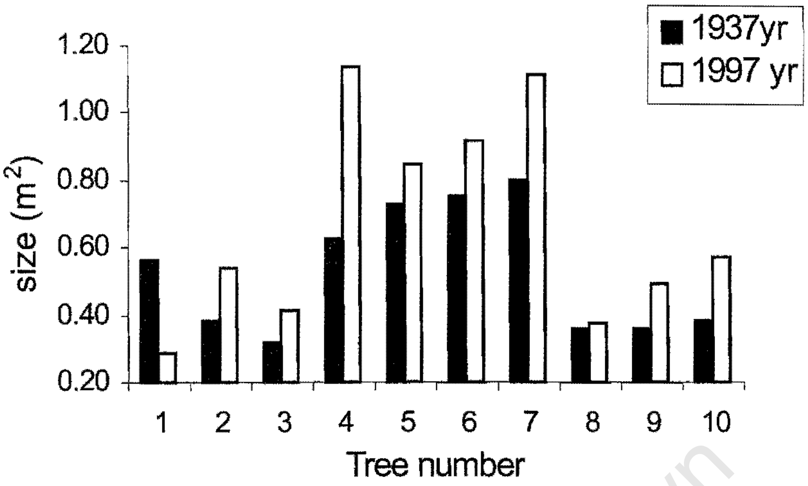


Figure 3.8: The measured size (m^2) differences of ten *Rhus undulata* individuals from two matched photographs taken in Kleinfontein (Paulshoek) 1937 and 1997. The tree numbers used are the same as those in Figure 3.7a and Figure 3.7b.

3.3.5 Radiocarbon dating of *R. undulata*

The radiocarbon dating exercise found the age of trees numbered 4, 5, and 7 to be approximately fifty years old. The stump parts tested were younger than what was expected, considering the harvesting history of the area. This information confirms the resilience and tolerance of *R. undulata*, but also implies that harvesting of parts of the below-ground material (stumps) impacts on growth processes. The trees will take longer to reach senescence, which means that availability of dead tree material for fuelwood purposes is also reduced. This would explain why, even though *R. undulata* were found to be abundant, people still walked far distances to collect fuelwood. *R. undulata* might be abundant, but the trees are young with a lot of green wood and contain very little dead wood.

3.3.6 Sustainability of fuelwood utilisation

The model developed in this study is simplistic and aimed at identifying whether the harvesting of *R. undulata* in Paulshoek is sustainable or not assuming the live mass remains constant. Only a few variables considered most important were used in the modelling process. Variables that were used are shown in Table 3.4. Variables such as rainfall or drought were not considered, as it did not appear to have any noticeable effect on the survival of *R. undulata*.

Population growth rates were also not tested in this model. The contribution of dead wood to the standing crop was calculated based on the number of live trees and percentage contribution of live wood to the dead wood pool. Various simulations were run with different percentages added to the dead wood pool. The simulations were run for 100 years at the present consumption rate.

Model simulation process

The diagram (Figure 3.9) indicates a stock of standing fuelwood influenced by an inflow of dead wood and an outflow resulting from household consumption. Dead wood is produced as the stock of standing fuelwood dies. The auxillary variables which represents the population of live trees multiplied by the percentage of trees which die annually, results in available dead wood. The rate of dead wood production (tree mortality) changes as the percentage of tree deaths is adjusted in the model. The percentage of trees that die are tested at 4%, 4.4% and 5% levels. Random testing of low dead wood production rates ranging from 1% to 10% was selected as production of dead wood appeared to be relatively slow in this area. After testing various percentage values, the results obtained from the 4.4% mortality rate indicated the most realistic production pattern. The 4% and 5% mortality rates provided evidence of more unrealistic dead wood production patterns for the Paulshoek area. Any value higher or lower than the 4.4% displayed an unrealistic dead wood production pattern. All the other variable (live trees, standing crop and household consumption) totals are kept constant during the simulation. The outflow of dead wood through household consumption suggests a draining process of available standing crop.

The sustainability of fuelwood utilization differed for the various fuelwood production percentages (Figure 3.10). Simulated availability of fuelwood decreased dramatically at a 4% production rate and the fuelwood was depleted within about 15 years. Production for harvestable fuelwood yields at 5% indicated a linear increase in fuelwood availability. An intermediate value of 4.4% showed a steady decrease of available fuelwood over the 100 year time span. At this rate of consumption it appears that the present amount of available fuelwood will be halved within about 100 years. If consumption rate increases were to be considered the available fuelwood would probably be denuded within the next 25-50 years.

Table 3.4: Results of available *R. undulata* fuelwood in Paulshoek and the demand of this fuelwood by households per year. The demand considered a total of 150 households. This information was used in running the model.

Available *R. undulata*	**Total**
Area (ha) of land covered	16 000
Standing crop (of dead wood) (t)	181.4
Live trees (t)	3668.5
Amount (t) consumed by 150 hh.	162.3
Percentage die	4.4%
Tree mortality (live trees * percentage die)	3668.5*4.4%

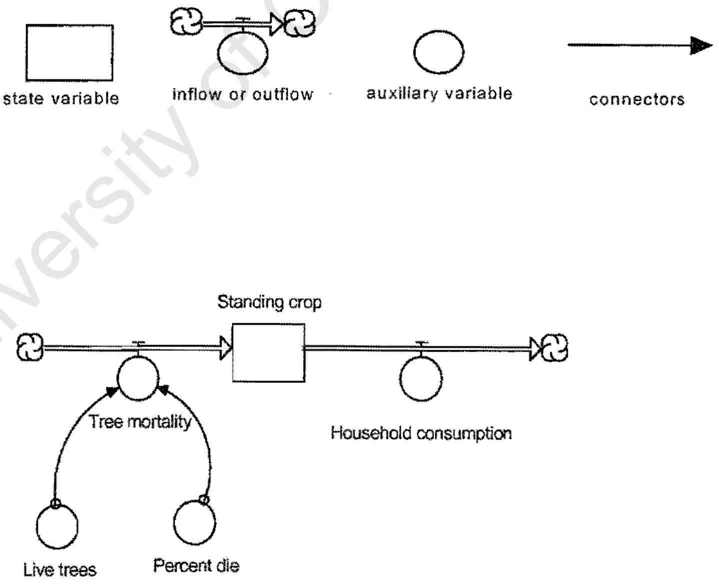
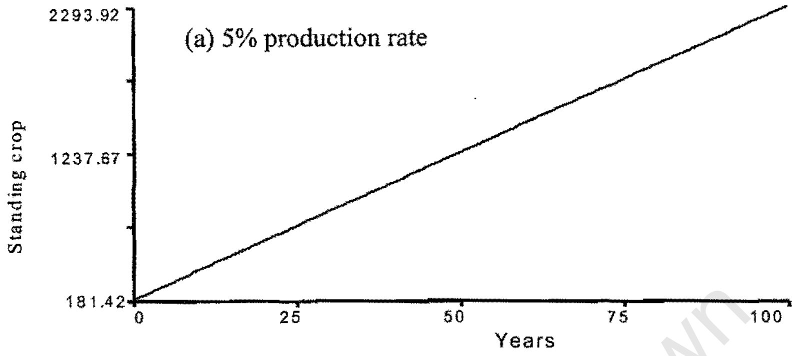
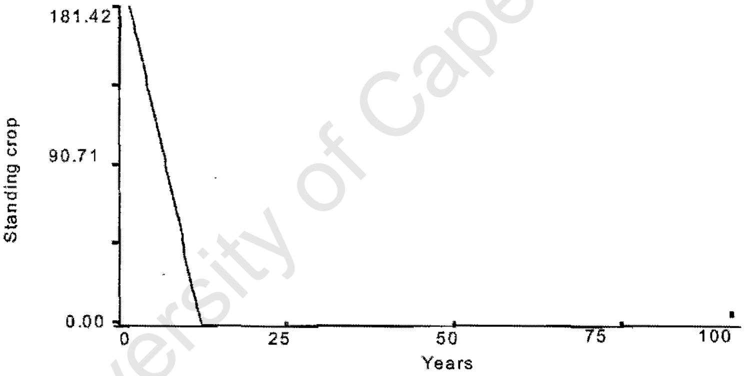


Figure 3.9: Diagram indicating Stella model structure for simulating harvesting impacts on *Rhus undulata* trees in Paulshoek. The building blocks of the model used, serve the following functions: State variables or Stock act as resources which produce flows, flows regulate activities, auxillary variable (converters) convert inputs into outputs and connectors links flow regulators.


(a) 5% production rate

(b) 4% production rate



(c) 4.4% production rate

Figure 3.10: The sustainability of fuelwood utilization in Paulshoek at various percentages of dead wood production which contribute to the harvestable fuelwood yield. The simulations were run at 4%, 4.4% and 5% annual dead wood increases. A production increase of 4.4% is most realistic.

It is evident that only at high dead wood production percentages that the sustainability of fuelwood in Paulshoek can be assured. It appears however, from previous information (chapter 2 & 3) that *R. undulata* trees don't die easily or quickly produce dead wood. Even though my data shows that the abundance of *R. undulata* has not changed over 30 years (Table 3.3), yet people have to walk far distances to collect available dead wood. Availability of fuelwood is therefore not increasing but decreasing in Paulshoek and therefore a 5% dead wood production rate is unrealistic for this area. The 4% and 4.4% dead wood production rates both indicate that the availability of fuelwood will decrease over different time periods. Any scenario with percentage values of dead wood production higher than 4.4% is unrealistic and anything less than 4.4% means that the fuelwood will be depleted within the next 15 years. It could therefore be said that the current fuelwood harvesting in Paulshoek is unsustainable.

3.4 Conclusions

The information obtained within this study appears to contradict the perceived stereotypical idea that harvesting of *R. undulata* for fuelwood causes irreversible environmental degradation. Expectations were that most areas would be denuded of tree cover as a result of over-utilization and over grazing. On the contrary, this is opposite to the results found in this research.

This study has found *R. undulata* to be remarkably tolerant and resilient to intensive harvesting treatments. Regrowth appeared to be stimulated by the intensity of harvesting. A negative impact on regrowth seemed rather to be as a result of harvesting of specific plant parts and the type of harvesting. *R. undulata* appears to rely on below ground material for re-growth and removal of these structures has disastrous implications. Unfortunately this is also the tree material highly preferred by wood collectors. This notion was confirmed when wood collectors removed stumps from the experimental sites. The continuous browsing by livestock also had a negative impact on the growth of shoots. Fortunately though, browsing only reduced the growth of shoots rather than the survival of whole plants. Contrary to other studies, the growth of shoots was also not coupled to seasonal rainfall. Evidence that seasonal climatic factors play a role in the growth of the tree was not concluded.

Historical information gained from the line transects matched photos and aerial photographs further confirm the resilience and strong survival ability of *R. undulata*. In fact, harvesting of

R. undulata by local villagers over the last ± 60 years has not reduced the number of individuals in the region although under heavy harvesting pressure, individual trees may be smaller. They may also have less dead wood available on the trees. This may explain why people perceive available fuelwood to have declined over time.

Based on the evidence, the survival of live *R. undulata* in the environment appears not to be threatened. *R. undulata* has evolved amazing resilient characteristics, which contribute to its survival.

Increase in human population numbers and unemployment may have an increasingly negative impact on the sustainable utilization of *R. undulata.* This study would thus strongly discourage the removal of below ground material (e.g. stumps) unless the tree is dead. The removal of live wood should also be discouraged as far as possible. Grazing impacts by livestock should also be controlled, as it reduces shoot regrowth. An obvious conclusion that can be drawn from this study is that sustainable utilization of *R. undulata* needs to be maintained. A long-term monitoring programme of *R. undulata* growth responses to environmental and human influences is required to ascertain how long a tree would take to grow to fuelwood harvesting potential. Very little is still known about the aging process of the trees. The study does indicate that *R. undulata* resilience in recovery and regeneration in response to heavy utilization is a defining characteristic of this environment.

Even though the abundance of *R. undulata* might not have changed, the availability of dead wood has changed. The modelled results support the villager's perception that fuelwood is less available in Paulshoek. The model suggests that fuelwood harvesting at present consumption levels is unsustainable and will be depleted within the next few years. Even at a 4.4% dead wood production rate (most realistic value) the available fuelwood will still decrease.

CHAPTER 4

THE IMPACT OF THE REMOVAL OF DEAD PLANTS ON THE SURVIVAL AND RECRUITMENT OF SEEDLINGS

4.1 Introduction

Fuelwood utilisation in Namaqualand includes the use of trees and any woody shrubs available. Human activities and the harsh arid climatic conditions limit the availability of woody plants in Namaqualand. Most of Namaqualand receives very low, unpredictable rainfall (Mander & Quinn 1995), which as in other desert areas, results in low plant biomass and productivity (Noy-Meir 1985). The frequent droughts experienced in this region contribute to killing established plants and seedlings, thus adding to vegetation changes (Milton & Hoffman 1994). Mander & Quinn (1995) suggest that 50% of the Namaqualand landcover is dominated by desert shrubland. Investigations in Paulshoek indicate that most shrub cover is dominated by an unpalatable collection of shrubs (Allsopp 1999, Todd 1997), which are not highly preferred as fuelwood.

Inhabitants distinguish between most preferred and less preferred fuelwood species based on the energy release quality (Archer 1994). Dead shrubs (skeletons) of the most preferred species are used for cooking & heating while skeletons of less preferred species are used for baking and kindling (see chapter 2). The stumps, branches and roots of a range of leaf succulent Mesembryanthemaceae (e.g. *Ruschia robusta*, *Leipoltdia schulzei*), asteraceous woody shrubs (e.g. *Eriocephalus microcephalus*) and Aizoaceae shrubs (e.g. *Galenia africana*) are utilised as fuelwood.

Two species, *G. africana* and *R. robusta* are highlighted in this chapter, because they are heavily utilised in the village. *Galenia africana* is a weak fuelwood and toxic to livestock. It establishes on degraded veld and its presence indicates high levels of land degradation (Todd & Hoffman 1999). The inhabitants, if given a choice, would not utilise *G. africana*. However, because of its high abundance and a lack of other preferred fuelwood, people are forced to use it. *Galenia africana* shrubs generally alter the immediate soil nutrient status (Allsopp 1999), thus favouring its own seedling recruitment and survival, especially in heavily grazed farming areas (Todd & Hoffman 1999). *Ruschia robusta,* on the other hand, which is palatable and also a highly preferred fuelwood shrub, forms coals that burn for extended periods. Inhabitants utilise *R. robusta* shrubs heavily as it is more readily available in some areas than, for example, *Rhus undulata*.

Over-utilisation of palatable shrubs by grazing animals has resulted in vegetation changes, which promote the growth of unpalatable shrubs in the environment (Noy-Meir 1985, Milton & Hoffman 1994, Todd & Hoffman 1999). These changes are caused by factors such as selective herbivory, trampling, disturbances, microhabitat availability, competition and drought (Milton & Hoffman 1994, Watson *et al.* 1997). A drought in an area of Western Australia resulted in increased mortality rates and decreased heights of *Eremophila maitlandii* and *E. forrestii* samplings in especially the grazed area (Watson *et al.* 1997). Fuelwood utilisation places additional pressure on the vegetation by reducing litter availability, which contributes to soil nutrients and soil moisture necessary for seedling survival. The removal of shrubs also exposes the soil to wind and rain thus contributing to erosion. Although Milton (1994) suggested that seedling survival is increased by the loss of established plants and availability of disturbed microsites, many other studies have found that shrubs are important in seedling recruitment and survival processes (Du Toit 1972, Cody 1993, Higgins *et al.* 1989).

Cody (1993) found that stem succulents in the Sonoran desert are late successional and recruited in shaded microsites of shrubs and trees. The grazing (Du Toit 1972, Ericsson *et al.* 1985) and removal of shrubs would, thus expose the woody vegetation to trampling, repeated grazing of seedlings, breaking off and uprooting of plants. Leaf succulents in the Karoo that are colonisers of open spaces would also be affected by these disturbances.

A combination of heavy grazing and fuelwood utilisation of the same limited number of species is likely to result in negative influences on the recruitment and survival of seedlings. This will have a direct impact on the ecological state of the area. Previous work in Namaqualand has not investigated the effects of shrub skeleton removal on vegetation structure and the impact it has on seedling recruitment and survival, under different grazing conditions as in Paulshoek, Namaqualand. The main objectives of this study have been divided into two sections;

i) Seedling recruitment within plots

a) to determine where seedlings recruit within the vegetation in relation to the abundance of live and dead adult shrubs.

ii) Skeleton removal experiment

a) to determine the effect of removing shrub skeletons on the growth and mortality of seedlings.

4.2 Methods

4.2.1 Seedling recruitment within plots

To determine the vegetation composition of the area, 12, 2 x 10 m^2 plots were randomly selected in commercial farming areas and 12, 2 x 10 m^2 plots in communal farming areas. A fence separated the two areas (Figure 4.1). The plots were placed at different distances away from the fence to ensure data collection from a variety of areas within the same vegetation area. Each 2 x 10 m^2 plot was divided into 2 x 2 m^2 subplots, for easy recording of variables.

The vegetation composition within the plots was identified by recording the following variables: a) the species composition within the plots, b) abundance of adult shrubs, c) distribution of seedlings in relation to the different microhabitats: live shrubs, dead shrubs and open areas. Seedling species were also placed into categories based on three growth forms: leaf succulents, palatable species and less palatable & poisonous species. Seedlings were defined as plants with a height of less than 10 cm. The presence of litter and animal droppings was also observed to provide the researcher with some idea of grazing intensity.

4.2.2 Shrub skeleton removal experiment

The purpose of the removal experiment was to assess the survival and growth of seedlings under exposed and protected conditions. A total of 86 dead shrubs (hereafter referred to as shrub skeletons) that had seedlings under them were removed. Fifty-two shrub skeletons were removed from the commercial area and thirty-four from the communal area. The removal process was identical to the method used by local fuelwood collectors. Shrub skeletons were randomly selected from commercial and communal farming areas. For each of the shrub skeletons that were removed, a control (intact) shrub skeleton with seedling(s) (Figure 4.2)

Figure 4.1: A fenceline contrast between Paulshoek and a neighbouring commercial farm. The left side (a) is the commercial area which has a greater cover of palatable and mesemb species (e.g. *Ruschia robusta*). The right hand side (b) is the communal area with more bare ground and unpalatable plants (e.g. *Galenia africana*).

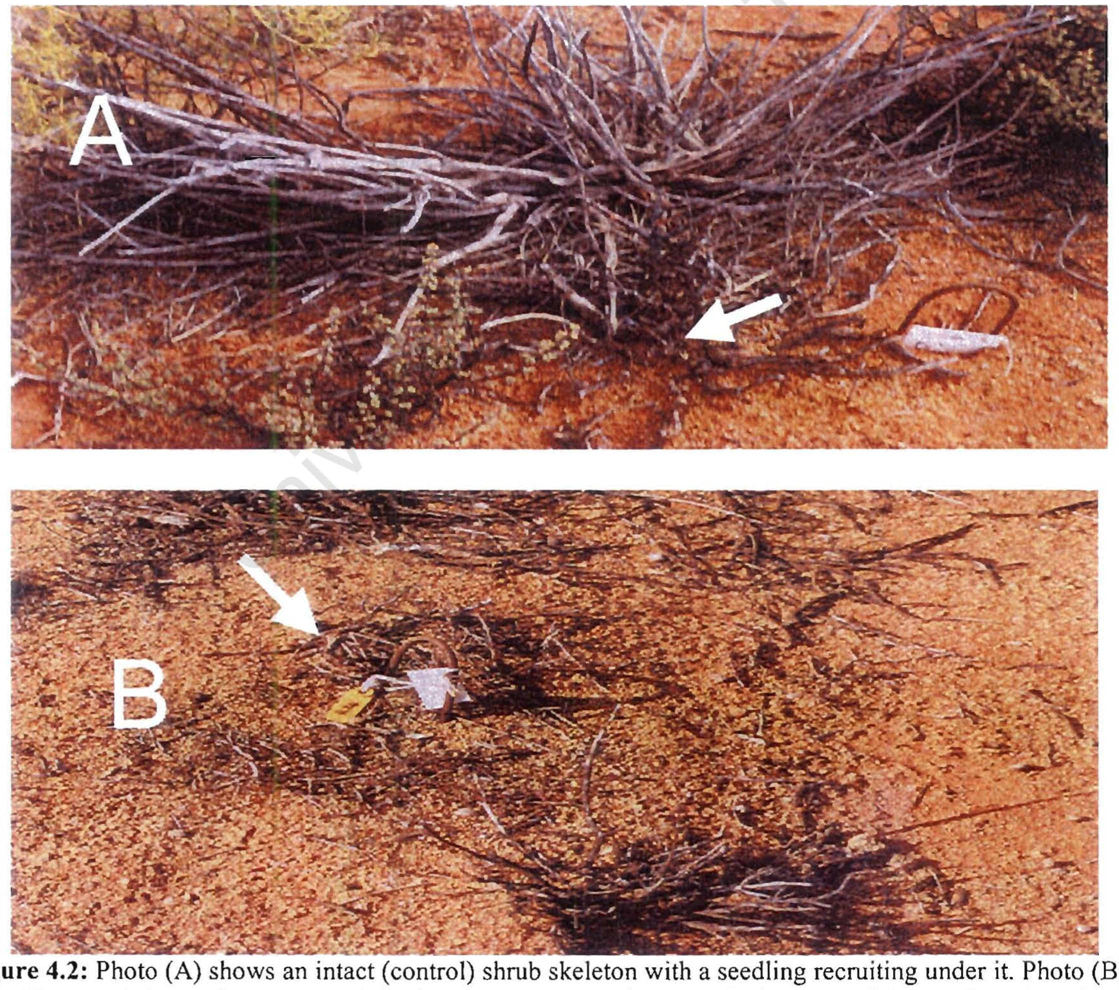


Figure 4.2: Photo (A) shows an intact (control) shrub skeleton with a seedling recruiting under it. Photo (B) shows a seedling surviving under a removed shrub skeleton. Arrows indicate the location of the monitored seedlings.

recruiting under it was left intact. This was done so that survival and growth of seedlings under control shrub skeletons and removed shrub skeletons could be monitored and compared. The initial height of the seedlings was recorded in November 1997 and thereafter height measurements (cm) were done every three months (Nov'97 to Nov'98). Height (cm) increments were measured with a ruler from the ground to the tip of the seedling. The intact shrub skeletons and removed skeleton areas were marked with plastic tags and iron rods that were secured in the ground. The tags and iron rods did not obstruct or interfere with the natural growth processes of the seedlings.

4.2.3 Statistical analysis

A Wilcoxon- Paired Signed rank analysis was used to test for significant differences in the abundance of live shrubs and dead shrubs in the commercial and communal area. The same analysis was also used to test for significant differences between microhabitats utilised by recruiting seedlings. A Chi-square analysis tested for significant differences between the seedling growth forms in commercial and communal areas. Significant differences in seedling height increments were compared using a Kruskal-Wallis analysis of variance test with Dunn's multiple range comparisons, which tested for individual differences. Significant differences in seedling mortality rates were tested with an Anova heterogeneity test.

4.3. Results

4.3.1 Seedling recruitment within plots

The mean abundance of adult live shrubs and shrub skeletons present in plots in commercial and communal farming areas are shown in Table 4.1. Results indicated no significant difference between the mean abundance of live shrubs in commercial and communal areas ($n = 24$; $Z = 0.82$; $p > 0.05$) and similarly between mean abundance of shrub skeletons present in commercial and communal areas ($n = 24$; $Z = 0.84$; $p > 0.05$). There were more live shrubs than shrub skeletons in commercial and communal areas (Table 4.1). The commercial area also had a greater collection of palatable species such as *Osteospermum sinuatum, Eriocephalus* *microcephalus* and *Ruschia robusta,* while the communal area had more unpalatable or spiny species like, *Galenia africana and Lycium ferocissimum.*

Table 4.1: The mean abundance of different adult live shrubs and skeleton (dead shrubs) species in 24, 2 x 10 m^2 plots. Twelve plots were situated in the commercial area and 12 plots in the communal farming area. Plots were surveyed during November 1997. Shrubs species occurring only once in all sampled plots were omitted from the results.

	Mean abundance (i.e. No. of individual shrubs in all plots)			
Species	**Live shrubs**		**Shrub skeletons**	
	Commercial	Communal	Commercial	Communal
Cheiridopsis denticulata	3.2 ± 7.0	0.3 ± 0.7	0.1 ± 0.3	0.0 ± 0.0
Chrysocoma ciliata	0.3 ± 0.8	2.7 ± 4.2	1.0 ± 0.3	2.2 ± 4.1
Drosanthemum hispidum	0.2 ± 0.4	0.2 ± 0.4	1.1 ± 2.3	0.0 ± .0.0
Eriocephalus microcephalus	4.4 ± 5.7	1.1 ± 1.5	2.0 ± 3.4	0.2 ± 0.4
Euphorbia decussata	0.6 ± 0.9	0.8 ± 0.9	0.21 ± 0.4	0.4 ± 1.1
Galenia africana	3.6 ± 3.0	7.4 ± 4.1	2.7 ± 3.1	3.8 ± 3.7
Hirpicium alienatum	2.7 ± 3.0	0.3 ± 1.1	0.6 ± 1.1	0.0 ± 0.0
Lampranthus suavissimum	3.4 ± 4.8	0.8 ± 1.7	0.7 ± 1.8	0.3 ± 0.6
Leipoldtia schulzei	1.8 ± 3.3	1.1 ± 1.9	1.1 ± 2.7	0.0 ± 0.0
Lycium ferocissimum	0.1 ± 0.3	1.2 ± 1.9	0.1 ± 0.3	0.3 ± 0.6
Osteospermum sinuatum	1.3 ± 2.9	0.2 ± 0.4	0.1 ± 0.3	0.0 ± 0.0
Pentzia incana	0.3 ± 0.4	1.0 ± 3.3	0.2 ± 0.4	0.2 ± 0.2
Ruschia robusta	12.0 ± 8.6	11.0 ± 7.8	7.25 ± 5.8	4.5 ± 5.3
Mean for all species	**3.23 ± 2.69**	**3.36 ± 2.10**	**2.05 ± 1.76**	**1.60 ± 1.85**

Table 4.2: The total number of seedlings of different species recruiting either under live shrubs, skeletons (dead shrubs) or open areas in 24, 2 X 10 m^2 plots. Twelve plots were located in commercial areas and 12 plots in communal farming areas. Plots were surveyed in November 1997.

	No. of seedlings					
	Live shrubs		**Shrub skeletons**		**Open**	
Species	Commercial	Communal	Commercial	Communal	Commercial	Communal
Anacampseros ustulata	1	1	1	0	0	0
Cheiridopsis denticulata	46	2	19	1	95	0
Chrysocoma ciliata	8	18	24	13	6	14
Drosanthemum hispidum	47	3	14	2	77	2
Eriocephalus microcephalus	15	4	17	2	16	1
Eulythrix croceum	0	1	0	0	0	0
Euphorbia decussata	12	22	2	8	0	2
Euryops dregeanus	0	0	1	0	0	0
Galenia africana	20	48	13	44	11	38
Hermannia cuneifolia	4	0	0	0	0	0
Hirpicium alienatum	46	6	39	4	14	0
Hypertelis salsoloides	27	5	9	1	72	1
Lampranthus suavissimum	39	12	13	5	30	2
Leipoldtia schulzii	11	7	42	3	33	6
Lycium ferocissimum	0	0	0	1	0	0
Osteospermum sinuatum	12	7	3	2	0	0
Pentzia incana	7	28	5	6	1	15
Pharnaceum croceum	2	0	6	0	6	0
Pteronia glauca	0	0	1	0	0	0
Ruschia robusta	58	34	24	20	84	17
Tetragonia fruticosa	1	0	0	0	0	0
Total	356	198	233	112	445	98

There was considerable spatial variation in the utilisation of microhabitats by different seedling species in the commercial and communal grazing areas (Table 4.2). Significantly more seedlings were present in the commercial area than in the communal area under live shrubs ($n = 24$; $Z = 2.17$; $p < 0.05$); under shrub skeletons ($n = 24$; $Z = 2.34$; $p < 0.05$) and in the open ($n = 24$; $Z = 2.03$; $p < 0.05$). There were more palatable shrub seedlings in the commercial area and more unpalatable shrub seedlings in the communal area.

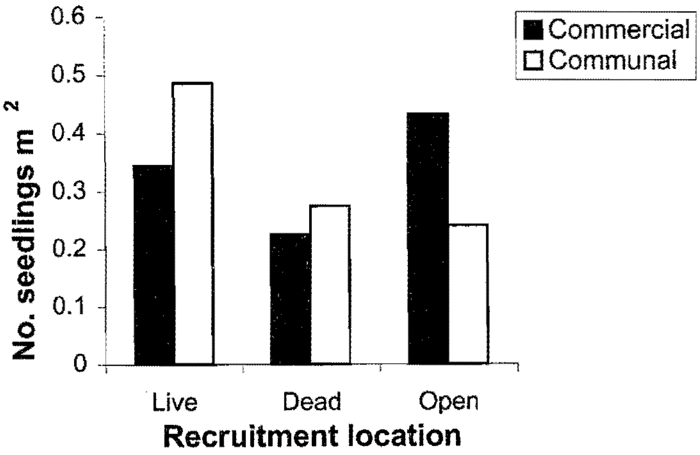


Figure 4.3: The frequency of seedlings recruiting either under live shrubs, skeletons (dead shrubs) or open areas in 24, 2 X 10 m^2 plots. Twelve plots were located in commercial areas and 12 plots in communal farming areas. Plots were surveyed in November 1997.

The frequency of seedling recruitment in different microhabitats varied between commercial and communal farming areas (Figure 4.3). Seedlings recruited more in the open in the commercial area, but recruited under shrubs in the communal area. The frequency of seedling recruitment under live shrubs in the communal area was higher than in the commercial area.

Table 4.3: The total number of seedlings of growth form types recruiting either under live shrubs, skeletons (dead shrubs) or open areas in 24, 2 X 10 m^2 plots. Twelve plots were in commercial areas and 12 plots in communal farming areas. Plots were surveyed in November 1997.

		Commercial area		
Species types		**Live shrubs**	**Skeletons**	**Open**
Leaf succulents	N = 768	288 (37.5%)	121 (15.8%)	359 (46.7%)
Palatable	N = 107	11 (10.3%)	66 (61.7%)	30 (28.0%)
Less palatable & poisonous	N = 95	35 (36.8%)	42 (44.2%)	18 (18.9%)

		Communal area		
Species types		**Live shrubs**	**Skeletons**	**Open**
Leaf succulents	N = 133	63 (47.4%)	42 (31.6%)	28 (21.1%)
Palatable	N = 17	10 (58.8%)	6 (35.3%)	1 (5.9%)
Less palatable & poisonous	N = 224	94 (42.0%)	63 (28.1%)	67 (29.9%)

The distribution of seedling growth forms within different microhabitats was influenced by commercial and communal farming conditions (Table 4.3). Significant differences were found between the recruitment of leaf succulents and palatable species ($n = 875$; $X^2 = 688.99$; $df = 2$; $p < 0.01$), leaf succulents and less palatable & poisonous plants ($n = 863$; $X^2 = 498.81$; $df = 2$; $p < 0.01$), palatable plants and less palatable & poisonous species ($n = 202$; $X^2 = 32.54$; $df = 2$; $p < 0.01$) within three different microhabitats in the commercial area. There were also more leaf succulent seedlings ($n = 768$) than seedlings of palatable species ($n = 107$) and seedlings of less palatable & poisonous species ($n = 95$) in the commercial area. The leaf succulent seedlings utilised the open microhabitat more for recruitment. Less palatable & poisonous species were least abundant in the commercial area. Most palatable (61.7%) and less palatable & poisonous species (44.2%) recruited under skeletons in the commercial area. Results of seedling recruitment in the communal area indicated significant differences between leaf succulents and palatable species ($n = 150$; $X^2 = 55.21$; $df = 2$; $p < 0.01$), palatable plants and less palatable & poisonous plants ($n = 241$; $X^2 = 2.33$; $df = 2$; $p < 0.01$), but no significant difference between succulents and less palatable & poisonous plants ($n = 357$; $X^2 = 4.98$; $df = 2$; $p > 0.05$). Most seedlings in total recruited under live shrubs. Most of the seedlings in the communal area were of less palatable & poisonous species ($n = 224$), while leaf succulents ($n = 133$) and palatable species ($n = 17$) were less abundant. Palatable seedlings recruited more under live shrubs (58.8%) and only (5.9%) recruited in the open. There were more leaf succulent and palatable seedlings in the commercial than in the communal area.

4.3.2 Shrub skeleton removal experiment

There were considerable differences in the heights of seedlings exposed to different microhabitat conditions (Table 4.4). Seedling heights increased during Nov'97 to Jan'98 and decreased thereafter. Growth was greater under control shrub skeletons than in the open space recreated by the removed shrub skeletons. The results showed decreases in seedling height during the 6th month. Large variations in height increments during (July'98 to Nov'98) indicates the different growth responses of plants to disturbance factors.

Table 4.4: The mean height (cm) and (± std. dev.) of different seedlings under intact shrub skeletons (i.e. control) and removed shrub skeletons. Seedling height was recorded every three months for twelve months (Oct'97 – Nov'98). Height measurements of seedlings took place in both commercial and communal farming areas with different grazing conditions. Degrees of freedom and results of a Kruskal-Wallis test (with Dunn's multiple range comparisons) are also given. Results along rows with similar superscripts are not significantly different.

	Commercial		**Communal**		
Time (months)	**Control**	**Removed**	**Control**	**Removed**	**Statistics**
0	5.79 ± 2.73^{ab}	5.51 ± 2.03^{a}	7.08 ± 3.28^{b}	7.05 ± 3.58^{b}	n = 454; K = 14.7; df = 3; $P < 0.05$
3	11.46 ± 7.69^{ab}	10.79 ± 7.53^{ab}	13.48 ± 6.66^{b}	10.93 ± 7.55^{a}	n = 301; K = 9.3; df = 3; $P < 0.05$
6	10.73 ± 9.07^{a}	9.41 ± 8.79^{a}	12.19 ± 7.89^{a}	9.48 ± 7.68^{a}	n = 256, K = 7.6; df = 3; $P = 0.06$
9	10.83 ± 10.26^{ab}	7.93 ± 8.90^{a}	13.2 ± 8.01^{b}	8.23 ± 8.02^{a}	n = 240, K = 24.7; df = 3; $P < 0.001$
12	10.67 ± 11.98^{ab}	8.07 ± 9.99^{a}	11.26 ± 9.20^{b}	7.23 ± 7.43^{a}	n = 206, K = 11.6; df = 3; $P < 0.05$

Table 4.5: The mean growth (cm) and (± std. dev.) of different seedling present under shrub skeletons (i.e. control) and removed shrub skeletons in November 1998. Growth measurements were recorded every three months for twelve months (Oct'97 – Nov'98). The monitoring took place on both commercial and communal areas with different grazing conditions.

	Mean heights of seedlings (cm)				
	Commercial side		**Communal side**		
Species	**Control**	**Removed**	**Control**	**Removed**	**Statistics**
Galenia africana	8.45 ± 5.74^{b}	1.79 ± 3.82^{a}	9.96 ± 10.34^{b}	8.11 ± 7.86^{b}	n = 157; K = 33.7; df = 3; $P < 0.001$
Ruschia robusta	3.72 ± 3.91^{a}	4.71 ± 4.19^{a}	4.23 ± 5.72^{a}	3.33 ± 5.84^{a}	n = 106; K = 4.4; df = 3; $P > 0.05$
All other shrub species	4.21 ± 5.72^{a}	3.12 ± 5.46^{a}	2.60 ± 3.20^{a}	2.58 ± 7.03^{a}	n = 79; K = 2.5; df = 3; $P > 0.05$

Most of the seedling species recruiting under intact/control shrub skeletons grew taller than seedlings under removed shrub skeletons (Table 4.5). *Euphorbia decussata* and woody palatable species (i.e. all other species) seedlings were most sensitive to the exposed conditions under removed shrubs in both commercial and communal areas. All the mixed species seedlings under removed shrubs in the communal area died. *Ruschia robusta* indicated an increase in height under removed shrub skeletons in the commercial area. *Galenia africana* had greater height increases under control shrub skeletons. However, the height of seedlings under shrub skeletons in the communal area was also relatively taller than the other species under similar conditions.

Table 4.6: The percentage mortality of seedlings growing under shrub skeletons (i.e. control) and removed skeletons (dead shrubs). Seedling presence was recorded every three months for twelve months (Oct '97 – Nov '98). Experimental treatments were done in both commercial and communal farming areas with different grazing conditions.

	Control/Intact			**Removed**		
Seedlings	**Alive**	**Dead**	**% Mortality**	**Alive**	**Dead**	**% Mortality**
Cheiridopsis denticulata	0	0	0	2	0	0
Drosanthanum hispidum	0	1	100	0	2	100
Eriocephalus microcephalus	4	3	43	0	1	100
Euphorbia decussata	5	1	20	8	10	56
Euryops dregeanus	0	0	0	1	0	0
Galenia africana	55	17	24	47	38	45
Hirpicium alienatum	5	2	40	1	3	75
Lampranthus suavissimum	1	1	50	3	2	67
Leipoltdia schulzei	2	4	67	0	3	100
Lycium ferocissimum	1	0	0	0	0	0
Osteospermum sinuatum	0	0	0	3	2	67
Pentzia incana	0	0	0	0	2	100
Ruschia robusta	26	12	32	36	23	39
Total number and average %	**99**	**41**	**29%**	**101**	**86**	**46%**

The total percentage mortality was greatest for seedlings under removed shrub skeletons than under control shrub skeletons (Table 4.6). Twenty nine percent of the seedlings recruiting under control shrub skeletons died, while 46% of the seedlings under removed shrub skeletons died. The greatest percentage seedling mortality was within the palatable and leaf succulent species growing under removed shrub skeletons. The percentage seedling mortality of *G. africana* was greatest under removed shrub skeletons (24% and 45%). The percentage seedling mortality of the palatable *R. robusta* was lower (39%) than the percentage seedling mortality of the unpalatable *G. africana* (45%).

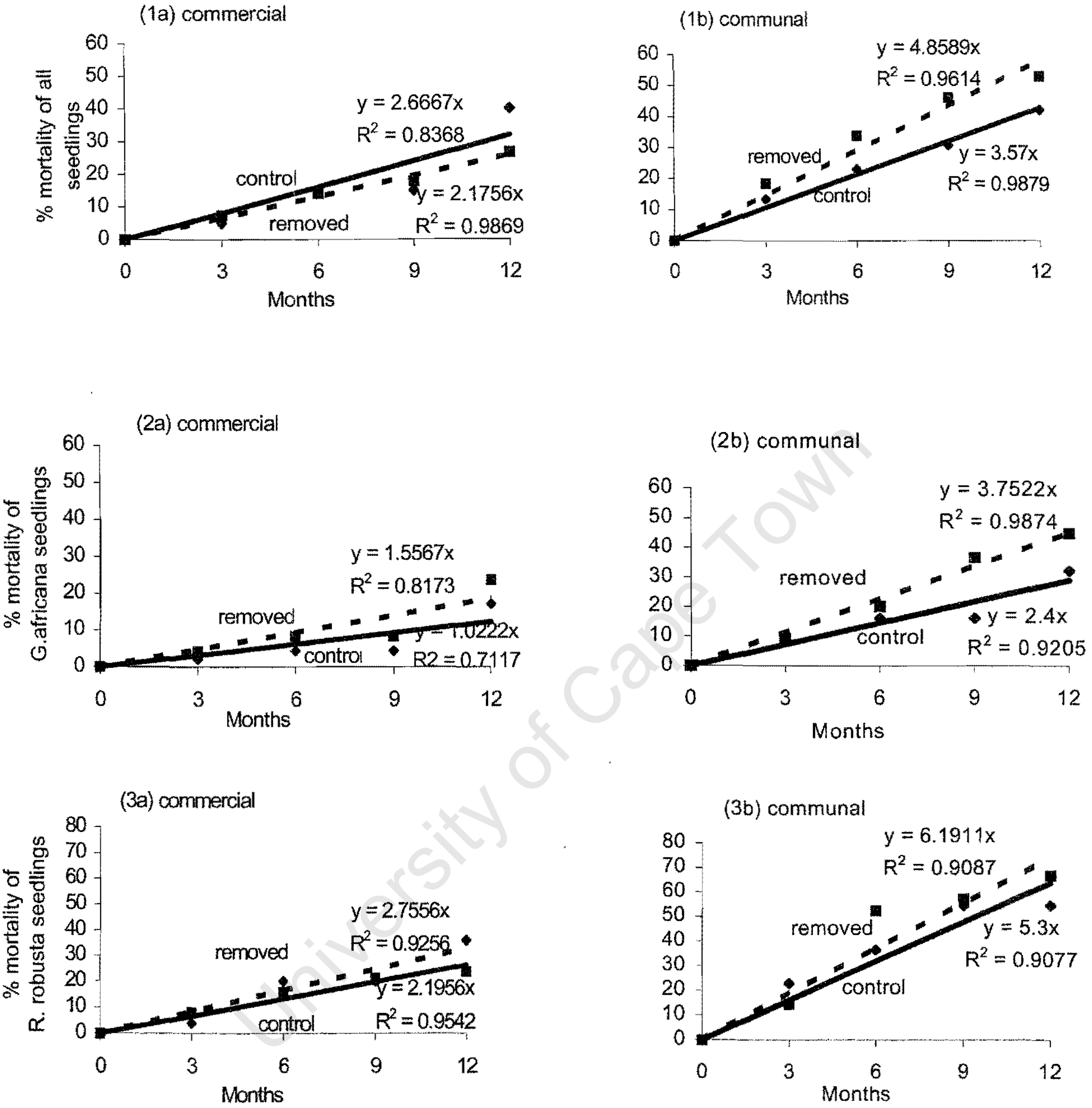


Figure 4.4: The percentage mortality of different seedlings recruiting under control shrub skeletons and removed shrub skeletons. The percentage mortality was recorded every three months for twelve months (Oct'97 to Nov'98). Seedling mortality was monitored on both commercial and communal farming areas with different grazing conditions.

The percentage mortality of seedlings differed significantly between communal and commercial farming areas (Figure 4.4). The percentage mortality of all seedlings recruiting in the commercial area were not significantly different under control and removed shrub skeletons ($n = 10$, $F_{(2,6)} = 0.88$; $p > 0.05$). The opposite result was true for the communal area, where significantly more seedlings died which recruited under removed skeletons than under control shrub skeletons ($n = 10$, $F_{(2,6)} = 11.65$; $p < 0.05$). The percentage mortality of *G. africana* seedlings under control shrub skeletons was not significantly different from seedling mortality under removed shrub skeletons on the commercial area ($n = 10$, $F_{(2,6)} = 1.14$; $p > 0.05$). *G. africana* seedlings showed significantly higher percentage mortalities in the communal area under removed shrub skeletons than under control shrub skeletons ($n = 10$, $F_{(2,6)} = 12.44$; $p < 0.05$). The results indicated no significant difference between the percentage mortality of *R. robusta* seedlings under control shrub skeletons and removed shrub skeletons in the commercial area ($n = 10$, $F_{(2,6)} = 2.15$; $p > 0.05$) and in the communal area ($n = 10$, $F_{(2,6)} = 0.76$; $p > 0.05$).

4.4 Discussion

4.4.1 Seedling recruitment within plots

4.4.1.1 Vegetation composition

Differences in the vegetation of commercial and communal areas are more noticeable in terms of shrub species composition than shrub species abundance. The abundance of unpalatable species like *G. africana* has increased in the heavily grazed communal area. Unpalatable species are said to increase when palatable species endure constant reproductive failure as a result of grazing (Westoby 1980, O'Connor 1991, Dean *et al.* 1995, Milton 1995a, Todd & Hoffman 1999). O'Connor & Pickett (1992) confirm that seed production depends largely on the abundance of the species in the established vegetation. If the shrub population is reduced then the seed bank will also be reduced (Milton & Dean 1990, O'Connor & Pickett 1992). Seed removal results in compositional changes, especially in heavily grazed veld, where unpalatable shrub species produce more seeds than palatable species. Such changes in the relative abundance of shrub species become obvious when seedling establishment fails to compensate for deaths of old plants.

The abundance of unpalatable adult species in the communal area as a result of increased seed availability (Todd 1997) allows for greater competitive ability over more palatable species. Through a reduction of plant productivity and resource availability, herbivores can modify competitive interactions between plant species. According to Milton (1995a) herbivory by animals greatly reduced the seed production of the palatable species *Pteronia empetrifolia* over the unpalatable species, because the competitive abilities of the rare seedlings had a smaller impact in determining the composition of the vegetation. As competition for nitrogen is important in determining plant growth and species composition (Riegel & Miller 1992), the soil-nutrient status of the area may also interfere with the competitive interactions between species. Allsopp (1999) found that *G. africana* depleted soil moisture and increased soil pH more than other shrubs. The shrub changes the soil conditions in the immediate environment in such a way as to ensure establishment of the *G. africana* seeds.

Productivity of semi-arid systems can be maintained, especially in times of limited resource supply, through utilisation of soil resources around plants. Removal of shrubs for fuelwood reduces the productivity of the vegetation by exposing the fairly infertile soils (Allsopp 1999), to increased erosion, depletion of soil nutrients and reduction of recruitment microhabitats required by seedlings.

4.4.1.2 Seedling microhabitats

Recruitment of seedlings was greatest in microhabitats that contributed to their survival by providing shelter, nourishment or both. The increased numbers of *G. africana* seedlings in the communal area, suggests that recruitment of unpalatable and poisonous seedlings is favoured and that they able to survive better under grazing disturbances. Shackleton (1993b) also found a greater proportion of woody seedlings in a harvested grassland area in the eastern Transvaal lowveld. Heavy grazing in the communal area kept the grasses short and thus reduced competition for resources. The reduced numbers of many other seedlings in the communal area of the present study, indicate that most species were highly sensitive to disturbances such as heavy grazing, trampling, uprooting, desiccation. Palatable species such as *E. microcephalus* and *O. sinuatum* were most affected by these disturbances in the communal area. Defoliation and florivory usually reduce seedling recruitment in many Karoo plants (Milton 1992). The correlations between the number of adult plants and number of seedlings suggests that seed production is the factor limiting recruitment in the communal area (Todd & Hoffman 1999). Milton & Dean (1990) found that sheep annually removed as much as 90% of the seeds produced in a southern Karoo area.

Most Karoo species do not have a persistent seed bank and therefore rely on a regular supply of seed to recruit and thus replace themselves (Esler *et al.* 1992, Milton 1992, Milton & Dean 1993, O'Connor 1991). O'Connor (1991) and Milton (1995a) suggest that grazing reduces the abundance of long-lived, palatable perennials that produce few non-dormant seeds by reducing their reproductive potential. Long-lived species also have limited opportunities for recruits to establish (Watson *et al.* 1997). Esler *et al.* (1992) found that the dominant succulent seedbanks consisted of only 1% annual seed densities produced, implying that persistent seed banks were of little importance in the re-establishment of perennial plants in the southern Karoo. This partly explains why the density of seedlings that emerged in the southern Karoo was generally lower than for example for seedlings of grassy and ephemeral vegetation types (Milton 1995b).

Seedlings recruited more in the open on the commercial side and under shrubs on the communal side due to different grazing conditions. Seedlings that recruited in the open in the communal area, were exposed to grazing, trampling and uprooting. Evidence of greater seedling herbivory in the communal area was observed during field visits. The established shrubs provided protection, establishment sites and nutrients to seedlings in the communal area. In a separate study in the Southern Karoo, *Ruschia spinosa* adults provided sheltered microhabitats to enable recruitment of various species (Yeaton & Esler 1990, Esler & Phillips 1994), while moisture and nutrients were derived from the soil-mounds created around the shrubs (Cunliffe *et al.* 1990). The multiple stems of succulents appeared to trap soil and organic matter around the base, which formed microhabitats for seedling establishment. Seeds may also be trapped in this way, thus increasing survival.

The recruitment of seedlings on the commercial side, appeared to be driven by a different set of factors than seedlings in the communal side. The seedlings recruited in the open spaces, because the impact of grazing, trampling and uprooting by livestock was lower. Competition for space, soil moisture and nutrients are probably greater determinants of seedling survival on this side of the fence. These are however only speculative assumptions as no emphirical data has been collected for this study to support these statements. Assumptions are based on evidence from other studies (Cunliffe et al 1990, Esler & Cowling 1993, Milton 1995b). Cunliffe *et al.* (1990) and Esler & Cowling (1993) have shown that plant size (e.g. *Leipoldtia constricta* and *Pteronia* species) is influenced by competition. Species which established closer to the nearest-neighbour were generally smaller than the species which established distances further away. Milton (1995b) found that soil moisture depleted faster under shrubs than from open areas. This means that competing plants would have less soil water available (Tromble 1988). It can thus be inferred that competition had a major influence in seedling selection of microhabitats.

The utilisation of microhabitats was determined by the different life forms of the seedlings. The present study found that leaf succulents in the commercial area recruited more in the open. Milton (1995b) also found similar recruitment patterns in the southern Karoo, where succulent seedlings with their small seeds generally colonised bare, fine-textured soils. The establishment of seeds in specific microhabitats appears to be influenced by the seed morphology. Cunliffe *et al.* (1990) also found that the perennial succulent *Leipoltdia constricta* established in open areas as a result of high levels of competition closer to neighbours. Yeaton & Esler (1990) and Wiegand & Milton (1996) suggest that seedlings of coloniser species like leaf succulents (e.g. *Ruschia spp.*) require large gaps in open vegetation to establish. Esler & Phillips (1994) found that the mound forming *R. spinosa* colonised open areas between existing vegetation. These succulents then provide establishment sites for woody shrubs. Findings from our study however, only partly conform to the recruitment pattern discussed above. Leaf succulent seedlings present in the communal side established more under shrubs than in the open. The heavy grazing, trampling, uprooting and increased numbers of less palatable & poisonous plants influenced seedling establishment. The increased number of less palatable & poisonous plants in the communal area in turn also means that the competitive abilities of leaf succulents for space, soil moisture and nutrients were reduced. The establishment of leaf succulent seedlings under shrubs in the communal area appears to be in response to their increased mortality rates in open areas.

Seedlings of palatable species generally recruited under shrubs. This pattern is even more visible in the communal area where very few seedlings of palatable species recruited in the open. Weigand & Milton (1996) and Cunliffe *et al.* (1990) suggested that seedlings of successor species such as *Pteronia spp*. and *Osteospermum sinuatum,* established in shaded sites under the canopy of coloniser plants. The adult shrubs provide protection, shading, soil moisture and soil nutrients required for growth and survival of the palatable plants. Heavy grazing in the communal area has greatly reduced the number of palatable seedlings through reducing the availability of seeds and increasing the abundance of unpalatable species.

4.4.2 Seedling responses to shrub skeleton removals

4.4.2.1 Growth of seedlings

The combination of grazing disturbances and drought has been shown to have disastrous effects on the growth and survival of seedlings (Milton 1995a). Seedlings showed overall height increases in both commercial and communal areas during the first three months of experimental monitoring. It is possible that the seedlings utilised soil moisture from the previous rainfall available in the soil for this growth. Grazing and drought pressures appeared to have a greater impact after the first three months when seedling growth was reduced and later showed variable growth responses. The presence of shrub skeletons in the commercial area limited the growth of *R. robusta* seedlings, possibly because of reduced light availability (Burgess & Shmida 1988). In the communal area however, *R. robusta* seedlings grew higher under control shrub skeletons, because the combination of grazing disturbances and drought impact prevalent under removed shrub skeletons reduced seedlings heights. Higgins *et al.* (1989) also found that Clanwilliam cedar seedlings had greater height increases under microclimate shelters during a drought period. Insufficient rainfall resulted in a delay of seed germination of some miombo woodland species (Chidumayo 1992). Shoot die-back of the miombo woodland seedlings occurred during the hot, dry periods when rainfall was absent. This in turn, implies that shoot die-back was due to great water stress, which ultimately resulted in shoot desiccation and mortality. Similar seedling die-back was observed after a few months of exposure to drought in this present study.

4.4.2.2 Seedling mortality

Seedling mortality was generally greater under removed shrub skeletons than under control shrub skeletons, especially in the communal area. Although some studies (Milton 1994, 1995b, Smith & Shackleton 1988) found that seedling survival increased due to a loss of established plants, many other studies found that survival decreased (Higgins *et al.* 1989, McAuliffe 1986, Cunliffe *et al.* 1990). Water stress and grazing appear to be major contributing factors to seedling mortality rates mainly under removed shrub skeletons in both the commercial and communal area. Various studies done in arid environments have attributed high seedling mortality largely to drought or increased water stress (Swaine & Hall 1983, Kennenni & Van des Maard 1990, Milton 1994). The high rate of seedling mortality in the Great Basin Desert of North America was due to water stress (Donovan & Ehleringer 1994). The reduced seedling mortality rate in the commercial area of this study in Paulshoek, could be ascribed to the fact that some succulents and woody perennials which had greater competitive ability to acquire moisture and nutrients in the open, were able to do so, in the absence of grazing disturbances. The opposite result is noticed in the heavily grazed communal area, where greater seedling mortalities were evident under removed shrub skeleton conditions.

Seedlings like *E. decussata* and other palatable species had lower mortality percentages under control shrub skeletons, which provided shelter and nutrients. It is common for these successor seedlings to recruit in branched shrubs that allow adequate light for photosynthesis. Trampling, uprooting and water stress holds the greatest dangers for the survival of *G. africana* seedlings in the communal area. Non-succulent shrubs are known to establish beneath low-growing, succulent plants which they generally outcompete (Yeaton & Esler 1990). Clanwilliam cedar seedlings also experienced lower mortality rates under shelters that provided high relative humidity to seedlings (Higgins *et al.* 1989).

Many studies have highlighted the variable drought resistance responses of different seedlings under drought or water stress conditions. *Ruschia robusta,* for example, indicated lower percentage seedling mortality than *G. africana* under removed shrub skeletons. The ability of *R. robusta* seedlings to tolerate drought conditions better than most seedlings can be attributed to physiological adaptations (Shmida *et al.* 1986). Esler & Phillips (1994) found that *R. spinosa* seedlings also tolerated drought conditions much better than most other species tested in the Richtersveld. A glasshouse experiment indicated that while all *O. sinuatum* seedlings had died after 120 days of drought conditions, only a few *R. spinosa* seedlings had died after 400 days (Esler & Phillips 1994). This drought tolerant ability is ascribed to the fact that these succulents are able to tolerate many different conditions and also to the ability of CAM succulents to take up atmospheric water vapour (Esler & Phillips 1994, Herppich *et al.* 1996). The plants maintain tissue water levels needed for photosynthesis longer than other species when the soils dries out (Burgess & Shmida 1988). These adaptations clearly provide these growth forms with some advantage over other species, which are less drought resistant. However, our study does indicate greater *R. robusta* seedling mortality under conditions where the seedlings are exposed to a combination of drought, competition, grazing, trampling and uprooting.

4.5 Conclusions

The natural vegetation forms an intricate network with the lives of the inhabitants who depend on it. People not only depend on the veld for grazing pastures but also for fuelwood harvesting, which has become such an inherent part of their lives. Inhabitants have however, suggested that the abundance of available fuelwood has been reduced over the last few years. This is not surprising, as similar patterns of fuelwood scarcity have been observed in many other countries (Eberhard 1986, Liengme 1983, Shackleton 1993a).

Villagers are forced to utilise less preferred fuelwood shrubs like *G. africana,* which establishes as a result of degradation. The more preferred fuelwood shrub species have been reduced in the surrounding area of the village and thus more difficult to obtain. Previous research done in this area suggests that over-grazing by livestock has resulted in severe veld degradation. Over-grazing has resulted in compositional changes of the vegetation, which favours unpalatable shrubs over more palatable vegetation. Findings from this present study found that fuelwood collection in the form of dead shrubs (skeletons) further contribute to the degradation in the area.

The presence of adult shrubs in the vegetation was highly important for growth and survival processes of seedlings. Dead shrubs were especially important in the communal area where a combination of climatic (e.g. drought) and heavy grazing disturbances impacted on seedling growth and survival. Removal of shrub skeletons resulted in reduced heights of seedlings and higher mortality rates of seedlings especially in the heavily grazed area. Seedlings of palatable species, which are used as forage, seem to be highly sensitive to the exposed condition created by the removal of shrub skeletons. The shrub skeletons shelter seedlings from grazing, trampling, uprooting and desiccation in the harsher environment. The shrub skeletons also provided soil nutrients, soil moisture and recruitment microhabitats to many seedlings. Removal of shrub skeletons reduced the availability of litter that directly affects nitrogen cycles.

The evidence in this study strongly suggests that the removal of shrub skeletons hold negative implications for future seedling recruitment, especially in the communal area. Shrub skeletons appear to be highly important in the communal area where there are grazing and fuelwood collection disturbances. Over–utilization of shrubs for fuelwood would also affect the forage availability for livestock. A combination of grazing and fuelwood removal may lead to further land degradation, not forgetting that the area is already overstocked. It would thus be suggested that the areas of collection be rotated and not totally denuded of shrub skeletons. Alternative energy sources would need to be investigated and supplied to ensure less pressure on the vegetation.

CHAPTER 5

CONCLUSIONS, MANAGEMENT STRATEGIES AND POLICY OPTIONS FOR FUELWOOD RESOURCE USE IN PAULSHOEK, NAMAQUALAND

5.1 Conclusions and implications

The research findings emphasise the energy dilemma of the inhabitants of Paulshoek. Fuelwood is still a primary energy source utilized by most of the inhabitants for cooking, heating, and baking activities. Unfortunately, the over-utilization of fuelwood resources has resulted in a decline of deadwood availability. Inhabitants are forced to walk longer distances and spend more time collecting fuelwood. This scarcity of fuelwood has also encouraged small scale commercialisation, which in itself has several negative implications for the community and the environment. People are increasingly using unsustainable methods of fuelwood collection such as cutting green wood, removing whole stumps of *Rhus undulata* and burning live trees to cause death. Households use as much as 8.7 kg of fuelwood per household per day, which amounts to about 2.18 tons of fuelwood per household per year. This is a rather high amount if compared with consumption quantities of other areas. The increasing unemployment rate of inhabitants greatly contributes to the increased fuelwood utilisation.

Even though utilisable *R. undulata* fuelwood (dead wood) has declined, this research has found that the abundance of live *R. undulata* trees have not been significantly impacted by fuelwood harvestings. In fact, the data indicate that intensive harvesting of above ground material stimulates growth. However, regrowth can only be assured if the below-ground material (i. e. stumps) is not removed. Unfortunately, stumps are the part of the tree most preferred and our findings have shown that the removal of below-ground material has disastrous effects on the growth and survival of trees. The fact that people have to walk long distances and spend more time collecting wood and use less preferred species supports the fact that the availability of usable dead fuelwood has declined. So, although trees are abundant, they usually have few dead branches and are not usable for fuelwood purposes. Trees closer to the village were generally smaller in size than trees further away from the village, indicating new growth and strong regenerative ability of harvested trees. A carbon dating exercise also found that tree individuals situated in a heavily utilized area, which were speculated to be very old, were in fact very young. This could mean that the older stump material was harvested and that what was tested, was the regrowth of existing below-ground material. Younger trees usually have more live material than dead material available that can be used as fuelwood.

Experimental data for rates of *R. undulata* deadwood production was not investigated in this study and therefore this information had to be modeled. The modeled data also excludes the contribution of shrubs to the fuelwood pool. Shrub information was inadequate for this type of assessment. The modeled data suggests that a 4.4% deadwood production rate contributed to the annual harvestable fuelwood yield. Any value higher or less than 4.4% displayed unrealistic scenarios. At the rate of 4.4% *R. undulata* deadwood production, available fuelwood would be depleted within a short period of time. This research thus concludes that the harvesting of *R. undulata* fuelwood in Paulshoek is unsustainable at the present harvesting rate.

Inhabitants use a small range of shrubs for fuelwood purposes. The use of shrub skeletons as fuelwood has many negative impacts on the environment. The shrub skeletons are important for the growth and survival of seedlings in the vegetation, especially in areas exposed to heavy grazing. Shrub skeletons provide shelter, shade, soil moisture and soil nutrients to seedlings, which recruit under them. The removal of shrub skeletons exposes seedlings to grazing, trampling, uprooting and climatic factors (i.e. drought) which limit survival. The removal of the shrubs also contributes to vegetation changes by changing soil nutrient status, causing erosion and ensuring the establishment of unpalatable species.

5.2 Management strategies

The greatest threat to sustainable fuelwood resource use in Paulshoek, is the increased removal of green wood material, removal of below-ground material (i.e. stumps), burning of live trees and removal of shrubs from the vegetation. The need for alternative energy sources is imperative, but more practical resource management guidelines could assist in ensuring future availability of wood resources. Inhabitants should refrain from removing green wood material, as this interferes with plant growth processes. It is a reality that people will not stop using stumps for fuelwood purposes. It is thus suggested that only dead stumps be removed and used for energy purposes. Whole live stumps should never be removed. The removal of live stumps reduces growth dramatically and will result in the death of the trees. Trees will only be able to coppice and grow if there are stumps available. The burning of live trees will result in the depletion of fuelwood resources. This method of collecting fuelwood should be discouraged. The areas, which are targeted for removal of shrubs should be rotated. Skeleton shrubs should rather be removed from areas, which are not heavily grazed. This would reduce the disturbance pressure placed on recruiting seedlings in heavily grazed areas. The sustainable use of the natural resources has ecological importance but also value in that it can contribute to ecotourism. The management strategies will only be successful if the community agrees to them and carries them out. It is important that these strategies are discussed with the community and their management committees, so that they are able to take collaborative ownership of ensuring sustainable utilization of the environment.

5.3 Policy implications for the research findings

Considering the findings of this research, it is clear that energy supply solutions and interventions are required to assist the community and to ensure reduced environmental degradation. Local people can only refrain from over-utilization of the environment if they have alternatives.

The current energy consumption pattern in Paulshoek, Namaqualand mirrors the energy dilemma of many other rural areas in South Africa. Many rural communities still find themselves relying on energy sources, which do not adequately contribute to or improve their living standards. Basic household needs such as cooking, water heating, space heating, lighting should be met through energy sources which are convenient, flexible, affordable and which reduces health risks and environmental degradation. Anon. (1998) considers the provision of adequate and sustainable energy supplies to rural households a priority, which in turn may also reduce poverty and increase livelihood security and living standards. Through the policy, the present government has committed itself to seeking solutions that would help mitigate the energy shortage problems of the rural communities.

The RDP policy drafted during 1994-1995, suggested the electrification of at least 2.5 million households by the year 2000. The annual targets have been exceded with 450 000 new connections (Ruffini 1999b). Although the Energy White Paper (1998) strongly encourages electrification of as many households as possible, it also recognises that grid electricity supply to some remote areas may not be feasible or possible. The grid connections which amounts to about 35% for rural areas, cannot be extended cost effectively, due to inaccurate economic projections. This means that approximately two million rural families, comprising more than 12 million people will not have grid electricity (Ruffini 1999b). The poor households may also not be able to pay for expensive electricity or for the expensive electrical appliances. Renewable energy alternatives to provide the least cost services have therefore been suggested. The proposed Renewable Energy Action Plan suggested the implementation of non-grid technologies as complementary to the National Rural Electrification programme. The objective is to ensure basic electricity to as many households as possible. Solar power and non-grid electrification systems such as home solar systems, solar cookers, solar pump water supply systems, hybrid electrification systems and wind power has been proposed as supply-side alternatives (Draft Energy White Paper 1998). One strategy proposed by the Renewable Energy Action Plan is to encourage the practice of passive solar designs for the low-cost housing programmes in rural areas (Mandhlazi 1999). The government has also called for energy supply proposals from the public, companies, consortiums and any other groups, which could help alleviate the energy crises in rural communities.

5.4 Energy alternatives

A study conducted by Borchers *et al.* (1990) indicated that most Namaqualand inhabitants wanted Eskom to extend power to all. Since then, more Namaqualand reserves have been electrified (Mander & Quinn 1995), but difficulty has been expressed, to extend grid-lines from a national grid to the remote areas such as Paulshoek (Kerridge 1997). The extension of grid-lines would be very costly for both Eskom and the inhabitants. The line extension from an existing grid is estimated between R1800 to R22000 per kilometer for 3-phase lines (Borchers *et al.* 1990). The cost of extending grid lines from Garies to Klipfontein for example, would amount to R1 250 000 for 17km. The fact that new electrification projects are also said to receive only R2 500 per household, means that a community of 130 households would have a shortfall of R1 315 000 (Kerridge 1997). Paulshoek is about 60 km from Garies and 30 km from Leliefontein, which means that the cost of extending grid lines to the households, will be more expensive. The total income per year for all households in Paulshoek was found to be R11 007.00, with variations of R1916/months for wealthy households and R183/month for poor households (Rodkin & Rhode 2000). Under these circumstances, it is clear that grid-electricity can only become a reality for the community, if adequate financial assistance is available. Another problem is the fact that not all home structures are perceived adequate for electrification processes. Adequate housing would have to be provided so that electrical wiring could be installed. Borchers *et al.* (1990) therefore suggested the supply of low-cost grid electricity. The capital cost incurred in extending grid lines results in electricity being expensive. However, the electricity cost can be reduced if many people use the electricity and in so doing, contribute to repayment of expenses incurred. It is also suggested that the ready-board box form of energy supply would be less expensive than most non-grid electricity alternatives. The installation of ready-board boxes will also eliminate the problem of first having to wait for new houses before electricity can be installed. The ready-board box can be installed into brick houses, zink or maatjies huts, without the complications of rewiring the house. A pre-paid card will provide inhabitants with the choice of buying variable amounts of electricity units, which they can use at their own discretion. This facility to buy the electricity can be housed at local shop or community centre. This ready-board box system appears to be working well in most other areas where it has already been implemented.

Any alternative non-grid electricity supply should only be considered if they can provide similar advantages as grid-electricity. Focus should be placed on affordability and applicability to ensure success. Mander & Quinn (1995) suggest the supply of a combination of affordable commercial fuels and discourages tree growing programmes. Their findings indicate that tree growing programmes would not be feasible, because climatic conditions are not favourable for rapid tree growth. A scarcity of adequate water supplies would weaken the successes of tree planting programmes. This also implies that hydro generated power may not be possible, as water is an extremely scarce natural resource in this semi-arid area.

Considerations for alternative energy sources should consider the climatic, geographical and environmental status of the area. The most obvious renewable resource in this area would be the sun, with solar radiation varying between 4,5 and 6.5 kWh/m (Ruffini 1999a). Countries like Botswana and Zimbabwe appear to have had great successes with the implementation of solar electric systems as a source of ensuring rural electrification. These systems provide power for most basic energy needs (Geche 1999, Bathidizirai 1999). Due to the fact that many rural households in South Africa, may not receive grid electricity Ruffini (1999a) also suggest that solar cell technologies be used to assist in electrification programmes. Photovoltaic systems with gas heating and cooking facilities are suggested. The success of the systems is ascribed to the fact that it is more easily acquired than grid electricity, designed to be implemented without major shelter adjustment and environmentally sustainable. The initial cost of the systems is however fairly expensive (Borchers *et al.* 1990, Ruffini 1999a). Borchers *et al.* (1990)

calculated the cost of a solar water heater to range between R1800 to R5000. Inhabitants will not be able to afford these systems, but if subsidised, it may prove much cheaper than grid-electricity. The government has however, developed joint ventures with sponsors such as Shell International Renewables to subsidise solar power systems. The project is investigating the possibility of providing solar power electrification to about 50 000 homes in rural areas. Cost could amount to about R150 for installation fees and R47 for monthly service fees (Ruffini 1999a). The system will be able to provide energy for the use of four lights, a 2,5 W radio and a 35 W monochrome television. Grid electricity connections to a rural household are estimated at R10 000, while the photovoltaic solar system would cost about R2 800. The latter option appears to be least costly for households located more than 3 km away from an electricity grid. However, since most fuelwood is used for cooking, this option will only alleviate part of the problem. People would still have to collect fuelwood for cooking, heating and baking.

Gas is already widely used by many households because of its convenience and the scarcity of fuelwood. The cost of a 9 kg container of gas costs about R60 and normally lasts between one and one and half months and it is mainly used for water boiling, especially in the poorer households. The wealthier households are usually able to afford regular purchasing of gas. A reduction of gas prices could help reduce the immediate pressure on the environment for fuelwood. People are familiar with gas and would more easily except gas as an alternative energy than any other non-grid supplies.

Fuelwood utilization forms part of the social fibre of the community and will probably remain that way for a long time to come. Suggestions for improved energy conservation methods such as hotboxes, wood stoves or fuel-efficient cooking stoves should therefore be investigated. The benefit of the hotboxes, for example, is that the households can construct them and expenses would amount to about R18 per household. This would be a more immediate energy saving device.

5.5 Recommendations

The supply of electricity in Paulshoek should be considered a priority and electricity should be extended to all households. All efforts to supply grid electricity should be made, before alternative non-grid electricity is considered. Inhabitants should also be made aware of the cost involved in purchasing of electrical equipment (i.e. electric stoves, kettles, and heaters).

Alternative energy supplies proposed should take into account the socio-economic and ecological circumstances of the community. As a result of poverty and high unemployment rates the inhabitants will not be able to afford expensive energy sources. It is vital that energy alternatives be affordable, durable and practical. Projects need to consider all the factors, which may hinder people's ability to change their energy utilisation patterns to environmentally sustainable practises.

The supply and distribution responsibilities should be taken by Eskom and adequate financial assistance schemes should be made available to households.

It is imperative for any project implemented, to follow an integrative and consultative approach with the community and other stakeholders. The community must have a sense of ownership towards the projects. This will ensure support and interest from the community's side. Expensive lessons from many projects where communities were not consulted and involved have been learned and should thus not be repeated.

Electrification projects should be implemented in such a way that they provide employment opportunities to local inhabitants.

Many of the inhabitants have never been exposed to electricity and therefore awareness raising and educational projects will be important. Proper understanding of how to use and maintain the electricity sources would ensure greater safety and success of the projects.

Environmental education programmes also need to be implemented to encourage sustainable utilization of the environment. Practical environmental education projects, which could cater from primary school children to adult groups need to be developed. The main focus should be to highlight ecological impacts which fuelwood collection exerts on the environment and to emphasise the value of conservation for both nature and the people.

The use of wood for energy is an inherent part of the lives of inhabitants in Paulshoek. The implementation of grid or non-grid electricity may therefore not completely eliminate the use of fuelwood. Respondents indicated that they would continue to use fuelwood for social and cultural events. This information should be considered in the energy planning process.

The planting of trees, which require little water (i.e. *Acacia spp.*) (Borchers et al 1990), could reduce the harvesting pressure exerted on presently used fuelwood species. Rehabilitation research that is presently being conducted in Paulshoek indicates that *Acacia spp.* adapt and grow very well in this area. The community inhabitants indicated enthusiasm at the idea of using *Acacia spp.* for fuelwood purposes.

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Appendix 1: Copy of the questionnaire used in the household surveys to determine fuelwood use in Paulshoek, Namaqualand

Questionnaire: Demographic information **Date:…………**

Interviewer's Name: ……………… **Name of respondent:…………….**

1. Gender:

Male	**Female**

2. Age:

younger 25	26-50 years	Older 50	

3.Type of house or shelter: Erf no.

Bricks	Asbestos or Sink	Maatjies

4. Do you have a cooking shelter?

5. What type of energy source do you use?

Gas	Firewood	Other

6. What type of transport do you own?

Car/ Bakkie	Donkey cart	Nothing

7. How long has your family been in Paulshoek?

Less then 5 years	
Between 5 and 20 years	
More then 20 years	

8. How many people stay in your house?

9. How many live outside of Paulshoek?

10. Where do you do your shopping?

Paulshoek	**Town**

11. How much stock in your herd?

Sheep	**Goats**	**Donkeys**	**Cattle**

12. Do you have a saaiperseel? Where is it?

Yes/no	
Where?	

Questionnaire for Firewood

These questions will be used as a means of collecting information about firewood use, value and assessment of impact.

Plants used

1. What plants do you use for firewood?

2. For what purposes do you use the different plants?

3. Which is the best wood and why?

4. Which parts of the plant / tree are used?

Method of collection

1 How do you collect firewood? (cutting, breaking, picking up etc.)

2. What transport do you use?

Location

1. Where is the wood collected (area and distance)?

Quantities

1. How much is used for each day?

2. What is the best wood to use?

3. Which parts of the plant/ tree is used and why?

Labour

1. Who collects the wood?

2. How often do you collect wood?

3. How long does it take (daily, weekly) to collect wood.

Economics

1 Do you sell wood and for how much money?

2. If there were no wood available would you buy from somewhere else?

3. How much would you be willing to pay for a bundle of wood?

4. How would you pay for the wood?

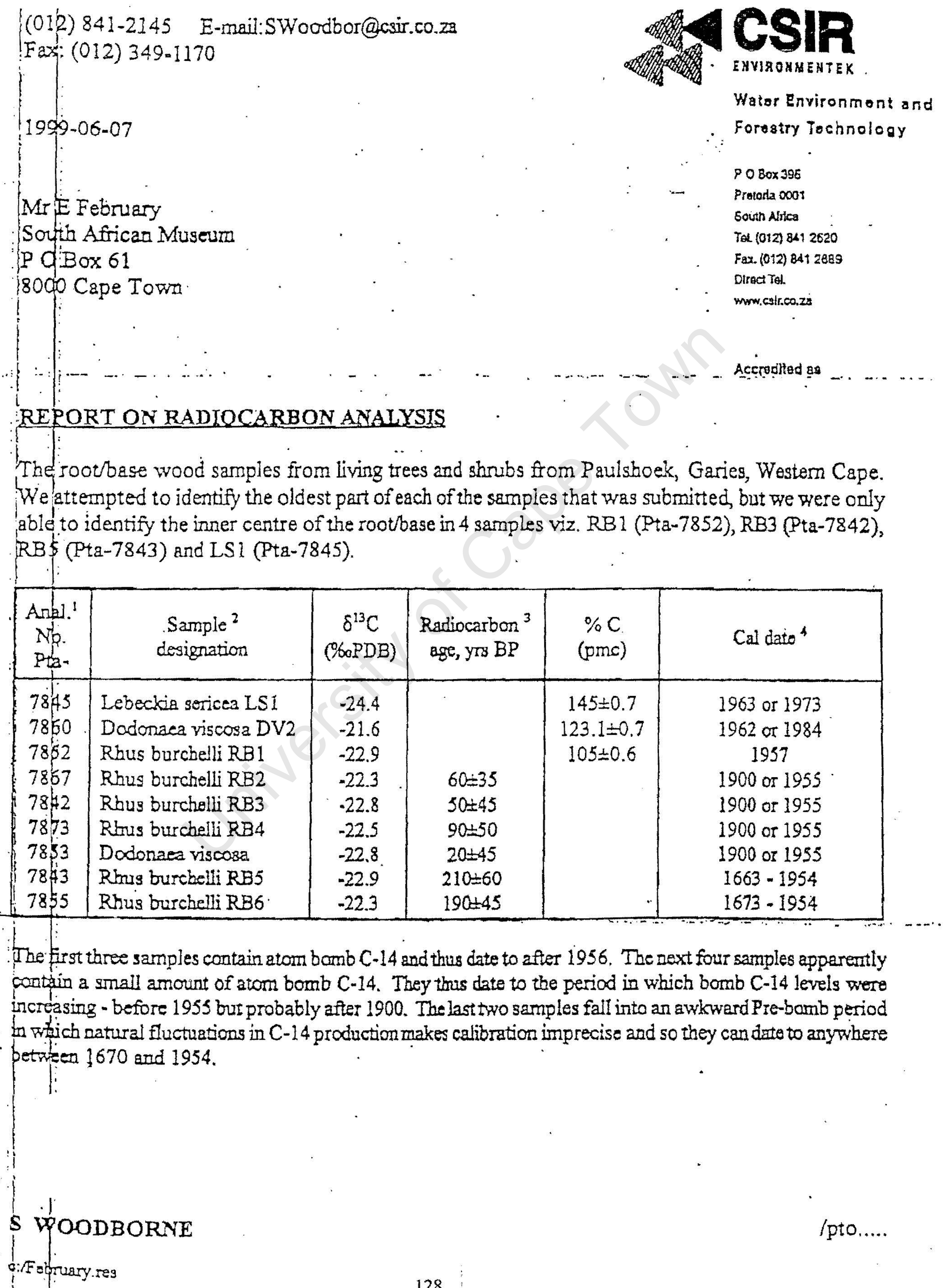
Impact

1. Can you substitute the wood with something else?

2. What resources have changed in abundance over the years and to what do you ascribe these changes?

3. How much effort is required to collect the resources.

Appendix 2: The report of the radiocarbon dating analysis done on different *Rhus undulata* (incorrectly indexed in the report as *Rhus burchelli*) stump material.



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REPORT ON RADIOCARBON ANALYSIS

The root/base wood samples from living trees and shrubs from Paulshoek, Garies, Western Cape. We attempted to identify the oldest part of each of the samples that was submitted, but we were only able to identify the inner centre of the root/base in 4 samples viz. RB1 (Pta-7852), RB3 (Pta-7842), RB5 (Pta-7843) and LS1 (Pta-7845).

Anal.[1] No. Pta-	Sample [2] designation	$\delta^{13}C$ (‰PDB)	Radiocarbon [3] age, yrs BP	% C (pmc)	Cal date [4]
7845	Lebeckia sericea LS1	-24.4		145±0.7	1963 or 1973
7860	Dodonaea viscosa DV2	-21.6		123.1±0.7	1962 or 1984
7852	Rhus burchelli RB1	-22.9		105±0.6	1957
7867	Rhus burchelli RB2	-22.3	60±35		1900 or 1955
7842	Rhus burchelli RB3	-22.8	50±45		1900 or 1955
7873	Rhus burchelli RB4	-22.5	90±50		1900 or 1955
7853	Dodonaea viscosa	-22.8	20±45		1900 or 1955
7843	Rhus burchelli RB5	-22.9	210±60		1663 - 1954
7855	Rhus burchelli RB6	-22.3	190±45		1673 - 1954

The first three samples contain atom bomb C-14 and thus date to after 1956. The next four samples apparently contain a small amount of atom bomb C-14. They thus date to the period in which bomb C-14 levels were increasing - before 1955 but probably after 1900. The last two samples fall into an awkward Pre-bomb period in which natural fluctuations in C-14 production makes calibration imprecise and so they can date to anywhere between 1670 and 1954.

S WOODBORNE

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Appendix 3: The five plots on the 1997 aerial photograph which were used to identify the change in abundance of *Rhus undulata* over time at various distances away from the Paulshoek village. Five plots were identified on a 1960 aerial photograph (job no. 443, strip no. 19, photo no. 5926, enlargement: 6X, scale: 1:6 666) and matched to the same five plots shown on this 1997 aerial photograph (job no. 998, strip no. 3, photo no. 0306, enlargement: 4X, scale: 1: 15 000).