UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Studies on the impacts of off-road driving and the influence of tourists' consciousness and attitudes on soil compaction and associated vegetation in the Makuleke Contractual Park, Kruger National Park

by

Gerhardus Petrus Nortjé

Submitted in partial fulfilment of the requirements of the degree

Doctor of Philosophy (Wildlife Management)

In the Faculty of Natural & Agricultural Sciences

University of Pretoria

Promoter: Prof. W. van Hoven

Co-Promoter: Prof. M. C. Laker

Pretoria **June 2013**

"Every living thing owes its existence and survival to soil.
The ultimate truism here was stated by Charles Kellogg,
'There can be no life without soil and no soil without life'."
Dean Ohlman, 2009

"We must be under no delusion,
if we continue to ill-use the soil the land will die,
and the people will die with it"
Matthews, 1956

And I will add to the above,
"Without soil there is no life!"
Gerhard Nortjé, 2012

"Soil erosion is South Africa's biggest environmental problem."
Clem Sunter, 20th August 1999, 'The Star'

"There is a tendency among politicians not to listen to or take seriously the warnings
of the scientifically sound research findings of scientists."
Prof. Michiel Laker, 1987, pers. comm

"Keep it simple, keep it wild",
a final plea in his final report concerning the Kruger National Park
James Stevenson Hamilton, 1945

Declaration

I, Gerhardus Petrus Nortjé, declare hereby that the work contained in this dissertation is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

……………………………

G.P. Nortjé

……………………………

Date

ACKNOWLEDGEMENTS

The work reported in this dissertation was carried out in the Makuleke Contractual Park, Northern Kruger National Park. The author wishes to express his sincere gratitude and appreciation to the following persons and institutions for contributing to this study, because this study was not only my effort but a team effort:

- My Lord and Saviour, Jesus Christ, for picking me up when I needed Him most and for His love, His joy and His strength since then
- My loving wife, Paula. Without her support and encouragement, and help with editing my articles, reports and thesis, this study would not have been possible. I love you to the moon and back
- Professor Wouter van Hoven (Centre for Wildlife Management, University of Pretoria) for accepting to be my promoter and for valuable guidance and support throughout the study period
- Professor Michiel Laker (Emeritus Professor in Soil Science, University of Pretoria) for acting as my co-promoter. Professor Laker is more than just my co-promoter. He is also my mentor and role model. Without his guidance, constructive criticism, motivation, support and long discussions, this study would not have been possible
- The staff at Pafuri Camp: Walter; Abe; Enos and the rest of the Guides' team; Willem; Ursula and all the staff at the Lodge; Ernest, Dereck, Eva and their teams; Rob and Landi Burns — thank you to all for your warm hospitality, your friendship, your support and your interest during the study period
- The Joint Management Board (JMB) of the Makuleke Contractual Park for making the area available for the study
- Wilderness Safaris, especially Chris Roche, Patrick Bonham-Whetham and James Ramsay for believing in my project and approving it and Tina Sears for all the accommodation arrangements
- Dr. Schalk Human and Joyce Jordaan for excellent help with the statistical analyses of the data
- Michelle Louw for the indispensable help with the off-road driving trials
- Dr. Johan van der Waals for the use of the penetrometer
- Lourens van Zyl for support with the GIS analyses
- My parents, brothers and sisters for their love, interest and for just being there for me. I love you all

ABSTRACT

Eco-tourism activities specifically, sometimes have very negative environmental impacts. One such activity which has been observed to have severe negative impacts is driving in dirt tracks (ungravelled natural soil) by game drive vehicles in private game reserves and some National Parks (Nortjé 2005; Laker 2009). It has also been observed that the severity of the impacts and the resilience (recovery potential) of the affected areas differ widely between different areas. It is strongly linked to the properties and qualities of different soils.

This study has shown that off-road driving (ORD) has the same effects, and to a greater extent, if it is not well managed and judiciously controlled. Wild animals tend to concentrate in areas with the most nutritious en most palatable vegetation. Consequently these are also the areas where predators, e.g. lion, leopard and cheetah are most likely to be found. It can be expected that these will be the areas with the highest frequencies of ORD in order to get close to these animals. In many landscapes these are the areas which are the most vulnerable to negative impacts by actions like ORD and have the lowest resilience. It has also been observed during game drives and personal communications at several occasions that there is tremendous ignorance amongst tourists regarding the negative environmental impacts of certain activities.

This study proved that ORD have strong negative impacts on vegetation recovery, soil resilience and root density distribution through soil crusting and sub-soil compaction. An important finding is that these negative impacts are during both dry and wet soil conditions. Game drive vehicles driving off-road damages the surface soil structure, which lead to soil crust formation and sub-surface compaction. A highly significant result is that most crusting and sub-soil compaction occurred during the first pass of the game drive vehicle, irrespective of the soil type and tyre pressure, thus rewriting the current guidelines for ORD of the South African National Parks, SANParks.

Furthermore, results of this study indicated that a significant area in the flood plains of the Makuleke Contractual Park is impacted by ORD. The impacts are serious if one looks at the amount of land that an ORD vehicle can disturb. One of the recommendations would thus be to drive in the same tracks when driving off-road, and lower the tyre pressures. Driving in the same tracks is known as "controlled-traffic" in the agricultural industry. Controlled traffic is very important to minimize compaction. Driving in the same

tracks during off-road incidents does not significantly affect the degree of compaction under the tracks, but greatly reduces the compacted area.

Further results indicated a strong lateral effect of the vehicle tracks, in most cases the whole area between the two tyre tracks as well as up to a distance outside of the vehicle tracks, thus increasing the total area disturbed by ORD. Comparing these vehicle impacts with animal path resulted in some important findings. Animals only caused a soil crust with soil strength values much lower than that of vehicles. The effects of animals are also much more vertical than lateral as with vehicles.

Another important finding is the role that historical human activities play in such study areas and how it may influence results. The results in this study are aggravated by the historical human activities in this study area, as indicated. These historical activities were the main cause of the surface crusting, and the resultant low vegetation growth in the area. This, therefore, explains partially the relatively high control values and also the soil's higher susceptibility to compaction due to vehicle ORD.

The root density trials had very interesting and important results. Significant differences occurred between mean root density fractions across all tyre pressures at all three trial sites. The trend is that an increase in tyre pressure causes a decrease in root density distribution. These results show clearly that even lower tyre pressures are harmful, but are more environmental friendly than higher tyre pressures.

Results of the second part of the study with regards to tourists' perceptions on ORD, and the impact of their activities on the environment, showed that the majority of tourists are ignorant when it comes to the impacts of their activities on soil and vegetation. Tourists' had significantly variable demographic characteristics. Tourists' environmental perceptions varied, but a significant majority of tourists agreed that ORD has a negative impact on the environment.

Contradictions exist between what they know or perceive as being damaging and what they prefer to act on. Results indicate a need for improved visitor education on the possible negative impacts of demands for ORD, and a need for government intervention with regards to the enforcement of legal measures to control ORD. The results also indicate that game guides and tourism operators can play a major role in educating the tourists.

The results demonstrate that both an understanding of the chemical and physical factors influencing soil compaction, as well as tourists' environmental views are important in formulating a management strategy to control and manage these impacts.

UITTREKSEL

Eko-toerisme-aktiwiteite spesifiek, het soms 'n baie negatiewe uitwerking op die omgewing. Een so 'n aktiwiteit wat waargeneem is om ernstige negatiewe impak te hê is veldry (natuurlike grond) deur die wildrit voertuie in private wildreservate en invan die Nasionale Parke (Nortjé 2005; Laker 2009). Daar is ook opgemerk dat die erns van die impak en die veerkragtigheid (herstelvermoë) van die geaffekteerde gebiede wyd verskil tussen verskillende gebiede. Die mate van die impak en herstelvermoë word sterk gekoppel aan die eienskappe van die verskillende gronde.

Hierdie studie het getoon dat veldry (ORD) dieselfde uitwerking het, en in 'n groter mate, indien dit nie goed bestuur word en oordeelkundig beheer word nie. Wilde diere is geneig om te konsentreer in gebiede met die mees voedsame en mees smaaklike plantegroei. Gevolglik, is dit ook die gebiede waar roofdiere, bv leeus, luiperds en jagluiperds mees waarskynlik gevind word. Dit kan verwag word dat dit ook die areas sal wees met die hoogste frekwensie van ORD om naby aan die diere te kom. In baie landskappe, is dit dan ook die gebiede wat die meeste kwesbaar vir negatiewe impakteis deur aksies soos ORD en het ook die laagste herstelvermoë. Daar is ook waargeneem tydens wildritte en persoonlike kommunikasie met verskeie geleenthede, dat daar 'n geweldige onkunde onder toeriste oor die negatiewe uitwerking op die omgewing van sekere aktiwiteite is.

Hierdie studie bewys dat ORD 'n ernstige negatiewe impak het op plantegroei herstel, grond her-stelvermoë, asook worteldigtheid-verspreiding as gevolg van korsvorming en sub-oppervlakte verdigting. 'n Baie belangrike bevinding is dat hierdie negatiewe impakte tydens beide droë en nat grondtoestande plaasvind. Wildrit voertuie wat in die veld ry, beskadig die oppervlakte grondstruktuur, wat lei tot grondkorsvorming en sub-oppervlak kompaksie. 'n Hoogs beduidende resultaat is dat die meeste korsvorming en sub-oppervlakte verdigting gedurende die eerste passering van die wildrit voertuig plaasvind, ongeag die tipe grond en banddruk. Hierdeur word die huidige riglyne vir ORD van SANParke, effektief herskryf.

Daarbenewens het die resultate van hierdie studie aangedui dat 'n beduidende area in die vloedvlaktes van die Makuleke Kontraktuele Park deur ORD geraak word. Die impak ernstig is as 'n mens kyk na die hoeveelheid grond wat 'n ORD voertuig kan versteur. Een van die aanbevelings sou dus wees om in dieselfde spore te ry en teen laer banddrukke wanneer daar in die veld gery word. Ry in dieselfde spore staan bekend as "spoorverkeer"

in die landboubedryf. Spoorverkeer is baie belangrik om kompaksie te verminder. Spoorverkeer tydens ORD insidente verhoog nie die graad van kompaksie onder die voertuig wiele beduidend nie, maar verminder wél die gekompakteerde area beduidend.

Verdere resultate dui op 'n sterk laterale effek van die voertuig spore. In die meeste gevalle is die hele gebied tussen die twee wielspore, sowel as 'n sekere afstand buite die voertuigspore, versteur deur ORD. Wanneer hierdie voertuig impaktevergelyk word met die impakte van diere paadjieslei dit tot interessante bevindings. Diere veroorsaak net 'n grondkors met grondsterktes baie laer as dié van voertuie. Die impakte van die diere is ook baie meer vertikale as lateraal soos met voertuie se impak. Nog 'n belangrike bevinding is die rol wat historiese menslike aktiwiteite speel in so 'n studie areas en hoe dit die resultate kan beïnvloed. Die resultate in hierdie studie word vererger deur die historiese menslike aktiwiteite in hierdie studie area, soos aangedui.Hierdie historiese aktiwiteite was dan ook die hoofoorsaak van die oppervlakte korsvorming en die gevolglike lae plantegroei in die studiegebied. Dit verduidelik dus gedeeltelik die relatief hoë kontrole waardes wat waargeneem is in die studie, asook die grond se hoër vatbaarheid tot grondverdigting weens ORD.

Die wortelverspreidingsproewe het baie interessante en belangrike resultate opgelewer. Statisites beduidende verskille is gevind tussen gemiddelde worteldigtheidsfraksies, oor alle banddrukke by al drie proefpersele. Die tendens is dat 'n toename in banddruk 'n afname in worteldigtheidsverspreiding veroorsaak. Hierdie resultate toon duidelik dat selfs laer banddrukke skadelik is, maar is wél meer omgewingsvriendelik as die hoër banddrukke.

Resultate van die tweede deel van die studie, wat betrekking het op die toeriste se persepsies oor ORD en die impak van hul aktiwiteite op die omgewing, het getoon dat die meerderheid van die toeriste onkundig is wanneer dit kom by die impak van hul aktiwiteite op die grond en plantegroei. Toeriste het aansienlike verskillende demografiese eienskappe. Toeriste se persepsies ten opsigte van die omgewing verskil, maar 'n beduidende meerderheid van die toeriste het saamgestem dat ORD 'n negatiewe impak op die omgewinghet.

Teenstrydighede bestaan tussen wat die toeriste weet of sien as skadelik en wat hoehulle verkies om op te tree. Resultate dui op 'n behoefte aan verbeterde besoeker opvoedingten opsigte van die moontlike negatiewe impak van aktiwiteite soos ORD, en 'n behoefte vir ingryping deur die regering met betrekking tot die toepassing van wetlike maatreëls om ORD te beheer. Die resultate dui ook aan dat gidse en toerisme-operateurs 'n belangrike rol kan speel in die opvoeding van die toeriste.

Die resultate toon dat beide, 'n begrip van die fisiese en chemiese faktore wat grondverdigting veroorsaak, sowel as toeriste se omgewings persepsies, belangrik is in die formulering van 'n strategie vir die bestuur en beheer van hierdie impak.

CONTENTS

CHAPTER 4 QUANTIFYING THE IMPACT OF OFF-ROAD DRIVING BY MEANS OF SIMULATED OFF-ROAD DRIVING TRIALS

CHAPTER 5 QUANTIFYING THE IMPACT OF OFF-ROAD DRIVING ON RESILIENCE OF THE VEGETATIVE COVER, ESPECIALLY GRASS

SECTION D CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

APPENDICES

SECTION A
GENERAL INTRODUCTION

CHAPTER 1
OFF-ROAD DRIVING IN THE KRUGER NATIONAL PARK

1.1 Background to the Introduction of Off-Road Driving

As part of the South African National Parks (SANParks) commercialization process in the Kruger National Park (KNP), concession areas were set aside for the exclusive use of private operators (Nortjé 2005). The objective of the commercialization process is to broaden the tourism product of the KNP and, thereby, increase the revenue for the SANParks (Nortjé 2005).

Concession operators are allowed certain tourist-attracting activities, including off-road driving (ORD), aimed at bringing tourists in close contact with members of the 'Big Five' in wildlife. It seems as if such activities are often implemented without knowledge regarding the full potential impacts of such activities on the environment and more particularly the soils (Nortjé 2005). Certain principles and guidelines were set for practising these activities in the concession areas, but some of these guidelines and principles have not been tested and/or scientifically proven. ORD is a case in point.

One of the guidelines for ORD states that: "Vehicles that drive off-road may not follow in each other's tracks" (van der Merwe 2004). This is the practised guideline that is still being followed after several years. The objective of the research reported here was to determine whether vehicular off-road traffic enhances soil compaction and if it does, to quantify the magnitude of the soil compaction.

1.1.1 When and why

A study on the impacts of off-road vehicles in some private concession areas in the KNP was initiated in 2003 when a research proposal was approved by the Scientific Services of the Park to carry out a research project on the impact of ORD on the environment. The study starting in 2004, started late in the sense that ORD already started in the KNP in 2001, when the first private concession areas came into operation (Nortjé 2005). These included four private concession areas in the central and southern regions of the KNP.

The result was that no scientifically based norms, regulations and standards existed by which ORD could be managed at the time the first ORD was allowed. Valuable baseline data were collected during the period 2004-2006, which included: frequencies of ORD during different seasons, ORD during dry and wet conditions, GPS positions of ORD incidents, soil types and geology of the areas in which ORD occurred, average distances travelled for ORD, average distances travelled for different animals, comparisons of ORD for different animal species and primary reasons for driving off-road (Nortjé 2005).

Off-road driving as a manageable concept is not well researched within the context of a National Park in South Africa. Very little is known about the impacts of ORD and the implications for biodiversity management. Some may argue that the activity will allow foreign tourists access to the 'Big Five' which in turn will generate funds to protect the greater components of biodiversity (van der Merwe 2004). Perceptions do however exist among wildlife managers that ORD is detrimental in the physical sense to the structure and components of the bushveld ecology. Intensive research is required to verify some of these perceptions (Roche 2009, pers. comm).

1.2 Objectives/Rationale of the Initial Baseline Study

The objectives of the above-mentioned study by Nortjé (2005) can be summarized as being:

- To establish a baseline for studying and monitoring ORD;
- To quantify the impacts of ORD and other concessionaire activities on soil and vegetation;
- To investigate different ways of quantifying impacts (e.g. satellite imagery, aerial photography, ground monitoring data, and GPS vehicle tracking);
- To investigate cost-effective, quick and accurate approaches to monitoring such impacts in the future.

1.3 Potential Impacts as Derived from Literature for Agriculture, Forestry and other National Parks/Reserves

This section is divided into three parts. **First**, South Africa's soil resources are reviewed from the point of view of physical and chemical characteristics, and the extent and occurrence of soil compaction and crusting. **Second**, literature is reviewed on the agricultural and forestry impacts on soil compaction in South Africa. **Third**, literature is reviewed of the impacts of ORD on soil compaction in game reserves, nature reserves and recreational areas which include: soil and vegetation damage, environmental damage and recovery of soil compaction caused by off-road vehicles.

1.3.1 Vulnerability of South Africa's soil resources to compaction and crusting

Most of South Africa's soils are extremely susceptible to sub-soil compaction and crusting (Laker 2005). They also are characterized by low resilience (recovery potential). This means that even small mistakes in land use planning and land management can be disturbing, with little chance of recovery once the degradation has been caused. In some cases as in the Drakensberg-Maluti area, environments are described as being robust against degradation, but having very low resilience once they give in (Bainbridge *et al.* 1991). Sub-soil compaction and crusting or surface sealing are widespread problems throughout South Africa, having serious implications with regards to biomass production, crop yield, root density distribution and quality (Laker 2005).

Disease incidence (Joubert 1993), water use efficiency and nutrient uptake (Laker 2001) are also negatively affected. Soil crusting can also lead to soil erosion as it promotes water run-off (Laker 2001). The soil compaction and crusting problems in South Africa's soils are aggravated by intensive mechanized agriculture, under both dry land and irrigated farming. Compared to the international norm, the problem of sub-soil compaction and crusting is much worse in South Africa (Laker 2005).

The lack of recovery of the large areas of bare patches in overgrazed rangeland (including game farms and nature reserves/national parks) and abandoned cultivated areas is mainly due to severe soil crusting (Laker 2005). The problem of soil compaction and crusting in agriculture has been thoroughly studied, but no studies on these problems in wildlife protected areas in South Africa have so far been conducted.

1.3.2 Impacts of vehicular traffic and other factors on soil compaction and crusting in agriculture and forestry in South Africa

<u>Soil compaction</u>

Sub-soil compaction is a widespread and serious problem in South Africa. Virgin sub-soils with natural bulk densities of higher than 1 650 $kg.m^{-3}$ are widespread (Bennie 1972).

Human-induced aggravated soil compaction is mainly serious under intensive mechanized crop production under both irrigated and dry land agriculture (Laker 2001).

Tillage research in South Africa has shown that soils with less than 15% clay in the plough layer are very vulnerable to compaction (Mitchell & Berry 2001). Large areas north of the Orange River in the Northern Cape Province and the western and northern parts of Limpopo province are also covered by such sandy soils (Mallet *et al.* 1985). In the 1960's severe soil compaction was found at the Vaalharts irrigations scheme. The soils there have very high fine sand contents and predominantly less than 10% clay (Bennie 1972).

Several studies on the effects of soil compaction have also been done in the South African Sugar industry. Van Antwerpen & Meyer (2001) and Van Antwerpen *et al.* (2000) reviewed soil compaction in the sugar industry. These studies looked at among others the effects of residue management and vehicle characteristics on soil compaction, the effects of increased soil organic materials on the compactibility of soils, and organic methods of alleviating soil compaction. They also investigated the changes in soil bulk density of a virgin soil due to compaction (van Antwerpen *et al.* 2007), as well as the effects of surface applied pressure by vehicles on the properties of a virgin soil (van Antwerpen *et al.* 2008).

Research in agriculture has established that vehicular traffic is the primary source of the mechanically applied forces to soils which lead to soil compaction, with concentrated pressure under the wheels being the greatest contributing factor (Bennie & Krynauw 1985). By far the biggest part of compaction (up to 90%) takes place during the first pass of wheels over an area (SASTA 2001). Uncontrolled haphazard movement of tractors, implements, etc. over cultivated fields during secondary operations can compact the whole field, causing the development of a sub-surface traffic pan.

In contrast, driving in the same tracks during all operations does not significantly affect the degree of compaction under the tracks, but greatly reduces the compacted area. Thus, du Preez *et al.* (1979, 1981) found that a simple cultivation system of controlled traffic greatly reduces soil compaction. Controlled traffic has been used by farmers in various parts of the world as an effective management technique to minimize soil compaction under intensive crop production systems for more than 30 years. It has also been practised very effectively by South African farmers for about that same period. Elsewhere it has been found that even in no-till systems, i.e. in essentially undisturbed soil, controlled traffic (driving in the same tracks) is essential in order to limit the areas compacted under the wheels during vehicular traffic over fields (e.g. Unger 1996).

Van der Watt & van Rooyen (1995) define controlled traffic as: "Tillage in which all operations are performed in fixed paths so that re-compaction of soil by traffic (traction or transport) does not occur outside the selected paths". It was found that the degree of compaction (density of the traffic pan) is determined by the tyre pressure of a vehicle travelling over the soil (SASTA 2001). The higher the tyre pressure is the more severe is the compaction. This is also the case in no-till situations (Unger 1996). The no-till findings are important relative to the study reported in this thesis since they deal also with soils that have not been loosened by cultivation.

A study in the semi-arid Karoo in South Africa, where extensive grazing is practised showed severe compaction in vehicle tracks compared to outside the tracks (Donaldson 2001). Compaction measurements were made on dry and artificially wetted plots in each of the following adjoining sites: 1) Veld path subjected to occasional vehicle traffic, 2) overgrazed veld and 3) veld protected from grazing for a period of 43 years (Donaldson 2001). Results of the study indicated highly significant differences in soil penetration resistance between the three sites. Soil penetration resistance was significantly higher at Site 1 (veld path with vehicle traffic), than at Site 2 (overgrazed veld) and Site 3 (veld protected for 43 years). Penetration resistance at Site 2 was also significantly higher than at Site 3. The latter comparison shows the severe negative impact of overgrazing on soil physical conditions.

In the South African forestry industry it was also found that overall productivity decline depends on the areal extent of the harvesting operations and thus on the area compacted during harvesting (Smith & Johnston 2001). Smith & Johnston (2001) pointed out that 40% growth loss over 10% of an area is very small compared to 20% growth loss over 80% of the area.

Each soil has a specific soil water content at which it is most susceptible to compaction when pressure is applied to it, for instance, by a tractor tyre. Numerous South African studies have been done on this in the agricultural and forestry sectors, as, for example reported by Bennie (1972) and Henning *et al.* (1986), and in several papers in SASTA (2001). It is accepted that maximum compaction occurs at fairly high soil water contents – just below field capacity.

Soil crusting (surface sealing)

Soil crusting is just as big a problem in South Africa as sub-soil compaction (Laker 2001). Unlike sub-soil compaction, human-induced soil crusting is not confined to cultivated areas, but is also a widespread problem in overgrazed rangelands, game reserves and national parks (Laker 2005). Although soils in the Western Cape (Stern 1990) and Eastern Cape (Bloem 1992) are particularly highly susceptible to soil crusting, it is a serious problem throughout all nine provinces of South Africa. Irrigated alluvial soils and soils derived from mudstones and shale in the Eastern Cape are seriously prone to crusting.

According to Botha *et al.* (1981) the soils with high fine sand contents which occur widespread on several irrigation schemes in the Free State and Northern Cape in South Africa normally have an "inherent inclination" towards crust formation. Laker (2005) as well as Nortjé (2005) has observed severe soil crusting in several overgrazed bare areas in the southern, central and northern parts of the KNP, as well as in the Associated Private Nature Reserves, APNR. Severe soil crusting has also been observed in irrigated areas along the north-western boundary of the Limpopo Province. Mills & Fey (2004) studied soil crusting at some sites in Limpopo, Mpumalanga, Kwazulu-Natal and the Eastern-Cape.

1.3.3 Impacts of vehicular traffic and other factors on soil compaction and crusting in eco-tourism areas in South Africa

Conditions under which ORD is done in game reserves are somewhat different from most of those in agriculture and forestry. The main difference is that in agriculture traffic is usually over disturbed (loosened) soil, except in no-till areas, while in game reserves ORD is usually done on virgin, undisturbed soils – although this is not always the case. Thus the wheel impact of vehicles may be somewhat different than in most agricultural and forestry scenarios. No previous studies on the impact of ORD in conservation areas have been done in South Africa, except the study by Nortjé (2005). Some studies have been done in game reserves and other protected areas elsewhere on the impacts of ORD on soil, vegetation and the environment, and are discussed below.

A study on the impact of ORD on soil compaction in desert areas was done by Adams *et al.* (1982). Their results showed severe soil compaction produced by off-road vehicles in camp sites, pit areas, and heavily used trails in the Mojave Desert. Intense compaction also occurred in well-used livestock trails. In controlled experiments on soil compaction produced by different numbers of motorcycle and four-wheel drive vehicles (Adams *et al.* 1982) found that 1) a motorcycle produced much smaller increases in soil strength than did a four-wheel drive vehicle, 2) soil strength of drying compacted soil (even slightly compacted soil) increased at a much greater rate than soil strength of drying un-compacted soil. This may be an explanation for observed reductions in annual desert plant growth even in areas with a relatively small amount of compaction.

Braunack (1986) showed that the impacts of a tracked vehicle passing over the soil resulted in a decrease in soil strength of the surface soil, an increase in bulk density, a decrease in saturated hydraulic conductivity and the formation of ruts. The degree of change depended on soil type, the number of vehicular passes and whether the vehicle was travelling in a straight line or turning. The results indicated that with dry soil conditions soil strength can be reduced by vehicular traffic. These results are contrary to the observation by Adams *et al.* (1982) where an increase in soil strength occurred after vehicular traffic. Adams *et al.* (1982), however, used a rubber tyre vehicle and not a tracked vehicle as reported in the Braunack (1986) study. The area of disturbance, both in terms of depth and width of ruts, is greater with an increasing number of vehicular passes.

Braunack (1986) found that soil bulk density increased with depth and with increasing number of vehicle passes. This agrees with the findings in South African research (Laker 2001; du Preez *et al.* 1979). However, the biggest change occurred after one pass, with subsequent passes having minimal effect (Braunack 1986). Adams *et al.* (1982) also demonstrated this trend. The degree of the change will depend on the soil water content at the time of vehicle passage (Braunack 1986). The increase in bulk density and decrease in hydraulic conductivity may affect plant growth and the erosion potential of an area after vehicular ORD. It also adversely affects the infiltration of rainfall and, thus, more water runoff.

In a study on the impact of heavy vehicles on sub-soil compaction Hakansson (1994) made the following conclusions:

- Shallow sub-soil compaction is determined by the inflation pressure of the vehicle tyres. This type of compaction is serious, because it restricts roots to very shallow depths;
- By contrast, in deep sub-soil layers, machinery-induced compaction is largely determined by the load on individual wheels.

Sub-soil compaction persists for decades and may even be permanent (Hakansson 1994). Sub-soil compaction usually leads to very persistent, possibly permanent crop yield reductions. Hakansson (1994) thus, recommended that a proper conservation strategy would be to avoid deep sub-soil compaction in the first place, rather than to attempt to cure it afterwards. Hakansson (1994) also made the following final recommendation: "From a soil conservation point of view it would be desirable to eliminate all random traffic by vehicles with high axle loads. One way to limit the impact is to limit the axle load. Another is the use of low-pressure tyres which may mitigate the effects in the upper part of the subsoil".

Results of a study by Webb (1978) on the environmental effects of soil property changes with off-road vehicle use showed that soil modifications caused by ORD included: (i) increased surface strength, i.e. crusting, (ii) increased bulk density, i.e. compaction and (iii) decreased soil moisture content in gravelly sandy loam, coarse sandy loam, sandy loam and clay soils. Decreases in soil pH, organic matter content, and plant nutrient content also occurred. These soil property changes contribute to accelerated erosion, and increase the environmental stress on plant seedlings, and thus create management problems in areas where ORD is practised.

In his study to assess the impact by off-road vehicles on desert soils Webb (1983) used dirt bikes to assess soil conditions after repeated passes of one, 10, 100 and 200. Results indicated that compaction usually occurs just below the surface and can extend up to one meter deep. Repeat passes revealed that compaction increased and infiltration decreased with the number of passes. Tyre tracks were visible after just one pass, while most annual vegetation was removed after ten. In addition to this study the United States Geological Survey (USGS) found that virtually all types of soils are vulnerable to off-road vehicle damage after examining more than 500 soils at more than 200 sites (Schubert & Associates 1999).

Dregne (1983) also showed that because of their weight, off-road vehicles compress and compact the soil, altering its ability to absorb and retain water and nutrients. Misak *et al.* (2002) also showed that by compacting and concentrating the surface flow of water, off-road vehicles increase erosion. Garland (1995) mentioned that if natural forests are protected as nature reserves, the soil can be stable against erosion. The opposite is true for plantations where gully erosion is extreme. In-depth erosion research by Garland *et al.* (1985) and Garland (1987, 1990) in mountain footpaths (hiking trails) in the Drakensberg, indicated that soil loss from these paths can be the most important form of accelerated erosion in wilderness and mountainous areas. This is also what could happen with tracks made by off-road vehicles (Nortjé 2005). These dirt tracks are sources of erosion. They are the starting points of gullies and run-off from these roads aggravates erosion (Garland 1990). A major result of soil crusting and soil compaction is soil erosion. Severe soil erosion is often found on game farms, game reserves and nature reserves (Laker 2004).

Game farms, game reserves and nature reserves are subjected to the same principles as domestic livestock farming (Laker 2004). Overstocking leads to overgrazing, soil crusting, and soil erosion. The most difficult situations are found in relatively small parks in sandstone areas, such as in the Waterberg or granite areas such as in the Lowveld of Mpumalanga and the Limpopo Province. In a game park, as opposed to a game farm or cattle farm where different veld types can be fenced off, fences are from an aesthetical point unacceptable. Game parks and game farms also tend to overstock because tourists want to see many animals (Gertenbach 2000). Because tourists want to come close to animals, these highly erodible soils are also where the dirt or off-road vehicle tracks occur, which become the starting point for dongas (Gertenbach 2000). The above-mentioned situation is aggravated if water drinking points are put in sensitive areas (Venter 1989).

Belnap & Warren (2002) studied the recovery of soil properties after disturbance by World War II-era military training exercises in the Mojave Desert. Recovery was measured approximately 55 years following disturbance. Tracks from military vehicles were still visible, particularly in areas of desert pavement. Soil penetrability was much lower in visible tracks than outside the tracks. Soils in tracks had fewer rocks in the top 10 cm of the soil profile than adjacent untracked soils. Larger particles (> 4.8 mm) formed a moderately well-developed pavement outside of the tracks, while smaller, loose particles (≤ 4.8 mm) dominated the surface of the tracks. The time required to restore the desert pavement is likely to be measured in centuries.

Knapp (1992) studied the residual effects persisting 75 years after the abandonment of two arid western Nevada town sites. It was found that significant differences remained in bulk density values between abandoned roads and undisturbed areas in both towns. Estimated soil recovery, based on a linear model using bulk density values, suggested that approximately 100-130 years would be required for complete recovery of abandoned roads to the original lower bulk densities. Up to 100 years could be required for complete recovery of the foundation periphery areas. The wetter town site, with more freeze-thaw days, finer-grained soils, and greater plant cover, had shorter recovery estimates. These findings suggest that the effect of human-induced impacts in arid areas may still be apparent long after disturbances cease. They also suggest that poorly structured soils (massive or single grained or with unstable prismatic structure) will take long to recover.

The above-mentioned results are in close agreement with similar previous studies that examined soil recovery times in the Mojave Desert (e.g. Webb & Wilshire 1980; Webb *et al.* 1986), and suggest that the results of soil compaction processes that occur in semi-arid and arid environments are long-lived, but are not irreversible. In Southern-Africa, areas which need to be careful for these kinds of impacts are Namibia and the western- and far-northern areas of South Africa.

In studies of the recovery of severely compacted soils in the Mojave Desert, Webb (2002) found that the recovery rates of these compacted soils appear to be logarithmic, with the highest rate of change occurring in the first few decades following abandonment. Using both linear and logarithmic models of recovery, recovery times varied between 92-100 years, and 105-124 years (85% recovery), respectively.

Recovery of soil compaction is significantly related to elevation, indicating that a complex interaction among the recovery mechanisms of wetting-and-drying cycles, freezing-thaw cycles, and bio-turbation is responsible (Webb 2002). Freeze-thaw cycles are greater at higher elevations (Webb 2002). Freeze-thaw cycles also occur at lower elevations at high latitudes, but not in tropical and subtropical areas and mid-latitude areas, such as those where the game parks of Africa are found. Wetting and drying cycles are effective only in swelling clay soils.

Kade & Warren (2002) also investigated soil and plant recovery after historical military disturbances which included both vehicle and foot traffic in the Sonoran Desert, USA. The extent of soil and plant recovery, which has occurred at specific camp site 56 year since abandonment, was assessed by comparing sites with historic disturbance to an apparently undisturbed control site. Different recovery results were found for the foot traffic site and the vehicle traffic site.

Wilshire *et al.* (1978) investigated the impacts of off-road vehicle traffic on soil and vegetation on natural terrain at seven sites in the San Francisco Bay area, USA. Plant cover of grass and chaparral (with shrubs to 4 m tall) was stripped by the two- and four-wheel vehicles in use. Impacts on loamy and sandy soils indicated reduced resilience of the land, which in turn adversely affects animal populations. Both the loss of plant cover and the physical changes caused by vehicles promoted erosion.

Studies by Wilshire *et al.* (1978) during the period 1976-1978 where observations were made at more than 400 sites in seven western states showed both direct and indirect impacts on vegetation. Direct effects included crushing and uprooting plants and indirect effects included modification of the soil so that plant damage is extended beyond the areas directly impacted by the vehicles and restoration of plant cover is inhibited.

Other studies by Cole & Bayfield (1983), Stensvold (2000) and Brown & McLachlan (2000) showed crushed vegetation, killing of seedlings and changes in the plant composition of forests, as well as the possible loss of sensitive plant species due to high ORD use.

Some studies have been done on the impact of ORD in Africa by Onyeanusi (1986), Bhandari (1998) and Nortjé (2005). The study of Onyeanusi in the Masai Mara Reserve in Kenya showed qualitatively negligible ecological loss due to ORD. But despite the light ecological damage recorded in this study, the negative aesthetic effects of the numerous secondary tracks, which are visible all over the reserve on the quality of game-viewing, constituted a management problem. The damage due to ORD was shown to be much less in the Masai Mara than in the Amboseli Reserve, also in Kenya. A possible reason for this can be that the greatest part of the Masai Mara consists of heavy black clay soils with swelling and shrinking characteristics ("black cotton" soils) (van Essen 2012, pers. comm).

In contrast to the study of Onyeanusi (1986), a study by Bhandari (1998) also in the Masai Mara Reserve and adjoining reserves in Kenya, where he assessed the impact of ORD, showed that ORD had strong negative impacts, which included: decreased biomass, reduced vegetation cover percentage, and changed and reduced species composition. Moreover, ORD had strong negative impacts on the soil, viz. higher soil compaction and lower infiltration rates. The results also showed that management intervention in the form of closure of areas for ORD has a significant positive impact on the environment of the damaged area. However, it was found that the vegetation recovery after closure for ORD was very slow. The general public as well as park personnel also believed that ORD had strong negative impacts on the vegetation, soil and wildlife.

Roots are particularly important because of the biopores which they leave when they decay. Biopores (comprising root channel and earthworm tunnels) can provide important pathways for root penetration of subsequent crops, and it is shown that they can result in significant yield increase. It is suggested that these "natural" processes can be developed and exploited as "modified" natural processes, and that a considerable potential exists for using them to improve our soils at a modest cost. Dexter & Hewitt (1978) also looked at the deflection of plant roots when meeting a compacted soil layer. When a plant root meets an interface within soil, either it is deflected or it penetrates the interface and enters the new medium. If the root has just grown across a void, it may buckle when it meets the interface and hence be deflected. If a number of roots have grown through a weak soil medium and meet a stronger soil medium, the proportion penetrating depends on the strengths of the two media and on the angle of incidence of the roots with the interface. The results of this study on wheat, barley and pea indicated the significance of soil structure and strength factors on the distribution and morphology of roots.

The effects of soil compaction on soil strength (the mechanical resistance of soil against root penetration) have been studied intensively in South Africa in the 1970's (Bennie 1972; Burger *et al*. 1979; Bennie & Burger 1979). High soil strengths in compacted layers limit roots to very shallow depths. This is true for both annual and perennial crops. There also are differences between different crops with regards to the degree to which their root development is restricted by high soil strengths. In general, crops with tap toot systems are extremely sensitive to high soil strengths and more so than plants with other kinds of root systems.

Bennie (1972) showed in experiments with wheat and cotton, that increasing soil strengths at ideal soil water conditions decreased the mass and volume of the root systems and the tap root lengths of wheat and cotton respectively. Bennie (1972) also indicated strongly decreased nutrient uptake of P, K and Ca due to soil compaction.

1.4 Guidelines

As mentioned before, no scientifically tested guidelines and norms exist in South African protected areas with regards to ORD. Basic best practice guidelines for ORD were determined in the "Concession's Best Practice Manual" for the concessions in the KNP (van der Merwe 2004). The ORD guidelines are shown in Table 1.1. In reality, each concession area in the KNP, practised different variations of these ORD guidelines (van der Merwe 2004).

Table 1.1 Concession best practice ORD guidelines

- The concession should develop a **Code of Conduct** for the ORD activity, and guides that apply a **sensible approach** towards this activity should be awarded;
- ORD should be **monitored** per guide, and any incident where **animal behaviour** was affected should be recorded. "Problem Guides" can then be identified and dealt with;
- Guides should be **trained** to recognize problem soils and have sufficient knowledge to take a decision on a possible ORD event. When in doubt guides must adhere to the "**precautionary approach**" and avoid ORD;
- No ORD is allowed on any **sensitive soils** as highlighted in applicable soil maps and zones of sensitivity. These zones are often red flagged during the environmental investigation assessment process. All other soils must still be treated with respect within the environmental framework described in the EIA document;
- ORD may only be pursued in the event of a **confirmed sighting** of the Big 5 including wild dog and cheetah;
- No ORD is allowed on duplex/sodic soils;
- No ORD is allowed on saturated clay soils;
- ORD is never permitted during **wet conditions**;
- ORD is not permitted near- or on **Research Monitoring sites**;
- ORD is not permitted near any known **cultural- or historical sites**;
- ORD is not permitted near any known **Red Data** plant communities;
- Vehicles that drive off-road may not follow in each other's tracks (concept requires further investigation and research);
- ORD is not allowed **near/at river crossings**, along riverbeds or within the vicinity of any camp;
- ORD is not allowed on **seep (drainage) lines**, over **bush clumps** or **termite mounds**;
- No ORD is allowed through **pans or seasonal troughs**, which may provide shelter for terrapins and other amphibians;
- No ORD is allowed on **over-grazed patches** or veld that has been recently burned;
- ORD is not permitted over logs, underground burrows, or wild dog dens. **Common sense** should prevail at all times;
- The Reserve Warden/Head Ranger will collect copies of all the daily ORD incidents as compiled in and ORD Register. He will monitor all Off-Road Driving Events (ORDE's) and compile a monthly register for submission to the Management Committee;
- All ORD sites must be rehabilitated in the event of these sites being damaged for whatever reason. The Reserve Warden must be compelled to register the site using GPS, take photographs and initiate an intensive rehabilitation programme. Never re-use the site again.

Other specific guidelines established for the purpose of this study and for the purpose of setting a baseline (reference) for predicting off-road driving damage should be as follows:

- Vehicles should not exceed speeds of 20 km/h (preferably 10 km/h) and areas requiring the use of low range gears are to be avoided altogether;
- No harvesting of vegetation for the purpose of path-clearing is permitted;
- Bush clumps and woody vegetation are not to be traversed;
- No off-road driving is to be permitted on newly burnt areas;
- Wheel spin is unacceptable under any conditions. Negotiate all inclines in low range (second gear) to avoid causing erosion spots where wheels spin;
- When driving through gullies, avoid exiting or entering at right angles. Enter or leave obliquely to avoid creating vertical channels for water run-off;
- Should the vehicle get stuck anywhere, or make deep ruts, the onus is on the ranger to return to the site and rehabilitate it. A photograph should be taken before rehabilitation and the site clearly marked and described on a map, preferably with a GPS coordinate, so that the Environmental Control Officer can visit the site even after the ranger is no longer working at the lodge (such photographs will be important as evidence that such events can be successfully rehabilitated - figures 5, 6);
- Rehabilitation should involve pushing the soil that has been displaced back into the ruts and smoothing over the soil

surface. If the ruts are very deep, it may be a good idea to place branches in the ruts to bind the soil and then to fill it in again. The most important aspect of rehabilitation is that the track must not be used again.

Off-road driving should avoid:

- Sensitive soils (see soils map legend for each concession);
- Areas that are waterlogged as a consequence of rainfall events;
- Any natural wetland area;
- Rocky outcrops;
- Steep slopes (slopes requiring the use of low range gears);
- Overgrazed areas.

The Concession Best Practice Manual (van der Merwe 2004) defines "off-road driving best practise" as follows: "**Off-road driving best practice** describes the activity of traversing off formal roads under the guidance of trained professionals, onto soils which can accommodate this activity and under specific conditions and guidelines (mentioned above) in order to optimise the activity of game viewing up close whilst not damaging the sensitive ecology of the area".

1.5 Survey of ORD in Selected Concession Areas in the KNP

Off-road driving was monitored in selected concession areas in the KNP and the damage qualitatively assessed over a period of three years from 2004-2006 (Nortjé 2005). A very important finding was that ORD was random in all cases, i.e. driving with no consideration for the environment and wildlife. Where more than one game drive vehicle going off-road approached a specific sighting they did not follow in the tracks made by the first one, but each vehicle followed a different route and made new tracks (Nortjé 2005). In doing this they followed the KNP guidelines, but in view of the results discussed earlier, these guidelines are probably opposite to what they should be. It was found that towards some sightings ORD was for substantial distances, even up to 2 000 m (or 2 km).

Nortjé (2005) found that ORD was concentrated in certain areas where there were bigger chances of seeing special animals, like lions, leopards and cheetahs. These included areas along rivers and plains, within limited distances from lodges. So, while ORD densities might have been low based on a total aerial base, they were quite high in some critical areas. No significant differences occurred between the distances driving off-road on the different soil types in the areas where ORD was concentrated. Results showed that ORD had strongly negative impacts on the soil and vegetation (soil compaction, ruts, erosion, broken shrubs and flattened grass). Off-road damage was much more severe on wet soils than on dry soils, and the damage on wet soils took much longer to recover (Nortjé 2005).

Off-road damage after the incidents was monitored using digital photography and this monitoring continued for a period of three years. Results from this monitoring showed that under certain climatic conditions and soil types, damage may not recover naturally, or recovery times may be very long. A very important finding was that the number of ORD incidents per year increased from the first, second and to the third year. This tendency was observed at all four concession areas. The results also indicated that ORD is random and not well organized and planned contrary to what was always believed (Nortjé 2005). The following quote describes the meaning of "random" excellently with regards to ORD in some of the APNRs: "you can imagine the type of driving going on here, as well as, all the 'tracks' visible all over the place, new and old!" (Anonymous 2012, pers. comm).

Especially important with regards to the above-mentioned quote is the accent on "tracks visible" (there is an aesthetic impact other than the impact on the soil and vegetation), "all over the place"(which means a lot of ORD), and "new and old" (the impact does not disappear quickly).

1.6 Conclusion

Increased soil erosion, damage to vegetation and habitat destruction are just some of the visible negative impacts of ORD. Hidden negative impacts of ORD with serious implications include soil compaction, leading to limited root penetration and consequently poor nutrient and water uptake by plants, and soil crusting (surface sealing), preventing seedling emergence and leading to poor germination. The literature review conducted for this study showed that a large number of compaction studies have been done in the agricultural sector, forestry, some in protected areas and some in arid areas. It also showed that recovery times of compacted and damaged soil are very long or may never happen, as indicated by Belnap & Warren (2002); Knapp (1992); Webb (2002); Webb *et al.* (1986); Webb & Wilshire (1980).

In the western world ORD is done mainly for the purposes of outdoor recreation, but in most African countries known for their wildlife, game reserves and national parks, it is mainly for game-viewing purposes as part of eco-tourism. In national parks and game reserves in Kenya, Tanzania, Botswana, Zimbabwe and other countries in southern and eastern Africa this practice has been done for more than 30 years (Bhandari 1998). ORD for recreational purposes has been practised for quite some time in South Africa. However, the use of ORD for game viewing purposes in game reserves and national parks is a new trend in South Africa. It started only about 11 years ago (Nortjé 2005).

Natural resource areas in developing countries are being depleted every day. High population pressures, causing an increasing demand for natural resources for various purposes is the reason for this destruction of natural resources (Barrow 1991). Increasing human population, mobility and participation in recreational activities have exerted pressure on finite resources of land and water all over the world. This threatens not only nature but also the quality of recreation itself (van der Zee 1992).

People, especially urban dwellers from developed countries, want a closer view of wildlife and they also want to study their behaviour closer (Bhandari 1998). The vastly greater international mobility has increased demands for closer wildlife viewing in game reserves and national parks in South Africa rapidly. This desire of tourists, but also the fact that ORD in protected areas has been allowed and legitimatized, has raised the question of soil and vegetation damage due to this practice.

With regards to research needs, the literature review suggested that special attention should be given to regional studies that consider particular qualities of the geography, soil, climate, human uses, tourists and land ownership patterns. This is exactly what has prompted the current study.

1.7 References

- Adams, J.A., Endo, A.S., Stolzy, L.H., Rowlands, P.G. & Johnson, H.B. (1982) Controlled experiments on soil compaction produced by off-road vehicles in the Mojave Desert, California. *J Appl Ecol,* 19/1, 167-175.
- Bainbridge, W.R., Motsamai, B., Weaver, L.C. (eds.) (1991) Report of the Drakensberg/ Maluti conservation programme. Natal Parks Board, Pietermaritzburg, South Africa.
- Barrow, C.J. (1991) Caring for the Earth: a strategy for sustainable living. Published by IUCN (World Conservation Union), UNEP (United Nations Environment Programme) and WWF (World Wide Fund for Nature). London, Earthscan, pp. 228.
- Belnap, J., & Warren, S.D. (2002) Patton's tracks in the Mojave Desert, USA: an ecological legacy. *Arid Land Res Manag*, 16, 245-258.

- Bennie, A.T.P. (1972) 'n Ondersoek na sekere aspekte van grondsterkte in gronde van die manganoserie. MSc(Agric) thesis, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Bennie, A.T.P. & Burger, R.d.T. (1979) Grondverdigting onder besproeiing op die Vaalharts besproeiingskema. Volume II: Die invloed van grondverdigting op die grond-plant sisteem. Dept. Grondkunde, Verslag, 79/2, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Bennie, A.T.P. & Krynauw, G.N. (1985) Causes, adverse effects and control of soil compaction. *S Afr J Plant Soil*, 2, 109-114.
- Bhandari, M.P. (1998) Assessing the impact of off-road driving on the Masai Mara National Reserve and adjoining areas, Kenya. Masters dissertation, International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands.
- Bloem, A.A. (1992) Kriteria vir die aanpassing van die ontwerp en bestuur van oorhoofse besproeiingstelsels by die infiltreerbaarheid van gronde. MSc thesis, University of Pretoria.
- Botha, F.J.P., Bennie, A.T.P. & Burger, R.d.T. (1981) The influence of polyvinyl alcohol stabilisation on the strength characteristics of fine sandy soils. *Agrochemophysica*, 13, 43-46
- Braunack, M.V. (1986) Changes in physical properties of two dry soils during tracked vehicle passage. *J Terramechanics*, 23/3, 141-151.
- Brown, A.C. & McLachlan, A. (2000) Sandy shore ecosystems and threats facing them: some predictions for the year 2025. *Environ Conserv*, 29/1, 62-77.
- Burger, R.d.T., Bennie, A.T.P., Botha, F.J.P. & du Preez, C.C. (1979) Grondverdigting onder besproeiing op die Vaalharts besproeiingskema. Volume I: Samevattende verslag. Dept. Grondkunde, Verslag, 79/1, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Cole, D.N., & Bayfield, N.P. (1983) Recreational trampling of vegetation: Standard experimental procedures. *Biol Conserv*, 63/3, 209-215.
- Dexter, A.R. & Hewitt, J.S. (1978) The deflection of plant roots. *J Agr Eng Res*, 23, 17-22.
- Donaldson, C.H. (2001) Simple techniques for estimating soil compaction. Grootfontein Agricultural Development Institute. *Karoo Agric*, 3/7 - article source: (accessed 12th February 2013) http://gadi.agric.za/articles/Agric/simple.php.
- Dregne, H.E. (1983) Physical effects of off-road vehicle use. In: *Environmental effects of off-road vehicles* (eds. Webb, R.H. & Wilshire, H.G.). Springer-Verlag: New York, pp. 15-30.

- Du Preez, C.C., Bennie, A.T.P. & Burger, R.d.T. (1979) Grondverdigting onder besproeiing op die Vaalharts besproeiingskema. Volume 3: Die oorsake en bekamping van verdigting van sanderige besproeiingsgronde. Dept. Grondkunde, Verslag 79/3, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Du Preez, C.C., Bennie, A.T.P. & Burger, R.d.T. (1981) Invloed van implementverkeer en besproeiing op grondverdigting te Vaalharts. *Agrochemophysica*, 13, 7-12.
- Garland, G.G. (1985) *Soil erosion in South Africa: a technical review*. Report for the Nat Dept Agric, Dir Res Cons Dept Geogr and Environ Sci, University of Natal, Durban.
- Garland, G.G. (1987) Rates of soil loss from mountain footpaths: an experimental study in the Drakensberg Mountains, South Africa. *Appl Geogr*, 7, 41-54.
- Garland, G.G. (1990) Technique for assessing erosion risk from mountain footpaths. *Environ Manage*, 14, 793-798.
- Garland, G.G., Hudson, C. & Blackshaw, J. (1985) An approach to the study of path erosion in the Natal Drakensberg, a mountain wilderness area. *Environ Conserv*, 12, 337-342.
- Gertenbach, W. (2000) Personnal communication. In: *Advances in soil erosion, soil conservation, land suitability evaluation and land use planning research in South Africa, 1978-2003* (ed: Laker, M.C.). *S Afr J Plant Soil*, 21/5, 345-368.
- Hakansson, I. (1994) Subsoil compaction caused by heavy vehicles: a long-term threat to soil productivity. *Soil Till Res*, 29, 105-110.
- Henning, J.A.G., Nel, D.J. & Harmse, H.J.v.M. (1986) Die invloed van verdigtingspoging, klei- en waterinhoud op verdigting van geselekteerde Hoëveldgronde. *S Afr J Plant Soil*, 3, 119-122.
- Joubert, D. (1993) Relationship between soil compaction and *Phytophtora* root rot of citrus. MSc (Agric) thesis, University of Pretoria, pp. 117.
- Kade, A. & Warren, S.D. (2002) Soil and plant recovery after historic military disturbances in the Sonoran Desert, USA. *Arid Land Res Manag*, 16, 231-241.
- Knapp, P.A. (1992) Soil loosening processes following the abandonment of two arid western Nevada town sites. *Great Basin Nat*, 52/2, 149-154.
- Laker, M.C. (2001) Soil compaction: effects and amelioration. *P S Afr Sug*, 75, 125-128.
- Laker, M.C. (2004) Advances in soil erosion, soil conservation, land suitability evaluation and land use planning research in South Africa, 1978-2003. *S Afr J Plant Soil*, 21/5, 345-368.
- Laker, M.C. (2005) *South Africa's soil resources and sustainable development*. Draft report for Dept Environ Affairs, South Africa.

- Mallet, J.B., Koch, C.D., Visser, P.A. & Botha, A.J. (1985) Tillage-related soil compaction and its effect upon maize grain yields on a Viljoenskroon fine sand. *S Afr J Plant Soil*, 2, 52-56.
- Mills, A.J. & Fey, M.V. (2004) Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. *S Afr J Plant Soil*, 21, 388-398.
- Misak, R.F., Al Awadhi, J.M., Omar, S.A, & Shahid, S.A. (2002) Soil degradation in Kabad area, southwestern Kuwait City. *Land Degrad Dev*, 13/5, 403-415.
- Mitchell, F.J. & Berry, W.A.J. (2001) The effects and management of compaction in agricultural soils. *P S Afr Sug*, 75, 118-124.
- Nortjé, G.P. (2005) The impacts of off-road driving and other concessionaire activities on physical soil degradation. MPhil thesis, Centre for Wildlife Management, University of Pretoria.
- Onyeanusi, A.E. (1986) Measurement of impact of tourist off-road driving on grass-lands in Masai Mara National Reserve, Kenya: a simulation approach. *Environ Conserv*, 13/4, 325-329.
- Schubert & Associates (1999) Petition to enhance and expand regulations governing the administration of recreational off-road vehicle use on National Forests. Published in Wildlands CPR, Missoula, MT, USA, pp. 188 - article source: (accessed 10th March 2010) www.wildlandscpr.org/orvs/ORVpetition.doc.
- Smith, C.W. & Johnston, M.A. (2001) Managing soil compaction to ensure long-term site productivity in South African forest plantations. *P S Afr Sug*, 75, 129-136.
- South African Sugar Technologist's Association (SASTA) (2001) Soil compaction work-shop proceedings, August 2001. CD-ROM. Mt Edgecombe, Durban.
- Stensvold, M.C. (2000) The conservation status of Ophioglossaceae in southern Alaska. *PBotany 2000*. August 6-10. Portland, OR.
- Stern, R. (1990) Effects of soil properties and chemical ameliorants on seal formation, run-off and erosion. DscAgric thesis, University of Pretoria.
- Unger, P.W. (1996) Soil bulk density, penetration resistance, and hydraulic conductivity under controlled traffic conditions. *Soil Till Res*, 37, 67-75.
- Van Antwerpen, R., Lyne, P.W.L., Meyer, E. & Brouwers, M. (2007) Changes in bulk density of a virgin soil due to compaction by commercial haulage vehicles. *P Int Soc Sugar Cane Techn*, 26, 470-475.
- Van Antwerpen, R., Lyne, P.W.L., Meyer, E. & Brouwers, M. (2008) Effect of surface applied pressure by vehicles fitted with pneumatic tyres on properties of a virgin soil. *P S Afr Sug*, 81, 408-417.

- Van Antwerpen, R. & Meyer, E. (2001) The effects of residue management and vehicle characteristics on soil compaction. *P S Afr Sug*, 75.
- Van Antwerpen, R., Meyer, J.H. & Meyer, E. (2000) Soil compaction in the South African Sugar industry: a review. *P S Afr Sug*, 74, 101-108.
- Van der Merwe, L. (2004) Guidelines for off-road driving in the private concessions of the Kruger National Park. Concessions Operations Manual, KNP.
- Van der Watt, H.v.H. & Van Rooyen, T.H. (1995) A Glossary of Soil Science, 2nd edn. The Soil Science Society of South Africa, Pretoria.
- Van der Zee, D. (1992) Recreation studied from above: air photo interpretation as input into land evaluation for recreation, ITC, Publication 12.
- Venter, F.J. (1989) Personal communication. In: *Advances in soil erosion, soil conservation, land suitability evaluation and land use planning research in South Africa, 1978-2003* (ed: Laker, M.C.). *S Afr J Plant Soil*, 21/5, 345-368.
- Webb, R.H. (1978) Environmental effects of soil property changes with off-road vehicle use. *Environ Manage*, 2/3, 219-233.
- Webb, R.H. (1983) Compaction of desert soils by off-road vehicles. In: *Environmental effects of off-road vehicles* (eds. Webb, R.H. & Wishire, H.G.). Springer-Verlag, New York.
- Webb, R.H. (2002) Recovery of severely compacted soils in the Mojave Desert, California, USA. *Arid Land Res Manag*, 16, 291-305.
- Webb, R.H., Steiger, J.W. & Wilshire, H.G. (1986) Recovery of compacted soils in Mojave Desert ghost towns. *Soil Sci Soc Am J*, 50, 1341-1344.
- Webb, R.H. & Wilshire, H.G. (1980) Recovery of soils and vegetation in a Mojave Desert ghost town, Nevada, USA. *J Arid Environ*, 3, 291-303.
- Wilshire, H.G., Nakata, J.K., Shipley, S., & Prestegaard, (1978) Impacts of vehicles on natural terrain at seven sites in the San Francisco Bay area. *Environ Geol*, 2, 295-319.

CHAPTER 2

BACKGROUND TO THE PRESENT STUDY

2.1 Motivation/Rationale

"Given the pressures of commercial ecotourism operations within the South African Lowveld and the belief that it is possible to engage in off-road driving without suffering major environmental impact, Wilderness Safaris has decided to take up the right as expressed in their respective contracts with the Makuleke Community Property Association to engage in limited off-road driving in the Makuleke Contractual Park. This contractual right was voluntary suspended by all three parties in 2005 pending a better understanding of the area" (Appendix A).

The impact of off-road vehicles on soil compaction in a Game Park has not previously been demonstrated in South Africa. Thus, the present study was undertaken in the Makuleke Contractual Park (MCP), in the far northern section of the Kruger National Park (KNP). The study has three main components:

- Measurement of the impact of off-road driving (ORD) on the environment, specifically sub-soil compaction, with the aim of improving the management of ORD in order to minimize its negative environmental impact;
- Studies on the perceptions and attitudes of tourists;
- Development of proposals for improving (i) awareness amongst tourists regarding the impacts of ORD, so as to minimize their expectations and demands of tourists that could lead to enhanced environmental degradation and (ii) legislation and regulations required to limit the environmental impacts of ORD.

2.2 Objectives

Concession operators are allowed certain tourist-attracting activities, including ORD, aimed at bringing tourists in close contact with members of the 'Big Five' in wildlife (van der Merwe 2004). It seems as if such activities are often implemented without knowledge regarding the full potential impacts of the activities on the environment and more particularly the soils (Nortjé 2005).

The objectives of this study were therefore four-fold:

1. To determine whether off-road vehicle traffic causes sub-soil compaction, and if so to what extent;
2. To quantify the impact of sub-soil compaction on vegetation growth, specifically root growth and distribution;
3. To determine to what extent tourists' perceptions and attitudes influence ORD;
4. To develop proposals for improving tourist awareness and legislation regarding ORD.

2.3 Selection of the Study Area and Identification of Experimental Sites

The specific study area was selected after Wilderness Safaris (WS), the concession eco-tourism operator, expressed its willingness to cooperate in such a study. They wanted to take up their right to drive off-road by contract, so as to remain competitive with the other concessions operating in the KNP. WS wanted to operate in a responsible way (Appendix A). They, thus, decided that pending the results of such study after a period of three years, they will decide whether to continue with the practice or not.

Wilderness Safaris, the eco-tourism partner in the Joint Management Board (KNP, Makuleke Community and WS) of the MCP was approached in 2008 and a proposal submitted to execute this study. WS was very receptive to this proposal, got all the relevant administration in order, and went through all the correct procedures to start with ORD for the three year trial period (Roche 2008, pers. comm). The objective of the proposal stated in short: "a study to quantify the impacts of off-road driving on soil compaction" (Appendix A).

Off-road monitoring in the MCP commenced on the 1st of April 2009. Monitoring continued for one year. After this one year period of monitoring three representative trial sites were chosen to conduct trials on the impact of ORD. The monitoring was done with the use of GPS tracking devices, as well as Geographic Information Systems (GIS) to determine 'hot' and 'cold' spots of ORD. The 'hot' and 'cold' spots of ORD represent the areas with the most and least ORD frequencies, respectively. The kernel density of ORD, which represents the number of off-road events per km^2 over this one year period, was calculated and mapped, to help in the selection of the trial sites (Fig. 2.1). Sites were chosen at the hot spots of ORD to represent the soil forms most likely to be used for ORD. The soils chosen represented two different soil forms in the South African soil classification system (Soil Classification Working Group 1991). According to this classification system, the two soil forms were Oakleaf and Dundee, where the Oakleaf soil form represented two of the trial sites (Sites 1 and 3) and the Dundee soil form one site (Site 2). The Oakleaf soils are classified as Cambisols according to WRB (1998) and the Dundee soils as Fluvisols.

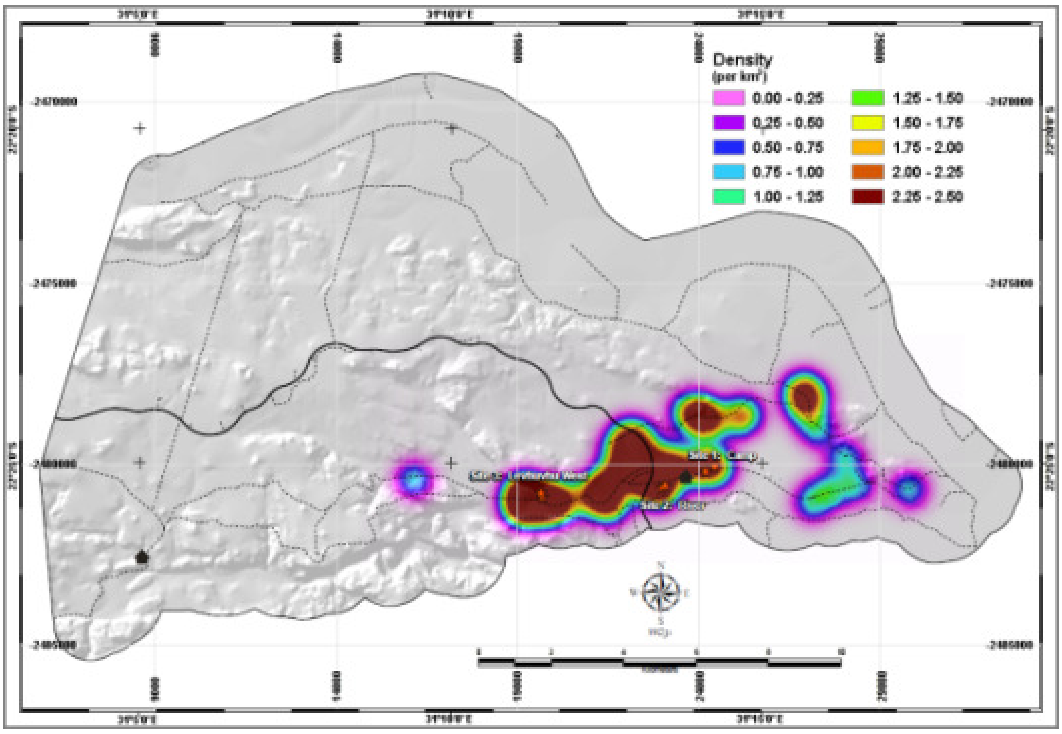


Figure 2.1 Map indicating off-road density in Pafuri between April 2009 and March 2010

2.4 Locality of the Study Area

The study was conducted in the MCP, in the far northern Pafuri section of the KNP, South Africa (22° 23' S; 31° 08' E) (Fig. 2.2). The study area covered 203 km^2 (1.2%) of the KNP or 20 255 hectares (Pafuri factsheet 2011). It is bordered by the Limpopo River, the boundary between South Africa and Zimbabwe, in the north, Mozambique to the east, and the Luvuvhu River, forming the natural boundary between the Makuleke area and the rest of the KNP, to the south. The western boundary of the MCP is fenced in and borders on the Limpopo Province of South Africa.

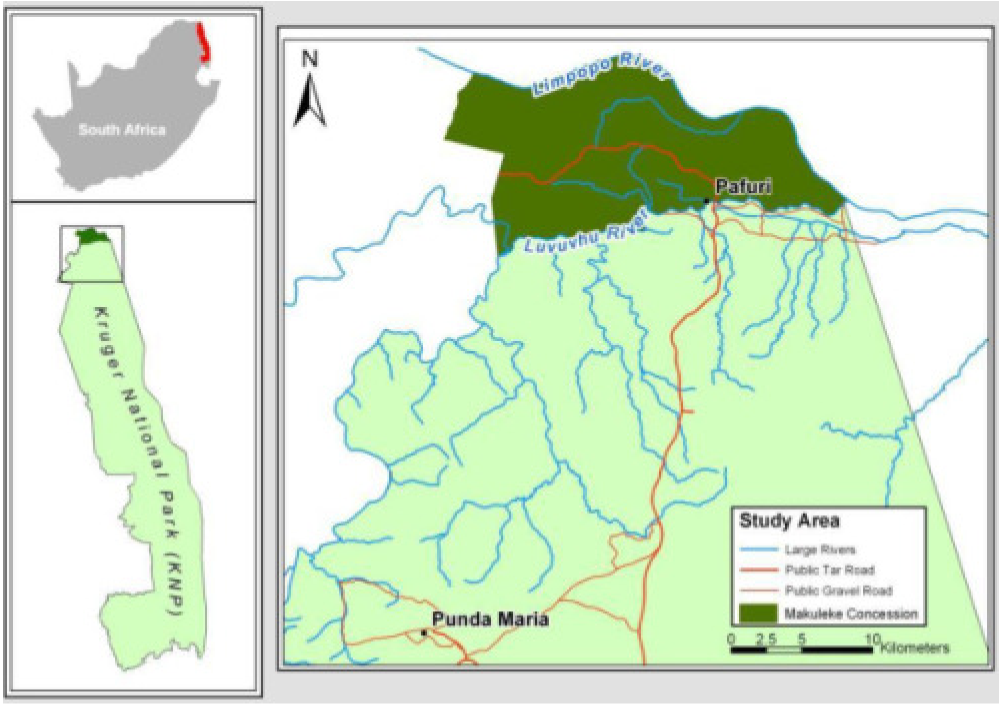


Figure 2.2 Makuleke Contractual Park, far Northern KNP

2.5 Description of the Study Area

2.5.1 Climate

The area is characterized by low rainfall and high temperatures (Tinley 1981a). The long term (80 years) average annual rainfall for the area, according to the official records of the South African Weather Service, is 422.8 mm (de Jager 2012, pers. comm). The four year average annual rainfall over the study period was somewhat lower at 389 mm (Nortjé 2013, pers. obs). Pafuri is reported to have the lowest rainfall in its region (Tinley 1981a). It has a nine to ten month arid period and two to three months moist, but no month exceeding 100 mm rainfall (Tinley 1981a). This is primarily due to the frequent high pressure system that forms above the Limpopo Valley, causing drought conditions along the entire eastern border (Tinley 1981a). The area has a short summer rain season, with almost no rain falling in winter (Fig. 2.3).

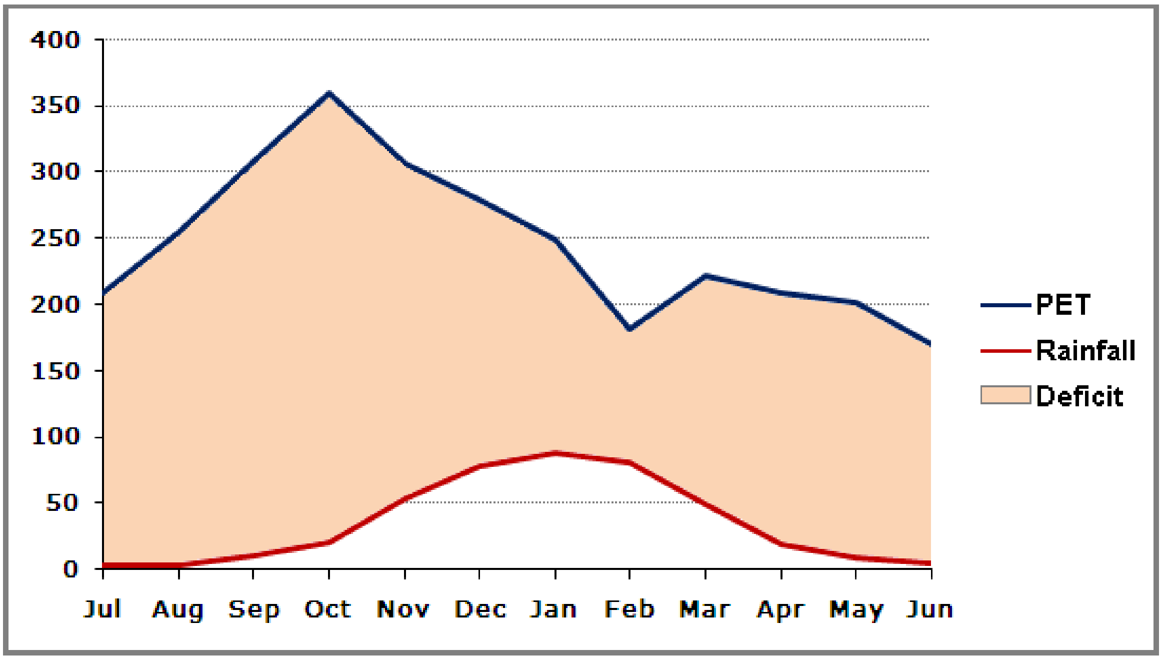


Figure 2.3 Pafuri long-term average rainfall, potential evapo-transpiration and water deficit (mm)

Throughout the year the Potential Evapo-Transpiration (PET) of the area far exceeds the rainfall, even during the rainy season, causing huge water deficits and making it a very dry area (Fig. 2.3, Table 2.1). Like virtually the whole KNP the climate of the area is classified as semi-arid (de Jager 2012, pers. comm), but here it borders on being classified as arid. Even Skukuza, in the south of the KNP with much higher rainfall, has a large water deficit (Fig. 2.4, Table 2.1) but much lower compared to Pafuri.

Table 2.1 Rainfall, PET and Deficit data for Pafuri and Skukuza

	Skukuza			Pafuri		
Months	**Rain**	**PET**	**Deficit**	**Rain**	**PET**	**Deficit**
July	9	96.6	-87.6	3.3	208.8	-205.5
August	7	126.9	-119.9	3.9	255	-251.1
September	24	160.7	-136.7	11.1	307.7	-296.6
October	35	179.9	-144.9	20.5	360.1	-339.6
November	75	169.6	-94.6	53.7	307.6	-253.9
December	86	194.8	-108.8	79.1	280	-200.9
January	96	198.6	-102.6	88.6	249.4	-160.8
February	92	166.3	-74.3	81.2	181.2	-100.0
March	72	160.6	-88.6	49.3	222.2	-172.9
April	35	124.7	-89.7	19.8	208.9	-189.1
May	14	103.9	-89.9	8.5	202.2	-193.7
June	8	85.8	-77.8	4.5	170.4	-165.9
Total	553	1768.4	-1215.4	423.5	2953.5	-2530

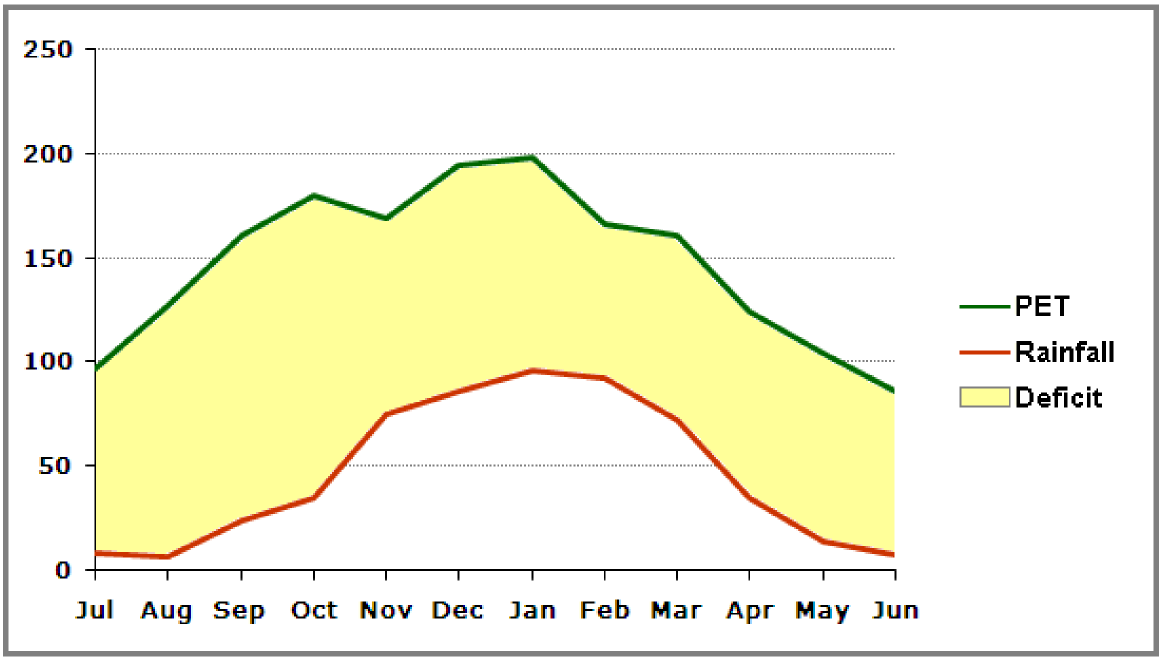


Figure 2.4 Skukuza long-term average rainfall, PET and water deficit (mm)

The lowest annual rainfall ever recorded in Pafuri was during 1983, when only 136.5 mm of rain fell (de Jager 2012, pers. comm). Another very dry period was during 2005 when only 142.4 mm of rain fell. Such dry periods alternated with regular flood periods during the years 1930, 1972, 1977/1978, 1999/2000 and 2003/2004 (de Jager 2012, pers. comm). The fact remains that drought periods are frequently experienced in this region of the KNP.

The temperature data over a period of 10 years for Pafuri (de Jager 2012, pers. comm) are given in Fig. 2.5. The record maximum and minimum temperatures vary between 47.5 °C for November to 0.8 °C for July, respectively. It is, therefore, possible that frost can occur in this area (van Rooyen 1978). From Fig. 2.5 it is clear that the maximum temperatures are very high and the maximum temperature difference, between summer and winter, is small. This is because the area lies within the tropics (north of the tropic of Capricorn) (Tinley 1981a). No other area of equal bio geographic importance in South Africa lies entirely within the tropics.

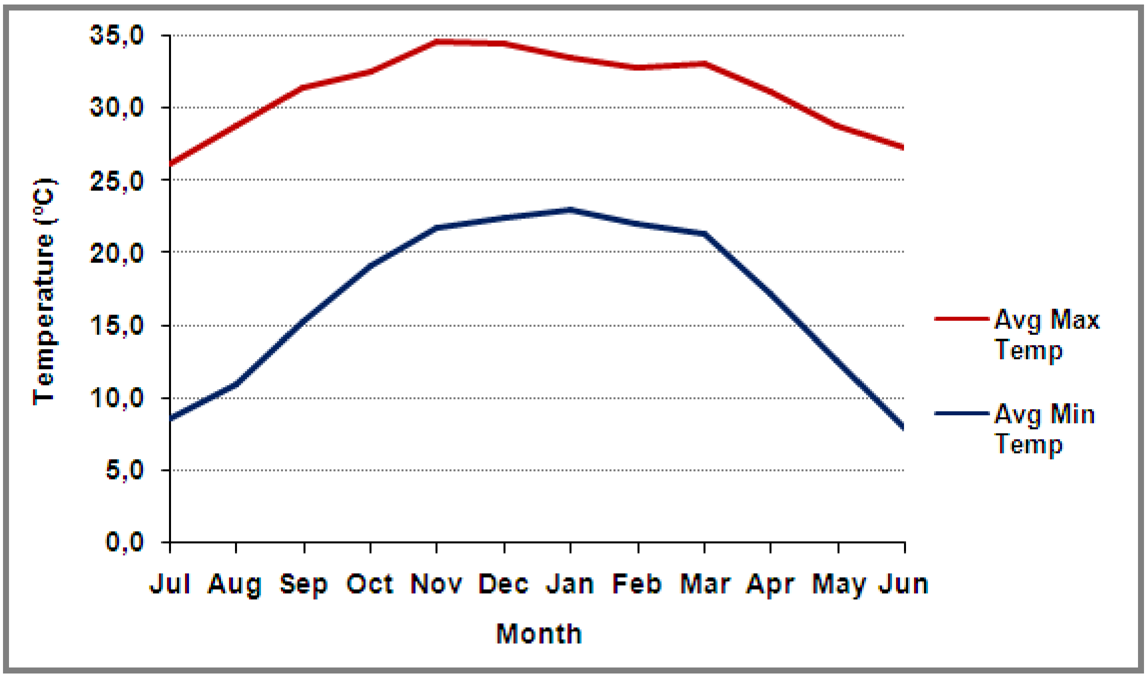


Figure 2.5 Pafuri average annual/monthly temperature distribution over 6 years (1994-1999)

The lowest daily minimum temperature recorded during the study period was 0 °C, and the highest daily maximum temperature recorded was 49.0 °C. The annual average temperature during the study period was 24.1 °C (Nortjé 2012, pers. obs). The wind in this region is mainly north easterly to south easterly, with some local deflection due to the topography (Seaton Thomas & Associates 2003). The south eastern wind brings cool weather, clouds and rain, whilst the north eastern wind brings fine weather. The area is also subject to the hot and dusty berg winds, which blow from the North West during autumn. In early spring, the winds come from the interior of South Africa, often preceding a cold front.

2.5.2 Topography

The topography of the area varies from strongly undulating, rugged low mountains and hills associated with elevated sandstone sediments in the central and western areas, to slightly undulating and concave land, associated with the alluvial deposits which flank the Luvuvhu and Limpopo Rivers in the northern, eastern and southern areas (Fig. 2.6) (Schutte 1974; Venter 1990).

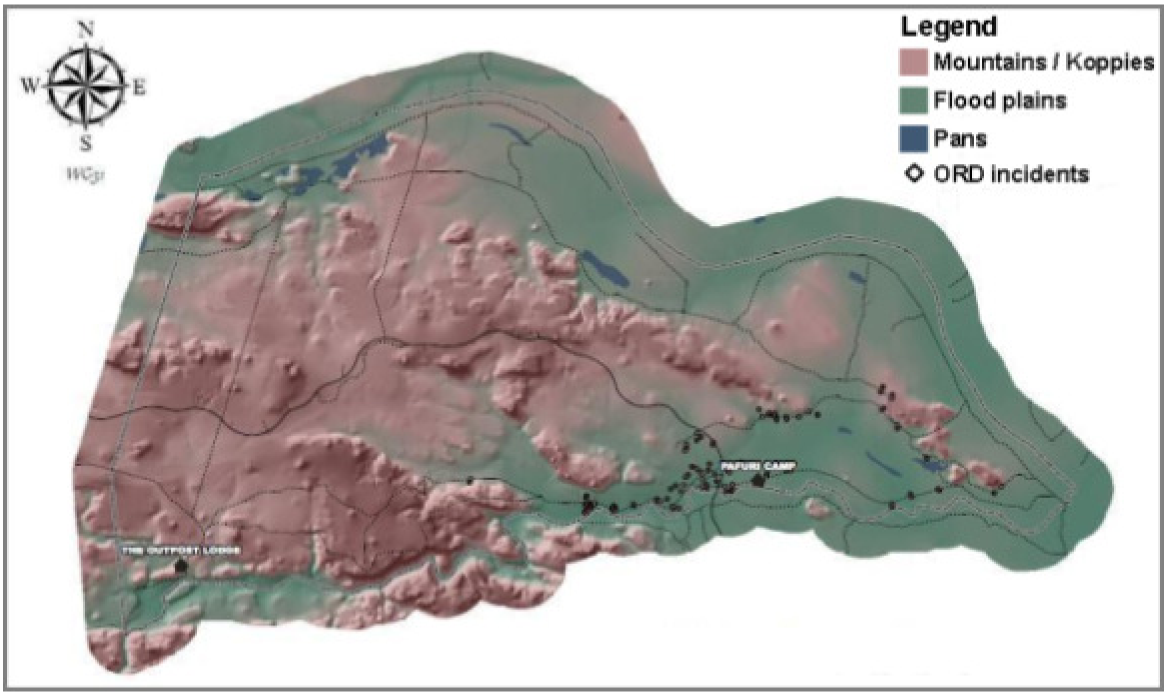


Figure 2.6 Topography of the Makuleke Contractual Park

The high relief which characterizes the central and western areas is mainly due to the resistance to weathering of the rocks, as well as to the erosive actions of the Luvuvhu River and its tributaries (Venter 1990). The elevation of the area varies between 150 m on the flood plains and 475 m in the mountains (Fig. 2.6). In the southwest the Luvuvhu River has cut a deep gorge into the local rocks.

The area of main concern with regards to this study is the Limpopo-Luvuvhu flood plains. The flood plains of the Luvuvhu River are where most animal and predator sightings and, therefore, ORD activities occur (Fig. 2.1). The other main landscapes are barely if not at all used for ORD (Nortjé *et al.* 2012). The Luvuvhu flood plains (Fig. 2.6) are characterized by flat to slightly undulating and concave land (Gertenbach 1983). Several large seasonal pans also occur in the flood plains of both the Limpopo and Luvuvhu Rivers (Fig. 2.6).

Large areas of the flood plains are occasionally temporarily inundated by flood water from either the Limpopo or Luvuvhu Rivers (or both), but the pans are more often than not replenished by runoff water, after heavy rains in their immediate catchment areas (Gertenbach 1983).

2.5.3 Geology

The MCP falls within the Pafuri Land System as defined by Venter (1990). This Land System is divided into five landscapes according to Gertenbach (1983), as discussed in Section 2.5.6.

The Land System is characterized by a diverse collection of rocks (Venter 1990). Its geology consists mainly of sandstones of the Soutpansberg group, shales, mudstones and sandstones of the Karoo sequence, lavas of the Karoo sequence, sandstones of the Malvernia formation and relatively extensive recent alluvial deposits and sandy sediments of the Malvernia formation (Fig. 2.7) (Venter 1990).

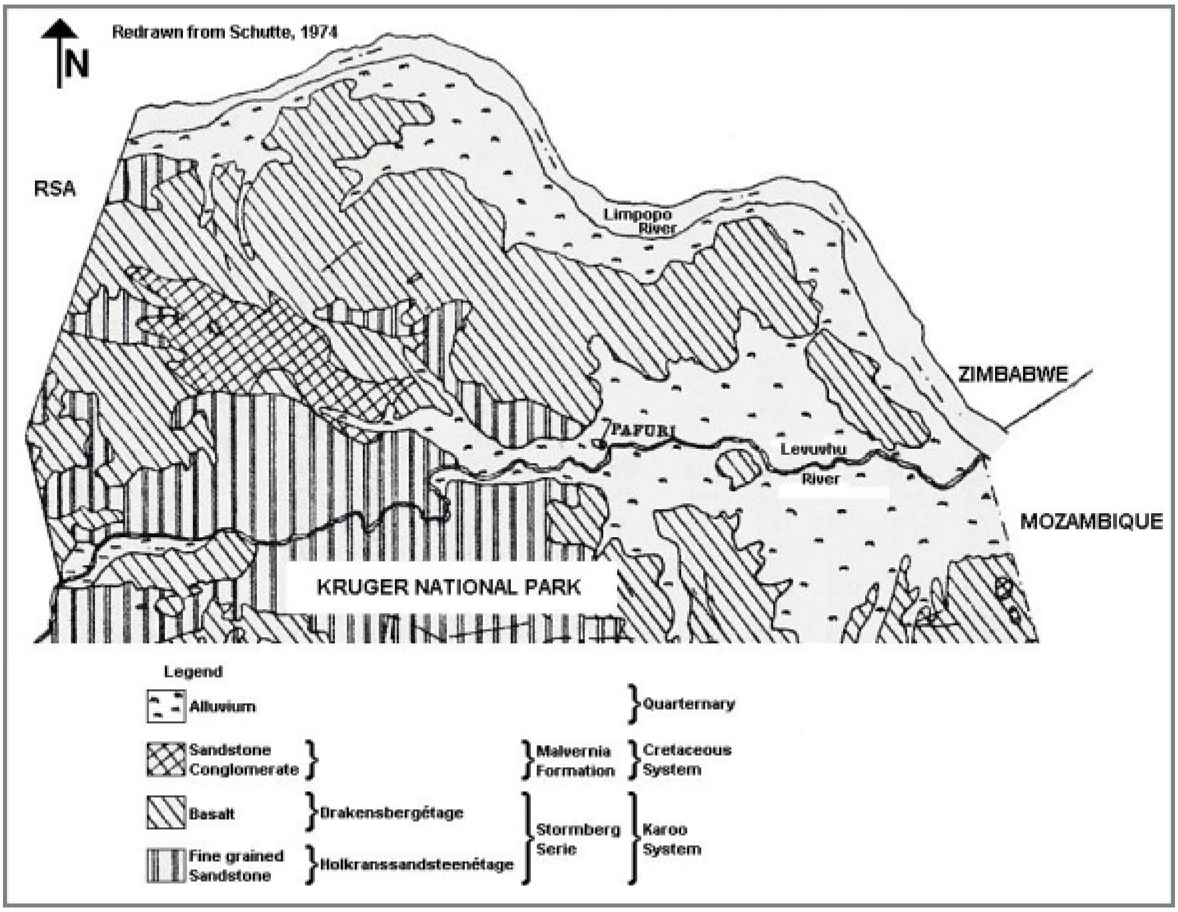


Figure 2.7 Geology of the Makuleke Contractual Park

The rocks of the Soutpansberg group occur on the south-western side of the Land System (Fig. 2.7). These strata have a northerly dip and consist of red quartzite, sandstone and conglomerate with intrusions of andesite. They are overlain to the east by sedimentary Karoo strata which have a slight easterly dip and which consist of shale, mudstone, grit, conglomerate and sandstone (Venter 1990).

The Karoo sedimentary rocks are overlain to the east and north by Karoo volcanic rocks which consist of nepheline-and olivine-rich basalt. The low-lying flood plain areas of the Luvuvhu and Limpopo Rivers are characterized by extensive alluvial deposits. Small, rounded basalt *koppies* sporadically protrude through the alluvium, and some of them are capped by well-rounded, quartzite boulders and cobblestones (Venter 1990).

2.5.4 Soils

As a result of the weathering and erosion of the varied geology in the catchments as well as in the study area, a variety of land forms and surfaces have been formed (Tinley 1981a). With the interaction of climate and drainage, soils have been formed in these areas which are similar to those of desert regions. The soils of the Makuleke region are either *in situ* developed soils or alluvial soils (Harmse *et al*. 1974). *In situ* developed soils occur in the mountainous areas in the central-western parts of the area, and the soils are usually shallow. Transported sediments cover nearly 50% of the total area and their development is related to the level and frequency of flooding. Small isolated areas of colluvium exist in the contact zone between the two formations.

Due to the geological differences between the catchment areas of the Luvuvhu and Limpopo Rivers (sibasa basalt and granitoid rock, respectively); there is also a marked difference in the alluvial deposits which flank these two rivers. The character of the source areas of the sediments is reflected in the soils. The Limpopo River soils are mostly sandy due the granitic highlands of the Northern bushveld and Botswana, where the upper reaches of the river are. The deep red silt and clay soils of the Luvuvhu flood plain originates from the Sibasa-Basalt south of the Soutpansberg (Venter 1990).

But, although there are differences in the soils which mark the Limpopo and Luvuvhu Rivers, there are also significant similarities. Some mineral, chemical and physical components of the Luvuvhu River flood plain soils originate from both the Limpopo River as well as the Luvuvhu River catchments (Eriksson 2010, pers. comm). The phi-value curves (Fig. 2.8) clearly indicate two distinctive sources of origin for the soils of the Luvuvhu flood plains. This is clearly indicated in that the patterns for the topsoil (T) and subsoils (S) of Site 3 (3T and 3S) are identical (indicating the same recent source); that the patterns for Site 1 (1T and 1S) are similar, but completely different from Site 3, indicating a different source; and that the subsoil of Site 2 (2S) tends towards Site 3, but its topsoil (2T) towards Site 1.

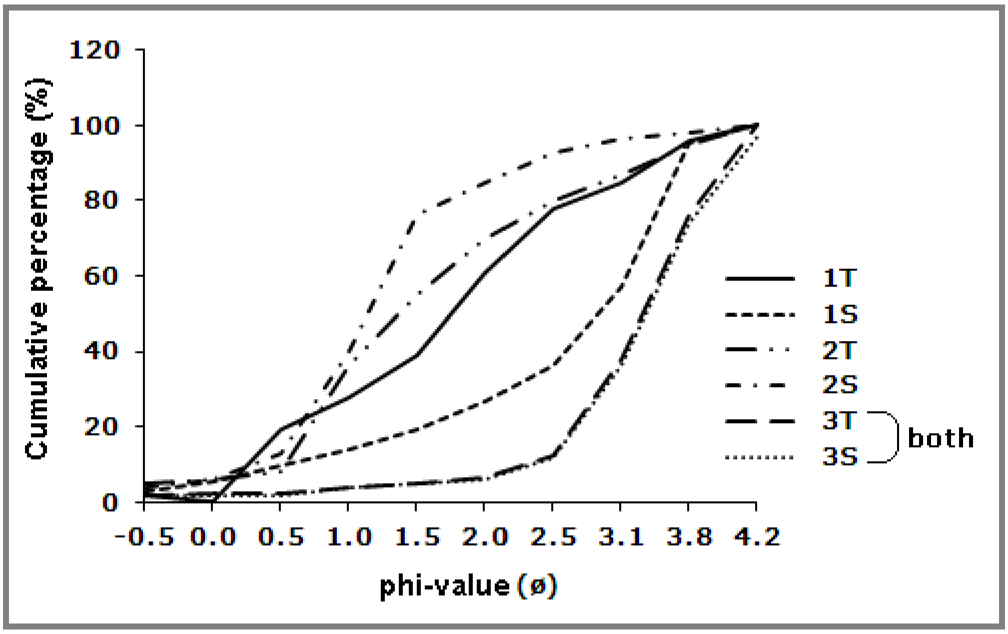


Figure 2.8 Cumulative phi-value curve

The soils of the area which flank the Luvuvhu River consist mainly of very deep, red, occasionally calcareous, neocutanic clay of the Oakleaf soil form, according to the South African soil classification system (Soil Classification Working Group 1991). These are Cambisols according to WRB (1998) (Fig. 2.9). This soil form is also frequently high in silt content. The outer fringes of the Luvuvhu River flood plain are usually characterized by deep, red and brown, para-duplex, calcareous clay of the Valsrivier soil form (Venter 1990; Harmse *et al.* 1974; Webber 1979). The first terraces of the Luvuvhu River are characterized by the Dundee soil form (Fluvisols according to WRB 1998) (Fig. 2.10).

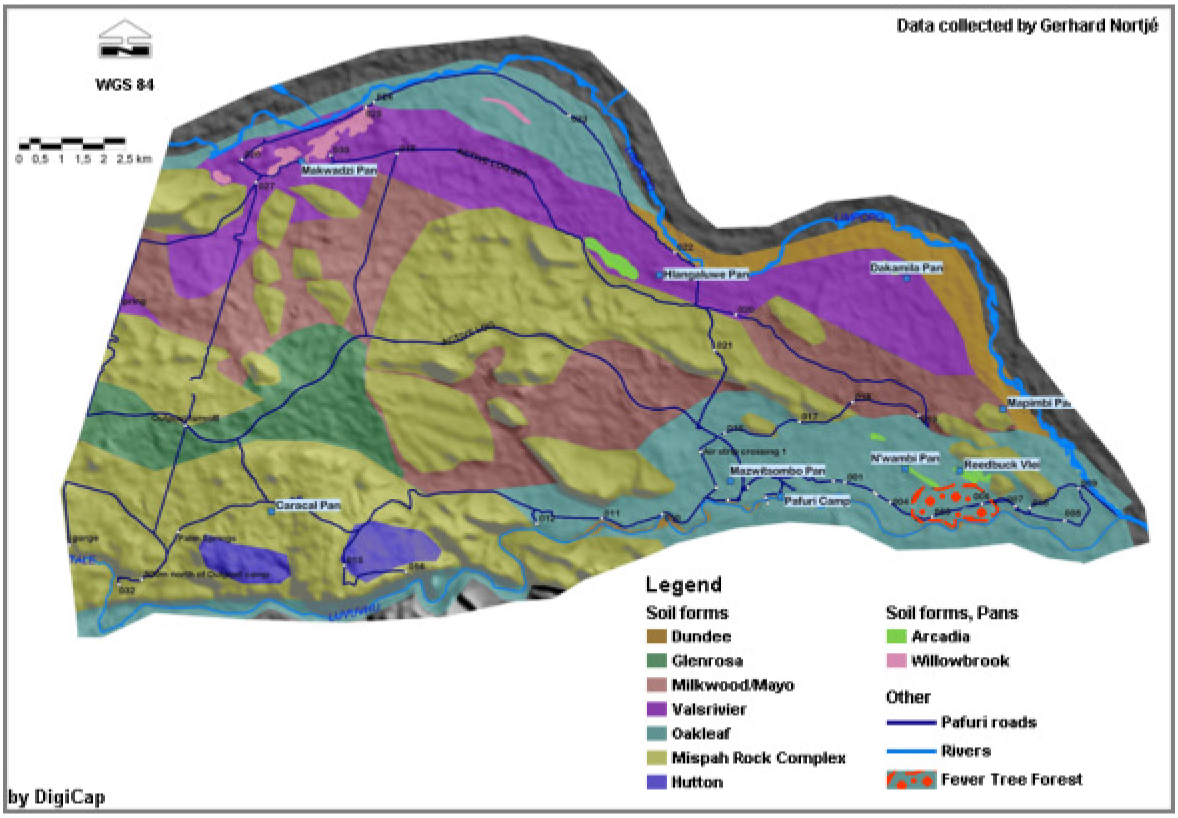


Figure 2.9 Soils map of the Makuleke Contractual Park

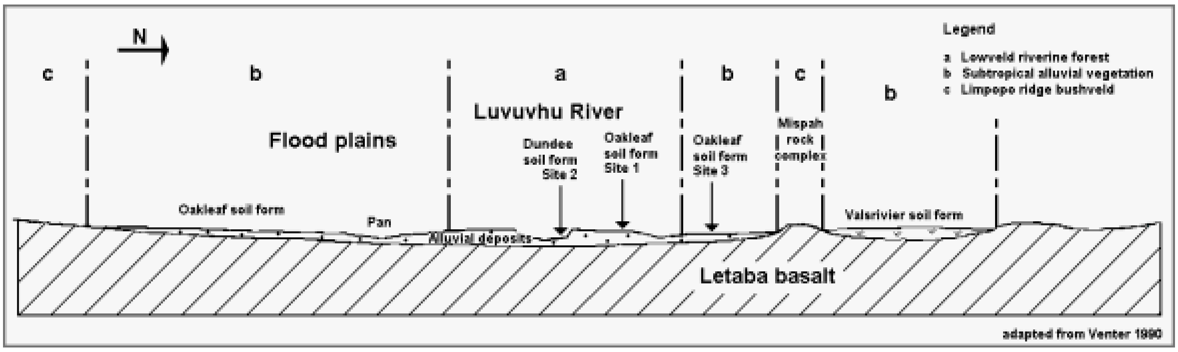


Figure 2.10 Pafuri flood plains soil, vegetation and landform pattern

Each soil is the product of specific dominant soil-forming processes under the influence of a combination of soil forming factors (Laker 1987). The characteristics of the soil-forming factors in a specific area determine the type of soil profile and thus the soil form which develop in that specific area.

Soil-forming processes which dominate in the MCP are *additions* (of water, soil and geological materials, minerals, salt, iron, clay, bases and carbonates), *translocations* (of clay, salts, carbonates, bases and pedoturbation) and *losses* (of water by evapo-transpiration and soil erosion and loss of organic material). The dominant soil forming factors influencing soil formation (pedogenesis) in this area are *climate and parent material*, with topography, living organisms and time also playing a role to a lesser extent.

Additions of water in this area are mainly through rain during the rainy season and flood water during times of regular floods. Soil and partly weathered geological materials are added mainly in the form of surface settlements, and is called alluvium. This alluvium occurs exclusively on the river terraces. Soils from alluvium are generally deep. Along the mid- and foot slopes of the mountainous areas in the western and central parts of the area, colluvium is found and these soils also tend to be deep.

Additions of salts, carbonates and bases are through the overflow of water during rains and floods. Carbonates are usually added from higher elevated areas to lower lying areas where they accumulate as lime concretions. These lime concretions are a characteristic all over the flood plains and are clearly visible. Bases accumulate in the same way in lower-lying areas and the soils are then characterized by high base saturation, higher pH and sweet veld.

Due to the arid climate of the area, transformations by humification of organic material and of transformation of primary minerals to secondary minerals and Alumino-Silicates are small. Translocations in this area are also limited due to the arid climate. The alluvial soils of the flood plains (Oakleafs, Dundee's) are young (recent) soils with minimal horizon differentiation. Translocation of clay from the A-horizon to the B-horizon is, thus, also limited. On the other hand, translocations of salts and carbonates in soils of arid and semi-arid areas are very important.

Under very arid conditions as in this area, salts like sodium salts or gypsum accumulate on or near the soil surface. Carbonate can also accumulate in the soil, usually in the form of lime concretions which are clearly visible in the Makuleke area. These lime concretions occur near the soil surface and indicate poor water movement into the soil. Termites in the area may be responsible for a significant amount of pedoturbation of the soil and thus the destruction of horizon differentiation.

The most important loss in the Pafuri area is the loss of **water** through evapo-transpiration (Fig. 2.3). The high average annual evapo-transpiration of almost 3 000 mm decreases the effectiveness of the small amount of rain that falls in the area. Soil formation is thus limited and the soils are shallow and stony, especially in the western-central areas of the area. Leaching is poor, except at the contact zones between mountains and foot slopes, and soils are shallow and rich in salts and carbonates. Natural vegetation is, thus, sparse and additions of organic material are limited.

Soil losses also occur from the steep slopes of the mountain areas, but especially from the poorly vegetated and crusted soils of the flood plains. This happens during both normal thunderstorms and during flood periods. The soil crusting causes poor water infiltration and increased run-off, which increases soil erosion (Fig. 2.11). This can clearly be seen by the shrubs on pedestals in the flood plains of the Luvuvhu River (Fig. 2.12). Losses of organic material as volatiles, for example CO_2, NH_3, and H_2O are also serious in this arid area.

Figure 2.11 Soil crusting found in the study area

Figure 2.12 Shrubs on pedestals, indicating removal of topsoil by sheet erosion

The most important soil-forming factors which dominate soil formation in the MCP are climate and parent material. They are discussed in detail below with special focus on the soil formation in the MCP.

With regards to climate, the two factors, which are especially important, are the combination of rainfall and temperature. In warm, arid areas as in the MCP weathering and leaching (and thus also soil formation) are limited by the limited amount of water available. Under these circumstances the high temperatures do not enhance soil formation but limit it, because it increases evapo-transpiration, and decreases the efficiency of rainfall. The depth of weathering is limited by the limited penetration of water. Soils in such areas are therefore shallow and stony except where deep alluvial deposits occur, as in the flood plains of the MCP.

The role of parent material is especially important in semi-arid to sub-humid areas. In other words, areas where significant soil formation (pedogenesis) has occurred, but an advanced stage of weathering was not yet achieved. The alluvial deposits of the Limpopo and Luvuvhu Rivers originate from Basalt (Sibasa Basalt) and Granite (Soutpansberg) respectively (Fig. 2.7). Other important parent materials for the different soils of the MCP are Sandstone and Conglomerate.

Basalt, is a basic igneous rock and of high importance in soil formation in South Africa. It is rich in bases, especially calcium and magnesium. This is because it consists of 46% plagioclase and 37% augite, which are both rich in bases (Laker 1987). Basalt is fine-grained and does not contain any quartz. The weathering products of plagioclase and augite forms clay, and soils formed out of basalt are thus clayey. In the low-lying areas of the flood plains, especially the pans black, clay soils with swelling and shrinking properties are associated with basalt (Arcadia and Valsrivier soil forms). Where these soils contain a lot of magnesium, they tend to be unstable, tend to form crusts, and are erodible. They are also rich in iron. On well-drained terrain red soils, which are clayey and with strong structure are formed from basalt. These red soils are stable against erosion and crust formation (red families of the Glenrosa soil form). Iron and calcium stabilize these soils. In dry areas as in the MCP, the calcium form the plagioclase precipitates as lime concretions in the soil profile. These soils are poor in potassium.

As opposed to basalt, granite is a coarse-grained, acid igneous parent rock. It contains about 52% of orthoclase (Potassium feldspar) and 12% of the potassium rich mica biotite. Soils which originate from granite consist of large amounts of coarse-grained sand which comes from quartz (Laker 1987). This is typical of the coarse-grained sand of the Limpopo flood plains in the MCP. Along steeper slopes it tends to give shallow, sandy soils. The orthoclase and biotite weather easily to secondary clay minerals where enough water is available. The clay is translocated to the subsoil through the sand through a sieve action. Duplex soils develop at lower slopes from granite. Granite soils are rich in potassium, but poor in calcium and magnesium. The latter easily leaches out of the soil and the weathering progress easily to the 1:1 stage. The soils easily become acidic.

Sandstone is a sedimentary rock which consists of quartz, feldspar, and mica. Sandstones contain enough weatherable minerals which supply clay that together with the sand-size quartz in it can develop into a good medium-textured soil. The mountain areas (Punda Maria Cave Sandstone) in the south-western and central part of the MCP are the parent rock of the medium-textured characteristics of the soils in the area.

Conglomerates are cemented coarse-grained particles with rounded fragments. The characteristics and composition of these fragments are determined by the source rocks which were responsible for the supply of them, the weathering processes and the conditions under which deposition took place (Snyman 1996). In the MCP, poly-cemented (multifarious particles) conglomerates are found (Nortjé 2009, pers. obs). These conglomerates consist of various rock types which represent their parent rock. They are cemented by finer carbonate, siliceous, clay or iron-containing bonding agents. Soils formed from these conglomerates of sand, clay, silt, calcium carbonate, silica and iron oxide, are characterized by coarse particles with red colours and rich in calcium.

2.5.5 Vegetation

The vegetation of the MCP area of the KNP is characterized by an exceptional diversity of plant life (Fig. 2.13). The vegetation form part of the Savanna biome which is the largest biome in southern Africa and occupies 46% of its total area and over one third the area of South Africa (van der Walt 2012). A major factor delimiting the biome is the lack of sufficient rainfall, which prevents the upper layer from dominating. Coupled with fires and grazing, this keeps the grass layer dominant.

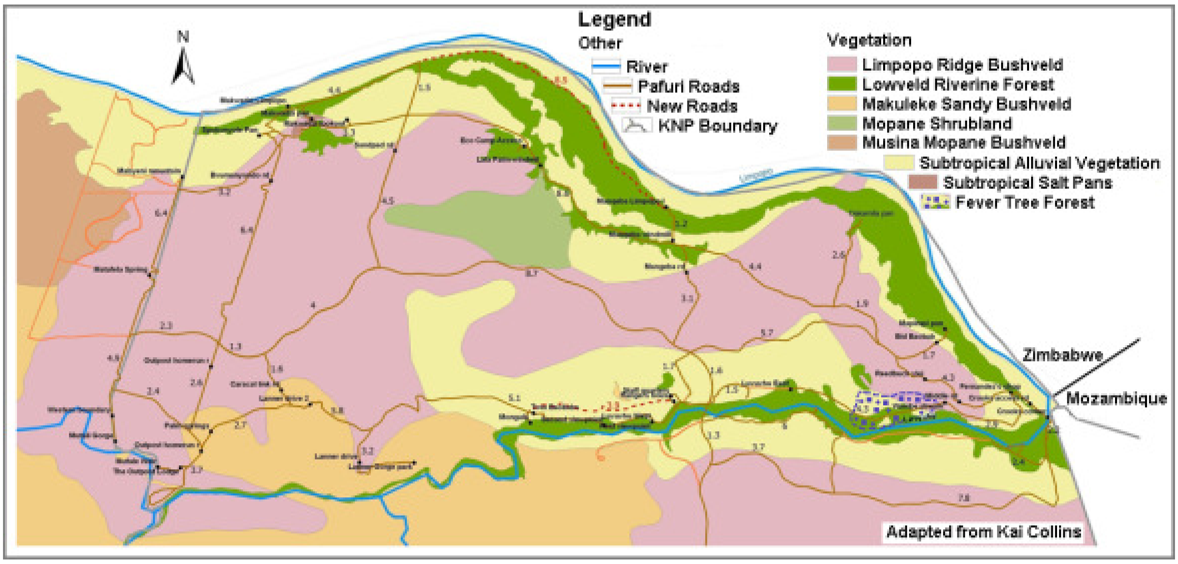


Figure 2.13 Vegetation map of the Makuleke Contractual Park

The MCP area of the KNP is more covered more specifically by the Mopane bushveld vegetation unit of the Savanna biome (Seaton Thomas & Associates 2003). Some of the major plant communities which occur in this area and not found elsewhere in South Africa are:

- The Lebombo ironwood forests;
- Mopane woodlands;
- Riverine woodlands;
- Baobab forests;
- Large Fever Tree forests (do occur in a few other areas in South Africa) which are a unique feature of this area.

The major vegetation types according to Fig. 2.13 are discussed in detail below:

1) Makuleke sandy bushveld:

Punda Maria Sandveld on Cave Sandstone is particularly rich in species diversity compared to other landscapes and constitutes a relatively small area in the south-western area of the MCP. A variety of *Commiphora* spp. is a distinctive feature of this landscape (Gertenbach 1983). The structure of the vegetation ranges from localised areas of numerous conspicuous, almost homogeneous, dense stands of *Androstachys johnsonii* thickets, to what may generally be described as a relatively open tree and shrub savanna. In this landscape the grass layer is generally poorly developed and attains a height of approximately 0.5 m with a relatively low ground cover (30-50%). Examples of dominant distinctive and common woody species of this landscape are:

Stadmannia oppositifolia, Boscias albitrunca and *angustifolia, Combretum apiculatum* and *Terminalia sericea, Commiphora mollis, Cassia petersiana* and *Euphorbia tirucalli*. The dominant tree species of the *koppies* and rocky areas are: *Ficus abutilifolia, Gyrocarpus americanus* and *Kirkia acuminata*. Examples of dominant grasses are: *Bothriochloa radicans, Enneapogon* and *Pogonarthria squarrosa*.

2) Limpopo Ridge bushveld

This landscape is an open savanna and the dominance of *Adansonia digitata* and *Colophospermum mopane* trees and shrubsgive the landscape its name (van Rooyen 1978). This landscape covers a large area in the central and western areas of the MCP. The following woody species occur regularly in this landscape: *Kirkia acuminate, Sclerocarya caffra, Combretum apiculatum, Commiphora glandulosa, Terminalia prunoides, Grewia bicolor, Acacia nigrescens, Commiphora mollis, Dichrostachys cinerea* subsp*. Africana* and *Combretum mossambicense. Enneapogon cenchroides, Aristida congesta* subsp*. congesta, Panicum maximum* and *Digitaria eriantha* var*. Pentzii* are the dominant grass species, and are sparsely distributed*.* The absence of *Themeda thiandra* is conspicuous.

3) Mussina Mopani bushveld

Structurally this landscape in the MCP is a tree savanna. This landscape as a whole is unique, not only in the KNP but also in South Africa. In the MCP it constitutes a relatively small area in the North-western area of the Park. This necessitates special conservation status for the area (Gertenbach 1983). The area is dominated by the following tree species: *Colophospermum mopane, Maytenus heterophylla, Grewia bicolour, Acacia nigrescens, Combretum apiculatum, Terminalia prunoides, Commiphora mollis* and *Zanthoxylum humilis*. *Enneapogon scoparius, Seddera capensis* and *Aristida congesta* subsp*. Congesta* are the dominant grass species. *Panicum maximum* does not occur in this area.

4) Mopane shrubveld

This landscape is an open tree veld with a large quantity of medium herbs and occurs as a small isolated area in the central part of the MCP. The tree stratum is well developed and, in spite of a clearly defined shrub stratum, the vegetation qualifies as an open tree savanna (van Rooyen 1978). The grasses are generally well developed and reach a height of 0.5-1.0 m and a relative ground cover of 70-90%. *Combretum mossambicense, Grewia bicolor, Sclerocarya birrea, Acacia nigrescens, Colos-phospermum mopane*, *Combretum apiculatum* and *Dichrostachys cinerea* subs. *Africana* are some of the dominant tree species in this landscape*.* The following shrubs are found in this landscape: *Colophospermum mopane, Sclerocarya caffra, Combretum apiculatum, Grewia bicolor, Acacia nigrescens, Boscia albitrunca, Dichroctachys cinerea* subsp. *africana, Combretum mossambicense* and *Bridelai mollis. Aristida* spp., *Panicum maximum, Urochloa mosambicensis* and *Digitaria eriantha* are some of the dominant grass species.

5) Lowveld Riverine forest and Subtropical Alluvial vegetation

Other than for the flood plains the composition and structure of the vegetation is similar to that of the first three landscapes mentioned above. These two landscapes occur along the flood plains and river banks of the Limpopo and Luvuvhu Rivers. Although there are local variations, the major feature of the riparian vegetation of both rivers is the prominence of dense stands of large trees (in excess of 15 m) (Gertenbach 1983). Where the dense tree stands occur the grass layer is generally sparse and poorly developed. The shrub stratum varies from open to dense thickets. On the flood plains, the well-developed grass layer, with a height of 1.5-2.0 m and relative ground cover of 90-100%, is the major feature. Trees are sparsely distributed, with occasional clumps of *Hyphaene coriacea*. <u>The Fever tree forest is a very important feature of this landscape</u> (Fig. 2.14). The major tree and shrub examples of dominant woody species of the flood plains are: *Acacia xanthophloea, Azima tetracantha, Diospyros mespiliformis, Faidherbia albida* and *Tabernaemontana elegans, Acacia robusta, Acacia tortilis, Ficus sycomorus, Kigela Africana* and *Xanthocercis zambesiaca*. *Dactyloctenium aegyptium* (common crowfoot grass), *Ischaemum afrum* (turf grass), *Setaria sphacelata (Goue mannagras), Panicum meyerianum, Sporobolus consimilis* and *Sporobolus ioclades* are examples of the dominant common grasses of the flood plains.

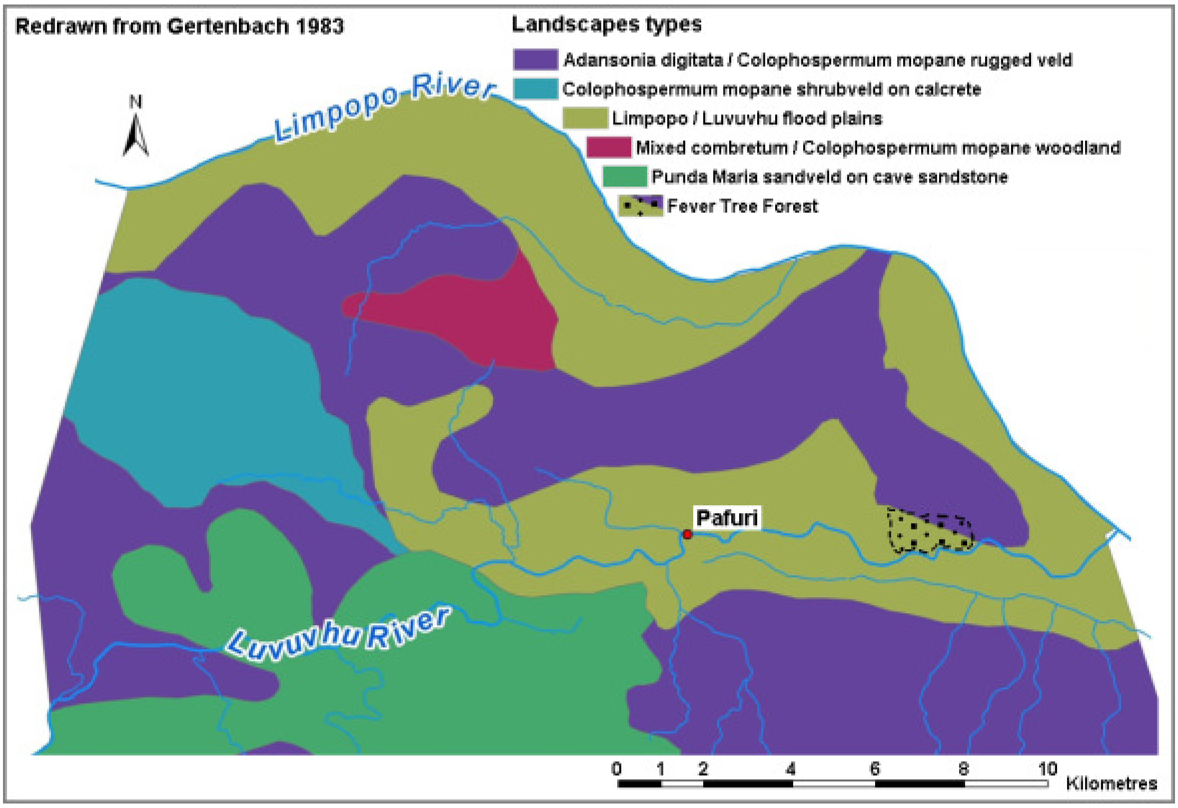


Figure 2.14 Landscapes of the Makuleke Contractual Park

2.5.6 Landscapes

The MCP part of the Pafuri Land System consists of five landscapes according to Gertenbach (1983) namely: Punda Maria Sandveld on Cave Sandstone, *Adansonia digitata /Colophospermum mopane* Rugged Veld, *Colophospermum mopane* Shrubveld on Calcrete, Mixed *Combretum* spp./*Colophospermum mopane* Woodland and Limpopo-Luvuvhu flood plains, as shown in Fig. 2.14.

<u>Punda Maria Sandveld on Cave Sandstone of the Clarens Formation</u>

This landscape form occurs as a small part in the South-western mountainous part of the MCP (Fig. 2.14). The altitude varies between 300 and 370 metres.

Cave Sandstone of the Clarens Formation forms outcrops extending from north-east of Punda Maria to just north of the Luvuvhu River (Schutte 1974; Gertenbach 1983). Clarens refers to the geological period concerned. This Cave Sandstone forms prominent koppies and is a unique and impressive landscape. The main component of the landscape is koppies or outcrops with sand plateaus and bottomlands.

The soils of this landscape are mainly lithosols or solid rock with a thin layer of soil (Mispah) in the hollow places. On the plateaus and bottomlands, a deep grey to yellow sandy soil, of the Clovelly or Fernwood Forms is present (Harmse *et al.* 1974; Venter 1990) (Fig. 2.9).

Adansonia digitata/Colophospermum mopane Rugged Veld

This landscape occurs mostly in the central and south-western parts of the MCP (Fig. 2.14).The basalt slopes towards the Luvuvhu River are physiologically dry as a result of the steep slopes and shallow calcareous soils. The terrain is strongly undulating and is comparable to the slopes of the Olifants, Letaba and Shingwedzi Rivers (Schutte 1974; Gertenbach 1983). Koppies occur regularly in this landscape.

The soils of this landscape are shallow, calcareous and contain a reasonable amount of clay. The soils are mostly dark in colour, but the structure of the topsoil is sometimes poorly developed. Dominant Soil Forms are Milkwood, Mayo, Mispah and Glenrosa (Fig. 2.9). Shallow lithosols occur on the koppies (Harmse *et al.* 1974; Venter 1990).

Colophospermum mopane Shrubveld on Calcrete

This landscape occurs mostly in the central-western parts of the MCP (Fig. 2.14).This mopane shrubveld occurs as two isolated areas in the far north of the KNP. One area is situated on the eastern boundary of the KNP, north of the Mnambia Sandveldand the other along the western boundary on the watershed between the Limpopo and the Luvuvhu Rivers. The underlying geological material of this landscape consists of the Malvernia Formations (Schutte 1974) which decompose to give rise to soil with a lot of lime concretions. The eastern and western sub-regions are drained by the Shilahlandonga and Mutale spruits, respectively. The terrain is intersected to undulating. The Malonga spring is located on the brink of this landscape.

The soils of this landscape are shallow and calcareous. According to Van Rooyen (1978) as much as 10% of the surface of the soil is covered by stones and the pH varies between 7.9 and 8.4. Most important soil Forms are Milkwood, Mispah, Glenrosa and Mayo (Fig. 2.9), while the occurrence of Lithosols is common (Harmse *et al.* 1974; Venter 1990).

Mixed *Combretum* spp./*Colophospermum mopane* Woodland

This landscape occurs mostly as an isolated area in the central-western part of the MCP (Schutte 1974; Gertenbach 1983) (Fig. 2.14). This landscape that is reasonably flat has its origins form the mixing of the white sand of quaternary origin with the gravel and basalt.

The soil is of mixed origin and consists of weathered products of basalt and Quaternary sand and gravel. The soils are deep and sandy at places, but normally well drained. Van Rooyen (1978) states that the soils are neutral (pH between 6.1 and 7.2) and up to 15% of the surface is covered with stone or gravel. Dominant soil forms are Hutton, Short-lands, Bonheim, Valsrivier, Swartland, Glenrosa, Mispah and Mayo (Harmse *et al.* 1974; Venter 1990) (Fig. 2.9).

Limpopo-Luvuvhu Flood Plains

This landscape occurs on the banks of the Limpopo and Luvuvhu Rivers (Fig. 2.14), and the banks of the Luvuvhu flood plains are also the area where most of the ORD occurs (Fig. 2.1). The underlying material of this area is alluvium that has been deposited over the years on the flood plains along the rivers (Schutte 1974; Gertenbach 1983). This is a low lying landscape with a flat to concave topography. When the Limpopo and Luvuvhu Rivers are both in flood, a blockage takes place above the confluence and because the area is flat, and sometimes concave, flooding of the land adjacent to the rivers takes place. Silt is deposited and pans that normally hold water for a long period, such as the Gwalala, Rietbok, Nyala, Nwambi, Makwadzi, Spokenyolo and Dakamila pans are filled (Fig. 2.9). These pans are a unique characteristic of this landscape while koppies do not occur.

The Limpopo River drained long ago, large areas of the current Angola, Zambia, Zimbabwe and Botswana. These include rivers which currently feed the Okavango Delta (Cuito and Cubango) and Zambezi (Kafue, Bo-Zambezi and Kwando). Later some of these rivers were blocked to form the Okavango Delta and Makgadigadi pans, while other changed direction to the current Zambezi mouth. These changes were causedby bending and faulting in the earth crust which is related to rift activities (Venter 2010).

During flood periods in the past the Limpopo river flooded the flood plains along its banks, but sometimes even up to the Luvuvhu River, depositing some of its geological material along the Luvuvhu River flood plains (Erikson 2012, pers. comm). Thus, the soils along the Luvuvhu River flood plains show some chemical and physical characteristics originating from the Limpopo River historical drainage as mentioned above (Fig. 2.7).

The soils of this landscape are alluvial and the material thus probably originates from granite, Waterberg Sandstone, Cave Sandstone, basalt, dolerite, as well as other parent rock formations. Expected soil forms are Inhoek, Dundee and Oakleaf on the flood plains, with Arcadia and Willowbrook soils in the pans (Harmse *et al.* 1974; Venter 1990)

(Fig.2.9). The Fever tree forest is a very important feature of this landscape and is dominated by Arcadia soils (Fig. 2.9).

2.6 Ecological Importance of the Area

The MCP is considered one of the most significant areas in the KNP from the perspective of its biodiversity, with high variability in landscapes, vegetation and associated species (Makuleke Contractual Park 2012). For instance, KNP have zoned the area as a botanical reserve. In the area there are several pan systems which, together with sections of the Limpopo and Luvuvhu River flood plains, were designated as a Ramsar Site on the 22nd May 2007 (Deacon 2007) (Fig. 2.15). Prominent features include riverine forests, riparian flood plain forests, flood plain grasslands, river channels and flood pans.

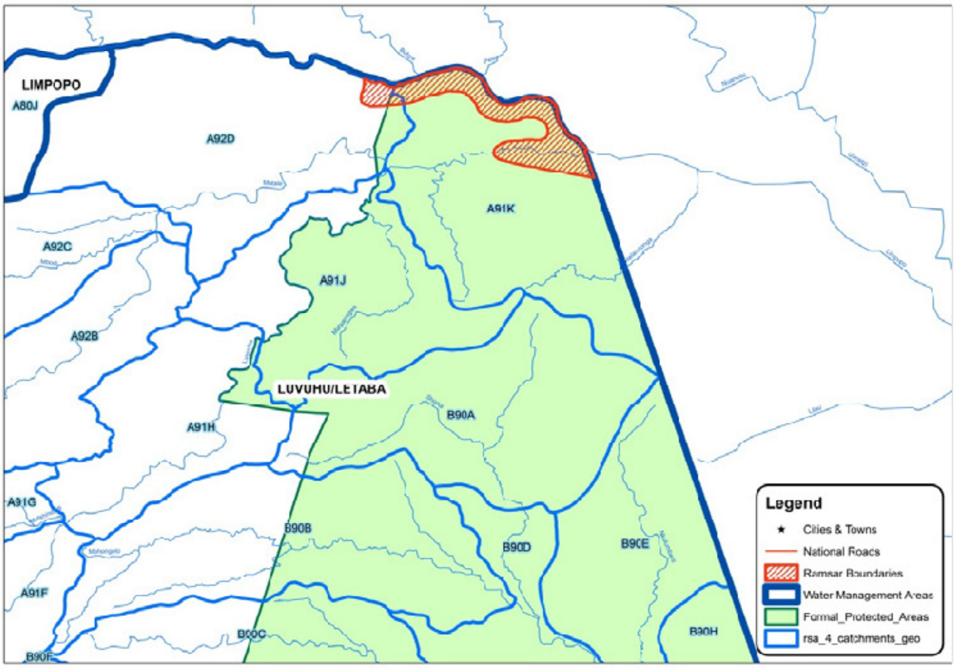


Figure 2.15 Location of the Makuleke Ramsar Site relative to the Limpopo and Luvuvhu Rivers

Three important criteria were followed which led to the designation of this area as a Ramsar wetland, viz (Deacon 2007; Makuleke Contractual Park 2012):

- *The area is an important flood plain wetland* - the Makuleke wetland is an excellent example of a flood plain vlei type (characteristic of the northern part of South Africa and the eastern part of Mozambique) that remains relatively unaffected by human influences. The flood plain and its associated pans provide flood reduction benefits, thereby reducing flood damage in the downstream areas of Mozambique. Flood plains also play an important role in recharging groundwater levels and maintaining riparian and flood plain vegetation;

- *Presence of vulnerable-endangered fauna and flora* - high densities of Nyala occur here as well as the last remaining herd of Hippopotamus east of Beit Bridge on the Limpopo River. The Nile crocodile and African python, both considered Red Data or vulnerable, also occur here. Mammals of ecological significance occurring in the area between the Luvuvhu and Limpopo Rivers, but not totally dependent on the wetland area, include: the Aardwolf, Brown Hyena, Serval, leopard and African wild dog (Tinley 1981a; de Villiers 1999);
- *High diversity of species supported* - the wetland system supports a high diversity of species, some of which have their centres of distribution in the area and others possibly being confined to this area alone. Species include the rare Samango monkey, four-toed Elephant shrew and African civet which occur in the riparian areas along the Luvuvhu and Limpopo Rivers. Rare bird species such as the pygmy goose, white crowned plover and nesting white backed vultures occur here, while the highest densities of Pel's Fishing Owl in South Africa are found in the Luvuvhu River valley. The Böhm's and Mottled spinetails, which are rare in South Africa, occur along the lower reaches. This area also represents the south-western limits of the range of distribution for the Dune Squeaker. The wetland has exceptional ecological features that are unique for South Africa as a country including a number of species which occur here and nowhere else in the country. Bats like Rüppels bat, Swinny's horseshoe bat, the Madagascar large free-tailed bat and Commerson's leaf-nosed bat are only known in the country from specimens collected in the areas adjacent to and constituting the site.

The Contractual Park has highly scenic landscapes with a wide range of habitat types, from flood plain grasslands through many types of savanna and thickets to spectacular riverine and fever tree forests (Deacon 2007). There is high bird diversity, including species not common in the rest of South Africa or even the KNP. While game density in the area has been traditionally low, there has been improvement in this regard largely due to the improved anti-poaching activities in the area as well as to the re-introduction of various game species to the area by both KNP and WS. The above-mentioned features will definitely influence any future developmental and anthropological decisions for example activities like ORD by tourists in the area. The Act that would cover this would be the Water Act (National Water Act No. 36 of 1998), which restricts certain uses of water resources. Wetlands are water resources, and any disturbance of them without a water use licence is prohibited. 'Water use' is quite a wide ranging word that would most likely cover driving through wetlands and disturbing them (Lindley 2012, pers. comm).

This 20 255 hectare area differs from the rest of the KNP with regards to larger mammals. It has compared to the rest of the KNP a low density of these larger mammals. The more common game species present is bushpig, bushbuck, kudu, nyala and grey duiker. Herds of buffalo are regularly encountered and elephant are frequently present traversing the area.

Due to the hilly nature of the landscape, klipspringers regularly occur. Baboons are plentiful especially along the rivers. Due to the low density of prey species, lion and other carnivores are generally scarce (Pederson 2009), although predator numbers have increased over the last three years from 2009-2011 (Fig. 2.16) because of an increase in the number of prey species. The number of off-road incidents also reflects this scenario (Fig. 2.16). This northern area of the Park is particularly well known for the number and diversity of bird species. The area along the banks of the Luvuvhu River to the picnic site/ Crook's Corner loop contains some of the most potentially productive birding territory in South Africa (Seaton Thomas & Associates 2003).

It is a good place to watch for Birds of Prey including the magnificent Crowned Eagle, and the Pel's Fishing Owl. A variety of other special bird species have also been found in this area (Tinley 1981a).

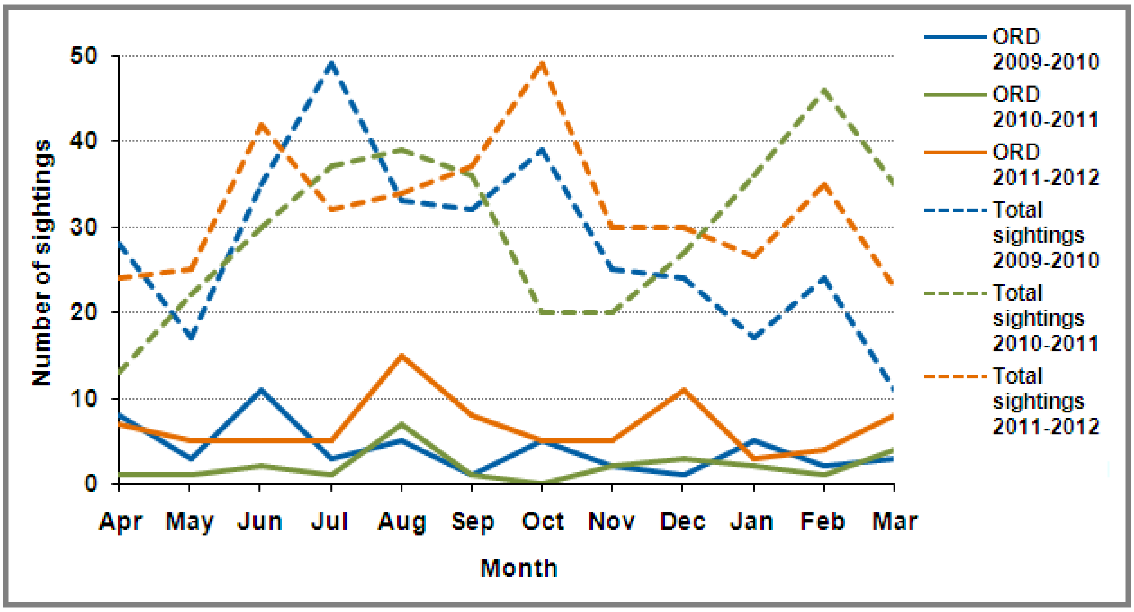


Figure 2.16 Off-road sightings vs. total animal sightings for the period 2009-2011 (mainly the large predators)

2.7 Economic Importance of the Area

According to Pederson (2009) the Pafuri area is since 1933 known as an area of high conservation value. The reasons for this is not just because of the fact that the Makuleke Community got the area back, and therefore could benefit by monetary income through employment and eco-tourism opportunities, but also because of the areas' geographic position. It is situated in the heart of the Great Limpopo Transfrontier Park, formed in November 2000 (Duffy 2006). The hope of this Transfrontier Park was to combine conservation efforts between South Africa, Mozambique and Zimbabwe, and extending the ranging areas for some larger animals like buffalo and elephant (de Villiers 1999; Wolmer 2003).

2.8 History of the Area

The presence of thousands of Early and Middle Stone Age tools that can be found all over the Pafuri area point to the fact that humans have lived here for millennia. In the 1820's the Makuleke people, a Shangaan clan, moved into the area from further south and settled at the confluence of the Limpopo and Luvuvhu Rivers (Pafuri factsheet 2011; Meyer 1983). This point is considered the heart of the heart of the Pafuri and the Makuleke people ancestral home (Fig. 2.17).

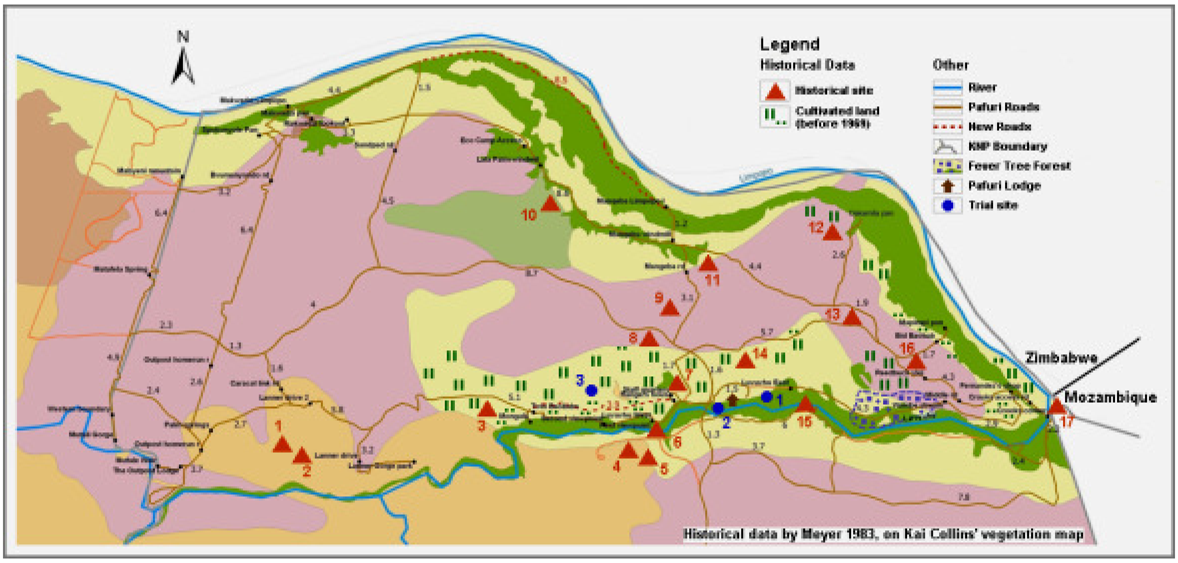


Figure 2.17 Pafuri historical sites in relation to trial sites (adapted by Nortjé)

Between 1820 and 1969 (a period of 149 years) the Makuleke people lived in the area. This included their normal daily activities like agriculture, hunting, collecting wood for heat and fishing (Meyer 1983). Agriculture included the cultivation of a wide range of products like millet, maize, peanuts, pumpkins, okra, sorghum, Bambara ground nuts, sweet potatoes and sweet cane (Appendix B). Veld was also regularly burned for protection against wildlife and clearing bush for cultivation. Although Van Rooyen (1978) mentioned that "the influence that the Makuleke people had on the environment of the area in the past, is not any more visible and the signs of old cultivated lands along the Luvuvhu River is all but erased", the fact is that the invisible impacts below the soil surface (sub-soil compaction), as well as the surface scars of bare patches (soil crusting) in the landscape are still visible and a reminder of the human activities of long ago (Nortjé 2009, pers. obs; Laker 2011).

These farming activities as well as the bush clearing, tree cutting and veld burning are the main reason for the degradation of the area in specifically the flood plains of the Luvuvhu and Limpopo Rivers (Nortjé 2009, pers. obs; Laker 2011). Severe sub-soil compaction as well as surface crusting is found in the soils on the flood plains. Donkey-drawn hand ploughs were used to plough and cultivate the land (Fig. 2.18) (Appendix B). The ploughs were turn ploughs and cultivated the soil about 200-250 mm deep. The sub-soil compaction layers are at this soil depth.

Figure 2.18 Donkey-drawn hand plough used for ploughing in the area

A three-way partnership: the private MCP represents a three-way partnership between the KNP, the Makuleke Community and WS. Title to the land is held by the community, with KNP responsible for conservation activities and WS for ecotourism development (Pafuri factsheet 2011).

2.9 State of the Natural Environment of the MCP

A general overview of the MCP when looking at topography, veld condition and the state of the soil during the study period (2009-2011) indicated that the two major characteristics of the area are that it can roughly be divided into the following two distinctive areas (Laker 2011):

- Higher altitude mountainous areas lying mainly in the centre and western parts of the park, and
- The lower lying areas, the flood plains next to the Limpopo and Luvuvhu Rivers.

The flood plains on the Luvuvhu side, the southern boundary of the concession were also the area where ORD was occurring, and thus the area of the three study sites (Fig. 2.1 and 2.14).

The most prominent feature of the flood plains along the Luvuvhu River is the bare patches. Some of the patches are almost completely bare with almost no grass cover (Laker 2011). The first response to these bare patches will be and often lead to the conclusion that they are the cause of overgrazing. The area is now for more than 43 years part of the KNP. These bare patches are in contrasts to the bare patches in the southern and central parts of the (KNP) where the main cause is overgrazing (Laker 2011, pers. comm).

A very prominent characteristic of the bare patches in the MCP is the severe soil crusting or surface sealing of the soils in the flood plains. This should have a very negative impact on veld recovery. It will firstly restrict water infiltration which will lead to dry soils which will especially during dry drought periods restrict survival of grass especially. Secondly it can restrict the emergence of especially plants with small seeds (like grasses) and dicotyledonous plants (legumes). It will thus be very difficult to establish a dense basal cover. Thirdly, the increased run-off due to the crusts and absence of a basal cover can lead to accelerated plate sheet erosion.

Sheet erosion can already be seen by the small trees and shrubs standing on little pedestals in the flood plains (Fig. 2.12) (Nortjé & Laker 2011, pers. obs). To explain the bare patches in the flood plains it was necessary to go back into the past between 192 and 43 years ago. As mentioned before, the Makuleke people moved into the area in 1820 and lived and farmed in the area until 1969 when they were removed from the area with the incorporation of the area into KNP. An investigation of the past and interviews with Makuleke elders in the Makuleke Village outside the KNP confirmed our theory. The Makuleke people lived in *kraals* in the area preferably on the outcrops in and around the flood plains (Meyer 1983).

They cultivated the area in the flood plains around the pans and to the edges of the Luvuvhu River (Appendix B). No farming activities occurred on the first terraces for fear of hippopotami. Irrigation was done with hosepipes out of boreholes. The areas they ploughed were in the form of squares and between 1 and 2 ha in size. Closer to the rivers the sites were smaller in size (40 m X 40 m). They used donkey pulled hand turn ploughs which turned the soil to a depth of 150-250 mm. The exact sites were identified and penetration resistance trials done with the idea of comparing these data with the controls of the trial sites (Fig. 2.1).

No significant differences were found to exist between the ploughed areas and the site controls at the 95% probability level. The conclusion was thus made that the cause of the bare patches was human farming activities until 43 years ago. In the Nylsvlei Nature Reserve in the Limpopo Province of South Africa, Coetzee (2005) and Tinley (1981b) also made similar observations with regards to long recovery times when looking at differences between the surrounding grasslands (controls) and soils hand-tilled a century earlier and left to lie fallow ever since. Severe soil crusting and sub-soil compaction was found at the control sites as well as in the ploughed areas which explain the poor vegetative cover, poor grass recovery and sheet erosion. Just imagine the long-term impact that non-sensible ORD may have on the soils' resilience and vegetation recovery. After 43 years after which there was no further human impact, there is still no recovery of soils and vegetation recovery in most of the flood plains.

A characteristic of the grass vegetation on the flood plains in the MCP is that they are totally bare during winter but recover well during the rainy season when good rains fall. This recovery is however very short-lived because the area is the driest of the whole KNP. The long-term average rainfall in this area is less than 400 mm and this rains is mostly during a three month period in the summer (Fig. 2.3). Temperatures in summer are also extreme (>40°C) (Fig. 2.5). This results in high evaporation, poor infiltration, high run-off because of the sparse grass cover, and poor seedling emergence and survival due to the soil crusts and high temperatures (Fig. 2.5).

The soil in the flood plains which is supposed to be naturally fertile and good for vegetative growth is now physically degraded (Nortjé 2009, pers. obs; Laker 2011). The grass which recovers during rains is quickly grazed by the grazing animals in the area because the grass is very palatable. This is the reason for the short-lived vegetation. This has very negative consequences for ecotourism as this area is mostly devoid of grass cover for most of the year. It was observed that no antelope are sometimes seen here for long periods of time. This then leads to the absence of predators from these areas for long periods during the year.

The above-mentioned aspects have serious negative consequences with regards to ORD. With the observation of the impact of current ORD incidents it was clear that the impact was much more serious where there was no grass cover than where there was grass cover. This makes sense as Barley & Greacen (1967) have proven in Australia that a dense stand of cover crop is the best "protector" against soil compaction in orchards and vineyards.

2.10 Conclusion

The locality and bio-physical characteristics of the MCP suggest that it may be extremely sensitive to anthropological activities and impacts. The area lies in the driest area of the KNP, with an annual average PET of close to 3 000 mm. The long-term average rainfall is much less at below 400 mm (Fig. 2.3). This classifies this area as very arid with desert characteristics. In the literature study in Chapter 1 it was shown that desert ecosystems are the most sensitive environments to human disturbance through activities like ORD.

The soils and vegetation of the area were also degraded over a period of 120 years by the farming activities of the Makuleke people until 1969 when they were removed from the area. The areas never recovered again even 43 years after their removal from the area. This degradation can still clearly be seen on the flood plains of the Luvuvhu River, where bare patches, sheet erosion and sparse grass cover are dominant features of the landscape.

In Section 2.6 of this Chapter (Fig. 2.15) it was also shown that the areas of the flood plains along the Limpopo and Luvuvhu Rivers were designated as a Ramsar wetland area (protected pan area) according to Deacon (2007) and the Ramsar Convention Secretariat (2010), and should thus be protected as such. The areas of the Luvuvhu flood plains as well as the important Fever Tree forests fall within this Ramsar area. But these areas are also where much of the ORD occurred during the past 3 years (Fig. 2.1), especially the areas along the Luvuvhu River.

The Act that would cover the protection of this Ramsar wetland area would be the National Water Act (1998), which restricts certain uses of water resources. Wetlands are water resources, and any disturbance of them without a water use license is prohibited. 'Water use' is quite a wide ranging word that would most likely cover driving through wetlands and disturbing them (Lindley 2012, pers. comm).

It is thus with this background in mind that the rest of this study on the impacts of ORD on the environment and tourists' perceptions of the impact should be observed.

2.11 References

- Barley, K. P. & Greacen, E. L. (1967) Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. *Adv Agron*, 19, 1-43.
- Coetzee, B. (2005) Birth of an African landscape. Published by Ben Coetzee. Collierville, Tennessee, USA.
- De Villiers, B. (1999) Land claims and National Parks: the Makuleke experience. Human Sciences Research Council, Pretoria.
- Deacon, A. (2007) Ramsar Information Sheet: Makuleke Wetlands, South Africa.
- Duffy, R. (2006) The potential and pitfalls of global environmental governance: the politics of transfrontier conservation areas in southern Africa. *Polit Geogr*, 25, 89-112.
- Gertenbach, W.P.D. (1983) Landscapes of the Kruger National Park. *Koedoe,* 26/1, 9-121.
- Harmse, H.J.v.M., van Wyk, P. & Gertenbach, W.P.D. (1974) Verkenningsgrondkaart van die noordelike gedeelte van die Krugerwildtuin. Unpublished map. University of Potchefstroom for CHE, Potchefstroom.
- Laker, M.C. (1987) Soil classification, land capability assessment and soil maps. Soil science 317, course notes, pp. 14.
- Laker, M.C. (2011) Visit reports 1 and 2 of the Makuleke Contractual Park. April 2011.

- Makuleke Contractual Park: conservation and development framework, April 2012.
- Meyer, A. (1983) 'n Interpretasie van argeologiese terreine in die Nasionale Kruger-wildtuin. Ongepubliseerd, Departement Argeologie, Universiteit van Pretoria.
- National Water Act, No. 36 (1998) Republic of South Africa.
- Nortjé, G.P. (2005) The impacts of off-road driving and other concessionaire activities on physical soil degradation. MPhil thesis, Centre for Wildlife Management, University of Pretoria.
- Nortjé, G.P., Van Hoven, W. & Laker, M.C. (2012) Factors affecting the impact of off-road driving on soils in an area in the Kruger National Park, South Africa. *Environ Manage*, 50/6, 1164-1176.
- Pafuri Factsheet (2011) Makuleke Cultural Heritage. Information Sheet to Pafuri Camp in the Makuleke Contractual Park, South Africa.
- Pederson, G. (2009) Habitat use and diet selection of reintroduced white rhinoceros (*Ceratotherium simum*) in Pafuri, Kruger National Park. MSc thesis. University of Stellenbosch, South Africa.
- Ramsar Convention Secretariat (2010) Managing wetlands: frameworks for managing Wetlands of international importance and other wetland sites. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland.
- Schutte, I.C. (1974) 'n Geologiese verkenningsopname van die Noord-Sentrale gedeelte van die Nasionale Krugerwildtuin. Geological Survey, Pretoria.
- Seaton Thomas & Associates (2003) Scoping Report for the proposed development of a 56 bedded Safari Camp in the Makuleke Area, Kruger National Park. Irene, Pretoria.
- Snyman, C.P. (1996) Geologie vir Suid-Afrika. Dept. Geologie, Universiteit van Pretoria
- Soil Classification Working Group (1991) *Soil classification: a taxonomic system for South Africa*. Department of Agriculture Development, RSA.
- Tinley, K.L. (1981a). The Northern Kruger National Park: an ecological inventory. *Afr Wildl*, Special Issue, 35, 6-23.
- Tinley, K.L. (1981b) Salient landscape features of the Nylsvley area and it regional environs. Report to the National Programme for Environmental Sciences, pp. 4, Typescript. CSIR, Pretoria.
- Van der Merwe, L. (2004). Guidelines for off-road driving in the private concessions of the Kruger National Park. Concessions Operations Manual, KNP
- Van der Walt, P.T. (2012) Bosveld: ekologie en bestuur. Briza publications. Queens-wood, Pretoria.

· Van Rooyen, N. (1978) 'n Ekologiese studie van die plantgemeenskappe van die Punda-Milia-Pafuri-Wambiya-gebied in die Nasionale Krugerwildtuin. MSc. thesis. University of Pretoria.
· Venter, F.J. (1990) A classification of land for management planning in the Kruger National Park. Unpublished PhD thesis. University of South Africa.
· Venter, F.J. (2010) Geologie van die Bosveld. In: *Bosveld: ekologie en bestuur* (ed: van der Walt, P.T.). Briza publishers. pp. 22.
· Webber, N.W. (1979) The effects of fire on soil/plant ecological relationships in the southern part of the Kruger National Park. A study in soil geography. MSc thesis. University of South Africa.
· Wolmer, W. (2003) Transboundary Conservation: the politics of ecological integrity in the Great Limpopo Transfrontier Park. *J S Afr Stud*, 29, 261-278.
· World Reference Base for Soil Resources (WRB) (1998) Rome: Food and Agriculture Organization of the United Nations (FAO).

SECTION B

STUDIES ON THE ENVIRONMENTAL IMPACTS OF OFF-ROAD DRIVING

CHAPTER 3
QUANTIFYING THE SPATIAL AND TEMPORAL PATTERNS OF OFF-ROAD DRIVING IN THE MAKULEKE CONTRACTUAL PARK

3.1 Introduction

The South African National Parks (SANParks) Environmental Best Practice Manual (van der Merwe 2004) mandates the practise of off-road driving (ORD) in the private concession areas of the Kruger National Park (KNP) under the regulation of Best Practice guidelines (Table 1.1).

The directive allowing ORD mandates that "the activity may only be undertaken by trained professionals on soils which can accommodate this activity and under conditions which are not irreversibly (after or following the next 25 mm of rainfall) harmful to the ecology of the area, especially the plants and animals, and which will allow for a sustainable recovery of the impacted zone" (van der Merwe 2004). ORD is a significant use of these private concession areas. The Makuleke Contractual Park (MCP) is a case in point. The Best Practice guidelines recognize the potential for negative impacts by ORD on natural resources, but they do not refer explicitly to damage to soils.

SANParks recognize the potential negative environmental impacts of ORD by the fact that they compiled some guidelines (Table 1.1), even though the guidelines were untested and not based upon or backed-up by any research results. The guidelines were purely "based on common sense and applicable knowledge to date" (van der Merwe 2004). Despite the lack of a sound scientific basis the document state that "following these guidelines will allow for controlled, sensible off-road driving events". Meanwhile, no ORD research has evaluated the effectiveness of these guidelines related to ORD in South African protected areas, and it is largely unknown whether these guidelines will result in natural resource conservation.

The present research program was initiated to evaluate the impact of ORD on soil compaction and vegetation recovery. This research is therefore focussed on testing some of the guidelines, especially the guidelines relating to vehicle impacts on the soil. To do this it was necessary to 1) quantify ORD use over a specific time period, 2) evaluate ORD effects on soil compaction and vegetation recovery and 3) monitor the spatial and temporal patterns of ORD, with the idea of identifying trial sites where ORD is most likely to occur.

Specifically, what is described here is a protocol for quantifying ORD use and the reporting of changes in the spatial and temporal patterns of ORD use in the MCP. Quantifying the spatial and temporal patterns of human activities on the environment is important to determine environmental impacts (Smallwood 2009; Matchett *et al.* 2004; Schlacher & Thompson 2007). Spatial and temporal patterns of ORD use were quantified in the MCP by recording off-road incidences and a variety of off-road-related data over the study period between April 2009 and April 2012 on a specifically designed register (Appendix C).

Total area of ORD routes decreased from 3 340 ha in the year 2009-2010, to 1 760 ha during 2010-2011, and then increased again to 6 410 ha during 2011-2012. Of the total area of 20 255 ha, 0.016% exhibited ORD disturbance during 2009-2010, which increased to 0.032% during 2011-2012. That means a 2 times increase. ORD use was concentrated on the flood plains relative to the mountains. If the same calculation was made for just the area of the Luvuvhu flood plains (± 4 659 ha) where all the ORD is taking place, the percentage area disturbed by ORD comes to 0.072% during 2009-2010 and 0.14% during 2011-2012. That is a 1.94 times increase.

The Makuleke area (20 255 hectares) currently has approximately 158 km of roads, which may be used for game drives which include (Makuleke Contractual Park 2012):

- 135 km of game viewing and tourism roads; and
- 23 km of transit road (tar road between the Pafuri gate and the Luvuvhu Bridge into the Kruger Park).

3.2 Methodology

For the planned ORD trials to be representative of the soils of the study area it was necessary to determine where ORD occurred most frequently. Therefore, the spatial and temporal patterns of ORD incidents were recorded with the use of GPS devices on a daily and monthly basis for a period of one year. A variety of data were collected in this way and recorded on a specially designed ORD register (Appendix C):

- Date and time of off-road incident
- Entrance and sighting GPS coordinates
- Distance and direction travelled between entrance and sighting
- Weather conditions
- Reason for ORD incident, i.e. type of animal sighting
- Vegetation, landscape and soil type
- Wet or dry soil conditions, i.e. rain or no rain
- Slope percentage and slope length
- How many times were off-road prevented?
- Visual damage before and after off-road incident
- Fires before incident
- Was a drainage line, spruit or river crossed or entered during incident?
- Number of vehicles per ORD incident
- Number of tourists per vehicle
- Vehicle tyre pressure, tyre make
- General remarks

The vehicle tracking and data collection continued for the duration of the study period of three years - April 2009 to April 2012 in order to determine trends in ORD. Overall, all four seasons of the year were covered three times.

3.2.1 ORD registers

The ORD data collected were recorded on an off-road register (Appendix C) which was specifically designed for the purpose of this study. The KNP was, apparently, the first to introduce the concept of off-road registers to its private concession areas in 2001 (Nortjé 2005; van der Merwe 2004). The purpose of this off-road register was four-fold:

- Monitoring of ORD
- Determining the spatial and temporal patterns of ORD
- Monitoring of possible negative impacts due to ORD
- Developing scientifically based guidelines to control ORD

A total of five game drive vehicles operated in the MCP, as part of Wilderness Safaris. Thus, a maximum of five vehicles could potentially drive off-road at each off-road site. Each game guide has the responsibility to record all relevant off-road data for each time he/she drives off-road on the central off-road register at the Main Camp. These are done on a daily and monthly basis.

Each Game Guide also has the responsibility to rehabilitate any visual damage caused by the ORD (Appendix A). This normally entails sweeping and brush packing of the damaged area. This damaged area is also then designated as off-limits to any further ORD.

3.2.2 GIS, GPS

Although most other studies on the impacts of off-road vehicles on the environment involved the use of aerial photographs (Bhandari 1998; Onyeanusi 1986; Griggs & Walsh 1981; Daneel 1992) or historical information (Webb 2002; Webb *et al.* 1986; Adams *et al.* 1982) of the impacts on the environment, it was found in a study by Nortjé (2005) and Smallwood (2009) that handheld GPS devices are accurate, practical and easy to use in recording the coordinates of each off-road incident over time.

The current study does not include historical ORD but the ORD taking place during the course of the study (Appendix A). Coordinates were recorded at the following two positions for each off-road incident: 1) at entrance (position where vehicle left the normal road network) and 2) turn-around point at the furthest final position of the animal sighting (Appendix C). The spatial and temporal patterns of ORD were mapped on a Geographic Information System -GIS- database and critical area boundaries for ORD density delineated over time.

3.2.3 Calculation of the area affected by ORD

With the calculation of the area affected by ORD the total vehicle width plus 1 m to the outside of the left tyre to 1 m to the outside of right tyre was used and not the tyre width. Research on the impacts of off-road vehicles by Bhandari (1998) and Onyeanusi (1986) on vegetation in the Masai Mara also indicated a much wider area affected than just the vehicle tracks. In Chapter 4 in this study it will also be shown that sub-soil compaction is horizontally much wider distributed than just below the vehicle tracks.

Included in the calculation was the distance between the entrance point of ORD and the turn-around point (sighting), to travel back to the road where the vehicle left the road. Meandering the vehicle to avoid obstacles or as the animal in question roamed was estimated and included in the equation to determine actual distance travelled (ADT), and thus actual area impacted (AAI).

Thus, the parameters for the calculation of ADT and the AAI by an ORD incident are as follows:

1. ADT (m) = distance between vehicle turn-around point and vehicle entrance incorporating a factor for meandering;
2. Width of area impacted (WAI) (m), a value of the vehicle width plus 2 metres;
3. Average Vehicle Turning Circle Area (AVTCA) (m^2) when turning around at sighting. In the present study a standard value of 110 m^2, determined by calculating the average turning area at 10 representative sites, was used.

Thus, the general equation for the calculation the AAI by an ORD incident is:

$$AAI\ (ha) = [(ADT \times WAI) + AVTCA]/10\,000$$

For the present study the equation was:

$$AAI\ (ha) = [ADT \times 3.7 + 110]/10\,000$$

In the studies of both, Bhandari (1998) and Onyeanusi (1986) in the Masai Mara National Reserve, they used number of annual vehicle entries in their calculations of area affected. They also included only the damage of off-road vehicles to the vegetation into the calculation of damage due to ORD. The specific formula which Onyeanusi (1986) came up with for estimating total vegetation damage included the following independent variables:

- Number of annual vehicle entries;
- Average distance driven off-road (in km);
- Tyre width (cm);
- Area of park (km^2);
- Percentage loss of standing crop per vehicle passage.

Bhandari (1998) physically sampled the biomass weight and vegetation cover percentages to examine the impact of ORD. Estimation of vegetation damage was visually made using expert knowledge and divided into different classes of damage.

3.2.4 Photographic follow-up

Photographic follow-up and soil and vegetation monitoring over time has proven to be a cost-effective way for monitoring vegetation recovery over time. Especially the so-called fixed-point photography is a well-known and accepted practice. Eckhardt (2003, 2010) used the technique of fixed-point photography in the KNP in monitoring the seasonal differences in vegetation (Joubert 2007).

Eckhardt (2003, 2010) and others (Howorth 2008; Burke & Strohbach 2000) have all applied this technique successfully in documenting changes in biodiversity components. Clear differences could be observed between dry and wet periods in the grass and shrub layers, because grasses and shrubs are dependent upon the water in the topsoil layer. It was found by Nortjé (2005) that this principle and a variation of this technique could also be successfully applied to the monitoring of off-road vehicle damage.

Fixed-point photography is also widely used to monitor soil erosion in the game ranch industry in South Africa (Bothma 2000). Photographs are taken annually at a fixed time from the same point and in the same direction. The same applies to monitoring of soil erosion recovery.

A variation of this technique was thus applied in this current study. The technique entails that off-road damaged sites be photographed over time from the time of damage, for as long as possible in order to determine soil and vegetation recovery. This adapted technique, best called "repeat photography" does not include following the strict protocols of fixed-point photography, but it does include the following parts of that protocol:

- Digital photographs are taken of the same off-road site over time;
- Photographs are taken from the same vantage point at each site;
- Photographs are taken from and towards the same direction at all times;
- No fixed time intervals are used, but intervals are used which are practical, i.e. monthly, bi-monthly, etc.

Arid and semi-arid areas experience lower levels (slower rates) of changes, including recovery rates over time, and thus need to be monitored in this way over longer time intervals (Eckhardt, 2010).

3.3 Results and Discussion

3.3.1 Frequencies of ORD

Number of ORD incidents on an annual basis over the whole study period

Off-road incidents occurred 158 times over the three years from April 2009 to March 2012. During April 2011 to March 2012 many more off-road incidents occurred than during April 2009 to March 2010 and April 2010 to March 2011 (Table 3.1). The author is not aware of any similar study where off-road incidents were counted. In the studies of Bhandari (1998) and Onyeanusi (1986) the authors counted the distances in kilometres that vehicles drove off-road by physically measuring the tracks.

Table 3.1 Number of ORD incidents per year

Period	**Number of ORD incidents**
April 2009 - March 2010	53
April 2010 - March 2011	25
April 2011 - March 2012	80
Total	**158**

The number of off-road incidents on a monthly basis per year during the study period, including an update up to the final write-up in December 2012, is represented in Fig. 3.1. It can clearly be seen that there was a major (71%) increase in off-road incidents between 2009/2010 and 2011/2012, with some decrease in off-road incidents during 2010/2011. The reason for the latter decrease was the world economic recession in Europe and the USA (Bonhan-Whetham 2010, pers. comm), leading to a decline in visitor numbers. Furthermore, during June and July of 2010 South Africa hosted the FIFA Soccer World Cup.

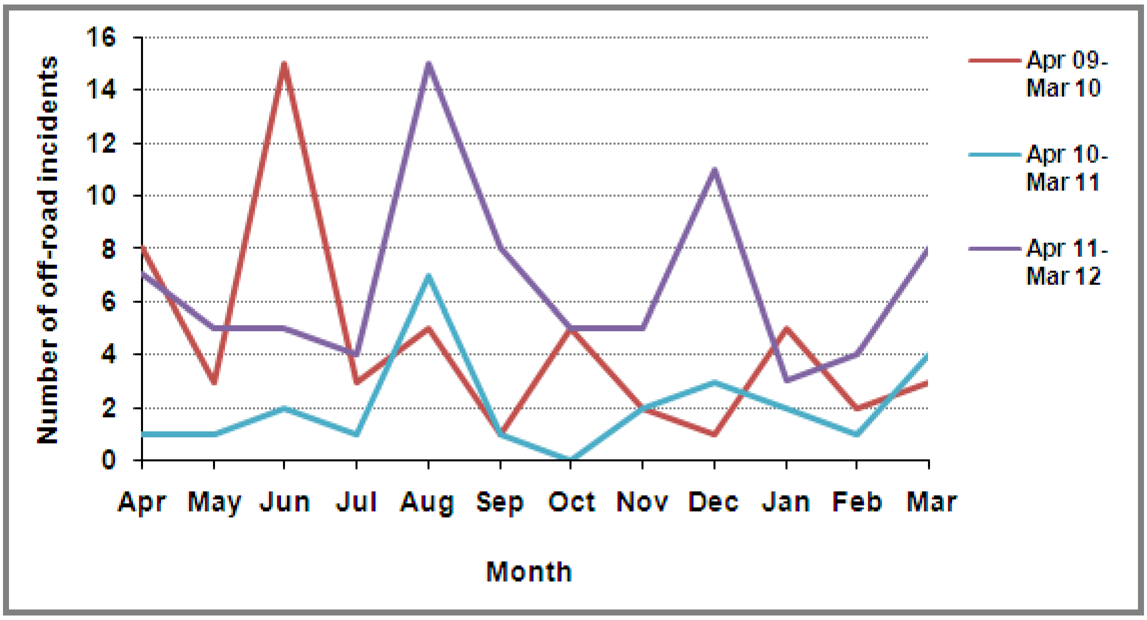


Figure 3.1 ORD in the Makuleke Contractual Park between April 2009 and March 2012

It was expected that during this period, tourism destinations including The MCP will be overwhelmed by tourists and fully booked. The opposite happened and during this period not many international tourists visited the area (Bonham-Whetham 2010, pers. comm). Reasons mentioned were much more expensive plane tickets and soccer spectators did not go to the KNP in large numbers as expected beforehand because of the long distance from the main soccer stadiums.

An important observation from Fig. 3.1 is that during November and December 2011 there was a sharp increase in ORD incidents compared with 2009 and 2010, especially during December. For November 2011 the number was 2.5 times as high as during November 2009 and 2010. For December 2011 the number was 11 times as high as during December 2009 and 3.7 times as high as during December 2010. During November 2012 the number of ORD incidents remained the same as during November 2011. During December 2012 the number of ORD incidents was somewhat down compared with December 2011, but it was still several times higher than during December 2009 and 2010. During December 2010 there was already an increase in the number of ORD incidents over December 2009, but much lower than during December 2011 and 2012. It seems that there is a tendency of an increase in ORD during the early part of the summer rain season. The November and December 2012 figures were important to check whether the November and December 2011 figures were just out shooters or not. They indicate that the latter was not the case (Table 3.2).

Table 3.2 Number of November plus December ORD incidents for four years

Year	November + December ORD incidents
2009	3
2010	5
2011	16
2012	12

Number of ORD incidents per calendar month over the whole study period

The monthly distribution of ORD over the study period is given in Table 3.3, which corresponds with the data in Table 3.1 and Fig. 3.1. The data also correlate well with number of tourists visiting the area (Fig. 3.2), because of the fact that ORD occurs when there are tourists in Pafuri Camp.

Table 3.3 Total ORD incidents per calendar month over the study period April 2009 to March 2012

Month	Frequency	Percentage	Cumulative percentage
April	16	10.1	30.3
May	9	5.7	36.0
June	22	13.9	50.0
July	8	5.1	55.1
August	27	17.1	72.2
September	10	6.3	78.5
October	10	6.3	84.8
November	9	5.7	90.5
December	15	9.5	100.0
January	10	6.3	6.3
February	7	4.4	10.7
March	15	9.5	20.2

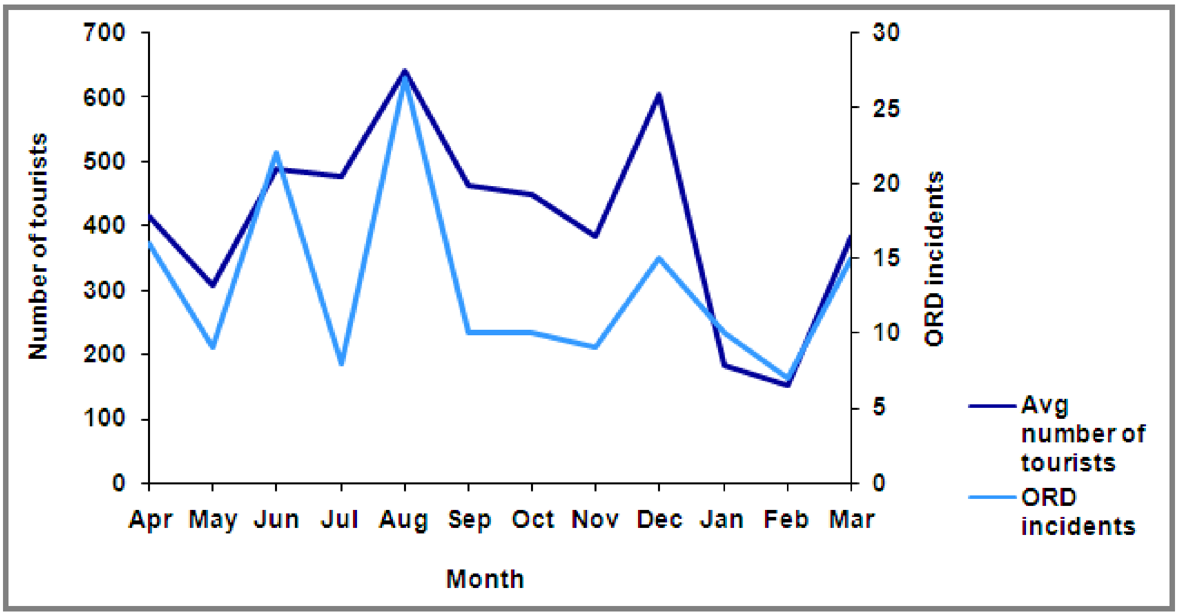


Figure 3.2 Pafuri average visitor bed-nights vs. ORD per month

The MCP is visited by both foreign and local tourists. Foreign tourists, especially those from the Northern hemisphere prefer to visit the area during winter and spring in the Southern hemisphere, as these are the cooler, more pleasant months in this hot area and also holiday season in the Northern hemisphere. South African or local tourists visit the area during all months (Nortjé 2011, pers. obs).

Distribution of ORD incidents per season over the whole study period

ORD was more-or-less evenly distributed over the four seasons during the study period April 2009 to March 2012 (Table 3.4). The four seasons were divided into the following months of the year for practical reasons and because of actual climatic conditions in the study area:

- Summer: November, December, January
- Winter: May, June, July
- Spring: August, September, October
- Autumn: February, March, April

Table 3.4 Seasonal distribution of ORD over the study period

Season	Frequency	Percentage	Cumulative percentage
Summer	34	21.5	21.5
Winter	39	24.7	46.2
Spring	47	29.8	76.0
Autumn	38	24.0	100.0

No mention is made by Bhandari (1998) and Onyeanusi (1986) of the seasons during which they found ORD to be occurring, but all indications are that they found it to be throughout the year.

Number of ORD incidents per individual rain and non-rain season

Continued high levels of ORD during rainy seasons would be a cause of concern, because ORD during wet conditions is very detrimental. If this would become a trend for the full five month rainy season (November to March) each time, it could be even more problematic. The data for the only three rainy seasons covered suggest that this could be a problem, especially when comparing it with the relatively small increases during the seven month (April to October) non-rain seasons (Table 3.5).

Table 3.5 ORD trends during rain seasons vs. non-rain seasons

Season	Year	Number of ORD incidents
Rain season (November-March)	2009-2010	13
	2010-2011	12
	2011-2012	31
Non-rain season (April-October)	2009	40
	2010	13*
	2011	49
	2012	35

*Note the earlier explanations of the reasons for the abnormal 2010 winter season

Number of ORD incidents during wet or dry soil conditions

The data here shows that 96.4% of ORD incidents occurred during dry soil conditions (Table 3.6). The other 3.6% represents times when at least 1 mm of rain fell before or during the off-road incident. These data correlate very well with the percentage of time when it was clear skies and partly cloudy, meaning no rain (Table 3.7).

Table 3.6 Soil condition during ORD

Soil condition	Frequency	Valid percentage	Cumulative percentage
Dry	142	92.2	92.2
Wet	12	7.8	100.0
Total	**158**	**100.0**	

Table 3.7 Weather conditions during ORD

Weather conditions	Frequency	Valid percentage	Cumulative percentage
Clear sky	135	86.0	86.0
Overcast	9	5.7	91.7
Partly cloudy	13	8.3	100.0

This is an encouraging situation as soils are much more prone to degradation by off-road vehicles when wet (Nortjé 2005; Bennie 1972; Henning *et al.* 1986; SASTA 2001).

3.3.2 ORD incidents vs. total animal sightings

ORD is only allowed for certain animal species. These species include: lion, leopard, rhino, cheetah and wild dog (Appendix A). Figure 3.3 thus include ORD and total animal sightings only for these animal species. ORD was not conducted and recorded for any other animal species, although all animal species sightings are recorded on a different recording sheet. What is quite clear from Fig. 3.3 is the fact that actual ORD only accounts for a small percentage (12.4%) of the total monthly animal sightings during the study period. But what is noteworthy is the fact that when looking at the data and graph month by month, there is no consistency in the relationship between total sightings and off-road. The following are examples of these inconsistencies: The August 2011 total animal sightings are low, and the ORD high. The numbers of ORD are almost half of the total animal sightings. But during October 2011 the total number of animal sightings is 10 times higher than the ORD. The same is true for the periods February 2011, April 2009, and December 2011.

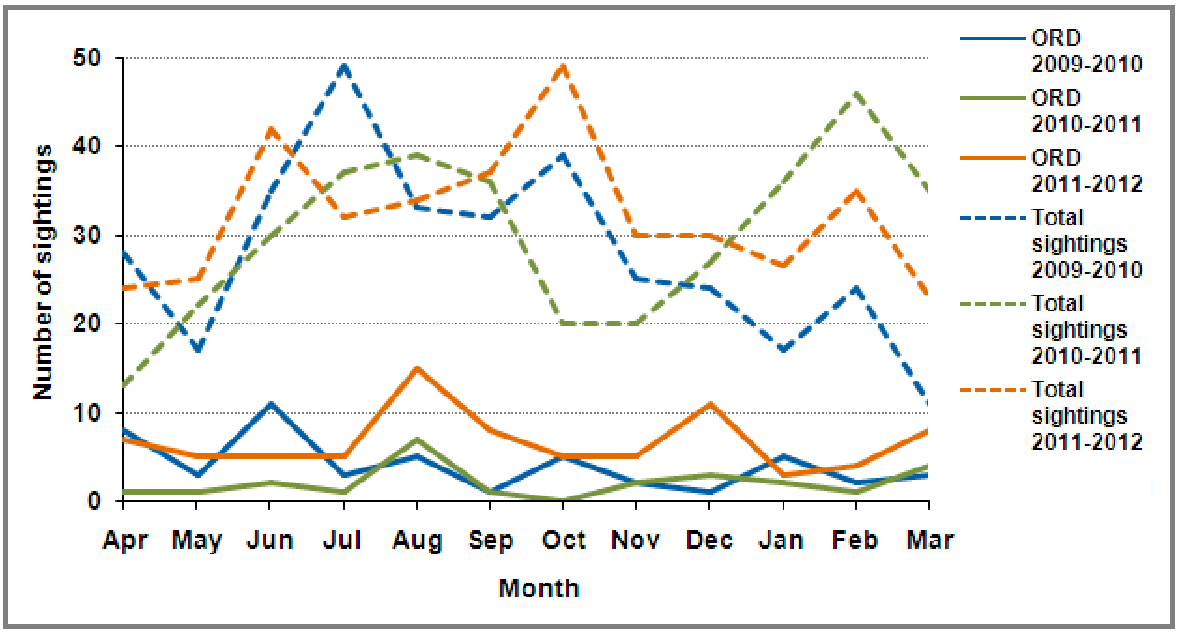


Figure 3.3 Off-road sightings vs. total animal sightings during study period

3.3.3 Geographic distribution of ORD

The 'hot' and 'cold' spots of ORD, representing the areas with the most and least ORD frequencies, respectively, were identified from the ORD monitoring data for the first year (1st April 2009 to 31st March 2010). The kernel density of ORD, which represents the number of off-road events per km^2 over this one year period, was calculated and mapped, to help in the selection of three trial sites (Fig. 2.1).

Sites were chosen at the hot spots of ORD to represent the soil forms most likely to be used for ORD. The soils chosen represented two different soil forms in the South African soil classification system (Soil Classification Working Group 1991). The Oakleaf soil form represented two of the trial sites (sites 1 and 3) and the Dundee soil form one site (site 2). The Oakleaf soils are classified as Cambisols according to WRB (1998) and the Dundee soils as Fluvisols. Off-road monitoring continued for the remainder of the study period of three years to determine the total area covered by off-road tracks (Fig. 3.4).

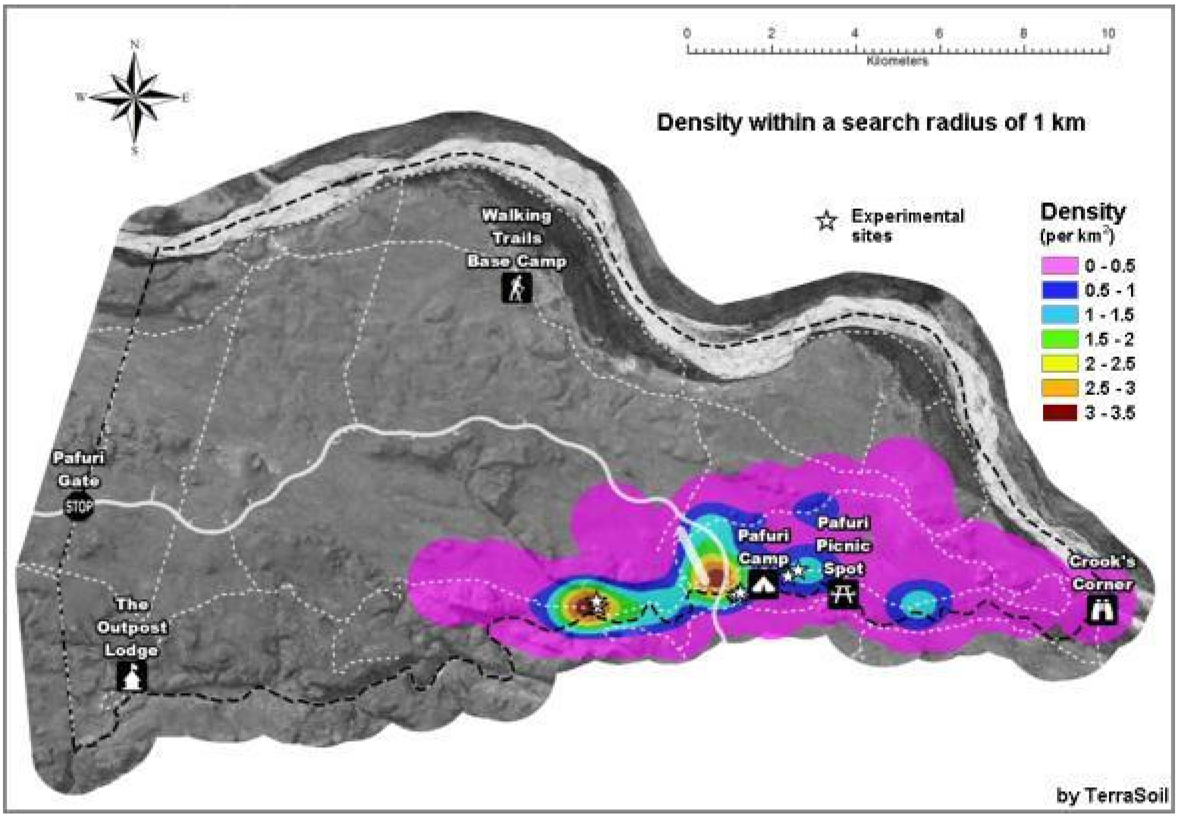


Figure 3.4 Map indicating off-road density in Pafuri between April 2009 and March 2012

As previously mentioned in Chapter 2, the majority of ORD during the study period occurred on the flood plains along the Luvuvhu River. The off-road density per km^2 decreased during the period April 2010 to March 2011, compared to the period April 2009 to April 2010. It then increased again during the period April 2011 to March 2012 to almost double the density during the period April 2010 to March 2011 (Fig. 3.5). These data correspond well with the data discussed in Section 3.3.6.1, which indicate a similar trend as mentioned above in distance (km) and area (ha) impacted or affected by ORD.

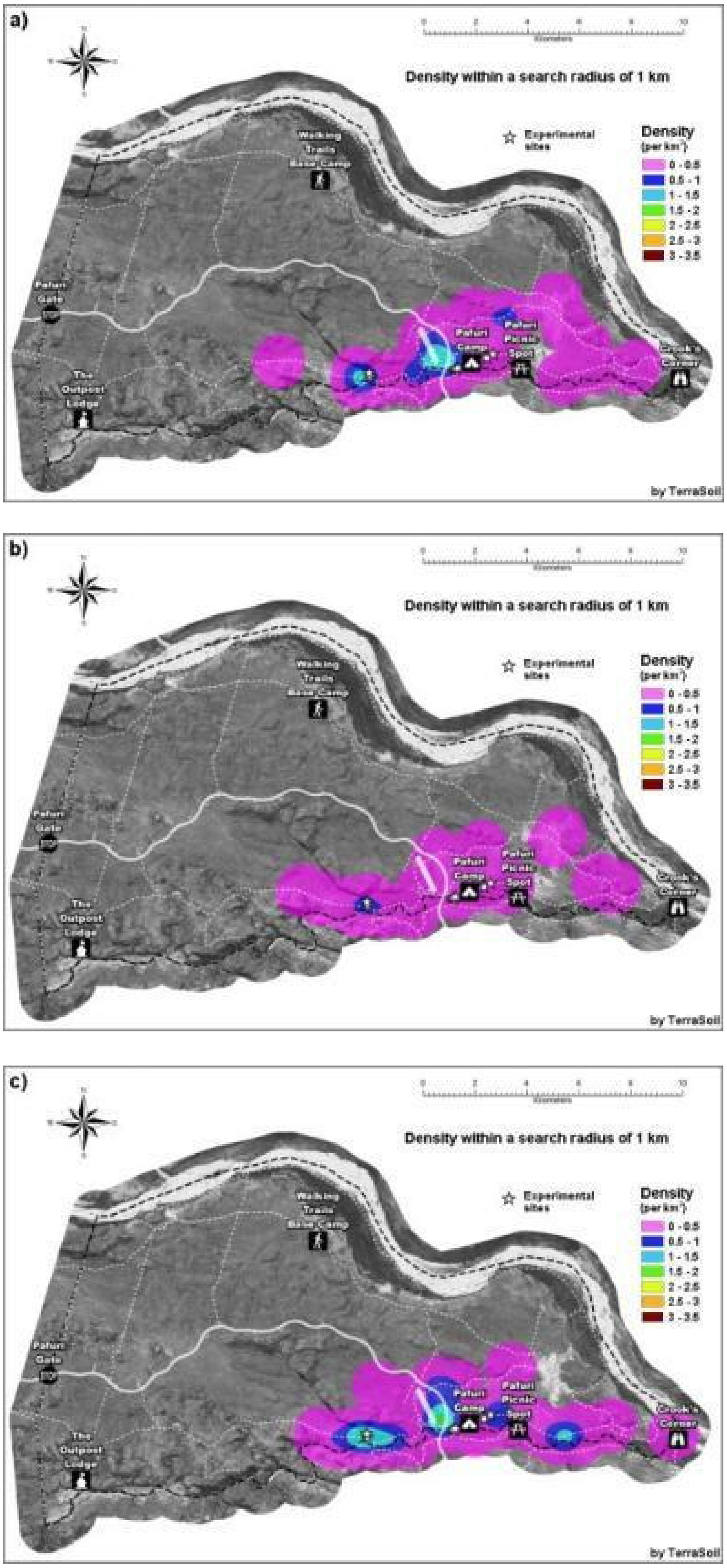


Figure 3.5 Off-road density in the Makuleke Contractual Park for:
a) April 2009-March 2010; b) April 2010-March 2011; c) April 2011-March 2012

During the period April 2009 to March 2010 ORD was concentrated mainly around Pafuri Camp area and towards Luvuvhu West. This distribution stayed the same during the period April 2010 to March 2011, but off-road density and area affected was less than the previous period. During April 2011 to March 2012 there was a drastic increase in both density and number of ORD incidents, and a movement of higher density off-road toward Luvuvhu East and the Fever Tree Forest area (Fig. 3.5).

3.3.4 ORD distances travelled and areas impacted by ORD

Off-road distances driven during the study period (April 2009 to March 2012) amounted to a total of 22 425km. Section 3.2.3 explains in detail how the off-road distances and areas affected were calculated. For two of the main predators for which ORD is allowed (lion and leopard), there was a statistically significant difference in the distance travelled (Table 3.8).

Table 3.8 Distances travelled for lion vs. leopard sightings

Animal species	Indicator	Distance (m)
Lion	Minimum	25
	Maximum	340
	Mean	146
	Median	105
Leopard	Minimum	15
	Maximum	387
	Mean	97
	Median	65

The significant difference is at the 5% (p=0.007) level. The results showed that distances for lion sightings are significantly longer than for leopard. Similar observations were also made by Nortjé (2005) in a study in four private concession areas in the southern and central parts of the KNP. In the study by Nortjé (2005) distances for lion and cheetah sightings were both significantly longer than distances to leopard. Mean distances for lions, leopards and cheetahs were 156 m, 118 m and 145 m, respectively, with maximums of 2 000 m, 1 000 m and 500 m, respectively (Nortjé 2005).

The above-mentioned could be explained by the fact that lions and cheetah prefer to hunt and live in open savanna areas, whereas leopard prefer the thicker riverine bush. In open savanna areas lions are also visible at fairly long distances from the roads and ORD is then done to bring tourists closer to them. Leopards are in thickets and trees and are not visible at such long distances. Lion tend to walk away from the roads and keep on walking while the game drive vehicles will follow, while leopard will stay in smaller areas and try to hide in the thick bush (Nortjé 2011, pers. obs). The implication of this would be that when driving off-road for lion a much larger soil and vegetation area would be compacted and damaged.

3.3.5 Landscape, topography, soil and vegetation of areas where ORD is practised

Landscape mostly used for ORD

Comparing the area where ORD is practised (Fig. 3.4) with the topographical and landscape maps (Fig. 2.6 and 2.14) shows that the landscape almost exclusively used for ORD is the Luvuvhu flood plain. The topography of this area consists of almost flat, slightly undulating land, associated with the alluvial deposits which flank the Luvuvhu River in the eastern and southern areas (Schutte 1974, Venter 1990). The other landscapes have terrain that is quite inaccessible to vehicular traffic.

The Levhuvhu flood plain is also the area where most animals, especially animals for which ORD are allowed, are found. The area surrounds the Luvuvhu River and a lot of pans, serving as water points for animals, occur in this landscape. The riverine bush is preferred habitat for leopard, while prey for lion, such as impala, bushbuck, kudu, warthog, zebra and buffalo, graze on the flood plain where palatable nutritious grass occurs year round, including the rainy season.

The finding that in the MCP ORD is almost exclusively limited to only one landscape is contrary to what was found elsewhere. Nortjé (2005) showed no significant differences between ORD in the different landscapes of study areas in the southern KNP.

Dominant soils on which ORD is practised

The dominant soils in this area are soils of the Oakleaf form on the flood plains, with minor areas of Dundee soils on the first terraces of the river beds, and Arcadia soils in the pans (Fig. 2.9). Because soils of the Oakleaf form cover such a large proportion of the area, most (82.9%) of the ORD was done on these soils (Table 3.9).

Table 3.9 Soil forms used for ORD

Soil form	Frequency	Valid Percentage	Cumulative Percentage
Oakleaf	131	82.9	82.9
Dundee	19	12.0	94.9
Mispah	4	2.5	97.4
Arcadia	2	1.3	98.7
Mayo	2	1.3	100.0

These findings apparently do not correspond with findings by Nortjé (2005) in the southern KNP, which showed no statistically significant differences between the soils on which ORD was practised. However, the study by Nortjé (2005) was in an area with a quite even spread of different soils, in contrast to the ORD area in the MCP, which is absolutely dominated by one kind of soil.

Vegetation types on which ORD is mostly practised

The vegetation types covering most of the area in which ORD is practised correlate well with the soils of the flood plains. Thus, ORD occurred predominantly in areas covered by lowveld riverine forest and subtropical alluvial vegetation, with 98% (Table 3.10) of the ORD incidents in these areas. The other 2% of ORD occurred in the Limpopo Ridge Bushveld (Table 3.10).

Table 3.10 Vegetation types used for ORD

Vegetation	Frequency	Valid Percentage	Cumulative Percentage
Lowveld riverine forest	48	28.0	28.0
Subtropical alluvial	106	70.0	98.0
Limpopo ridge bushveld	4	2.0	100.0

A significant percentage (6.8%) of the ORD took place in the Fever tree Forest (Fig. 2.9). At least three occurred in pans (Reedbuck vlei) (Fig. 2.6 and 2.9), which are part of a Ramsar wetland (Fig. 2.15), all of which is included in the Subtropical Alluvial vegetation. This will have serious negative consequences due to ORD and should not be allowed. These are compared with ORD in the Masai Mara National Reserve which occurred mostly in the grassland flood plains (Bhandari 1998; Onyeanusi 1986), which consist largely of *Themeda triandra* grasslands.

Driving in drainage lines or shortly after veld fires

Because of the known fact that vehicles driving in and out of rivers, drainage lines and *spruits* can cause serious soil compaction and/or soil erosion, these data were collected. When vehicles exit at steep slopes or wet areas, wheel slip is caused. Wheel slip has two effects, viz. (i) it aggravates the degree of soil compaction and (ii) it aggravates the formation of ruts which channel water during subsequent rains and aggravate erosion. Rivers, *spruits* or drainage lines were crossed during 17.6% of all off-road incidents. Drainage lines were crossed the most (52.0%), with *spruits* second most (28.0%) and rivers the least at 20.0% of the time (Table 3.11).

Table 3.11 Types of crossings during ORD

Crossing	Frequency	Percentage
River	5	20.0
Spruit	7	28.0
Drainage line	13	52.0
Total	25	100.0

Fires also expose the soil to vehicle damage as the vegetative protection is removed. Mills & Fey (2004) found that frequent fires intensify soil crusting. Rainfall simulation studies showed that burned plots crusted more rapidly than unburnt plots and at lower rainfall intensity. Mills & Fey (2004) ascribed the increase in dispersion of clay in burned plots partly to the decrease in humus content and the associating disaggregating effect. Fortunately, during the present study period, no ORD occurred shortly after veld fires before basal vegetation had time to recover (Nortjé 2012, pers. obs).

3.3.6 Damage due to ORD (before vs. after)

When discussing damage under this section it means visual or surface damage to the soil and vegetation. Sub-soil damage will be discussed in Chapter 4. Visual damage was rated "before" and "after" each ORD incident (Tables 3.12 and 3.13). Damage before the off-road incident was overwhelmingly rated as none (84.6%) with others like "bare soil" (5.6%), "sparse grass" (3.7%), "flattened grass by animals" (0.6%), "flattened grass by tyres" (2.5%), and "slight soil erosion" (1.2%) very small.

Table 3.12 Visual damage before off-road incident

Visual damage	Frequency	Percentage	Cumulative Percentage
None	137	84.6	84.6
Bare soil	9	5.6	90.2
Sparse grass	6	3.7	93.9
Flattened grass-tyre marks	4	2.5	96.4
Good grass cover	2	1.2	97.6
Slight erosion from road	2	1.2	98.8
Flattened grass, animals	1	0.6	99.4
Game path	1	0.6	100.0

Table 3.13 Visual damage after off-road incident

Visual damage	Frequency	Percentage	Cumulative Percentage
None	1	0.6	0.6
Tyre tracks	151	86.3	86.9
Flattened grass-tyre marks	16	9.1	96.0
Bare soil	1	0.6	96.6
Broken tree/branches	5	2.9	99.5
Ruts in soil (made by tyres)	1	0.6	100.1

The damage shown in Table 3.13 corresponds well with damage due to ORD observed by Bhandari (1998) and Onyeanusi (1986). But they only mention "flattened grass", "tyre tracks" and "ruts". The percentage values in Table 3.13 were calculated by comparing the number of times the damage occurred during off-road incidents with the total number of off-road incidents during the study period.

3.3.6.1 Area impacted by ORD

To calculate the area impacted by ORD during the study period the equation given in Section 3.2.3 was used. The total area impacted by ORD during the three year study period is indicated in Table 3.14 and Fig.3.6.

Table 3.14 Area impacted by ORD

Period	Distance impacted (km)	Cumulative distance impacted (km)	Area impacted (ha)	Cumulative area impacted (ha)
April 2009-March 2010	6.478	6.478	3.34	3.34
April 2010-March 2011	3.498	9.976	1.76	5.1
April 2011-March 2012	12.449	22.425	6.41	11.51

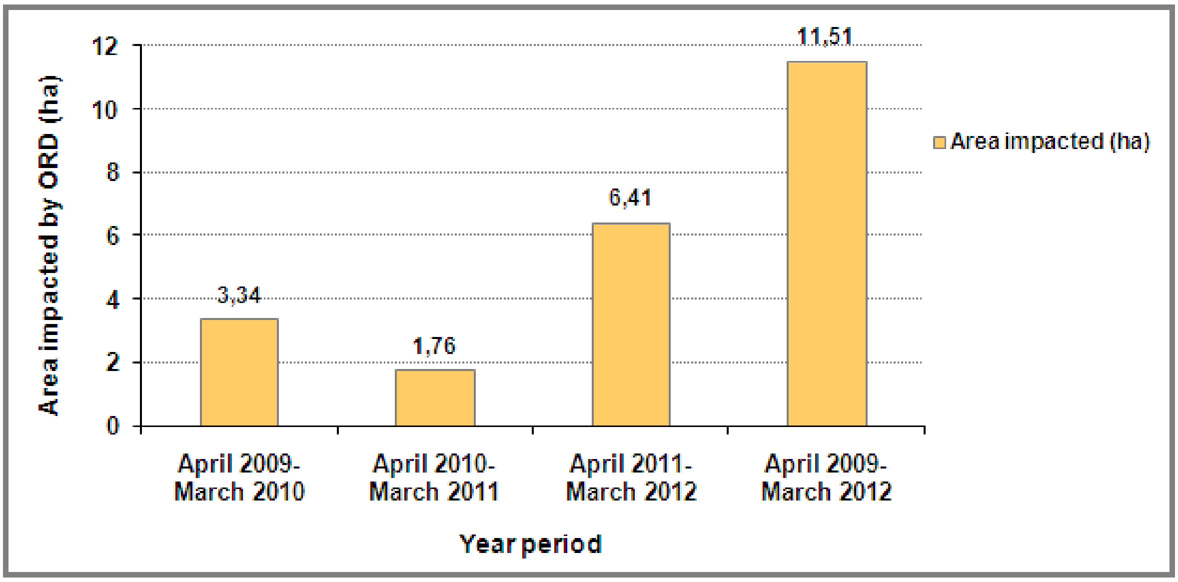


Figure 3.6 Areas (ha) damaged by ORD during the study period

3.3.6.2 Area impacted by ORD as a percentage of whole area, the flood plains and the high intensity areas

The area impacted by ORD can with the use of GIS also be calculated as percentage (i) of the total area, (ii) the flood plains or (iii) the high intensity areas:

(i) 11.51 ha/20 255 ha x 100% = 0.057%;

(ii) 11.51 ha/4 000 ha (approximate size of Luvuvhu flood plains) x 100% = 0.29%. This is 5 times higher than on the basis of the total area (i);

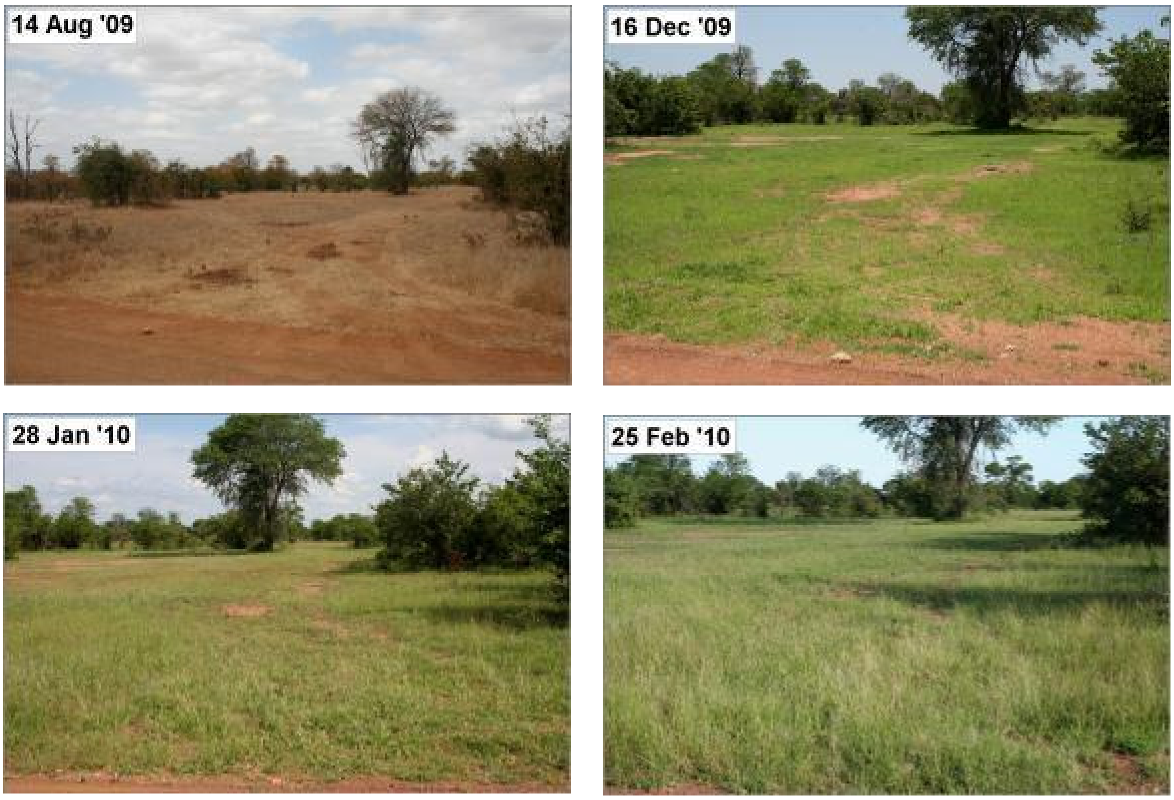
(iii) 6.98 ha/193.9 ha (hotspot area) x 100% = 3.60%. This is 63 times higher than on the basis of the total area(i);

Bhandari (1998) and Onyeanusi (1986) calculated vegetation or standing crop loss as percentage of the total area in the Masai Mara Reserve in Kenya, as 2% and 1.38%, respectively. This is much more compared to the total damage by ORD in this study, but it must be said that their calculations was for close to 3 000 vehicles compared to only 158 in this study.

Darlington (2003) mentioned that a motorcycle tyre disturbs one acre (half hectare) of topsoil in twenty miles (32 kilometres) of travel. And that an ATV (All-Terrain Vehicle) churns up to 6 acres (3 hectares) every 20 miles (32 kilometres). He mentioned that this should not be an issue if the vehicles stay on the existing vehicle track network or practise "controlled-traffic". But it is important to point out that he refers to only the direct areas under the tyres being "churned up", but not to the wider effects.

3.3.7 Photographic (repeat photography) follow-up and monitoring of soil and vegetation recovery after ORD

Repeat photography of a ORD site from August 2009 to August 2011, a period of two years, is shown in Fig. 3.7. The photographs represent the off-road track of one vehicle driving off-road one time during August 2009 during dry conditions (Nortjé 2009, pers, obs). Covering all seasons of the year twice, including dry periods and periods with good rainfall, it can be seen that even after two years the off-road tracks can still easily be seen.




17 Sep '10


29 Oct '10


3 Dec '10


6 Jan '11


18 Feb '11


25 Mar '11


15 Apr '11


17 Jun '11

Figure 3.7 Off-road site, August 2009 to August 2011

This means that after two years the damage due to sub-soil compaction of the soil has not yet recovered. The sub-soil compaction is reflected in the no recovery of the grass cover. What also can be seen in Fig. 3.7 is the damage is not restricted to the width of the vehicle tyres, but much wider. Similar observations have been made in the Masai Mara National Reserve by Bhandari (1998) and Onyeanusi (1986), and in the MCP by Nortjé & Laker (2011, pers. obs). This trend was also observed between 2004 and 2006 in four private concession areas in the KNP (Nortjé 2005).

The photographic follow-up by the use of digital photography for repeat photographic monitoring was effective in monitoring soil and vegetation recovery over time (Fig. 3.7). This same method was also applied with all the off-road incidents during the study period, as well as for monitoring extreme damage due to wet soil conditions. Eckhardt (2003, 2010) and others (Howorth 2008; Burke & Strohbach 2000) have all applied this technique successfully in documenting changes in biodiversity components.

It was stated in the introduction that, according to the directive in the ORD guidelines, ORD may not cause damage that is such that the ecological system (e.g. grass) does not recover after 25 mm rain (van der Merwe 2004). Here (Fig. 3.7) a situation is illustrated where the vegetation did not recover after much more than 25 mm rain and after a long period. It, therefore, clearly shows that the guideline requirements cannot be met. Many such cases have been monitored, finding the same pattern and outcomes (Nortjé & Laker 2011, pers. obs).

Some of the serious implications of the above-mentioned are:

- the directive in the off-road guidelines allowing ORD on soils which can handle it and will recover (after 25 mm rain), is not valid and needs to be adapted;

- soil damage due to compaction in this study area did not recover even after two years of wet and dry cycles under natural conditions. Thus, the recovery potential (resilience) of these soils are low;
- it was shown that the area impacted by off-road vehicles is much larger than just below the vehicle tyres;
- the Luvuvhu flood plain where most ORD occurs is already physically degraded, in the sense that severe soil crusting and bare soil patches occur over large parts of the area. Vegetation cover is also poor, and did not recover after 43 years of time for natural recovery. The ORD will just add to this already degraded area.

3.4 Conclusion

The results in this chapter show clearly that a significant area in the flood plains of the MCP is impacted by ORD. The impacts are very serious if one looks at the amount of land that an off-road vehicle can disturb. The total area damaged by ORD during the study period is 11.51 ha.

The Luvuvhu flood plains are the landscape where nearly all ORD incidents occurred. These flood plains are approximately 4 000 ha in size. The area affected by ORD is 5 times larger when determining the area impacted as a percentage of the Luvuvhu flood plains, compared to the whole study area. This means that the soils and vegetation of these flood plains are also mostly affected. There is a disturbing trend of sharp increases on off-road incidents during the rainy season, which starts especially during the beginning of December. If one ignored the abnormally low winter season during 2010, which was the result of the Soccer World Cup, the absolute increase in the last rainy season was higher than the increases in the previous non-rainy seasons, but especially the relative (%) increase in the rainy season was much higher.

A recommendation would be that less ORD can be accommodated by a better planned road network. This better planned road network would traverse through all the important areas where most animals, especially predators are seen, but it takes the pressure off of making new road by driving off-road. Extra roads added during the study period through off-road driving added up to 22 425 km. Much less better planned roads could be added than these 22 425 km of unplanned roads, with much less impact on the soil and vegetation. Existing roads, like especially the badly located Luvuvhu-east main tourist road could be closed and replaced by shorter better planned tourists' roads. The recommendation is thus, a planned system of "controlled traffic".

Driving in wetlands is prohibited as indicated in Chapter 2. The flood plain areas surrounding the Luvuvhu and Limpopo flood plains are classified as RAMSAR areas (Fig. 2.14 and 2.15). It is, therefore, wetland protected areas (pans). Especially during the period 2011 to 2012 there have been a disconcerting shift in the increased driving in those areas and fever tree forest area to the east of Pafuri Camp.

3.5 References

- Adams, J.A., Endo, A.S., Stolzy, L.H., Rowlands, P.G., Johnson, H.B. (1982) Controlled experiments on soil compaction produced by off-road vehicles in the Mojave Desert, California. *J Appl Ecol*, 19/1, 167-175.
- Bennie, A.T.P. (1972) 'n Ondersoek na sekere aspekte van grondsterkte in gronde van die manganoserie. MSc(Agric) thesis, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Bhandari, M.P. (1998) Assessing the impact of off-road driving on the Masai Mara National Reserve and adjoining areas, Kenya. Masters dissertation, International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands.
- Bothma, J.d.P. (2000) Monitering op die wildplaas. In: *Wildplaasbestuur*, derde uitgawe (uitgewers Van Schaik), pp. 31.
- Burke, A. & Strohbach, B.J. (2000) Review: vegetation studies in Namibia. Biology Department, University of Namibia, Windhoek.
- Daneel, J.L. (1992) The impact of off-road vehicle traffic on the gravel plains of the central Namib Desert, Namibia. Unpublished MSc thesis. University of KwaZulu-Natal, South Africa.
- Darlington, D. (2003) Untracked Utah. In: *Off-road vehicles and their effects on National Parks* (ed: Johnson, S.),pp. 4.
- Eckhardt, H.C. (2003) Long term changes in the structure of the woody vegetation component in the Kruger National Park, South Africa. In: *Rangelands as dynamic systems — vegetation change in rangelands* (ed: Huenneke, L. & Ward, D.). *Afr J Range For Sci*, 20/2, 89-100.
- Eckhardt, H.C. (2010) Gras- en bosharmonie. In: *Bosveld: ekologie en bestuur*, (ed. van der Walt, P.T). Briza publishers, Pretoria.
- Griggs, G. B. & Walsh, B. L. (1981) The impact, control and mitigation of off-road vehicle activity in the Hungry Valley, California. *Environ Geol*, 3/4, 229-243.

- Henning, J.A.G., Nel, D.J. & Harmse, H.J.v.M. (1986) Die invloed van verdigtingspoging, klei- en waterinhoud op verdigting van geselekteerde Hoëveldgronde. *S Afr J Plant Soil*, 3, 119-122.
- Howorth, R. (2008) Fixed-point photography survey of the Knepp estate. 2005-2008 (July). Sussex Wildlife Trust.
- Joubert, S. (2007) The Kruger National Park: a history. Published by High Branching, Johannesburg. Volume 2, pp. 379.
- Makuleke Contractual Park: conservation and development framework, April 2012.
- Matchett, J.R., Brooks, M.L., Gass, L., Mathie, A.M., Vitales, R.D., Campagna, M.W., Miller, D.M. & Weigand, J.F. (2004) Spatial and temporal patterns of off-highway vehicle use ate the Dove Springs OHV open area, California. US Department of the Interior, US Geological Survey, Sacramento.
- Mills, A.J. & Fey, M.V. (2004) Frequent fires intensify soil crusting: physicochemical feedback in the pedoderm of long-term burn experiments in South Africa. *Geoderma*, 121, 45-64.
- Nortjé, G.P. (2005) The impacts of off-road driving and other concessionaire activities on physical soil degradation. MPhil thesis, Centre for Wildlife Management, University of Pretoria.
- Onyeanusi, A.E. (1986) Measurement of impact of tourist off-road driving on grass-lands in Masai Mara National Reserve, Kenya: a simulation approach. *Environ Conserv*, 13/4, 325-329.
- Schlacher, T.A. & Thomson, L.M.C. (2007) Exposure of fauna to off-road vehicle (ORV) traffic on sandy beaches. *Coast Manage*, 35, 567-583.
- Schutte, I.C. (1974) 'n Geologiese verkenningsopname van die Noord-Sentrale gedeelte van die Nasionale Krugerwildtuin. Geological Survey, Pretoria
- Smallwood, C.B. (2009) Spatial and temporal patterns of recreational use at Ningaloo Reef, north-western Australia. PhD thesis. School of Environmental Science, Murdoch University, Australia.
- Soil Classification Working Group (1991) *Soil Classification: a taxonomic system for South Africa*. Department of Agriculture Development, RSA.
- South African Sugar Technologist's Association (SASTA) (2001) Soil compaction work-shop proceedings, August 2001. CD-ROM. Mt Edgecombe, Durban.
- Van der Merwe, L. (2004) Guidelines for off-road driving in the private concessions of the Kruger National Park. Concessions Operations Manual, KNP.

- Venter, F.J. (1990) A classification of land for management planning in the Kruger National Park. Unpublished Phd thesis. University of South Africa.
- Webb, R.H. (2002) Recovery of severely compacted soils in the Mojave Desert, California, USA. *Arid Land Res Manag*, 16, 291-305.
- Webb, R.H., Steiger, J.W. & Wilshire, H.G. (1986) Recovery of compacted soils in Mojave Desert ghost towns. *Soil Sci Soc Am J*, 50, 1341-1344.
- World Reference Base for Soil Resources (WRB) (1998) Rome: Food and Agriculture Organization of the United Nations (FAO).

CHAPTER 4
QUANTIFYING THE IMPACT OF OFF-ROAD DRIVING BY MEANS OF SIMULATED OFF-ROAD DRIVING TRIALS

Nortjé, van Hoven & Laker (2012),
Factors Affecting the Impact of Off-Road Driving on Soils
in an Area in the Kruger National Park, South Africa;
Environmental Management 50/6, 1164-1176 (published 16th October 2012)

4.1 General Introduction

As part of the South African National Parks (SANParks) commercialization process in the Kruger National Park (KNP), concession areas were set aside for the exclusive use of private operators (Nortjé 2005). The objective of the commercialization process is to broaden the tourism product of the KNP and, thereby, increase the revenue for the SANParks (Nortjé 2005).

Concession operators are allowed certain tourist-attracting activities, including off-road driving (ORD), aimed at bringing tourists in close contact with members of the 'Big Five' in wildlife. It seems as if such activities are often implemented without knowledge regarding the full potential impacts of the activities on the environment and more particularly the soils (Nortjé 2005). Certain principles and guidelines were set for practising these activities in the concession areas, but some of these guidelines and principles have not been tested and/or not scientifically proven. ORD is a case in point.

One of the guidelines for ORD states that (van der Merwe 2004): "Vehicles that drive off-road may not follow in each other's tracks". This is the practised guideline that is still being continued after several years. The objective of the research reported here was, thus, to determine whether vehicular off-road traffic impacts on soil compaction and if it does, to quantify the magnitude of the impact on soil compaction.

Soil compaction is defined as the process of bringing soil to a dense state, i.e. increasing its bulk density (van der Watt & van Rooyen 1995). Soil compaction can basically be distinguished as (i) soil crusting (formation of a seal at the soil surface) and (ii) subsurface compaction (the formation of a dense soil layer some distance below the soil surface). The latter is usually meant when the term "soil compaction" is used. Numerous studies on the effects of soil compaction on plant growth have been conducted since about the early 1960s, mainly in the USA, Australia and South Africa. These have been reviewed by, amongst others, Bennie & Krynauw (1985), du Preez *et al.* (1979, 1981) and SASTA (2001). The vast majority of these studies were conducted in croplands, both dry land and irrigated.

The key factor is the effects of soil compaction on root penetration. The researchers came to the conclusion that bulk density was not the best parameter to use in root penetration studies. In addition, it is quite cumbersome for routine determinations. It was found that "soil strength", defined as "a general term referring to the ability of a soil to resist deformation by applied forces" (van der Watt & van Rooyen 1995) or the soil's mechanical resistance to penetration by plant roots. The instrument used to measure this is a penetrometer, which measures "penetration resistance". A thin metal probe is driven into the soil and the soil's penetration resistance, i.e. the force required to drive it in, measured. In modern penetrometers, the probes are driven in electrically at a constant rate and resistances determined and recorded electronically.

The effects of high soil compaction on plants include:

- Inability of roots to penetrate through the compacted layer and thus inability to utilise water stored in the subsoil. This makes plants much more vulnerable to drought stress, especially when dependent on low and erratic rainfall;
- Roots not only becoming shorter, but also thicker, thus having lower specific surfaces (less feeding surface per unit root mass). The consequence is very poor uptake of a whole range of essential plant nutrients, especially phosphorus (Bennie & Laker 1975; du Preez *et al.* 1979, 1981; Merotto & Mundstock 1999). This leads to induced nutrient deficiencies and poor plant growth.

In addition to the reduction in soil productivity, soil compaction also increases erodibility, thus "affecting additional compartments in the surrounding ecosystems" (Horn & Fleige 2009). Soil compaction is mostly irreversible (Horn & Fleige 2009), meaning that the soil will not recover unless the compacted layer is broken up with tined implements, as used in crop farming.

Research in agriculture has established that vehicular traffic is the primary source of the mechanically applied forces to soils which lead to soil compaction, with concentrated pressure under the wheels being the greatest contributing factor (Bennie & Krynauw 1985). By far, the biggest part of compaction (up to 90%) takes place during the first pass of wheels over an area (SASTA 2001; du Preez *et al.*1979, 1981). Subsequent wheel passes on the same tracks increase the degree of compaction under the tracks little compared with the first pass. Thus, uncontrolled haphazard movement of tractors, implements, harvesting machinery, lorries, etc., over cultivated fields during secondary operations can compact the whole field, causing the development of a sub-surface "traffic pan". In contrast, du Preez *et al.* (1979, 1981) found that a simple system of controlled traffic greatly reduces the compacted area. Van der Watt & Van Rooyen (1995) define controlled traffic as: "Tillage in which all operations are performed in fixed paths so that re-compaction of soil by traffic (traction or transport) does not occur outside the selected paths". Controlled traffic has been used by farmers in various parts of the world as an effective management technique to restrict soil compaction to defined zones under intensive crop production systems for more than 50 years. It has also been practised very effectively by South African farmers for about that same period of time.

In the South African forestry industry it was also found that overall productivity decline depends on the areal extent of the harvesting operations and thus on the area compacted during harvesting (Smith & Johnston 2001). Smith & Johnston (2001) pointed out that 40% growth loss over 10% of an area is very small compared to 20% growth loss over 80% of the area. Bekker (1961) found that subsoil compaction caused by wheels is not confined to the area directly under the wheels. On both sides of a track compaction takes place at angles of 45° from the side of the track. Thus, the area compacted is much wider than the wheel track itself.

It was found that the degree of compaction (density of the traffic pan) is determined by the tyre pressure of a vehicle travelling over the soil (SASTA 2001). The higher the tyre pressure is the more severe is the compaction. Each soil has a specific soil water content at which it is most susceptible to compaction when pressure is applied to it, for instance, by a tractor tyre. Numerous South African studies have been done on this in the agricultural and forestry sectors, as, for example, reported in several papers in SASTA (2001), Bennie (1972) and Henning *et al.* (1986). It is accepted that maximum compaction occurs at fairly high soil water contents – just below field capacity. Conditions under which ORD is done in game reserves are somewhat different from those in agriculture and forestry. The main difference is that in game reserves ORD is usually done on virgin, undisturbed soils – although this is not always the case. Thus the wheel impact of vehicles may be somewhat different than in agriculture and forestry. Some studies have been done elsewhere on impacts of ORD in game reserves, for example, by Bhandari (1998), Onyeanusi (1986), McCool (1981) and O'Brien (2002).

The latter studies mentioned above did not include basic measurements of the effects of ORD on soil physical conditions, such as sub-surface compaction. No clear guidelines and recommendations could, therefore, be derived from them. A comprehensive study was thus conducted regarding the potential impacts of ORD on soil conditions and consequently on plant growth. It is often assumed that grazing animals do not damage the soil, either through crusting or subsoil compaction (Savory 1988). Compaction measurements of animal paths were therefore also conducted as a comparison to vehicle compaction. The results indicated a totally different reality in the field than the above-mentioned assumptions, especially when animals walk in animal paths.

4.2 Methodology

4.2.1 Selection of trial sites

Three trial sites were chosen by identifying the areas in which ORD occurred most and selecting a representative site in each of these (Fig. 2.1). This was conducted by analysing off-road data from animal sightings after one year of practising ORD in the area. They were selected to represent the most important soil types in the specific areas (Fig. 2.9).

4.2.2 Soil profile descriptions

Camp Site (Site 1) and LW Site (Site 3) are on soils of the Oakleaf form, and River Site (Site 2) on a soil of the Dundee form according to the South African soil classification system (Soil Classification Working Group 1991) (Fig. 4.1). The Oakleaf soils are classified as Cambisols according to WRB (1998) and the Dundee soils as Fluvisols. The soils of Sites 1 and 3 are typical Oakleaf soils, being pedogenetically young soils in early stages of development on a large sub-recent river terrace (the second terrace). There is a clay increase from the topsoil to the weakly structured subsoil. The Dundee soil of Site 2 is a typical soil with alluvial stratifications on the lowest terrace next to the river, presently being affected by sediment deposition by the river. There were important differences between the three soils regarding their chemical and physical properties and characteristics (refer to Section 4.2.3).

Figure 4.1 Soil profiles at: a) Site 1, Oakleaf; b) Site 2, Dundee; c) Site 3, Oakleaf

4.2.3 Particle size (multiple sieve), chemical and clay mineralogical analyses of soils

Particle size distribution (soil texture) is closely related to bulk density and is an important indicator of a soil's susceptibility to compaction (Reed 1983). "It was established that of many factors that may influence soil compactibility, particle-size distribution is the most important for a group of soils studied" (van der Watt 1969). The particle size distribution of the three trial sites differ substantially in respect to aspects that may affect soil compaction (Table 4.1).

These soils differ substantially in regard to their fine sand content, a very important factor regarding susceptibility to soil compaction (Laker 2001; Bennie & Burger 1988). The soil at Site 1 has a much lower fine sand (<100 μm) content (26.7 and 29.7% for top- (1T) and subsoil (1S), respectively) than the soil at Site 3 (49.8 and 38.4% for the top- (3T) and subsoil (3S), respectively). This means that the fine sand plus silt content of the soil at Site 1 is more than 60% and at Site 3 more than 70%, with the topsoil nearly 80%. Serious compaction is normally expected in soils with more than 50% fine sand plus silt, especially if silt is more than 20%, and less than 35% clay (Laker 2001). Expressed as a fraction of the sand content of the soils the fine sand proportions are about 60% for the topsoil at Site 1 and 82% for the subsoil, compared with more than 95% for both the top- and subsoil at Site 3. The implications of these are discussed later.

In contrast to the others, the soil at Site 2 is a sandy soil. The subsoil (2S), with only 2% clay and 3% silt, is classified as having pure sand texture. The sand fraction is also much coarser than at the other two sites, being dominated by medium sand and with relatively little fine sand.

Table 4.1 Particle size distribution

Site name	1000 (%)	500 (%)	250 (%)	180 (%)	125 (%)	106 (%)	63 (%)	53 (%)	Pan (%)	0.05-0.02 (%)	0.02-0.002 (%)	<0.002 (%)	Texture	Sand (grade)	Compactability
	µm														
Site 1 top (1T)	0.47	7.77	8.91	12.69	4.16	4.11	4.63	0.68	0.39	21.15	15.15	18.81	Lm	fine	high
Site 1 sub (1S)	0.6	2.75	3.04	4.78	1.82	7.89	13.6	1.12	0.45	19.17	15.87	27.92	Lm-ClLm	fine	low-medium
Site 2 top (2T)	0.57	4.5	36.23	13.96	4.7	6.24	5.72	2.61	0.23	8.22	6.42	9.09	LmSa-SaLm	fine	very high
Site 2 sub (2S)	1.23	7.05	63.48	10.33	2.91	4.27	2.47	0.28	0.08	2.08	1.88	2.08	Sa	fine	very high
Site 3 top (3T)	0.41	0.12	0.34	1.1	4.29	13.8	19.13	10.07	0.88	20.32	9.62	19.48	Lm-SaLm-SaClLm	medium	medium-high
Site 3 sub (3S)	0.4	0.02	1.33	0.32	1.24	12.83	18.47	4.68	0.84	21.97	11.8	25.18	Lm	medium	medium-high

The degree of sorting of the sand fraction of a soil is also a factor to consider. At Site 1 sorting in the sand fraction of both the topsoil and subsoil is poor, but close to moderate due to fairly sharp increases in parts of the cumulative phi value curves (Table 4.2 and Fig. 2.8). At Site 3 sorting is moderately well, as indicated by sharp increases in cumulative curves between phi values of 2.5 and 3.8. At Site 2 the topsoil (2T) is very close to moderately sorted and the subsoil moderately well. Henning *et al.* (1986) found that soils with moderately sorted sand fractions were more prone to soil compaction than soils with poorly sorted sand fractions. Moolman & Weber (1978) found extreme compaction of well-sorted fine sandy soils in the south-western cape of South Africa. They did not expect such well-sorted soil to be prone to compaction, but "yet it happens". They expected that a well-graded soil, with a good mixture of different particle sizes would be a prerequisite for severe compaction. Bennie & Burger (1988) describe the majority of soils that are susceptible to compaction at Vaalharts as "(...) characterised by a high fine sand fraction, low clay and organic matter content, single grain to weakly massive structure and particle size with good sorting". Thus, sorting of their sand fractions could contribute to making the soils at the trial sites more vulnerable to compaction, although it is evident that sorting alone does not give complete explanation for the vulnerability of soils to compaction.

Table 4.2 Sand fraction sorting (sorting, skewness and curtose)

Soil	**phi value**	**Class**
1T	1.25	Poor
1S	1.15	Poor
2T	1.02	Poor
2S	0.61	Moderately well
3T	0.62	Moderately well
3S	0.62	Moderately well
Relevant class limits		Class limits
Moderately well sorted		0.50-0.70
Moderately sorted		0.70-1.00
Poorly sorted		1.00-2.00

Clay mineralogy plays an important role in determining the susceptibility of soil to disaggregation of aggregates, and thus also in its vulnerability to crusting and erosion (Stern 1990; Bühmann *et al.* 1996; Rapp 1998). This would also be the case with vulnerability to compaction. Usually soils with clay fractions dominated by smectite are considered the most vulnerable to dispersion and disaggregation, while those dominated by kaolinite are considered to be quite stable (Rapp 1998). However, in South African studies, it has been found that soils in which kaolinite is dominant, but occurs in combination with significant amounts of smectite, are very vulnerable to disaggregation (Stern 1990; Bloem & Laker 1994). On this evidence the Oakleaf soils of Sites 1 and 3 should be highly prone to disaggregation and compaction (Table 4.3). It has been found that soils with high quartz contents in their clay fractions are found widespread in South Africa (Laker 2004). It has been found that soils with high quartz contents in their clay fractions are extremely prone to disaggregation, crusting and erosion (Bühmann *et al.* 1996) and also to subsurface compaction (Moolman & Weber 1978). This would then be an important factor at especially Sites 1 and 2.

Table 4.3 Mineralogy Clay Analysis

	Clay Mineral (%)						
Site name	**Quartz** (Qz)	**Smectite** (St)	**Kaolinite** (Kt)	**Mica** (Mi)	**Talc** (Tc)	**Feldspar** (Fs)	**Hematite** (Hm)
Camp (1T,1S)	35	28	29	8	0	0	0
River (2T,2S)	41	13	10	22	5	9	0
LW (3T,3S)	15	30	41	11	1	0	2

In terms of chemical properties all the soils in this study have low organic matter contents (Table 4.4), which would increase their vulnerability to disaggregation and compaction. Relatively high exchangeable sodium contents or lopsided Mg:Ca ratios would also increase the vulnerability of soils to disaggregation (Bloem & Laker 1994), but these are not problems in the soils of the present study (Table 4.4). It would thus seem that *unfavourable particle size distribution* and *clay mineralogical composition* of the soils in the study could be key factors aggravating their potential vulnerability to both crusting and subsurface compaction.

Table 4.4 Soil chemical properties

Site name	pH (H_2O)	Na	K	Ca	Mg	S-value	CEC	% C (top soil)
		cmol(+)/kg						
1T	6.20	0.33	0.40	6.65	4.05	11.43	13.91	1.12
1S	6.69	0.40	0.29	10.57	5.77	17.02	17.42	
2T	7.97	0.07	0.23	6.18	2.86	9.34	8.32	1.15
2S	8.10	0.02	0.06	2.23	1.27	3.58	2.59	
3T	6.91	0.47	0.46	7.49	4.21	12.63	13.33	1.06
3S	5.61	0.13	0.16	10.53	5.98	16.79	19.02	

4.2.4 ORD simulation

The vehicle used to simulate ORD situations was a game drive vehicle with a roof rack, having a vehicle mass of 3 025 kg (Fig. 4.2). It was loaded with 10 sand bags averaging 70 kg per bag, representing the maximum number of passengers, plus the driver/Guide. Thus the total mass came to 3 795 kg. The vehicle had tyres 190 mm wide and inflated to 320, 240, 160 and 80 kPa, equivalent to 320, 240, 160 and 80 kPa, respectively. The game drive vehicles operate at a tyre pressure of 2.4 bars or 240 kPa. The vehicle was driven across each trial site at a steady speed to produce sets of tracks which consisted of one, two and three vehicle passes.

Figure 4.2 Game drive vehicle used to simulate ORD

These passes were done for all tyre inflation pressures mentioned above and were 10 m in distance. A diagrammatic representation of the trial layouts is shown in Fig. 4.3. For each tyre pressure the first pass of the vehicle was in the direction indicated by the arrow for a distance of 10 m. The second pass was in reverse, and the third pass again in the direction indicated by the arrow (the numbering letters, A to I, were used for statistical purposes and indicate control readings).

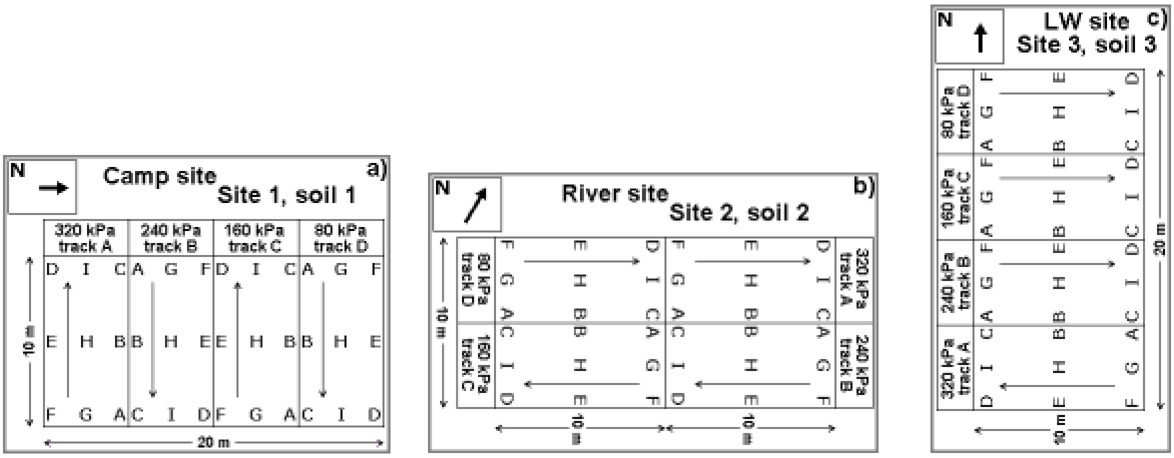


Figure 4.3 Soil compaction trial layouts

4.2.5 Penetration resistance measurements

A Geotron-P5 electronic penetrometer (Geotron Hand Penetrometer Model G 94), with a 30° cone tip was used to determine the penetration resistance for each treatment (Fig. 4.4 a, b). Each single treatment consisted of one tyre pressure, while driving over the same track, three times. Each treatment was conducted on a separate track. The penetration resistance, or soil strength, was measured at the following positions on and in between the tyre tracks: front/entrance (F G A), middle (E H B) and rear (D I C) of the tracks (Fig. 4.3).

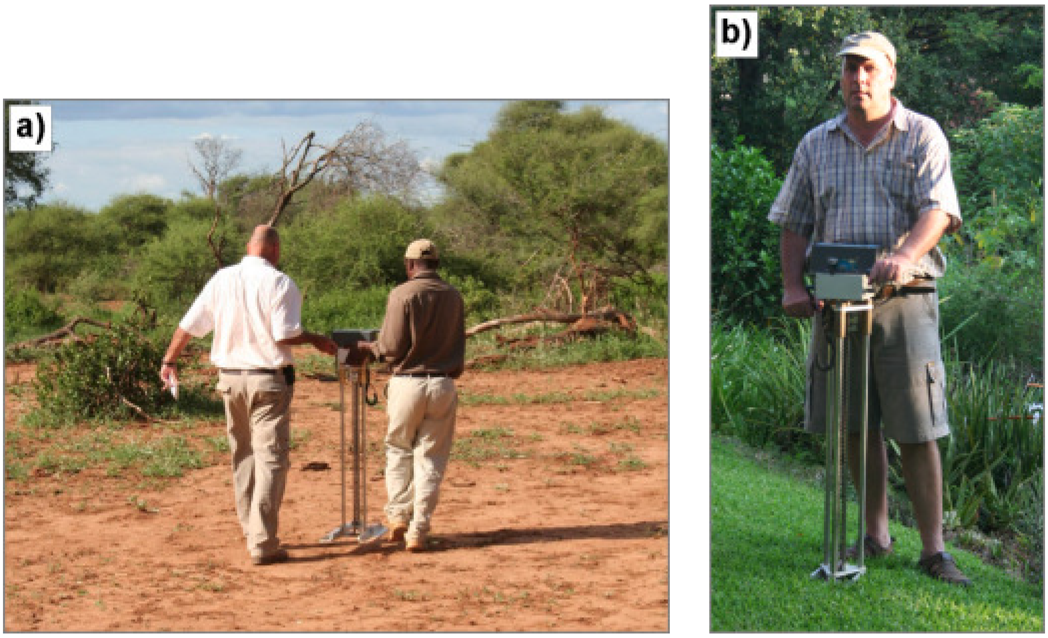


Figure 4.4 P5 Electronic handheld penetrometer

A total of 12 measurements were taken for each treatment as follows: before the passing of the vehicle over the track (control measurements) and after each pass of the vehicle for a total of three passes at the same positions. Control measurements were taken (i) before the first pass in line with where the vehicle tracks would follow and (ii) in the middle between the tracks and at a specific distance outside of the vehicle tracks after the passes were completed.

Thus the total number of measurements for each treatment was equal to 60. For a total of four tyre pressures this amount to a total of four times 60 = 240 readings per trial. The compaction trials were conducted at two moisture regimes at each site. The dry condition trials were done during March 2010. Usually this is during the end of the rainy season, but in 2010 it was a dry period. The wet condition trials were done during April 2010 after good rains. Gravimetric soil water content was determined by taking representative top soil and sub-soil samples at different depths before each experiment commenced. This was conducted early in the morning for all three trials for consistency. The soil samples were weighed on an electronic scale and then microwave dried for up to 10 minutes whilst weighing at 1 minute intervals until a constant mass was obtained. The soil water content values are given in Table 4.5. Soil water content is given as a mass percentage per mass oven-dry soil, i.e. $(m_w \times 100)/m_{s,}$ as is convention in soil physics.

It has been found that the soil water tension at which water is held after all free water has drained from a soil differs widely between soils. Thus, the traditional approach of using the soil water content at 33 kPa soil water tension as indicator of so-called "field capacity" is no longer considered valid. Instead field determined field capacity, or the "drained upper limit" (DUL), is used as the upper limit of water held by a soil (e.g. Cassel *et al.* 1983; Annandale *et al.* 2011). Field water content in this trial was thus determined by wetting of the soil and allowing all free water to drain from the soil to a constant mass after 2-3 days.

Table 4.5 Soil water contents

Soil depth (cm)	**0 - 20**	**20 - 40**	**40 - 60**	**Field Capacity** (%)		**Top soil pH**
Site name	**Average Soil Water** (% dry mass)			**Top soil**	**Sub soil**	
Camp Site (dry)	6.35	3.75	3.16	18.18	19.79	6.20
Camp Site (wet)	14.25	9.76	7.47			
River Site (dry)	3.31	3.76	4.32	14.80	8.34	7.97
River Site (wet)	14.02	7.86	7.28			
LW Site (dry)	7.56	6.73	5.35	19.13	21.09	6.91
LW Site (wet)	13.89	10.18	8.03			

Animal paths, at each above-mentioned trial site, were selected to determine the compaction created by animals walking in paths. A total of 10 penetrometer measurements were taken in triplicate on each animal path at 1 m intervals and the same number of control measurements at a distance of 1 m from the animal path. Soil water content was assumed to be the same as that determined at the specific trial site. With almost no exception, these animal paths were in a southerly direction towards the Luvuvhu River. A clear visual difference could be made between animal paths traversed also by larger animals like elephants and animal path traversed almost exclusively by antelope, discussed in Section 4.4.2.4.

4.3 **Statistical Analysis** (Appendix D)

4.3.1 Differences between number of vehicle passes

One-way Analysis of Variance (ANOVA) (SPSS V.19.0®) was performed to compare the average soil strengths across the number of passes at depths of 0-5, 6-15, 16-25 and 26-35 cm below the soil surface, for each trial site ($p = 0.05$). Multiple comparisons, Bonferroni correction, were performed *post hoc* to determine between which passes the statistically significant differences occurred (Appendix D.1).

4.3.2 Horizontal threshold distances for soil strength

One-way Analysis of Variance (ANOVA) (SPSS V.19.0®) was performed to compare the average soil strengths at horizontal distances of 0.25, 0.50, 1.0, 1.5 and 2.0 m from the outside of the right vehicle track, at depths of 0-5, 6-15, 16-25 and 26-35 cm below the soil surface, for each trial site ($p = 0.05$). Multiple comparisons, Bonferroni correction, were performed *post hoc* to determine at which distances the statistically significant differences occurred (Appendix D.2).

4.3.3 Coefficients of variation between the control values

Estimates of the coefficient of variation (CV) of the means of the control values were determined by using the following formula, at all depths and all three vehicle passes for the three trial sites: CV *percentage* = $100 * s/\bar{x}$ (where s = standard deviation; $\bar{x}$ =sample mean). A CV for soil under natural conditions >25% is normal. The very high variation of the control values in the topsoil under natural conditions is a common occurrence (Appendix D.3) (Laker 2010, pers. comm).

4.3.4 Soil strength of animal paths

One-way Analysis of Variance (ANOVA) (SPSS V.19.0®) was performed to compare the average soil strengths between the controls (next to animal path) and animal paths at depths of 0-5, 6-15, 16-25 and 26-35 cm below the soil surface, for each trial site ($p = 0.05$). This was performed at all tyre pressures of 80, 160, 240 and 320 kPa (Appendix D.4).

4.3.5 Soil strength comparison between vehicle paths and animal paths

One-way Analysis of Variance (ANOVA) (SPSS V.19.0®) was performed to compare the average soil strengths between animal paths and one vehicle path at depths of 0-5, 6-15, 16-25 and 26-35 cm below the soil surface, for each trial site (p = 0.05). This was performed at all tyre pressures of 80, 160, 240 and 320 kPa (Appendix D.5).

4.4 Results and Discussion

4.4.1 Penetration resistances of controls

The penetration resistance values of the control measurements were high throughout. Table 4.6 gives the control readings at all six trial sites unto a depth of 50 cm. It must be noted that these are average control values. Actual penetrometer readings were sometimes much higher than those shown here.

Table 4.6 Average control penetrometer readings to a depth of 50 cm

	Site 1, dry				Site 1, wet				Site 2, dry				Site 2, wet				Site 3, dry				Site 3, wet			
Depth (cm)	80 kPa	160 kPa	240 kPa	320 kPa	80 kPa	160 kPa	240 kPa	320 kPa	80 kPa	160 kPa	240 kPa	320 kPa	80 kPa	160 kPa	240 kPa	320 kPa	80 kPa	160 kPa	240 kPa	320 kPa	80 kPa	160 kPa	240 kPa	320 kPa
1	39	22	53	37	30	23	18	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1303	651	765	872	546	473	339	453	22	147	0	15	156	39	42	168	379	103	8	48	147	153	42	42
3	2836	1962	2325	2358	1561	1306	956	1274	204	944	3	256	1160	367	371	825	1017	560	108	397	547	769	336	647
4	3775	3121	3439	3215	2218	1811	1343	1791	687	1947	75	733	2483	1411	1244	1897	2100	1583	789	1369	742	1189	839	1422
5	3996	3156	3243	4358	2534	2297	1610	2147	1271	2583	291	1328	3383	2050	2033	2658	2844	2617	2231	2275	947	1350	1261	1731
6	3500	3094	4004	4150	2718	2289	1669	2225	1725	2418	762	1762	3488	2578	2561	3057	3336	3542	3092	2636	1103	1411	1419	1815
7	3135	3025	4079	3250	2443	1898	2170	2170	1929	2610	1093	2022	3329	2942	2994	3246	3472	3981	3864	2966	1244	1725	1542	1869
8	2765	3050	3325	3450	2258	1903	2081	2081	1961	2719	1364	2158	3175	3019	3075	3046	3353	4083	4151	3172	1325	2178	1831	1878
9	2221	2921	3413		1138	379	758	758	1904	2783	1526	2214	3321	2986	2936	2972	3158	4032	4261	3258	1431	2451	2419	1892
10	2042	2717	3938		1313	438	875	875	1875	2577	1576	2296	3300	2872	2786	3344	3053	3947	4061	3344	1650	3033	2790	1950
11	2117	2508	3350		1117	372	744	744	1857	2633	1568	2386	3613	2744	2647	3254	2753	3685	3944	3389	1844	3307	3249	2250
12	2446	2392	2925		975	325	650	650	1853	2791	1628	2522	3458	2650	2547	3483	2531	3267	3746	3267	1743	3542	2963	2697
13	2698	2188	2000		667	333	500	500	1850	2855	1636	2612	3333	2736	2539	3583	2392	3025	3672	3215	1963	3533	3413	3419
14	2965	1967	1850		925	463		694	1897	2894	1679	2690	3208	2836	2686	3627	2314	2775	3619	3169	1522	3482	3796	3790
15	3319	2142	2350		1175	4800		2988	1972	2932	1714	2823	3117	3089	2742	3425	2156	2567	3549	3107	1636	3383	3563	4042
16	3094	2467	3100		4900			3600	2107	3082	1761	2932	3125	2906	2750	3196	2097	2463	3483	3058	1806	3431	4092	4171
17	2306	2238	3300						2300	3198	1864	3046	3229	2733	2917	3073	2158	2450	3396	2988	1892	3492	4025	4179
18	1944	2488	3500						2497	3243	1911	3115	2933	2804	2994	3046	2219	2388	3267	2951	2158	3383	4163	3858
19	1956	2400	3550						2657	3310	2007	3176	2833	2656	3128	3175	2392	2479	3167	2697	1938	3243	4375	3717
20	2316	2413	3325						2780	3395	2050	3200	2742	2715	3119	3350	2208	2538	3175	2704	2163	3118	4338	3575
21	4150	2325	3775						2851	3481	2108	3208	2542	2799	3257	3583	2349	2646	3310	2713	2208	3001	4313	3956
22		2988	4150						2918	3626	2172	3173	2383	2939	3301	3272	2463	2613	3364	2683	2522	2985	4438	4375
23		2700							2979	3708	2271	3144	2075	2968	3324	3747	2475	2746	3431	2628	2303	2799	4525	4713
24									2987	3677	2364	3183	1967	2847	3417	3909	2485	2829	3367	2596	2500	2597	4213	4550
25									2980	3574	2426	3234	1958	2704	3456	4009	2664	3000	3308	2504	2700	2690	4138	4975
26									2935	3471	2544	3273	2150	2640	3525	4047	2525	3050	3271	2831	2817	3061	4113	
27									2864	3373	2597	3178	2342	2514	3629	4059	2503	3067	3892	2989	3158	3525	4338	
28									2732	3280	2633	3069	2450	2388	3554	4047	2408	3079	3750	2908	2825	3500	4438	
29									2565	3218	2614	2955	2458	2238	3447	4103	2078	2917	3450	3083	1250	3550	4438	
30									2485	3101	2594	2934	2583	2242	3369	4216	2160	2958	3500	3150	1150	3963	4350	
31									2433	3014	2567	2917	2592	2325	3253	3738	2404	2917	3500	3313	1175	2988	4100	
32									2414	2839	2568	2900	2508	2222	3082	3850	2460	3500	3300	3525	1200	3275	3850	
33									2419	2710	2575	2892	2583	2104	2849	3825	2469	3842	3250	2792	1400	4163	3800	
34									2396	2624	2554	2849	2517	2140	2683	3913	2431	3929	4075	2767	2750	4500	3875	
35									2406	2563	2535	2851	2375	2150	2515	3938	1892	3942		2858	3800		4400	
36									2379	2478	2478	2884	2233	2171	2460	4113	1914	3275		3342	4550			
37									2349	2371	2428	2911	2125	2208	2522	4263	1889	3558		3475	4300			
38									2240	2313	2428	2846	2100	2235	2554	4288	1817	3692		4092	3625			
39									2207	2288	2465	2746	2033	2204	2515	4350	1872	3733		3138	3150			
40									2125	2260	2542	2605	2033	2086	2403	3650	1928	4308		3288	3525			
41									2057	2138	2601	2536	2125	1988	2346	3500	1969	4325		3150	3600			
42									2001	1948	2650	2512	2525	1940	2310	3362	2019	4400		3375	3650			
43									1980	1846	2662	2476	2558	1975	2310	3112	2164	4675		3488	3850			
44									2024	1814	2729	2398	2217	1944	2258	2975	2292			3363	4000			
45									1972	2001	2804	2339	2042	1907	2192	2775	2547			3563	4200			
46									1903	2183	2850	2303	1892	1915	2149	2625	2886			3675	4400			
47									1812	2224	2921	2283	1758	1801	2108	2375	2929			4000	4575			
48									1796	2180	2996	2283	1650	1686	2025	2150	2417			4250	4000			
49									1781	2153	3112	2217	1650	1646	1903	1975	2025			4525	3425			
50									1765	2154	3189	2090	1733	1626	1786	1950	1925			4750	3850			

Naturally occurring dense subsoils are not uncommon in South Africa (Bennie 1972). It was also found in the Eastern Cape for Oakleaf soils with textures very similar to those at Sites 2 and 3 of the present study (du Preez & Botha 1980) in a region where quartz in the clay fraction is common.

In some cases at Sites 1 and 3 there are distinct very high soil strength values close to the soil surface. It was later found that the Makuleke people cultivated these areas up to 1969, when they were removed (Pafuri factsheet 2011). This resulted in severe crusting of the soils. Some large areas were still, after 42 years, barren and devoid of any vegetation, showing the very poor resilience (recovery potential) of these soils. Webb (2002) found similar results in the Mojave Desert, in California. The trial sites were not on such extreme areas. Sub-surface compaction did not occur, because ploughing was conducted by animal-drawn implements and other operations by hand cultivation with hoes. No mechanised implements were employed and thus no traffic pans could develop.

4.4.2 Effects of vehicular traffic on penetration resistances

Vehicular traffic affected penetration resistances of the soil at all three sites, at all tyre pressures under both dry and wet conditions. Most of the differences were not statistically significant, though. It must be kept in mind that one is dealing here with a natural system with high spatial variability even over short distances due to, *inter alia;* effects of old root channels, termites, etc.

4.4.2.1 Differences between number of vehicle passes

Penetration resistance results

Penetration resistance (soil strength) results are presented in the figures on this Section, where Site 1, Site 2 and Site 3 are discussed. These are only for the cases where statically significant differences were found. Differences were found in all cases but several were not statistically significant.

It will be noted that in all cases soil strength values start at very low values at the soil surface and then increases with depth over a fairly shallow depth. This is an artefact of the penetrometer measuring technique. Because of the cone shaped tip, soil is pushed up around it to the unconfined soil surface. Visual inspection revealed that in most cases these soils had dense crusts (surface seals) (Fig. 2.11). Penetrometers cannot be used to detect or measure surface crusts. In the present study this is not relevant, because the study aimed at determining subsurface compaction only.

Some authors consider a soil strength of 2 500 kPa as the threshold value above which root growth becomes restricted (e.g. Greacen & Sands 1980; Laker 1987), while others consider 2 000 kPa to be the threshold (e.g. Adams *et al.* 1982; van Huysteen 1983; Bengough *et al*. 2011). This lower soil strength threshold value of 2 000 kPa seems to be more generally accepted presently (van Antwerpen 2011, pers. comm) and was therefore chosen for this study.

Site 1

Penetration resistances for Site 1 are illustrated in Fig. 4.5.

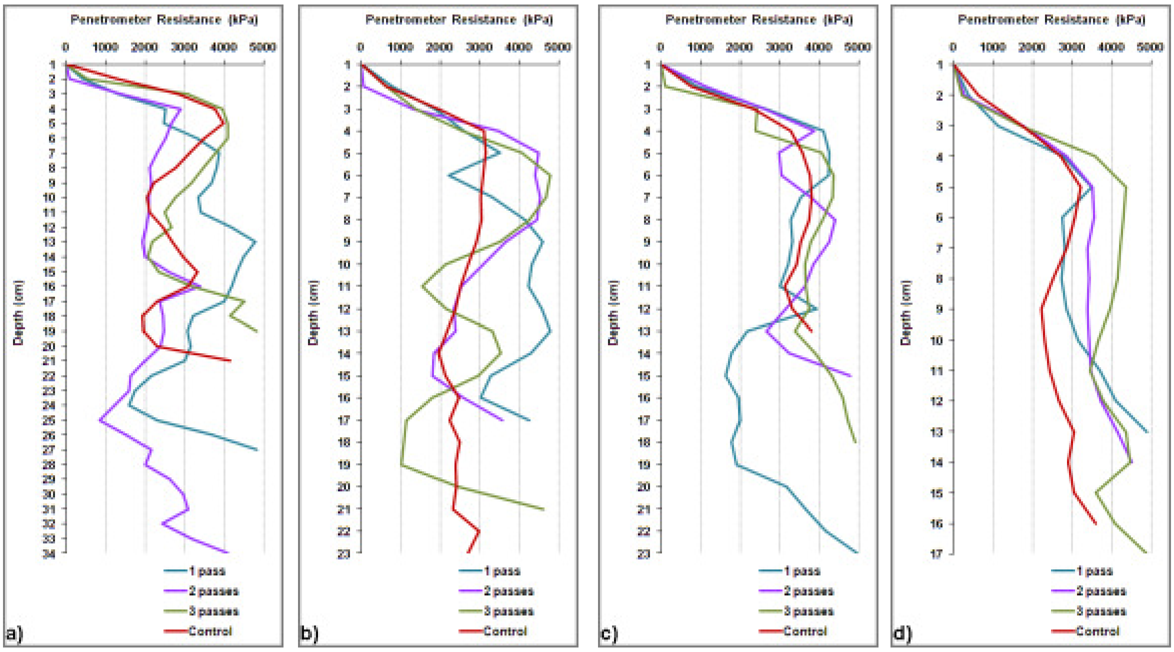


Figure 4.5 Effects of ORD on soil penetration resistance at Site 1,
on average control value vs. track values and 1 to 3 passes:
a) at 80 kPa (dry); b) at 160 kPa (dry); c) at 240 kPa (wet); d) at 320 kPa (wet)

Under dry conditions at Site 1 statistically significant differences occurred only at low tyre pressures (80 and 160 kPa).The outstanding features at 80 kPa (Fig. 4.5a) are:

- The major increase in penetration resistance, compared with the control, over the soil depth from 7 to 20 cm due to the first pass of the vehicle. Under mechanised cropping conditions there is normally a loose soil layer from 5 to 15 cm due to secondary cultivation and a very dense and severely restrictive traffic pan from 15 to 25 cm depth, about the same thickness as the one here (Bennie 1972). The much shallower occurrence of the compacted layer here has major implications in regard to root development and water availability;
- At 25 cm the first pass caused a very sharp increase in penetration resistance, indicating the top of a second severely compacted layer, similar to what Bennie (1972) indicated at the same depth;
- After the second pass the penetration resistance decreased to similar values as for the control. It could be due to cracking of the massive layer caused by the first pass, according to the mechanism described by (Braunack 1986a and b);

- During the third pass there was significant re-compaction near the soil surface and clear indication of the top of a severely compacted layer at 15 cm depth. This is about the depth where one normally finds plough layer compaction under cropping conditions (Bennie 1972), that is, the forming of a compacted layer in the bottom part of a loose plough layer. In this case in the relatively loose soil layer formed by the second pass.

At 160 kPa tyre pressure there were certain similarities with the patterns at 80 kPa tyre pressure (Fig. 4.5b), including:

- Severe compaction of the layer between a soil depth of about 7 and 17 cm by the first pass;
- Lowering of the penetration resistance in the bottom part of this layer during the second pass;
- Re-compaction in the latter relatively loose layer during the third pass;
- Clear indications of the development of severely compacted layers deeper in the profile after all three passes. The difference is that the top of this layer after the third pass was much deeper in the profile than at 80 kPa tyre pressure.

A slight difference in this case is the serious compaction close to the soil surface (crust formation) after two and three passes, although not very different from the pattern after three passes at 80 kPa.

Under wet conditions at Site 1 statistically significant differences occurred only at high tyre pressures (240 and 320 kPa). The outstanding features at 240 kPa (Fig. 4.5c) are:

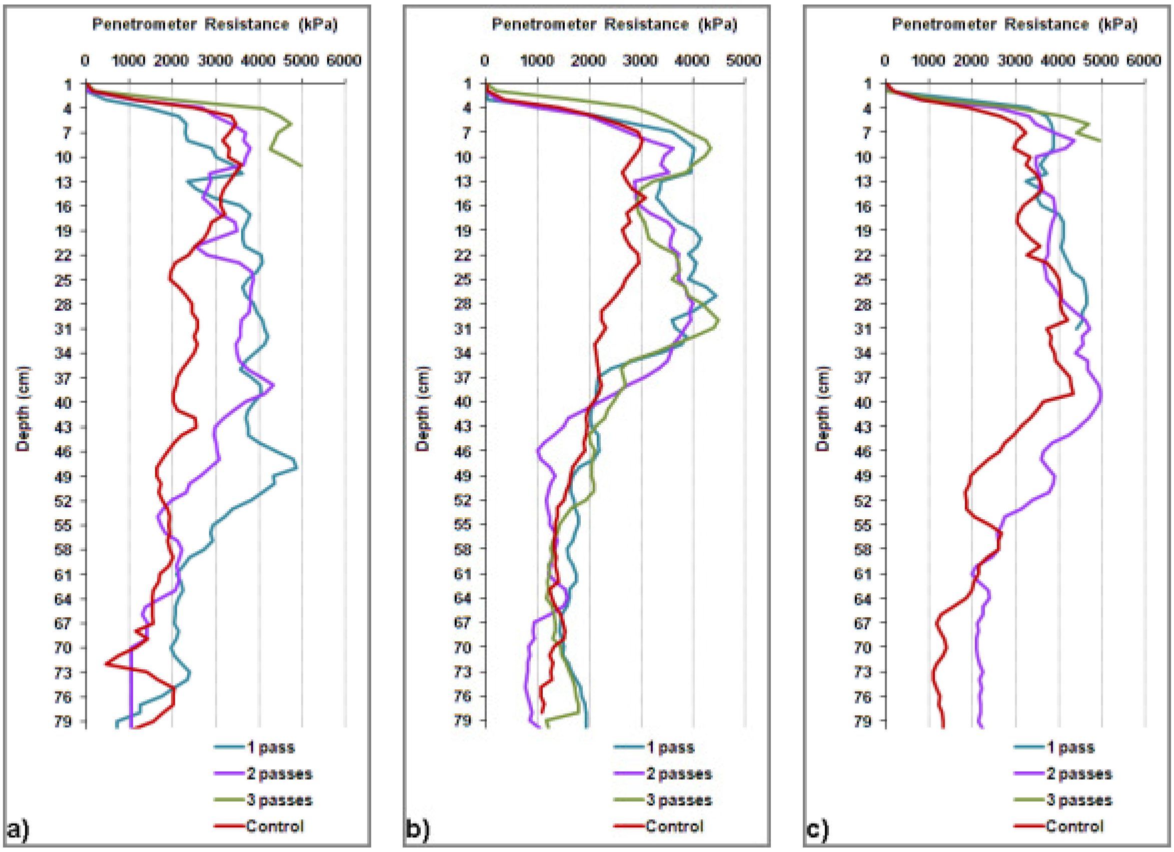
- The control values were high throughout and over most of the depth to which there are control values there were no significant effects of vehicular traffic. Like under dry conditions there was a depth where the first pass increased soil strength, the second pass lowered it drastically and the third pass re-compacted it to the same value as after the first pass. This was at a very shallow depth (about 3 to 7 cm), in other words, a dense crust;
- At greater depth, below the depth at which there are control values available, the soils had relatively low penetration resistance values after the first pass, which was drastically increased by the second pass. So, it seems that there is a pattern that the first pass over soil with a relatively low penetration resistance is the really damaging one.

At 320 kPa tyre pressure under wet conditions the first pass started giving higher values than the control only at about 9 cm depth. Only at about 11 cm this became a clear increase and joined the values for the second and third passes (Fig. 4.6d). From this depth downward in the profile the values for the three passes joined and were clearly much higher than the control, that is, the first pass was the damaging one. At very shallow depth (in the zone of a crust) the third pass was clearly the damaging one.

Under wet conditions the development of a crust due to vehicular traffic is the over-riding consequence of ORD on this soil. Crusting has serious long lasting effects like inhibiting root growth (Laker & Vanassche 2001), germination and seedling emergence, the latter especially of small-seeded plants like grasses. Thus, wetlands should be absolutely prohibited areas as far as ORD is concerned, particularly at the normal tyre pressures used.

<u>Site 2</u>

Penetration resistances for Site 2 are illustrated in Fig. 4.6.



Figures 4.6 Effects of ORD on soil penetration resistance at Site 2, on average control value vs. track values and 1 to 3 passes: a) at 80 kPa (wet); b) at 160 kPa (wet); c) at 320 kPa (wet)

At Site 2, the very sandy soil, statistically significant differences were found only under wet conditions. In the plots of the 80 kPa applied pressures (Fig. 4.6a) the mean penetration resistance values in the top part of the profile, to about 20 cm, were very high, before decreasing to values at or just above the threshold value of 2 000 kPa down to about 45 cm. From there downwards it drops to below the threshold value. The main impacts of vehicular traffic were:

- Down to about 10 cm depth the first pass lowered the soil strength, which then became re-compacted to its original value by the second pass and further seriously compacted by the third pass. Again a pattern of a dense layer broken up and then re-compacted. No readings could be taken deeper for the third pass because at 5 000 kPa the penetrometer cuts out as safety measure. Again, serious crusting is a major issue when driving over a wet soil;
- Between about 15 and 60 cm soil depth the first pass caused serious compaction of this relatively loose soil (compared with that at Site 1). Down to about 40 cm the values for the second pass more-or-less follow those for the first pass, thereafter dropping below them, down to about 60 cm, from where traffic had no further impact and the lines for the two passes joined that of the control. Normally one would not expect an impact to such depth, but this is an extremely sandy soil dominated by medium sand.

At 160 kPa tyre pressure the pattern was much the same as at 80 kPa, with just some depth differences (Fig. 4.6b). The main impacts were:

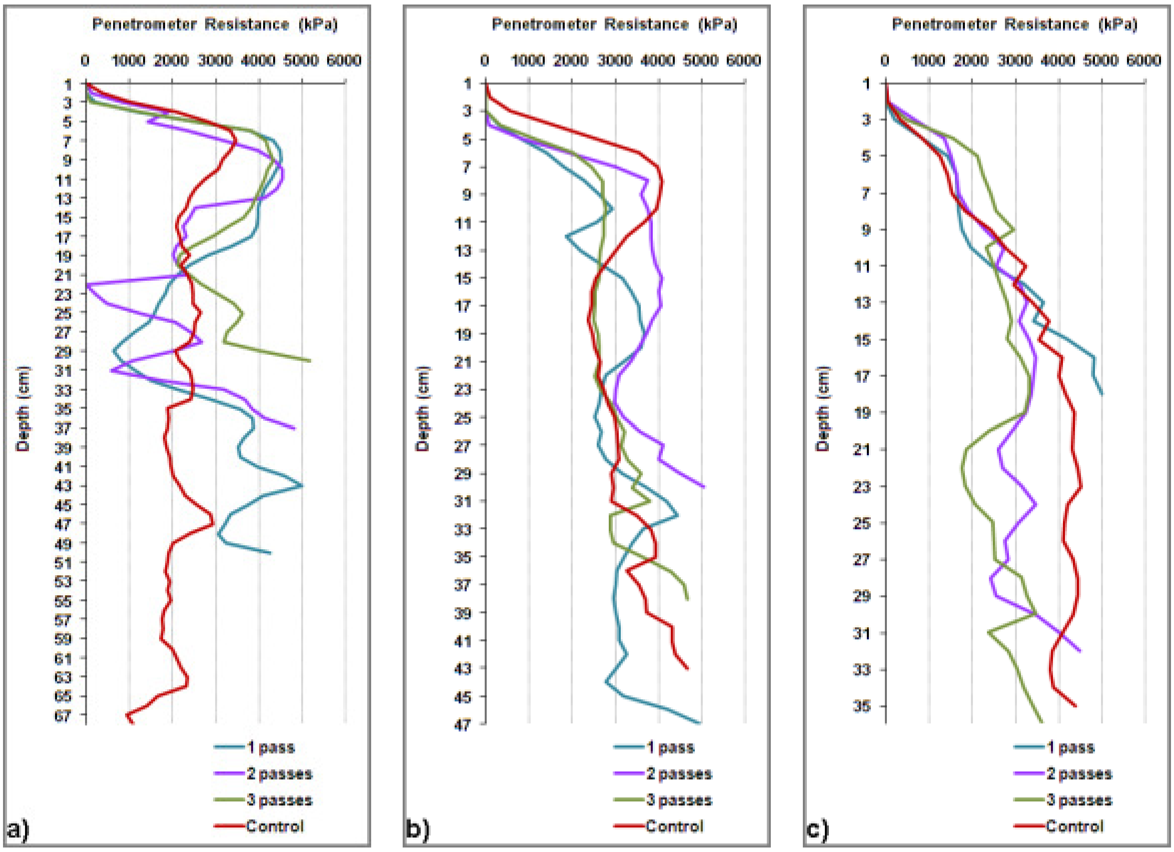
- Compaction at a shallow depth (around 10 cm) by the first pass, followed by lowering of the soil strength by the second pass and re-compaction by the third pass;
- Serious compaction by the first pass, with no further compaction by the subsequent passes, as shown by the lines for the three passes running together. From about 37 cm deeper the vehicular passes had no effect, as shown by all four lines, including the control, running closely together.

At 320 kPa tyre pressure the most outstanding feature is again serious compaction near the soil surface (around 10 cm) by vehicular traffic under wet conditions - increasing with increasing number of passes (Fig. 4.6c). Again the measurement for the third pass stopped at shallow depth because a value of 5 000 kPa was reached. Deeper in the soil the first and second passes had little effect because the control already had very high soil strength values.

Thus, the findings for Site 2 strongly support those for Site 1 that vehicular traffic brings about severe crusting under wet conditions and that wetlands should clearly be declared prohibited areas in regard to ORD. On this sandy soil a much stronger crust formed than in the medium-textured soil at Site 1. On this very sandy soil serious subsurface compaction was also found due to vehicular traffic under moist conditions.

Site 3

Penetration resistances for Site 3 are illustrated in Fig. 4.7.



Figures 4.7 Effects of ORD on soil penetration resistance at Site 1, on average control value vs. track values and 1 to 3 passes: a) at 80 kPa (dry); b) at 160 kPa (dry); c) at 240 kPa (wet)

Under dry conditions at Site 3 vehicular traffic caused significant differences in soil strength at low tyre pressures (80 and 160 kPa), as was found in the similar soil at Site 1.

The main findings at a tyre pressure of 80 kPa were (Fig. 4.7a):

- The control soil in these plots had near-surface compaction (crusting) at a depth of between about 5 and 11 cm. The first pass caused a big increase in the penetration resistance of this layer and made it much thicker, covering a depth from 5 to 20 cm.

The second and third passes did not bring about any further increases in the compaction;

- From about 20 to 35 cm depth the first pass reduced the soil strength below that of the control. The central part of this, where the biggest reduction took place, was re-compacted by the second pass;
- From about 30 cm depth there were very sharp increases in penetration resistance values over very short distances, indicating the top of a compacted layer, after both the first and second passes. After the third pass this feature shifted to a shallower depth. This is similar to what was found in the similar soil at Site 1 with the same tyre pressure.

The plots at a tyre pressure of 160 kPa showed a similar compaction at a shallow depth around 10 cm (Fig. 4.7b). Main affects of vehicular traffic in this case were:

- At this higher tyre pressure the first pass broke up the compact layer, which was then re-compacted by the second pass and broken up again by the **third** pass. This fits in with findings at the other sites;
- Below this layer the first pass brought about some compaction and the **second** pass more, which was then actually broken up by the third pass.

Under wet conditions at Site 3 differences were found only at 240 kPa tyre pressure and these were quite abnormal (Fig. 4.7c). There was no sign of near-surface compaction in the control. Penetration resistances of the topsoil were actually quite low. The first pass of the vehicle had no effect to a depth of about 15 cm below which there was a fairly sharp increase in penetration resistance above the control until it cut out at 5 000 kPa. The second and third passes then broke this up and produced significantly lower penetration resistances than the (quite dense) control and the first pass. The presence of termite activity in this area could be a complicating factor affecting the results. The differences are more extreme, but probably not completely different from trends found under wet conditions at the other sites.

4.4.2.2 Horizontal threshold distances for soil strength

During the start of the trials in March 2010 control measurements were initially recorded in between the vehicle tyre tracks as well as at a distance of 1 m outside of the tyre tracks. But it was soon realized during the data analysis that there was possible interference with the in between controls by the compaction created by the left and right vehicle tracks. It was then decided to do separate new trials close to the previous ones at the three selected sites. These trials were done for only one vehicle pass. In addition to control readings and readings under the tracks after one vehicle pass, readings were taken at different distances at the outside of the right tyre track, to try and determine minimum safe threshold distances for future control readings. These threshold measurements at different distances were compared with the one vehicle pass. These were done for Site 1 and Site 2 under dry soil conditions, and the data are reported here.

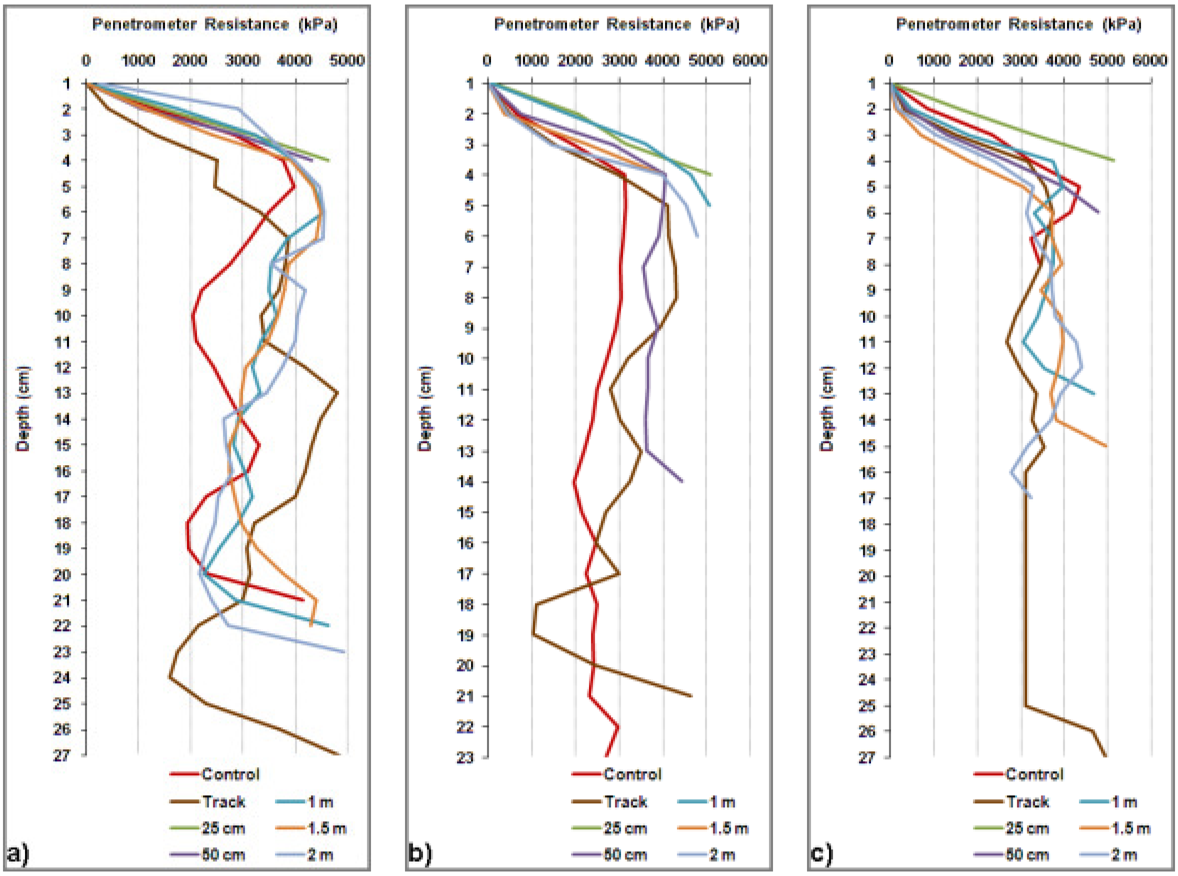
Penetration resistance values at different distances outside vehicle tracks

The results of these trials indicated clear lateral effects of vehicle tyre impacts at shallow soil depths, but also at deeper depths. Lateral vehicle tyre impacts different between different cases, but varied from 25 cm to as far as 2 m from the vehicle tyre. These results have severe implications with regard to area impacted by a game drive vehicle. The damaged area due to soil compaction is now not just under the vehicle tyres but also in some cases up to 2 m sideways from the outside of the vehicle tyre. And this is on both sides of the vehicle.

Site 1

Dry soil conditions

Theoretically, one would expect the control values and depth patterns to be the same for all cases. However, they differ quite notably, being an indication of the large spatial variability in the soil (Fig. 4.8).



Figures 4.8 Average penetration resistance values for Site 1 at distances of 25 cm, 50 cm, 1 m, 1.5 m and 2.0 m from tyre track, at:
a) 80 kPa; b) 160 kPa; c) 320 kPa

Despite the large differences between the patterns of the controls for the different cases, there are some notable effects of the vehicle, such as:

- There is a very sharp increase in penetration resistance, compared with the relevant control, under the track at a certain depth in all three cases. At 80 and 320 kPa this is at 24 and 25 cm, respectively (essentially identical). At 160 kPa it is at 19 cm, just slightly shallower. It is interesting to note that these are all near the boundary between the A and B horizons of the soil (Fig. 4.1a);
- Both, the sharpness and the big magnitude of the increases, are important. Roots cannot adapt to such abrupt increases in soil penetration resistance (Bennie 1972), due to the abrupt transition in soil strength. Bennie (1972) discusses why roots cannot adapt to such sharp increases. Roots are limited to the shallow topsoil layer. Bennie (1972) mentioned that root penetration and development are stopped by the compacted subsoil layers and the roots turn horizontal due to the high soil strength of the compacted layer. The effect is aggravated in the case of plants with tap roots;

- In the 80 kPa tyre pressure, control and the distant (1.0, 1.5 and 2.0 m) measurements, showed sharp increases at a few cm shallower than under the track. At the 160 kPa tyre pressure, the control stayed relatively low right through, but under the track there was again a very sharp increase – this time, at about the depth at which the above increases occurred in the 80 kPa tyre pressure. The importance is the compaction effect under the track irrespective of whether it was predisposed or not. In the 320 kPa tyre pressure, no comparison could be made with the control, because measurement at the latter shut out at a very shallow depth;
- In the 80 and 160 kPa tyre pressures there are under the track very clear decreases in penetration resistances over a short distance just before the sharp increases pointed out in the first bullet. At 320 kPa there is a slight decrease over a bigger distance;
- It is notable that under the tracks there are humps (increases) in the penetrometer readings at about 12 cm depth. The magnitude of the humps decreased from 80 kPa to 160 kPa and from there to 320 kPa. A possible explanation for these humps is that the penetrometer cone hit the top of an underground termite mound at this depth (as this is exactly the depth at which the termite mounds start to occur). It must be remembered that the first pass over the soil is at 320 kPa tyre pressure which loosens the surface layers. The third and fourth vehicle passes at 160 kPa and 80 kPa tyre pressure re-compacts the soil and, therefore, the increases in the humps or compaction at these lower tyre pressures. It may also indicate that at higher tyre pressures there are much more lateral movement and compaction of soil in the top layer under the vehicles tyres;
- At 80 kPa, the readings under the track form a quite big bulge above the control from about 7 cm to about 20 cm depth. This type of bulge fits in with the patterns in figures in Section 4.4.2.1. At 160 kPa there was such a bulge (but of smaller magnitude) between about 5 and 18 cm depth. For 320 kPa it could not be determined, because of the lack of control values;
- At both 80 and 320 kPa the readings at 25 and 50 cm from the track became so high at very shallow depth that the penetrometer shut out. At 160 kPa the same was true for the 25 cm distance. At 160 kPa the penetrometer did not shut out at a very shallow depth, but the readings were as high as those under the track down to 13 cm depth, where they shut out. It is absolutely clear that the wheels had extremely strong negative impacts on soil strength (penetration resistance) at very shallow depths up to a distance of at least 50 cm from the tracks. Since the effect is at such shallow depth,

it amounts to the formation of a thick, very strong crust. This has serious implications for the vegetative cover (drought, germination and emergence);

- The above crust situation also has implications in terms of erosion due to increased run-off. An interesting point is that at shallow depth the penetration resistances under the track were relatively low compared with the rest. This probably relates to Savory's (1988) belief that a high density of animals can be beneficial in the sense that they "crack" crusts that form. Maybe a crust can be "crushed" by the wheels. But then the much bigger negative effects kick in – subsurface compaction under the tracks at some depth and serious crusting next to the tracks due to lateral impacts of the wheels.

The following hypothesis presents a possible explanation (Laker 2010, pers. comm) (Fig. 4.9) for how the soil particles are moved sideways. Normally people only think about forces beneath the vehicle tyres and vectors as in Fig. 4.9a. Fig. 4.9b attempts to point out that the soil particles are forced into the soil particles beneath them by the strong downward force of the vehicle tyre. But on the right-hand side from the one far right where there is no downward force, so that the particles are forced to the outside of the vehicle track and move there into other particles - with consequent compaction. Fig. 4.9c shows that there is a further factor, namely the diagonal force beneath the side of the tyre track.

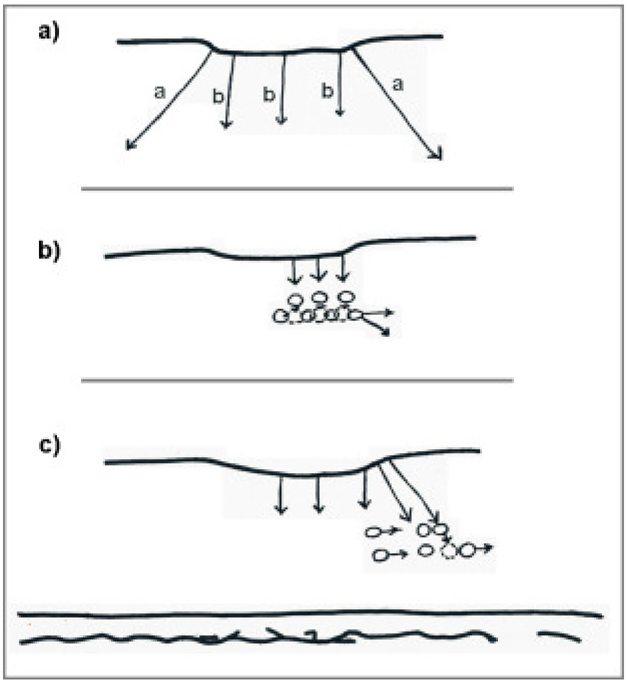


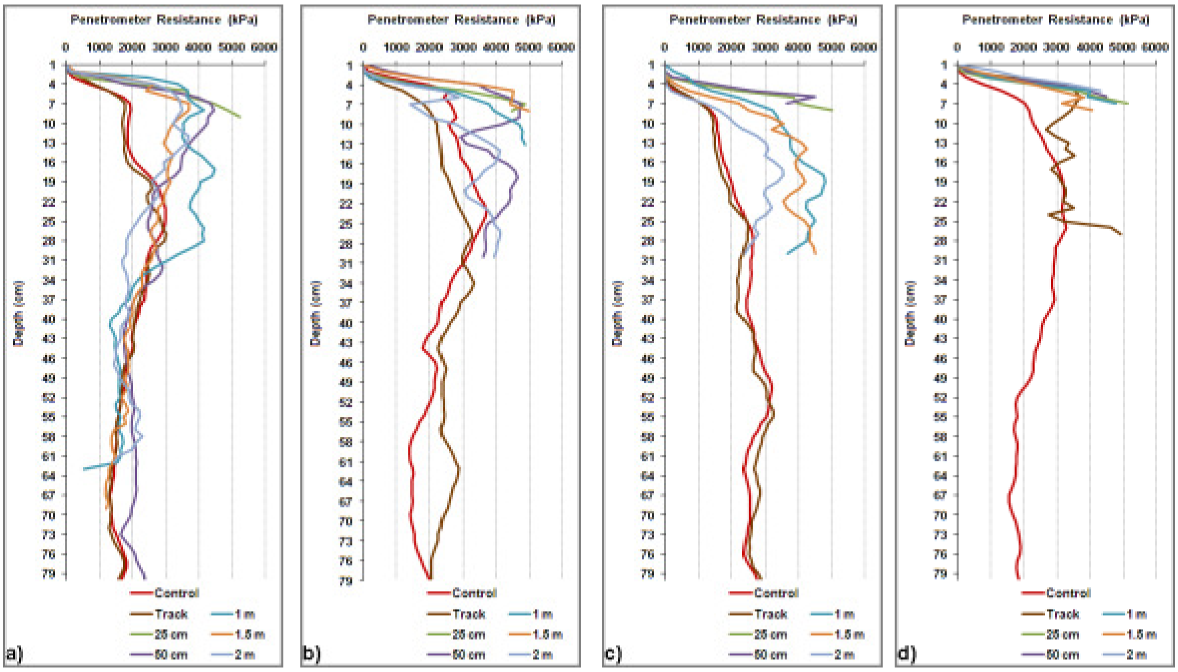
Figure 4.9 Indicating lateral vehicle tyre compaction impacts and sideways movement of soil particles

The particles which as a result of sideways (lateral) movement under the influence of a vertical force that forced other particles on the left-hand side in, moved to the outside of the tyre track and caused compaction, blocks on that side particles under the influence of the diagonal vector force. This "weaker" force pushes particles in-between other particles, but the particles can now only move to the right (Fig. 4.9c), in other words, away from the track where it cause compaction. This may lead to the unexpected wide distance of the effect. In the middle, between the two vehicle tracks, this effect works from both sides and aggravates the effect (discussed in the following Section).

Site 2

<u>Dry conditions</u>

The patterns for Site 2 differ markedly from those for Site 1, in some respects. In some other respect, they show important similarities (Fig. 4.10). Clear lateral vehicle tyre effects can also be seen in Fig. 4.10. But where it differs from Site 1 is that the effects are not just very much lateral at shallow depths, but also tend to be much deeper than Site 1. Lateral effects vary between 25 cm to 2 m and to soil depths up to 79 cm. What is quite clear is that the vehicle tracks did not create much vertical sub-soil compaction and the graph in most cases followed the control. The only difference was under 320 kPa tyre pressure where there was severe vertical compaction under the vehicle track at depths of 7-25 cm.



Figures 4.10 Average penetration resistance values at distances of 25 cm, 50 cm, 1 m, 1.5 m and 2.0 m from tyre track, at: a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

Some of the detailed observations in Fig. 4.10 include:

- The controls for Site 2 were quite similar, almost remarkably so, in contrast to the big differences between controls for Site 1. A possible explanation for these differences in controls is that the Site 2 was a more pristine one, whereas Site 1 had been predisposed by the impacts of human activities;
- In Site 2 there was no subsoil compaction under the tracks. But this does not mean that there were no negative impacts of ORD. The followingbullet explains this;
- In all four cases, penetrometer readings, at 25 cm from the track, shot through the roof (shut out) at a very shallow (less than about 7 cm) depth;
- At 240 and 320 kPa, the readings at 50 cm from the track, shut out at the same shallow depth. At 80 kPa, the reading at 50 cm from the track, at the shallow depth was very high (higher than at the further distances) and then dropped down with depth. At 160 kPa it was also very high;
- At 80 kPa, the "peak heights" for the different distances at about 7 cm depth decreased with increasing distance, i.e. 25 cm>50 cm>1.0 m>1.5 m>2.0 m. The magnitude of the differences, i.e. reading at 25 cm minus reading at 50 cm, reading at 50 cm minus reading at 1.0 m, etc., decreased with increasing distance. All were MUCH higher than the control and under the track;
- At 160 kPa the peak values at shallow depth were very high at 25 cm, 50 cm, 1.0 m and 1.5 m and much higher than the control and under the track. At 2.0 m the value at this depth was much lower, i.e. much less wheel impact;
- In addition to the very big impact at shallow depth in the 80 kPa case, particularly at 25 cm (and 50 cm) from the track, there were the following effects: at the next distance there was a huge impact right through to a depth of a bit more than 31 cm; at all distances there was a big impacts (above the values for the control and under the track) to a depth of about 20 cm up to the measured distance of 2.0 metres;
- Almost the same as above could be said at 160 kPa. Up to 1.5 metres the big effect was at shallow depth, as indicated earlier. At 2.0 m the effect was deeper, almost like the 1.0 m effect at 80 kPa.
- At 240 kPa there were also major effects at depths up to about 30 cm at the 1.0 and 1.5 m distances, with a clear, but smaller effect at 2.0 m;
- At 320 kPa there were huge effects at shallow depth at all distances, including 2.0 m. Here there was an important effect under the track. The readings under the track remained more-or-less constant to a depth of about 25 cm. At that depth, the

penetration resistance, under the track increased dramatically, giving a pattern similar to that found with Site 1 and at a depth similar to Site 1.

An important aspect of "controlled traffic" is positioning of vehicular tracks as far as possible away from plant rows. Laker (2012, pers. comm) found in a fertilizer experiment with maize that yields differed per row and not per treatment. It was then found that yield depended on the distance between the tractor wheel track and the maize row. Rows where the wheel track was closer to the row gave lower yields than where the tractor wheel was further from the row.

In the sugarcane industry it has been found that in the traditional 1.5 m row spacing tractor and vehicle wheels running on the side of rows have very bad impacts due to soil compaction (van Antwerpen *et al.* 2000; SASTA 2001). Elsewhere very high yields were obtained by 1.8 m row spacing, with wheel tracks running in the middle of the inter-row areas.

According to Smith & Johnston (2001), who stated the following, this is also important in the South African forestry industry: "The effects of soil disturbance, e.g. rutting, loosening and compaction in close proximity caused by logger operations, have had a greater effect on growth than operations causing deep compaction". This suggests that key growth processes, such as fine root development and nutrient cycling in the topsoil, have been affected. Keep in mind that such effect will be both outside and between the tracks. Between the tracks it becomes aggravated, because the impact is from both sides (discussed in the following Section).

During a visit to experiments on the effects of soil compaction by tractor wheel traffic on sunflower at the Federal Agricultural Research Centre at Braunschweig, in Germany, Laker (2013, pers. comm) observed that the tractor wheel not only had an extremely severe effect on the sunflower plants in the row next to the tractor wheel track, but also had a major lateral effect on the sunflower plants in the second row from the wheel track.

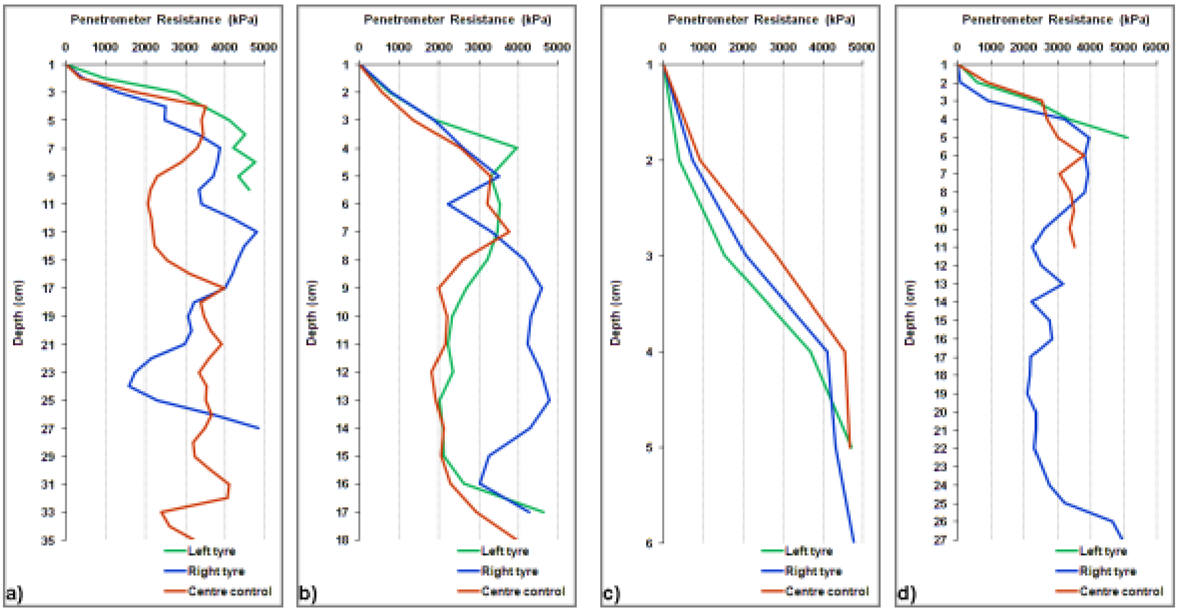
Penetration resistance values midway between the vehicle tracks

As explained in Section 4.4.2.2, the following graphs describe the lateral influence from both the left and right tyre tracks to in-between the vehicle tracks. The distance between the right and left vehicle tracks was 1.7 m, and the distance to the middle of the tracks therefore 0.85 m (or 85 cm). As mentioned in the previous section, lateral compaction occurred at shallow depths up to a distance of 2.0 m outside of the vehicle tracks. It must be remembered that this lateral compaction is on both sides of both tyre tracks and this means that of the 1.7 m distance between the vehicle's tracks the whole area will be compacted in-between the tracks. The implications of this are that no control measurements can be taken in-between the vehicle tyre tracks in studies such as these, but also that the total area affected by soil compaction is much larger than previously thought.

Site 1

Dry conditions

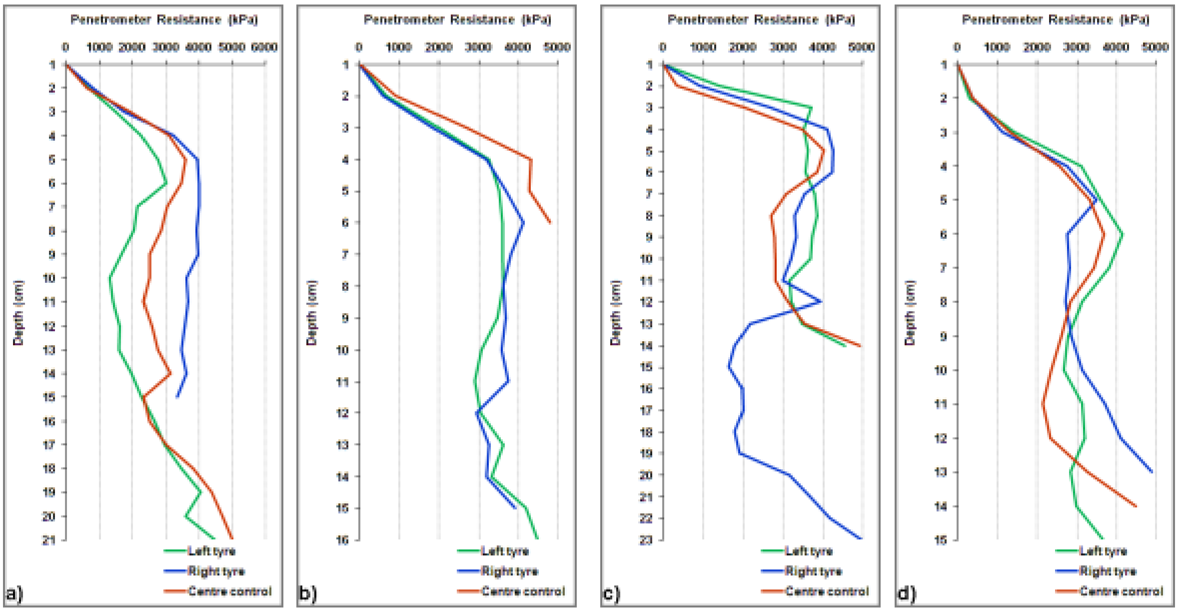
In Fig. 4.11 it can clearly be seen that at shallow depths of 0-4 cm the penetration values follows that of the controls in-between the tracks, and then at further depths >4 cm below the vehicle tracks increase sharply compared to the controls.



Figures 4.11 Average penetration resistance values between the left and right tyre and centre control at:
a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

Wet conditions

The same pattern can be seen here under wet conditions, except the depth to which the controls are equal to the tracks are deeper than 5.0 cm (Fig. 4.12).

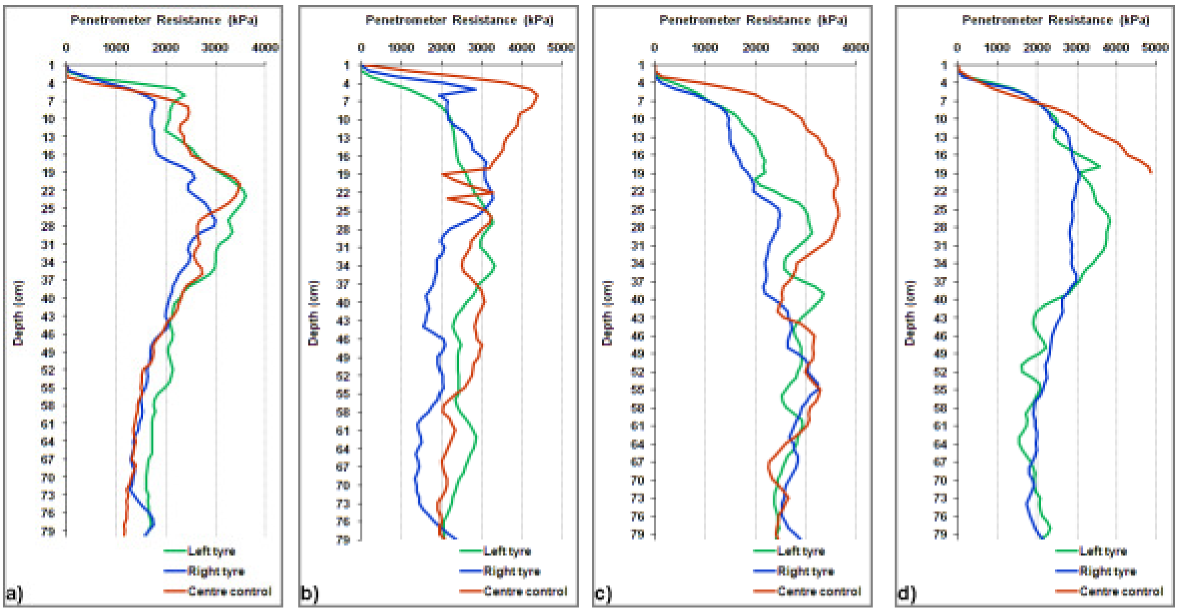


Figures 4.12 Average penetration resistance values between the left and right tyre and centre control at:
a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

Site 2

<u>Dry conditions</u>

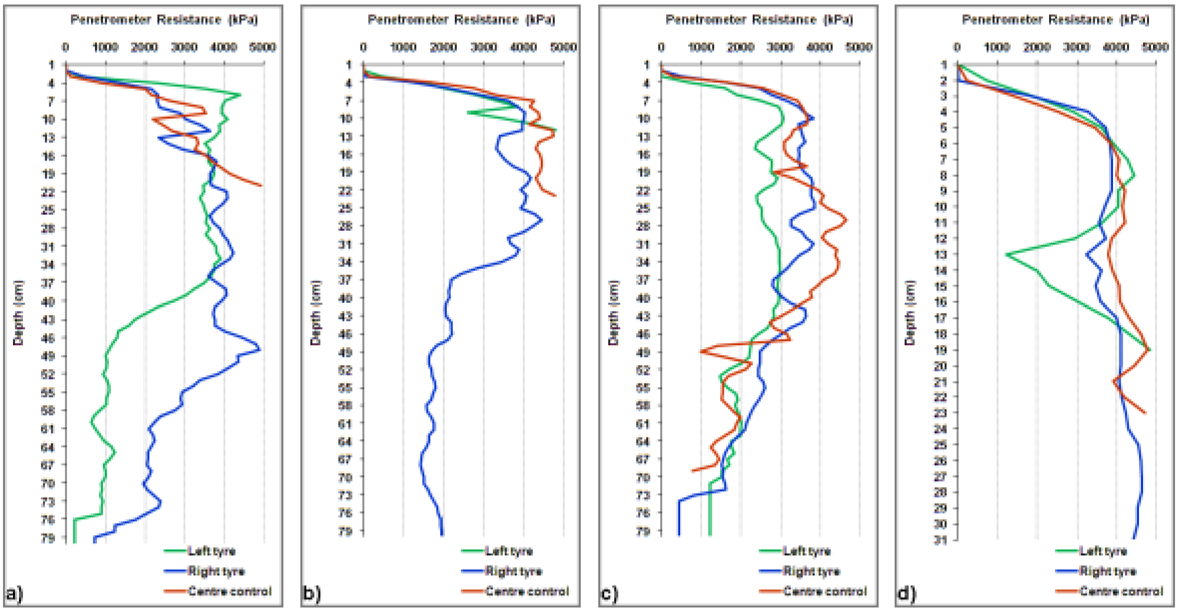
In this case (Fig. 4.13), 320 kPa lowers the soil strength to much lower than the control. At 240 kPa, this difference between the control and the tracks is larger. At 160 kPa, the tracks interfere with the control at a depth of 19 cm. At 80 kPa, there is interference with the control up to a depth of 79 cm.



Figures 4.13 Average penetration resistance values between the left and right tyre and centre control at:
a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

Wet conditions

Under wet conditions, the track and control values are the same at shallow depth of 0-7 cm for 80, 160 and 240 kPa. At 320 kPa, they are the same to a depth of 11 cm (Fig. 4.14).

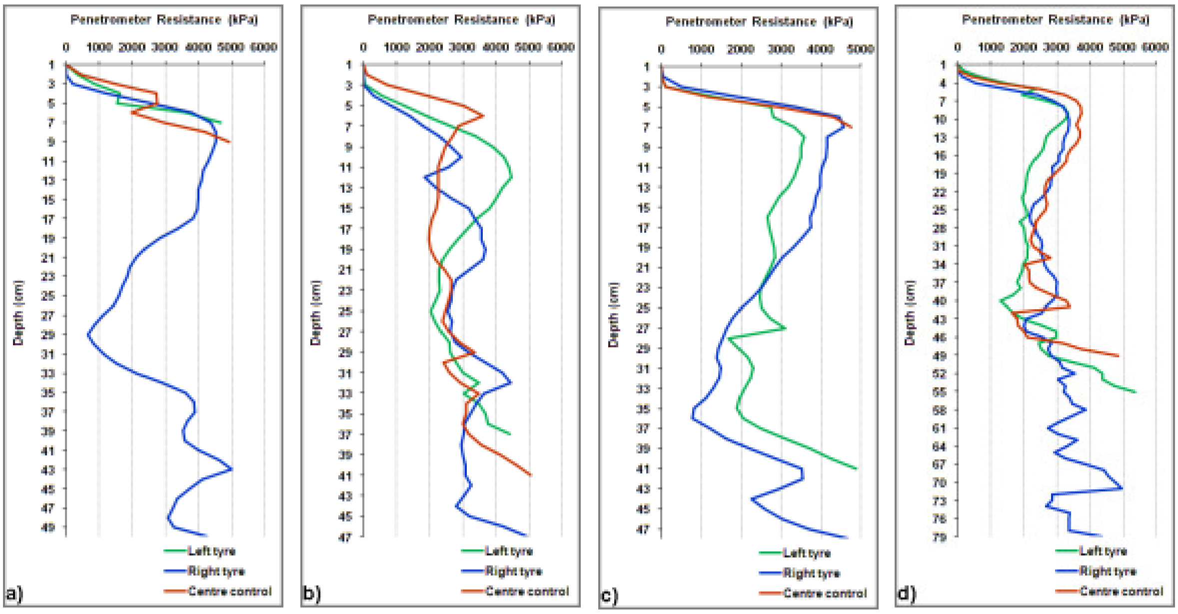


Figures 4.14 Average penetration resistance values between the left and right tyre and centre control at: a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

Site 3

Dry conditions

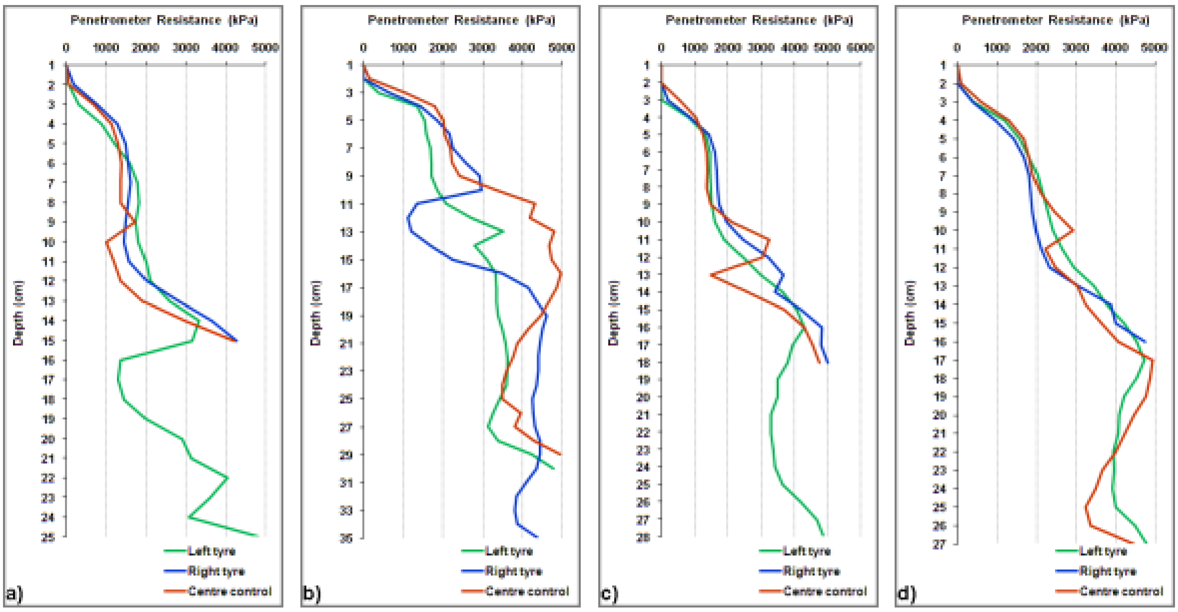
Clear interference of vehicle tracks with the in-between control at shallow depth (0-7 cm), can be seen in Fig. 4.15. At 80 kPa tyre pressure, this interference is at a shallow depth of 1-7 cm (Fig. 4.15a). But at higher tyre pressures (160, 240 and 320 kPa) these interferences are to soil depths of 41-52 cm (Fig. 4.15b-d).



Figures 4.15 Average penetration resistance values between the left and right tyre and centre control at:
a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

<u>Wet conditions</u>

Clear interference of vehicle tracks with the in-between control to soil depths of 1-15 cm (Fig. 4.16a), 30 cm (Fig. 4.16b), 19 cm (Fig. 4.16c) and 37 cm (Fig. 4.16d). The tendency it seems is that under wet soil conditions the interference of the vehicle tyres with the control value is to deeper depths compared to dry soil conditions.



Figures 4.16 Average penetration resistance values between the left and right tyre and centre control at:
a) 80 kPa; b) 160 kPa; c) 240 kPa; d) 320 kPa

4.4.2.3 Coefficients of variation between the control values

The CV is defined as the ratio of the standard deviation to the mean. It shows the extent of variability in relation to mean of the population. CV values of 25% and above under these natural conditions are normal. The very high variation in the topsoil is also common (Laker 2011, pers. comm). According to Jordaan (2011, pers. comm) if the CV is less than ½ of the mean value, then the CV is correct.

The CV between the control values of all three sites is very high. But this is natural for soil under natural conditions. The trend with all the soils under dry and wet conditions is also that the CV decreases with soil depth as seen in the following figures. This is the case except for Site 1 during dry conditions and one vehicle pass. CV values of 25% and above under these natural conditions are normal. The very high variation in the topsoil is also common (Laker 2011, pers. comm).

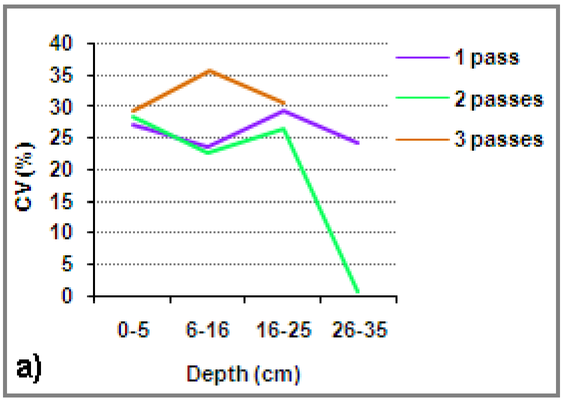
Site 1

<u>Dry</u> (Fig.4.17a)

- After one vehicle pass - a definite decrease in CV from the topsoil (0-5 cm) to the subsoil, with a slight increase in CV at a depth of 16-25 cm (higher than topsoil);
- After two vehicle passes - slightly lower values than for the situation after one vehicle pass, but with the same trend;
- After three vehicle passes - higher CV values than after one and two vehicle passes. Increase in CV from topsoil to 6-15 cm depth, but then a decrease to the subsoil (26-35 cm).

<u>Wet</u> (Fig. 4.17b)

- After one vehicle pass - a slight increase in CV from topsoil to 6-15 cm depth. But then further down much lower and decreasing;
- After two vehicle passes - topsoil CV a little higher than for one vehicle pass, but subsoil much lower than after one vehicle pass. General trend of decreasing CV percentages from top to bottom.



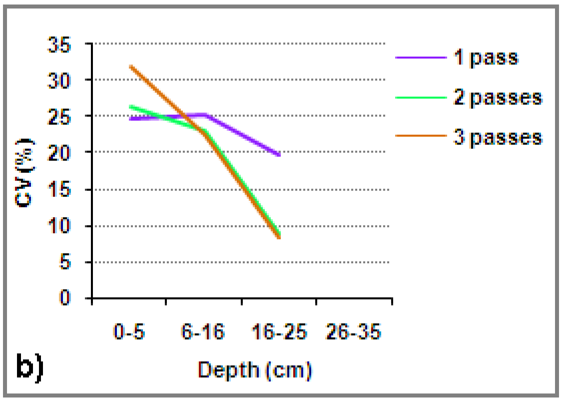


Figure 4.17 Site 1 - coefficients of variation at different depths and 1 to 3 passes: a) dry; b) wet

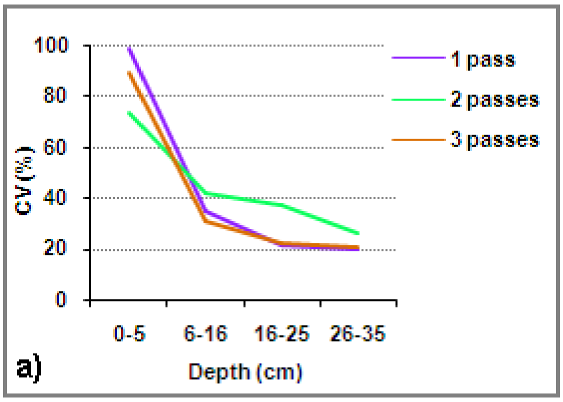
Site 2

Dry (Fig. 4.18a)

- After one vehicle pass - extremely high CV percentage (98%) in topsoil. But then decreasing sharply to subsoil;
- After two vehicle passes - CV of 73% in the topsoil, followed by sharp decrease in CV to subsoil. Generally much higher CV values than for Site 1;
- After three vehicle passes - CV percentage (98%) the same as after one vehicle pass. Then a similar sharp decrease to subsoil.

Wet (Fig. 4.18b)

- After one, two and three vehicle passes the same trend - much lower CV in topsoil (0-5 cm) than under dry conditions (50%). The CV values are still much higher than Site 1. Further down, a decrease in CV to subsoil with a slight increase at 26-35 cm depth.



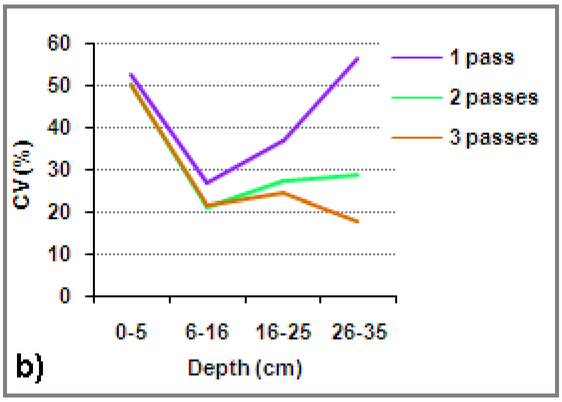


Figure 4.18 Site 2 - coefficients of variation at different depths and 1 to 3 passes: a) dry; b) wet

Site 3

Dry (Fig. 4.19a)

- After one and two vehicle passes - topsoil (0-5 cm) much higher CV (47%) than for Site 1, but much lower than Site 2, followed by a decrease to subsoil, with a sharp increase at 26-35 cm depth;
- After three vehicle passes - a much higher CV (62%) in topsoil, followed by slight decrease to subsoil (all CV values ≥ 30%).

Wet (Fig. 4.19b)

- After one vehicle pass - topsoil high CV (51%), then a decrease to subsoil. Higher values than under dry conditions;
- After two vehicle passes - topsoil high CV (70%), decreases to 37%, 50% and 41% at depths of 6-15, 16-25 and 26-35 cm, respectively;
- After three vehicle passes - topsoil CV high (55%). Then decrease to 36%, 44% and 45% at depths of 6-15, 16-25 and 26-35 cm, respectively.

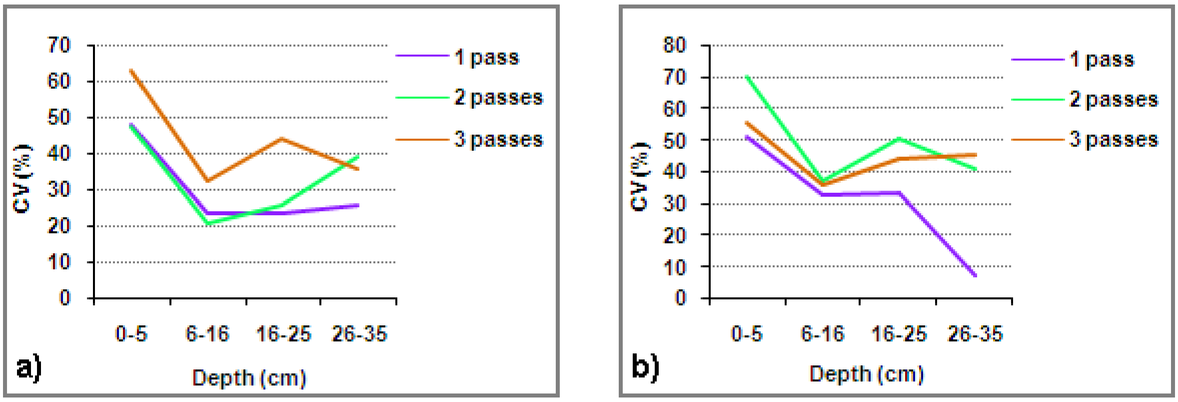


Figure 4.19 Site 3 - coefficients of variation at different depths and 1 to 3 passes: a) dry; b) wet

The increase of CV at Site 3 under both dry and wet conditions is possibly due to soil mixing by termites at that depth (Nortjé 2010, pers. obs). The very high CV values at Site 2 during dry and wet conditions are due to the fact that it is classified texturally as a very sandy soil, with stratified layers, and its position in the landscape (1^{st} terrace). At Site 1, the CV values are the consequence of animal movements throughout the area, as well as the historical impacts of the Makuleke people.

Holloway & Dexter (1990) have reported similar high (CV) values in their study of soil compaction on virgin soils in a semi-arid environment. Maximum CV values of the two sites studied were >30% and >70%, respectively. CV of penetration resistance values of a virgin soil was high before any vehicle passes, but decreased after five vehicle passes. They concluded that because variability of soil properties is synonymous with soil structure, these reductions in CV values potentially indicate a corresponding decrease in soil structure as compared to the virgin soil.

Harr (1987) also mentions CV values of 37%. Lipiec & Hatano (2003) also reported maximum CV values at shallow depths (0-5 cm) of between 40% and 55% for loamy sand as affected by tractor passes. Kiliç *et al.* (2004) in a study of assessing spatial variation in penetration in Turkey of a loamy soil found CV values in the top soil (0-5 cm) of above 50%. The highest variability was obtained for penetration resistance (CV 56.6%) in a study of the effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard (Ferrero *et al.* 2005).

4.4.2.4 Soil strength of animal paths and comparison between vehicle paths and animal paths

The question could be asked whether the impact of ORD is a real concern when considering what the impact of animal paths may be. Soil strength measurements were, therefore, also made beneath animal paths and at different distances to their side. Results are given here for one elephant path and for three antelope paths (one for each soil studied).

Animal paths

Elephant path

At all distances away from the elephant path very high penetrometer values (cut-off value, 5 000 kPa) at a soil depth of between 5.5 and 6.0 cm were found (Fig. 4.20). For both the control and under the elephant path (Fig. 4.21) these were found at a soil depth of about 7.0 cm. Thus, the elephant path showed no impact in terms of soil compaction compared with the control.

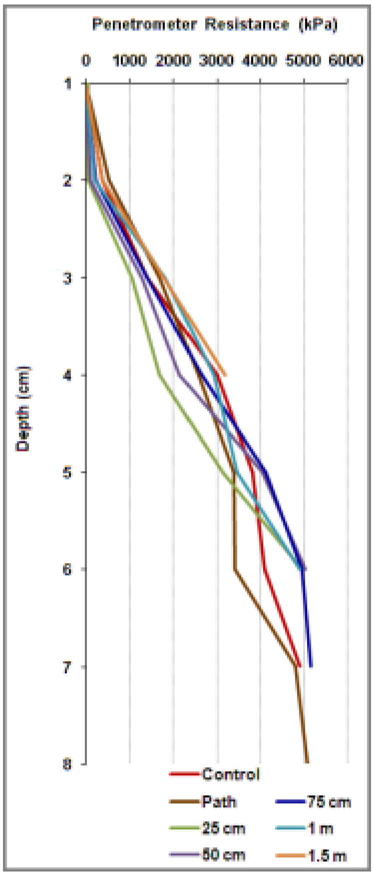


Figure 4.20 Penetrometer values between the elephant path, the control and controls at different distances from the elephant path

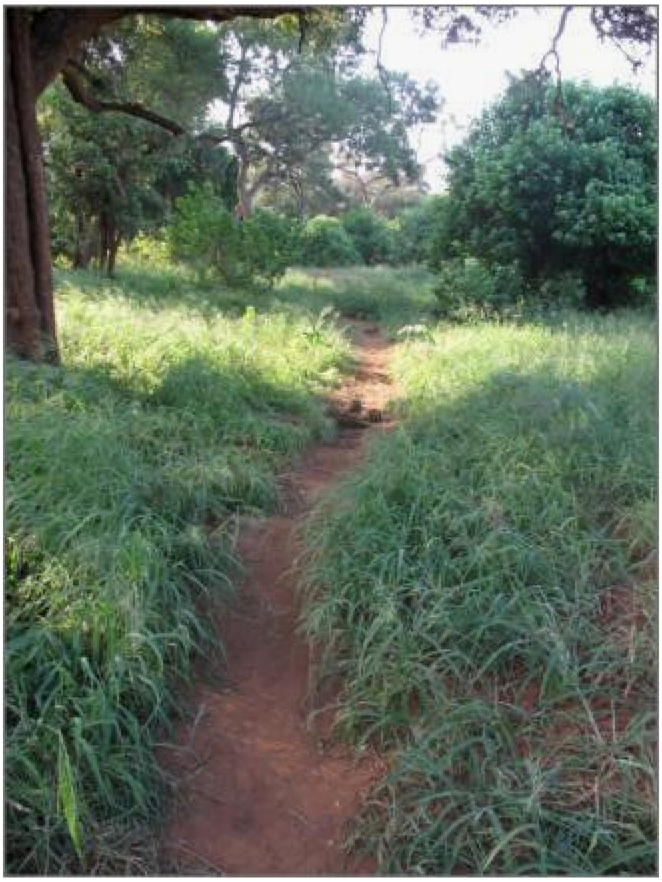


Figure 4.21 Elephant path

For all practical reasons, the graphs of the elephant path and control are basically lying on top of each other. The difference in depth at which the very high cut-out value was reached away from the track is insignificant. Therefore, there is in this case at these soil depths basically no difference between the control and the measurements on and next to the elephant path. In all cases very severe crusting was found.

This is totally different than in the case of the threshold values with the vehicle tracks at soil Sites 1 and 2 (Section 4.4.2.2). There the penetrometer values at shallow depths were much lower for the controls and under the tyre tracks, than the values at the different distances from the side of the vehicle tracks. Note the lush growth of the grass up to right next to the path in Fig. 4.21. This is in comparison to the poor vegetation growth pattern to the side of the vehicle tracks in the previous chapter.

There was therefore a definite effect. With the elephant path we have a soil with a very severe soil crust. At Site 3, which was close to the elephant path, the peak control values at shallow depths was not exceptionally high, compared to what is the case here with the elephant path. The highest was between 3 000 and 4 000 kPa. In most cases, the values stayed surprisingly constant with soil depth. Quite clear was that the differences between individual cases (different tyre pressures) for Site 3 were relatively small - very much like at Site 2, but contrary to the high variations at Site 1.

Antelope paths

Wild animals walking in small paths do have an impact on the soil. The impact is mainly limited to shallow depths and not as laterally distributed as with vehicular traffic. An antelope foot path (Fig. 4.22) at Site 1 during dry conditions showed that severe soil crusting occurred at shallow depth (1-4 cm) until the penetrometer shut down at 5 000 kPa (Fig. 4.23a). During wet conditions soil crusting was severe at depths of 1-11 cm.

Figure 4.22 Antelope path

Again, where there is vegetative growth it is right up to the path. See especially the patch fairly deep into the photograph (Fig. 4.22).

Site 1

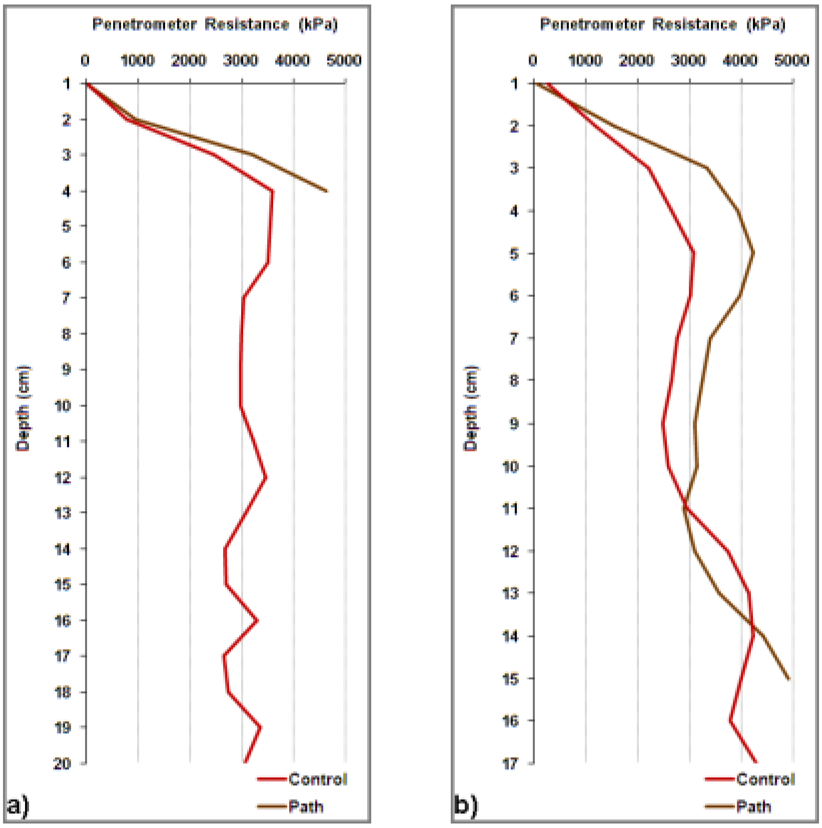


Figure 4.23 Antelope path vs. control values for Site 1:
a) dry conditions; b) wet conditions

Site 2

An antelope path at Site 2 (Fig. 4.24) showed sub-soil compaction to depths of 3-78 cm during dry conditions, but during wet soil conditions severe soil crusting (5 000 kPa) at shallow depth.

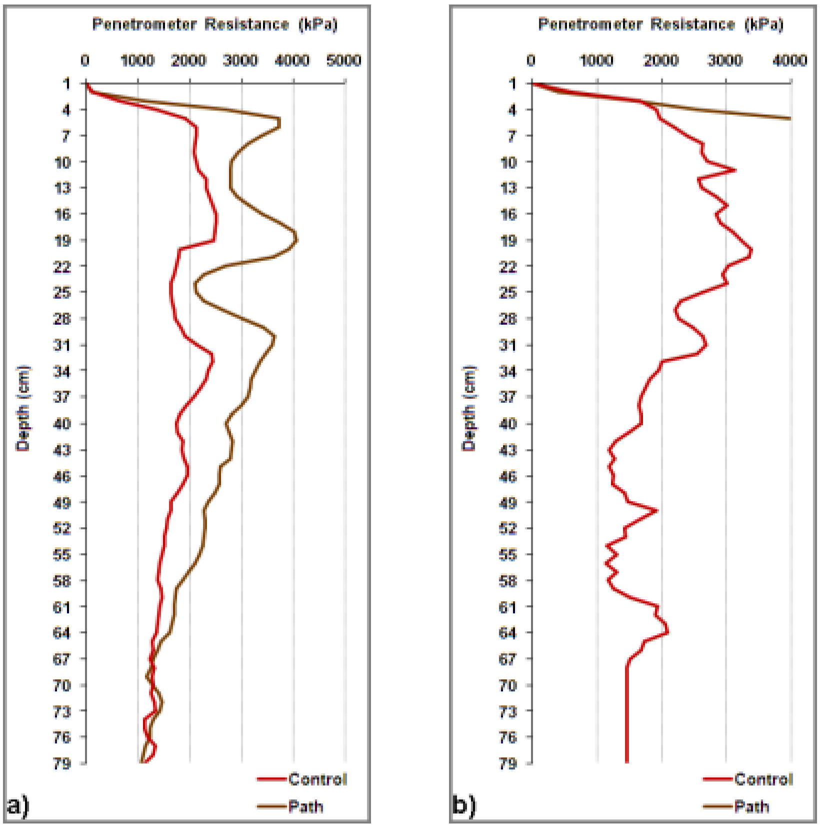


Figure 4.24 Antelope path vs. control values for Site 2:
a) dry conditions; b) wet conditions

Site 3

The situation at Site 3 (Fig. 4.25) was similar to the one at Site 1. Severe soil crusting occurred at shallow depths (1-11 cm), but then during wet conditions sub-soil compaction much higher than the control to depths of 2-18 cm.

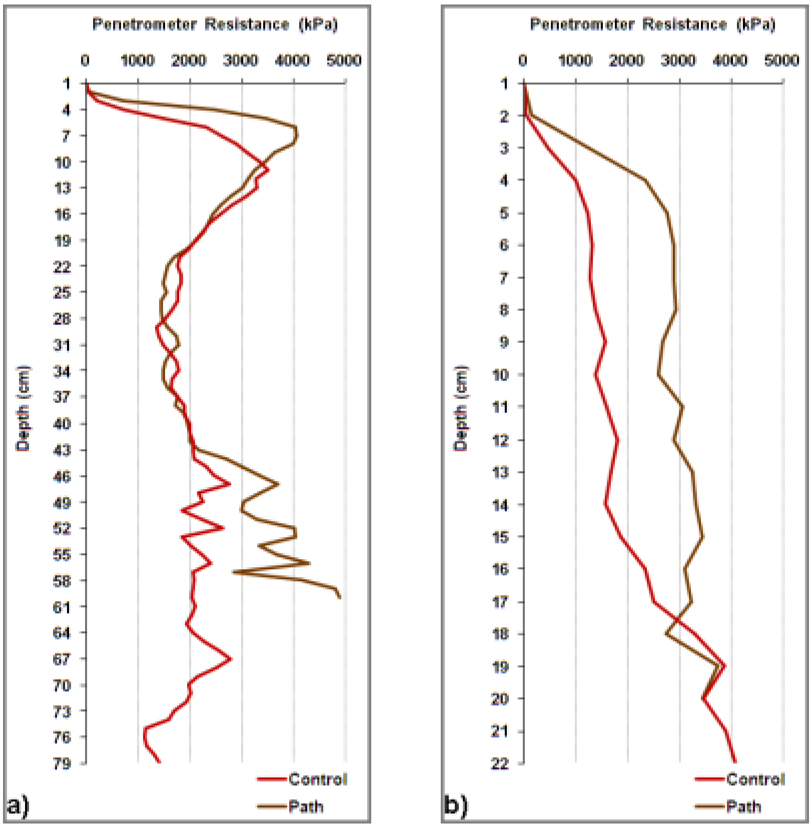


Figure 4.25 Antelope path vs. control values for Site 3:
a) dry conditions; b) wet conditions

These results clearly show compaction by animal hooves, even though they are limited to shallow depths and not as much laterally distributed as vehicle paths. What happens is that animal hooves break the surface crust but then re-compacts the soil beneath the broken crust.

The comparative values between the animal paths and the controls are interesting. These are opposite to the views of Savory (1988), who propagates that livestock do not compact the soil but alleviate especially crusting. There are very large differences between the control values and the animal paths (Fig. 4.23, 4.24, 4.25). There is also a large difference between the control values for Site 3 and the elephant path (Fig. 4.20).

Severe compaction can be caused by treading by livestock under intensive farming systems, e.g. by dairy cattle on irrigated pastures (Mitchell & Berry 2001). The worst compaction is by "pugging", i.e. plastic flow around the hoof of the animal, in wet soil. It should be the same for wild animals grazing under wet soil conditions.

4.5 Conclusion

This study pointed out statistically significant impacts of ORD on the soils of the MCP. It was shown that, in the areas where ORD are practised, sub-soil compaction and soil crusting was significantly more than in areas where no ORD occurred.

As expected, vehicular traffic caused soil compaction below the wheel tracks. This occurred even when driving on dry soil and even at low tyre pressures. The negative effects of this on plants (both above ground mass and root development) were clearly observed (Chapter 5). As expected, compaction was more severe when driving on wet soil than when driving on dry soil. On wet soil higher tyre pressures caused more damage. Fewer vehicle passes also caused less compaction than more passes on the same tracks, but most compaction occurred during the first pass (Nortjé *et al.* 2012). Thus, driving on the same tracks, more than once, is less damaging than driving once, on different tracks. Controlled traffic should be considered when developing management strategies for ORD, in wildlife protected areas.

The impacts of ORD on soil compaction were not only significant under the tracks, but in most cases in the whole area in-between the two tyre tracks and also up to a distance of 2.0 m outside of the vehicle tracks. There is a strong lateral effect of the vehicle tyres. This lateral effect will be both outside and in-between the tracks. Between the tracks it becomes aggravated, because the impact is from both sides (Fig. 4.11-4.16).

This is contrary to what Bhandari (1998) found in the Masai Mara National Reserve where the degree of impact in-between the tracks was less than under the tracks. A possible reason for this difference is that the soils differ greatly between the two areas. The soils in this study, in the MCP, are typical alluvial sandy-loam to sandy soils, whereas in the Masai Mara, large areas are dominated by heavy swelling clay soils.

If anyone doubted the lateral effects of wheel impacts, the results for these two very different soils have undoubtedly dispelled all such doubt. The original results found between the tracks together with the photographic evidence (Fig. 3.7) are important prove of the lateral effects of vehicle tyres.

There is a definite trend in coefficient of variation values decreasing with soil depth. The CV values are very high in the topsoil at all sites, but the highest at Site 2. These high CV values are normal under these conditions and also confirmed by the literature.

Comparing the effects of animals walking in animal paths with the vehicle impacts resulted in some interesting observations. Apart from the fact that the animals only caused a soil crust and do not cause high sub-surface compaction, the animal paths' crusts also do not give soil strength values close to or greater than 5 000 kPa. Sometimes, it was even much lower than that. Animal paths' effect are also more vertical than lateral. With the vehicle tyres there is a totally different result, especially at higher tyre pressures (240 and 320 kPa).

4.6 References

- Adams, J.A., Endo, A.S., Stolzy, L.H., Rowlands, P.G. & Johnson, H.B. (1982) Controlled experiments on soil compaction produced by off-road vehicles in the Mojave Desert, California. *J Appl Ecol*, 19/1, 167-175.
- Annandale, J.G., Stirzaker, R.J., Singels, A., Van der Laan, M. & Laker, M.C. (2011) Irrigation scheduling research: South African experiences and future prospects. *Water SA*, 37, 751-763.
- Bekker, M.G. (1961) Mechanical properties of soil and problems of compaction. *Trans ASAE*, 2, 231-248.
- Bengough, A.G., McKenzie, B.M., Hallet, P.D. & Valentine, T.A. (2011) Root elongation, water stress and mechanical impedance: a review of limiting stresses and beneficial root tip traits. *J Exp Bot*, 62/1, 59-68.
- Bennie, A.T.P. (1972) 'n Ondersoek na sekere aspekte van grondsterkte in gronde van die manganoserie. MSc(Agric) thesis, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Bennie, A.T.P. & Burger, R.d.T. (1988) Penetration resistance of fine sandy soils as affected by relative bulk density, water content and texture. *S Afr J Plant Soil*, 5, 5-10.
- Bennie, A.T.P. & Krynauw, G.N. (1985) Causes, adverse effects and control of soil compaction. *S Afr J Plant Soil*, 2, 109-114.
- Bennie, A.T.P. & Laker, M.C. (1975) The influence of soil strength on plant growth in red apedal soils. *Proc 6th SSSSA Congr*, Blydepoort, July 1975, 259-275.
- Bhandari, M.P. (1998) Assessing the impact of off-road driving on the Masai Mara National Reserve and adjoining areas, Kenya. Masters dissertation, International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands.
- Bloem, A.A. & Laker, M.C. (1994) Infiltrasie onder veld- en laboratoriumtoestande. *Water SA*, 20, 133-138.

- Braunack, M.V. (1986a) Changes in physical properties of two dry soils during tracked vehicle passage. *J Terramechanics*, 23/3, 141-151.
- Braunack, M.V. (1986b) The residual effects of tracked vehicles on soil surface properties. *J Terramechanics*, 23/1, 37-50.
- Bühmann, C., Rapp, I. & Laker, M.C. (1996) Differences in mineral ratios between disaggregated and original clay fractions in some South African soils as affected by amendments. *Australian J Soil Res*, 34, 909-923.
- Cassel, D.K., Ratliff, L.F. & Ritchie, J.T. (1983) Models for estimating in-situ potential extractable water using soil physical and chemical properties. *Soil Sci Soc Am J*, 47, 764-769.
- Du Preez, C.C., Bennie, A.T.P. & Burger, R.d.T. (1979) *Grondverdigting onder besproeiing op die Vaalharts besproeiingskema.* Volume 3: Die oorsake en bekamping van verdigting van sanderige besproeiingsgronde. Verslag 79/3, Departement Grondkunde. Universiteit van die Oranje Vrystaat, Bloemfontein.
- Du Preez, C.C., Bennie, A.T.P. & Burger, R.d.T. (1981) Invloed van implementverkeer en besproeiing op grondverdigting te Vaalharts. *Agrochemophysica*, 13, 7-12.
- Du Preez, C.C. & Botha, F.J.P. (1980) Amatola Basin rural development project - soils of the Amatola Basin. Report 3/81. Agric and Rural Development Res Inst, University Fort Hare.
- Ferrero, A., Usowicz, B. & Lipiec, J. (2005) Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyards. *Soil Till Res*, 84, 127-138.
- Greacen, E.L. & Sands, R. (1980) Compaction of forest soils: a review. *Aust J Soil Res*, 18, 163-89.
- Harr, M. E. (1987) Reliability based design in civil engineering. McGraw Hill, London.
- Henning, J.A.G., Nel, D.J. & Harmse, H.J.v.M. (1986) Die invloed van verdigtingspoging, klei- en waterinhoud op verdigting van geselekteerde Hoëveldgronde. *S Afr J Plant Soil*, 3, 119-122.
- Holloway, R.E. & Dexter, A.R. (1990) Compaction of virgin soil by mechanized agriculture in a semi-arid environment. *Land Degrad Rehabil*, 2, 107-115.
- Horn, R. & Fleige, H. (2009) Soil susceptibility to compaction. Accessed 18th August 2012, http://eusoils.jrc.ec.europa.eu/library/themes/compaction/Precompression.html.
- Kiliç, K., Özgöz, E. & Akbas, F. (2004) Assessment of spatial variability in penetration resistance as related to some soil physical properties of two fluvents in Turkey. *Soil Till Res*, 76, 1-11.

- Laker, M.C. (1987) Soil compaction and soil crusting. Soil Science 317 course notes.
- Laker, M.C. (2001) Soil compaction: effects and amelioration. *P S Afr Sug*, 75, 125-128.
- Laker, M.C. (2004) Advances in soil erosion, soil conservation, land suitability evaluation and land use planning research in South Africa, 1978-2003. *S Afr J Plant Soil*, 21/5, 345-368.
- Laker, M.C. & Vanassche, F.M.G. (2001) Alleviation of soil crusting in a citrus orchard by means of a coal-derived humic product. In: *Programme and extended abstracts*, Joint Congr 2001, Pretoria January 2001, 265-266.
- Lipiec, J. & Hatano, R. (2003) Quantification of compaction effects on soil physical properties and crop growth. *Geoderma*, 116, 107-136.
- McCool, S.F. (1981) Off-road vehicles in National Park areas: some information needs. Wildlands Recreation Management. School of Forestry. *Leisure Sci*, 4/3.
- Merotto, A. (JR) & Mundstock, C.M. (1999) Wheat root growth as affected by soil strength. *Rev Bras Cienc Solo*, 23:197-202.
- Mitchell, F.J. & Berry, W.A.J. (2001) The effects and management of compaction in agricultural soils.*P S Afr Sug*, 75, 118-124.
- Moolman, J.H. & Weber, H.W. (1978) 'n Ondersoek na die bydrae van die fynsand-fraksie tot die verdigbaarheid van fynsandgronde in Suid-Kaapland. *Agrochemophysica*, 10, 39-46.
- Nortjé, G.P. (2005) The impacts of off-road driving and other concessionaire activities on physical soil degradation. MPhil thesis, Centre for Wildlife Management, University of Pretoria.
- Nortjé, G.P., van Hoven, W. & Laker, M.C. (2012) Factors affecting the impact of off-road driving on soils in an area in the Kruger National Park, South Africa. *Environ Manage*, 50/6, 1164-1176.
- O'Brien, D. (2002) Off-road or off-limits-recreational driving in the National Parks. Council for National Parks, London.
- Onyeanusi, A.E. (1986) Measurement of impact of tourist off-road driving on grass-lands in Masai Mara National Reserve, Kenya: a simulation approach. *Environ Conserv*, 13/4, 325-329.
- Pafuri Factsheet (2011) Makuleke Cultural Heritage. Information Sheet to Pafuri Camp in the Makuleke Contractual Park, South Africa.
- Rapp, I. (1998) Effects of soil properties and experimental conditions on the rill erodibility of selected soils. PhD thesis, University of Pretoria.
- Reed, A.H. (1983) The erosion risk of compaction. *Soil Water*, 11, 29-33.

- Savory, A. (1988) Holistic Resource Management. Island Press, Washington D.C., USA, 41-44.
- Smith, C.W. & Johnston, M.A. (2001) Managing soil compaction to ensure long-term site productivity in South African forest plantations. *P S Afr Sug*, 75, 129-136.
- Soil Classification Working Group (1991) *Soil Classification: a taxonomic system for South Africa*. Department of Agriculture Development, RSA.
- South African Sugar Technologist's Association (SASTA) (2001) Soil compaction workshop proceedings, August 2001. CD-ROM. Mt Edgecombe, Durban.
- Stern, R. (1990) Effects of soil properties and chemical ameliorants on seal formation, run-off and erosion. DScAgric thesis, University of Pretoria.
- Van Antwerpen, R., Meyer, J.H, & Meyer, E. (2000) Soil compaction in the South African sugar industry: a review. *P S Afr Sug*, 74, 101-108.
- Van der Merwe, L. (2004) Guidelines for off-road driving in the private concessions of the Kruger National Park. Concessions Operations Manual, KNP.
- Van der Watt, H.v.H. (1969) Influence of particle size on soil compactibility. *Agrochemophysica*, 1, 79-86.
- Van der Watt, H.v.H. & Van Rooyen, T.H. (1995) A Glossary of Soil Science, 2nd edn. The Soil Science Society of South Africa, Pretoria.
- Van Huysteen, L. (1983) Interpretation and use of penetrometer data to describe soil compaction in vineyards. *S Afr J Enol Vitic*, 4/2.
- Webb, R.H. (2002) Recovery of severely compacted soils in the Mojave Desert, California, USA. *Arid Land Res Manag*, 16, 291-305.
- World Reference Base for Soil Resources (WRB) (1998) Rome: Food and Agriculture Organization of the United Nations (FAO).

CHAPTER 5

QUANTIFYING THE IMPACT OF OFF-ROAD DRIVING ON RESILIENCE OF THE VEGETATIVE COVER, ESPECIALLY GRASS

5.1 General Introduction

For plants to derive benefits from water and nutrients in soil, plant roots must be able to reach them. Therefore, soil strengths that prevent root penetration or reduce root elongation rates may reduce plant development and yields, because water and nutrients beneath the restricting zone are unavailable to the plants (Unger & Kaspar 1994).

As mentioned in Chapter 4, the key factor is the effects of soil compaction on root penetration. Also mentioned in the same chapter is that the studies that have been conducted since about the early 1960s in the USA, Australia and South Africa, on the effects of soil compaction on plant growth have been reviewed by, amongst others, Bennie & Krynauw (1985), du Preez *et al.* (1979, 1981) and SASTA (2001). Studies on the relationship between root penetration and soil strength have been done by, amongst others, Taylor *et al.* (1966), Unger & Kaspar (1994), Barley & Greacen (1967), and Martino & Shaykewich (1993).

The objectives of this study were: 1) to do qualitative sequential photographic monitoring of the impact of ORD on above ground vegetative growth at the trial sites; 2) to determine the effects of vehicle traffic on root development by comparing the root area distribution below tracks at each of the following tyre pressures, 80, 160, 240 and 320 kPa, with those outside tracks; and 3) to evaluate a photographic method for quantifying these relationships.

5.2 Methodology

The vehicle used to simulate ORD situations was a game drive vehicle with a roof rack, having a vehicle mass of 3 025 kg (Fig. 4.2). It was loaded with 10 sand bags averaging 70 kg per bag, representing the maximum number of passengers, plus the driver/Guide. Thus the total mass came to 3 795 kg. The soils' chemical, physical and mineralogical properties are described in sections 4.22 and 4.2.3.

5.2.1 Above ground biomass determinations

Quantitative biomass, in this study grass biomass, determination is a proven and acceptable method of veld evaluation. The best estimate of the biomass of a grass layer is obtained by direct harvesting of the grass layer. This approach is often used to determine the phyto-mass of the grass layer over a season or a year (Grunow 1977).

This approach was considered in this study. However, it was decided against grass biomass determinations because of the fact that not enough grass biomass was available for such determinations (Fig. 5.1). It would, therefore, not have been possible to perform any statistical tests on the biomass data collected. This situation with almost no grass cover continued for months during the study period. As mentioned in Chapter 2 the area of the trial sites is highly degraded by soil crusting, and therefore grass recovery was not sufficient for biomass determination.

Figure 5.1 Typical grass biomass at Site 1 during the study period

Consequently, only qualitative determinations were made by means of repeat-photography follow-up similar to what was done for monitoring of the off-road incidents (Chapter 3), to monitor the trial sites for biomass recovery - as possible indicator of natural soil compaction alleviation. This was done from March 2010 to February/March 2012, i.e. over a two year period that included two full rain seasons.

5.2.2 Quantitative root surface area determinations

For the reasons mentioned in Section 5.2.1, it was decided to execute root density determinations instead of grass biomass determination. The method followed was a combination of the Profile Wall Method (Bohm 1979) and Photographic Image Analysis by making use of ImageJ Software (Rasband 2011; Bekker 2007; Schneider *et al.* 2012 and Plaza-Bonilla *et al.* 2012). These were preferred to other methods that are often discussed in the bibliography as tedious and time-consuming.

Three weeks after the first substantial summer rainfall after conducting the off-road driving (ORD) experiments, root density distribution was determined at the three ORD simulation sites where driving was done on dry soil. The determinations were done during the beginning of December 2010, eight and a half months after the ORD simulation trials. This was done in order to allow for sufficient grass recovery if possible for the root density determinations. In total, 218.2 mm of rain was measured between the off-road trials in March 2010 and the root density distribution determinations. Soil profiles were excavated under each vehicle track representing a tyre pressure of 80, 160, 240 or 320 kPa and at control positions. Root density distribution was assessed for the grass species growing at the study sites. This was done in triplicate.

According to Bohm (1979) it is only necessary to remove a thin layer of soil about 1 cm thick or less from the profile wall to see the roots after excavation. For plants with fibrous root systems, such as grasses in this study, a square of 5 cm x 5 cm has proven satisfactory for studying grass root distribution. The size of the grid in this study was 430 mm (vertical) x 330 mm (horizontal), a little bit smaller than the 1000 mm x 600 mm proposed by Bohm (1979). This was sufficient for this study as the grid only needed to cover at least 150 mm on either sides of the of the tyre track width in order to include most grass roots (Fig. 5.2).

Figure 5.2 Grid covering soil profile for root density determination

A digital photograph of the exposed roots was taken at a set distance of 500 mm from the each soil profile with a Canon 350D digital camera (8 megapixel, 18-55 mm lens). Photographs were analysed using the computer software ImageJ 1.33u (Rasband 2011). The photos were converted from a RGB colour type photo to an 8-bit image. A threshold (upper threshold 255, lower threshold level 170-195) was assigned to the foreground colour (the yellow/white grass roots) and the remaining pixels to the background colour (soil surface), where after the photos were converted to a black and white picture. Pixels not related to roots, including leaf material, rope, grid wire and grass litter (background noise) in the photos were deleted from the pictures. The pictures were then computer analysed, and area fraction determined and recorded as a percentage root density.

5.2.2.1 Statistics

One-way Analysis of Variance (ANOVA) (SPSS V.19.0®) was performed for each of the three sites, to compare the average root area fractions across the five (including the control) different tyre pressures ($p = 0.05$). Pair-wise comparisons, Least Significant Differences (LSD), were performed *post hoc* to determine between which tyre pressures the statistically significant differences occurred.

5.3 Results and Discussion

5.3.1 Qualitative photographic recordings of above ground vegetative growth

Site 1

<u>Soil dry when trial driving was done</u>

At the time of the ORD trials the soil at Site 1 was totally bare and devoid of vegetation. This is the normal situation during the dry seasons on the Levuvhu flood plains (Fig. 5.3).

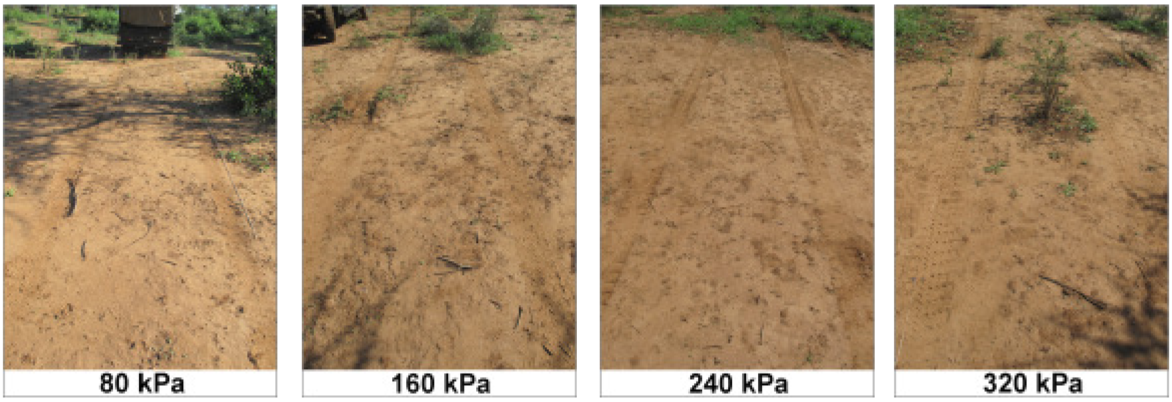
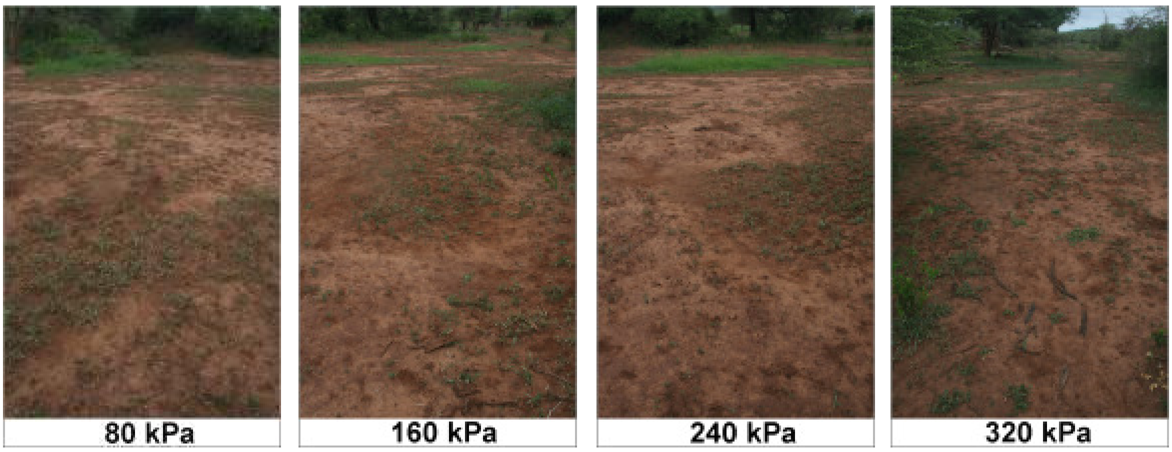


Figure 5.3 3rd March 2010 - tracks and vegetation at Site 1, dry, immediately after driving at different tyre pressures

After good summer rains some vegetation recovery took place, but this was for a short period of time and with no follow-up rains the soil surface quickly turned virtually barren again (Fig. 5.4). It is also clear in the photos that erosion has started to occur in and around the vehicle tracks. The track acted as rills (Fig. 5.3) into which water is channelled, thus predisposing the soil to erosion.



Figures 5.4 7th January 2011 - tracks and vegetation at Site 1, dry, towards the end of one rainy season 10 months after driving and after receiving a total of 295.2 mm rain since driving

The vegetation at Site 1 never really recovered to a condition of lush vegetation, even two years after driving and despite the substantial amount (698.2 mm) of rainfall since driving (Fig. 5.5). The erosion scars can still be seen, especially the wide shallow gully where driving was done at 320 kPa tyre pressure.

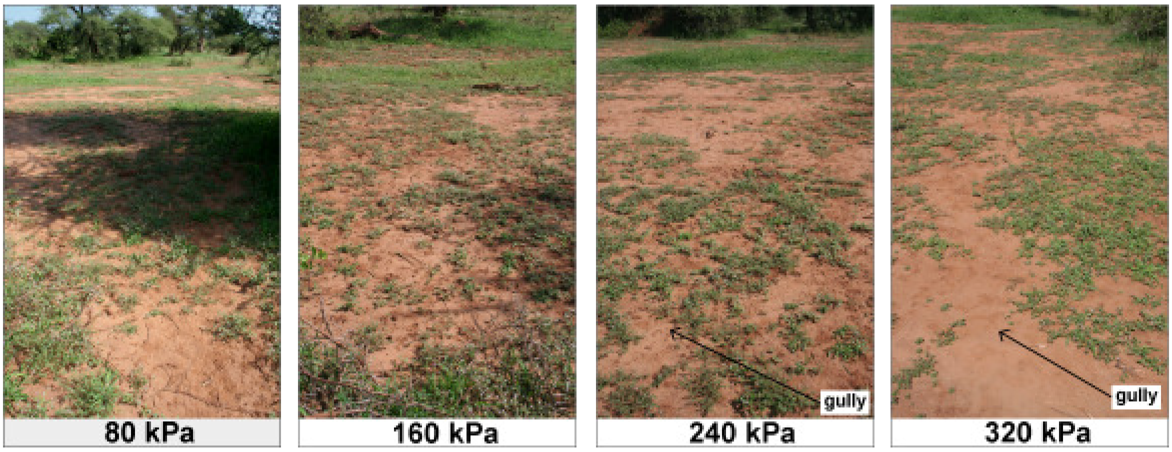


Figure 5.5 20th February 2012 - tracks and vegetation at Site 1, dry, towards the end of two rainy seasons almost two years after driving and after receiving a total of 698.2 mm rain since driving

Soil wet when trial driving was done

The soil at Site 1 was also totally barren when the wet trials were conducted, although this was after some rain (Fig. 5.6). The gullies formed by the tracks are conspicuous.

Figure 5.6 3rd March 2010 - tracks and vegetation at Site 1, wet, immediately after driving at different tyre pressures

A year after driving, and after receiving 380.2 mm rain since driving, the most notable feature is the severe erosion, caused by the water channelling by the tracks (Fig. 5.7). The erosion scars are much wider than the tracks, due to lateral rushing of water into the tracks. This is similar to what was also seen in the off-road monitoring pictures (Chapter 3, Fig. 3.7).

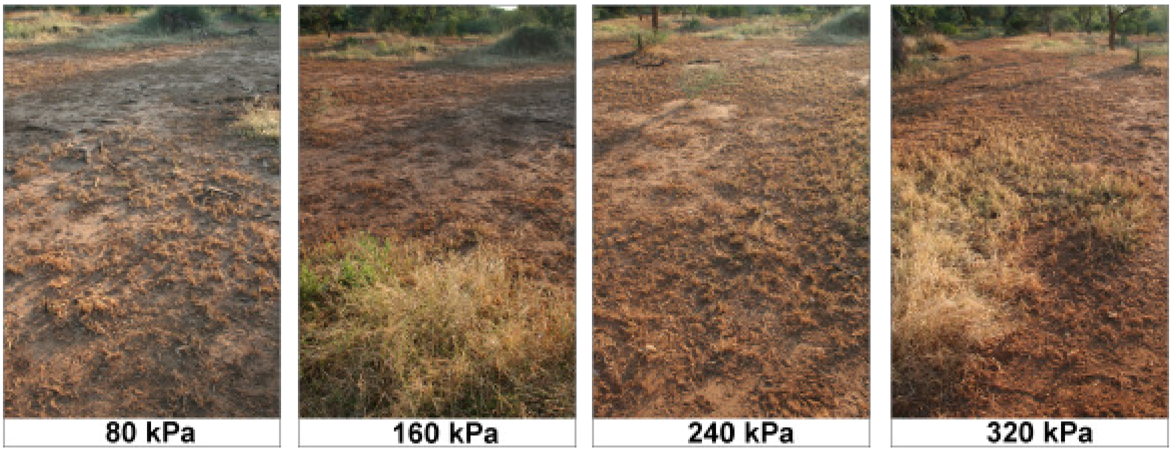
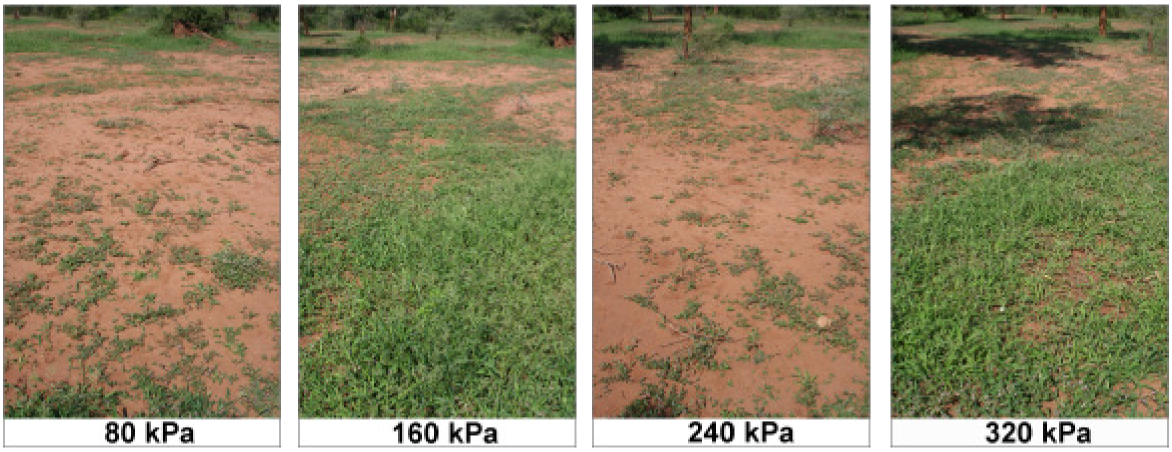


Figure 5.7 25th March 2011 - tracks and vegetation at Site 1, wet, at the end of one rainy season one year after driving and after receiving a total of 380.2 mm rain

There was some vegetation recovery after two seasons of rain (698.2 mm) since driving was done (Fig. 5.8). An interesting observation is that at 320 and 160 kPa tyre pressure there was more recovery than at the other tyre pressures. Even these are only small pioneer plants with very little value.

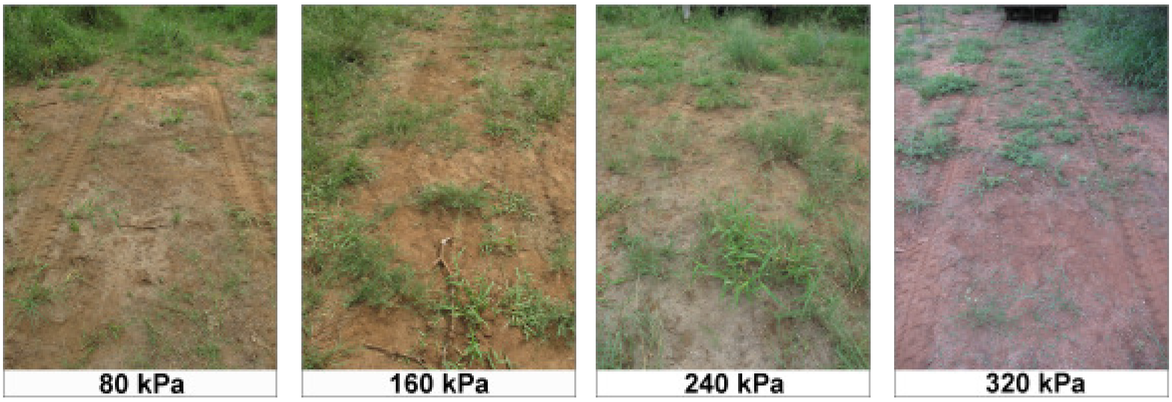


Figures 5.8 20th February 2012 - tracks and vegetation at Site 1, wet, at the end of two rainy seasons two years after driving and after receiving a total of 698.2 mm rain

Site 2

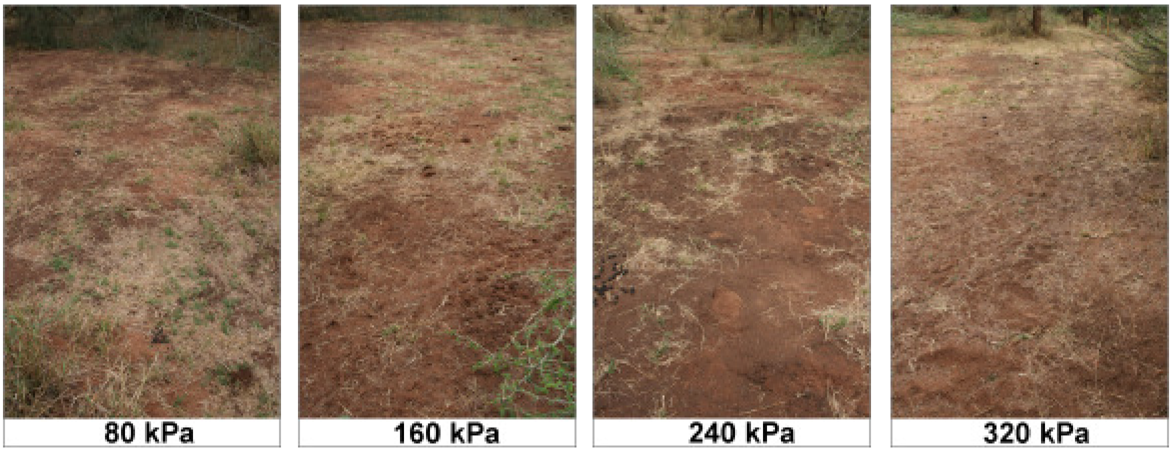
Soil dry when driving was done

In contrast to the barren state at Site 1 when driving was done, there was some sparse live vegetation, almost exclusively small shrubs, at this site when driving was done (Fig. 5.9).



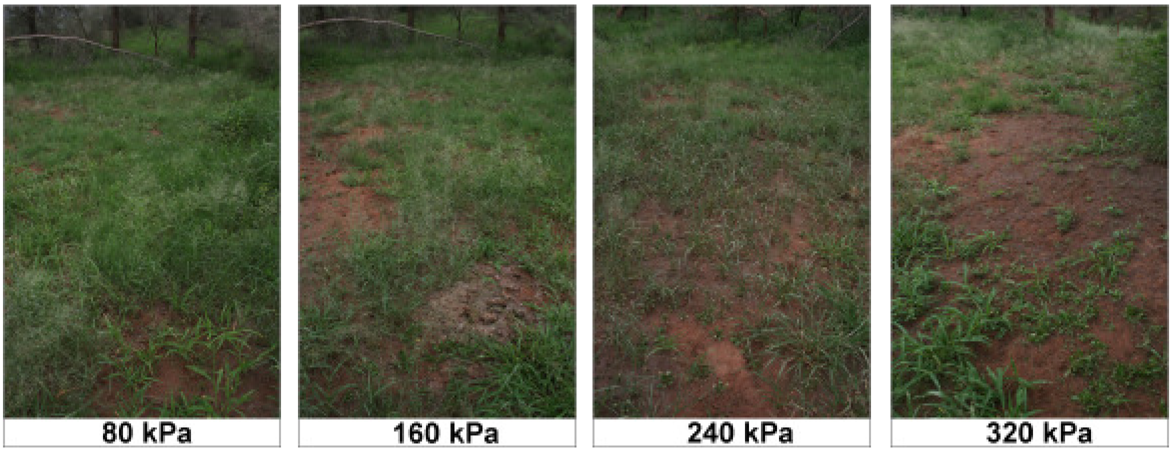
Figures 5.9 2nd March 2010 - tracks and vegetation at Site 2, dry, immediately after driving at different tyre pressures

The negative effect of the vehicle tracks were still clearly visible eight months after driving, with 157.7 mm having been received since driving (Fig. 5.10). What is important is that the poor situation was caused by driving under dry conditions.



Figures 5.10 30th October 2010 - tracks and vegetation at Site 2, dry, at the end of the first dry season after driving, almost 8 months later, receiving a total of only 157.7 mm rain since driving

Deep into the first rain season after driving, 11 months later and having received 295.2 mm rain since driving, there was some recovery of the vegetation, but the negative impacts were still visible (Fig. 5.11). The impact increased with increased tyre pressure, not only under the tracks, but also between the tracks at the three higher tyre pressures.



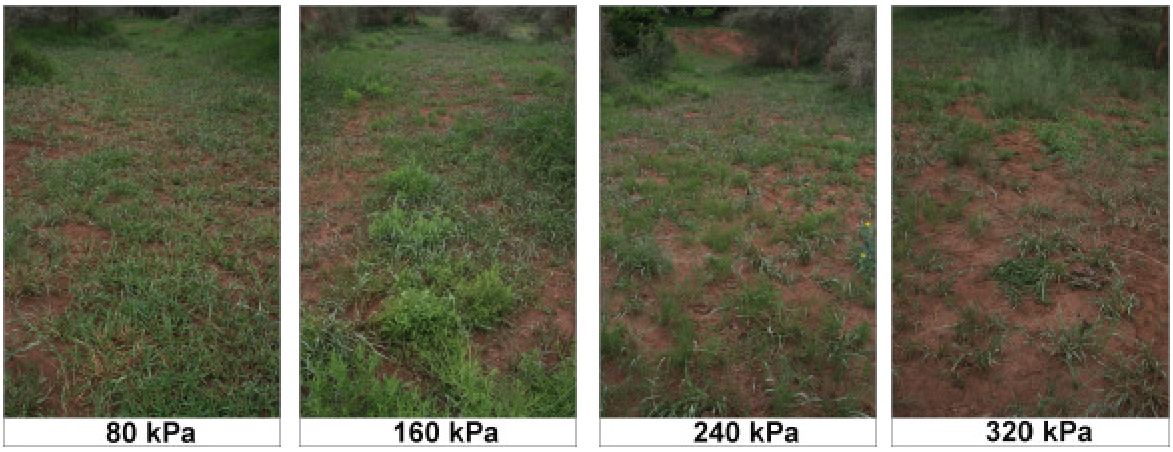
Figures 5.11 7th January 2011 - tracks and vegetation at Site 2, dry, at the end of the first rainy season after driving, 10 months later, receiving a total of 295.2 mm rain since driving

Soil wet when driving was done

The area where driving was done under "wet" conditions at Site 2 also had some vegetative cover, but with large spatial variation (Fig. 5.12).

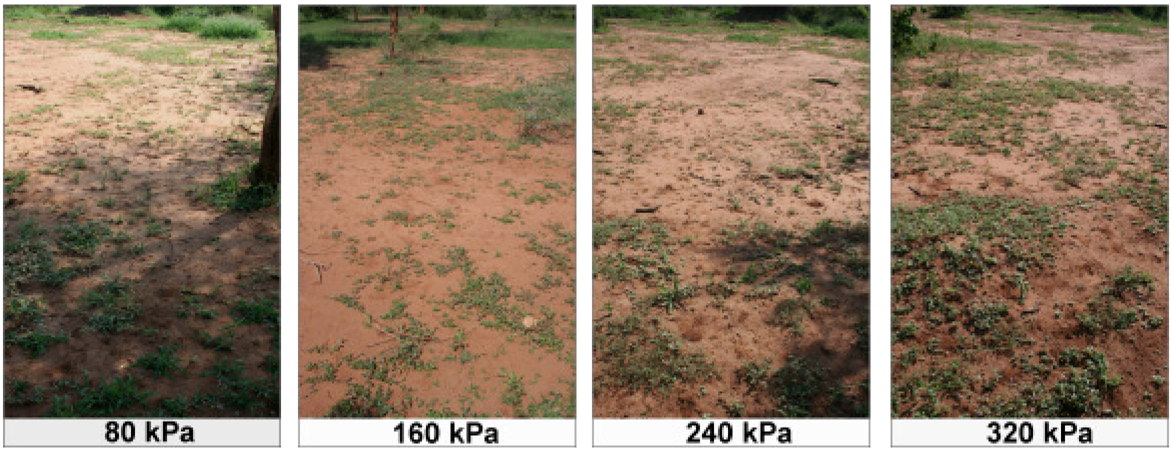
Figures 5.12 3rd March 2010 - tracks and vegetation at Site 2, wet, immediately after driving at different tyre pressures

There seems to be clear negative impacts of the vehicle tracks on the vegetation, even after nearly 300 mm rain since driving (Fig. 5.13). Noteworthy are the effects seen at the two lower tyre pressures, with the poor vegetative growth under the tracks conspicuous. A very striking difference is at 80 kPa, where there was a fairly uniform vegetative cover at the time of driving (compare Figs. 5.12 and 5.13). At the two higher tyre pressures the tracks are still visible (especially at 320 kPa), but less conspicuous. This is due to the poor vegetative growth between (and outside) the tracks at these tyre pressures, indicating wide impacts at these pressures.



Figures 5.13 7th January 2011 - tracks and vegetation at Site 2, wet, near the end of the first rainy season after driving, 10 months later, receiving a total of 295.2 mm rain since driving

After two years, at the end of two rain seasons after driving, receiving a total 698.2 mm rain since driving the situation had degraded further due to the impact of the driving on vegetation at this site (Fig. 5.14). Differences in vegetative growth between the experimental areas and the vegetation towards the top parts of the photos are clear. Especially at 160 kPa tyre pressure the (now wide) impact of the tracks can be seen further into the photo. Of particular concern is the retrogression of the vegetative cover at the 80 kPa plot, which started with a fairly uniform covering when driving was done and the tracks were basically on top of the vegetation (Fig. 5.12). It is usually expected that wheel impact would be relatively small in such situation.



Figures 5.14 20th February 2012 - tracks and vegetation at Site 2, wet, after two years at the end of two rainy seasons after driving, receiving a total 698.2 mm rain since driving

At this stage there was also serious soil erosion where driving was done at the higher tyre pressures (Fig. 5.14). After the first rain season the vegetative cover was poor over a wide area under, between and to the side of the tracks (Fig. 5.13). The second dry season after the driving then obviously led to bare areas (due to wheel impact), leading to this erosion during the next rain season. Even at the low tyre pressures some sheet erosion is visible.

Site 3

<u>Soil dry when driving was done</u>

Here there was much more vegetative cover than at Site 1 during the same date and time (Fig. 5.15). The cover was much more uniform than at Site 2, with much less spatial variation. It was also short shrub-like vegetation and not grass.

The indentations made by the tyres were much smaller than at the other sites.

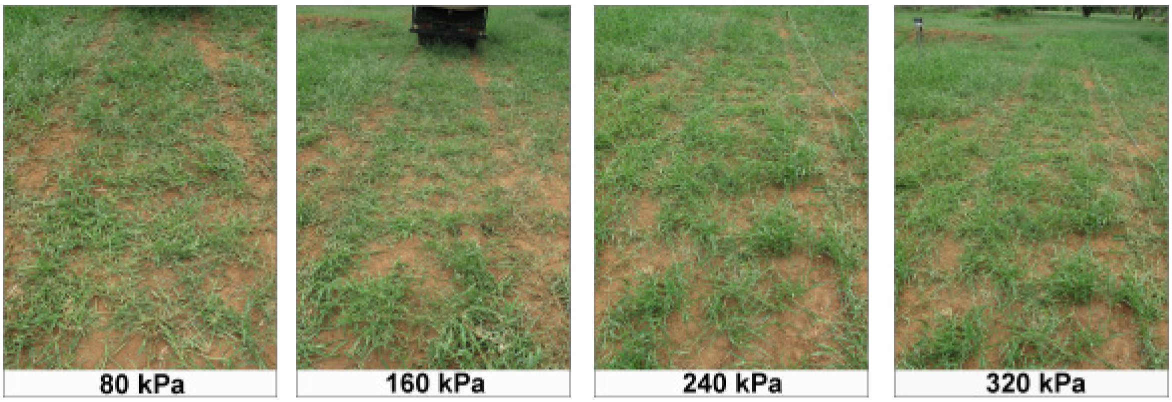


Figure 5.15 10th March 2010 - tracks and vegetation at Site 3, dry, immediately after driving at different tyre pressures

At the end of one rainy season one year after driving the experimental areas had sparse, dry vegetation, unlike the almost completely bare areas at Site 1 (Figs. 5.7 and 5.16). The difference relates back to the original states at the two sites. The sandy soil at Site 2 showed green vegetative growth at this stage. A key difference is that the soils at Sites 1 and 3 had serious surface crusting, which was not the case at Site 2.

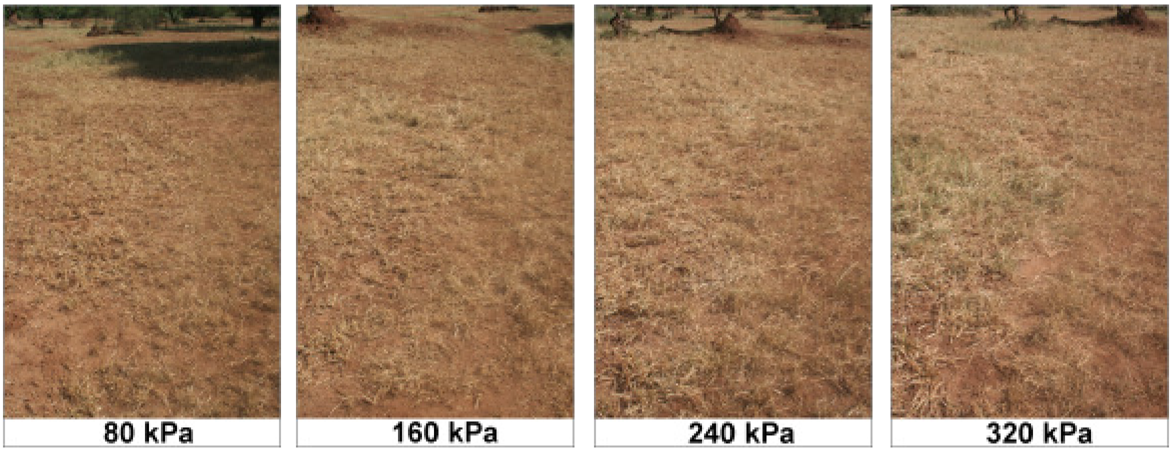


Figure 5.16 26th March 2011 - tracks and vegetation at Site 3, dry, at the end of one rainy season one year after driving and after receiving a total of 380.2 mm rain

Figure 5.16 also shows erosion due to water channelling in and around the vehicle tracks, especially at the three higher tyre pressures. It is less severe than at Site 1, because of the somewhat denser vegetative cover here.

Of key importance is the impact on the soil seen under the tracks at this stage after it appeared to be minimal immediately after driving.

After two rainy seasons a lot of vegetation recovered (Fig. 5.17). Close inspection of the photos reveals that there is only partial recovery at the tracks of the vehicles. This was observed very clearly in the field. It again points towards the "invisible" negative impact on the soil under the tracks when there is green vegetation, as was discussed when comparing Figs. 5.15 and 5.16.

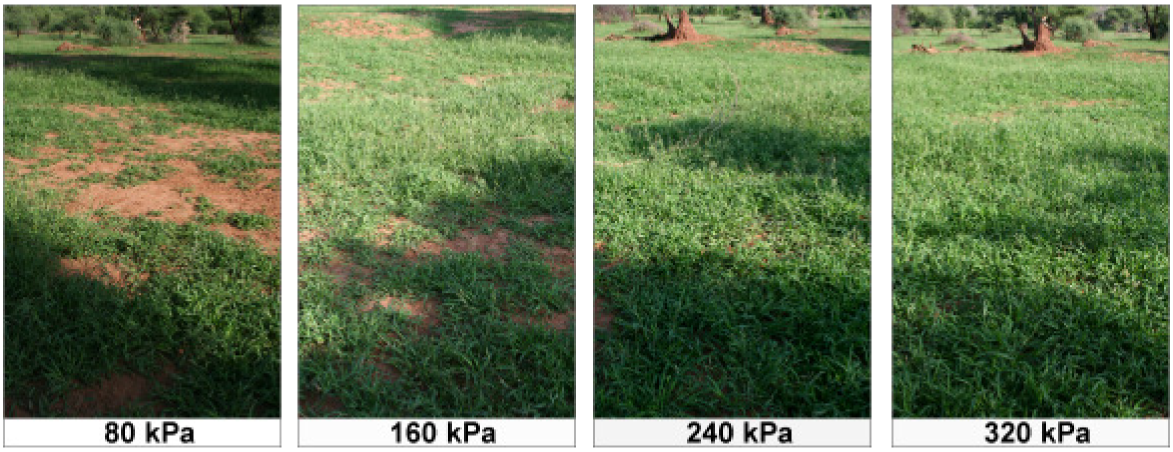


Figure 5.17 20th February 2012 - tracks and vegetation at Site 3, dry, after two years at the end of two rainy seasons after driving, receiving a total 698.2 mm rain

<u>Soil wet when driving was done</u>

When driving on this soil in a dry condition, the tyre tracks were only very weakly visible (Fig. 5.15). Under wet conditions very clear indentations were created in the soil, especially at the two highest tyre pressures (Fig. 5.18).

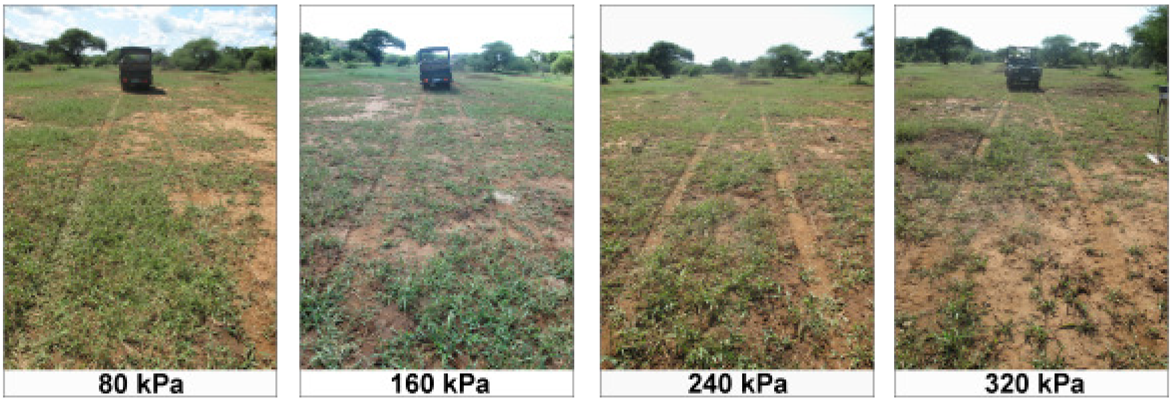


Figure 5.18 5th March 2010 - tracks and vegetation at Site 3, wet, immediately after driving at different tyre pressures

One year after driving, and after receiving 380.2 mm of rain, the soil was barren and dries (Fig. 5.19). This was caused by hot and dry weather of a few weeks' duration after the last rain. This is worse than the situation at the same site at the same time where driving was done on dry soil. Serious soil erosion is seen in some tracks at all tyre pressures.

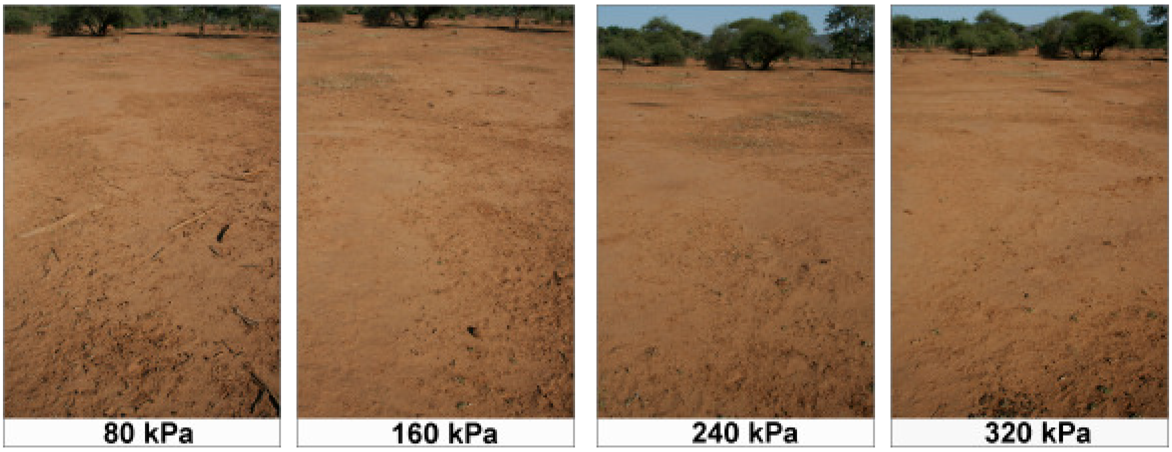


Figure 5.19 26th March 2011 - tracks and vegetation at Site 3, wet, at the end of one rainy season one year after driving and after receiving a total of 380.2 mm rain

Two years and two rains seasons, and after receiving 698.2 mm rain after driving, vegetation recovery was very poor at the experimental site, compared with the situation outside it, towards the top of the photos (Fig. 5.20). This is in contrast to where driving was done under dry conditions at this site (Fig. 5.17), indicating that doing ORD under wet soil conditions is more harmful than when it is done under dry conditions.

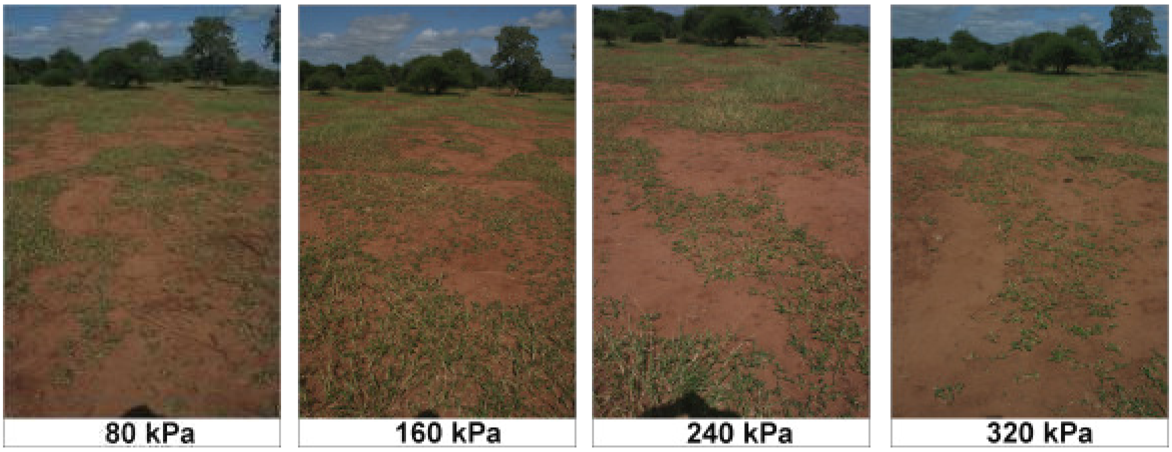


Figure 5.20 20th February 2012 - tracks and vegetation at Site 3, wet, after two years at the end of two rainy seasons after driving, receiving a total of 698.2 mm rain

The impact of the wheel traffic can be seen clearly, especially at 240 and 320 kPa tyre pressures. The width of the tyre impact is also striking, as well as the impact between tracks.

Like in some of the other cases the impact of the driving was much more pronounced and serious two years and two rain seasons after the driving was done than one year and one rainy season after it was done. This was triggered by inadequate vegetation recovery during the first season, thus predisposing the vegetation and soil to degradation during the next season.

General

Some patterns of huge importance emerged from the photographic recording of ORD over time (Figs. 5.3-5.20). No vegetation recovery has taken place at all three study sites even after two rain seasons. Partial recovery after one rainy season may be misleading. It may not mean increased recovery during the next season, but actually predispose the situation to very severe further degradation during the next season - and after that season even more so during a following season.

In Chapter 3 it was indicated that the directive allowing ORD mandates that "the activity may only be undertaken by trained professionals on soils which can accommodate this activity and under conditions which are not irreversibly (after or following the next 25 mm of rainfall) harmful to the ecology of the area, especially the plants and animals, and which will allow for a sustainable recovery of the impacted zone" (van der Merwe 2004). The lack of recovery after a lot of rain shows that this mandate cannot be met. The impact of ORD was more severe when driving on wet soil than when driving on dry soil, thus supporting the spirit of the guideline in Appendix A that: "Off-road driving is not permitted in wet conditions. A period of 24 hours must pass following rainfall of 10-20 mm". However, even driving on dry soil had serious negative impacts, leading to poor recovery over a substantial period of time. ORD is, therefore, not a sustainable practice and cannot be justified. As indicated in Chapter 4 the effects of soil crusting at Sites 1 and 3 surfaced in the photographs of these two sites. The soil crusting leads to poor water infiltration and induced drought conditions at the end of the first rainy season. It also led to water erosion on and around the tracks as is clearly indicated in the photographs (Figs. 5.4, 5.7, 5.20).

Soil crusting, as in the case of Sites 1 and 3, inhibits germination in four ways (Laker 2013, pers. comm):

- It causes the soil to be dry due to the poor infiltration of water. In arid areas like The Makuleke Contractual Park it has an extremely serious effect. Mills & Fey (2004) say the following with regards to crusting: "A crust on the soil surface need only be 0.1 mm wide to reduce the infiltration rate by a factor of 1800 (McIntyre 1958). Failure to account for the effect of crusting on infiltration can result in gross overestimation of water intake by the soil (McIntyre 1958; Hillel & Gardner 1969; Levy & Rapp 1999). This is especially true in arid areas, where high intensity rain events are the norm (Shainberg & Singer 1985)";
- Crusting causes poor aeration/gas exchange leading to build-up of carbon dioxide (CO_2) (which cannot escape) under the crust and a deficiency of oxygen (O_2) which cannot penetrate the soil. Mills & Fey (2004) again mentions the following with regards to this statement: "Besides reduced water infiltration, the strength and **oxygen-excluding** nature of crusts may impede root growth near the surface and **curtail germination** and growth of seedlings (Bristow 1988, Shainberg & Levy 1994; Hillel 1998)";
- The strength of the crust prevents the emergence of seedlings because the seedlings cannot break through the soil crust. Often the seeds germinate but die under the soil surface. Dicotyledons tend to break their necks trying to break through the soil crust.

The coleoptiles of most small-seeded monocotyledons, like most grasses, are too weak to break through a crust;

- The few seedlings that do emerge through the soil crust, scorch from the drought and die because 1) the soil is dry and 2) root growth is impeded by the poor aeration. Roots need to respire in order to grow. As a cause of this soil crusting and impeded respiration roots also cannot function physiologically. They cannot take up nutrients and water. As a consequence they cannot grow deeper in order to access water and if they reach the water they cannot take it up. This is the reason for the shrivelling of the vegetation after a few weeks of dry conditions combined with the warmer temperatures (Figs. 5.7, 5.10, 5.14, 5.16 and 5.19).

The degradation was enhanced during the following seasons and was aggravated by the ORD. The vehicle tyre impacts are much wider than just the width of the tyres and this can clearly be seen in most of the photos. The area inside the two tyre tracks as well as some distance outside of the tyre tracks is affected. This correlates well with what was found with actual ORD site monitoring over time in Chapter 3 (Fig. 3.7) and quantified in Chapter 4 (Section 4.4.2.2).

Although the impacts of ORD is during both dry and wet conditions as indicated in Chapter 4, and as can be seen in the above photographs, the impacts are much worse during wet conditions. Vegetation recovery after two years is much less in the case of the wet condition trials (soil wet when driving was done) (Figs. 5.8, 5.14 and 5.20), than during the conditions when the soil was dry when driving was done.

5.3.2 Root densities

Root density fractions, as indicators of root development, differed significantly between treatments (control and four tyre pressures applied) at all three sites where driving was done on dry soil (Table 5.1).

Table 5.1 Root density fraction statistics for Sites 1, 2 and 3

Soil	**Tyre pressure**	**Mean**	**Standard deviation**	**Minimum**	**Maximum**	**Range**	**LSD** (0.05 or 5% level)
	Control	2.3833	.10408	2.30	2.50	.20	
	80 kPa	.6000	.05000	.55	.65	.10	
1	160 kPa	.4600	.06000	.40	.52	.12	0.128
	240 kPa	.3167	.08021	.24	.40	.16	
	320 kPa	.1633	.05686	.10	.21	.11	
	Control	2.4200	.12530	2.30	2.55	.25	
	80 kPa	2.1200	.10817	2.00	2.21	.21	
2	160 kPa	1.3733	.07506	1.30	1.45	.15	0.152
	240 kPa	.3533	.05508	.30	.41	.11	
	320 kPa	.7667	.03512	.73	.80	.07	
	Control	3.6333	.20817	3.40	3.80	.40	
	80 kPa	2.2167	.12583	2.10	2.35	.25	
3	160 kPa	2.9033	.11240	2.78	3.00	.22	0.229
	240 kPa	.3500	.05568	.30	.41	.11	
	320 kPa	.2667	.06506	.20	.33	.13	

Site 1

As can be seen in Table 5.1, the root fraction percentage in the control was much (4.0 to 14.6 times) higher than under the wheel tracks at all tyre pressures used. The differences between the control and the four tyre pressures are statistically highly significant. There is a curvilinear negative relationship between tyre pressure used and root fraction percentage across the control and four tyre pressures. For the four tyre pressures alone there was a linear negative relationship between the root fraction percentage under the wheel tracks and tyre pressure. Root fraction percentage under the wheel tracks differed statistically significantly in the order 80 kPa>160 kPa>240 kPa>320 kPa. All the above are well illustrated in Fig. 5.21.

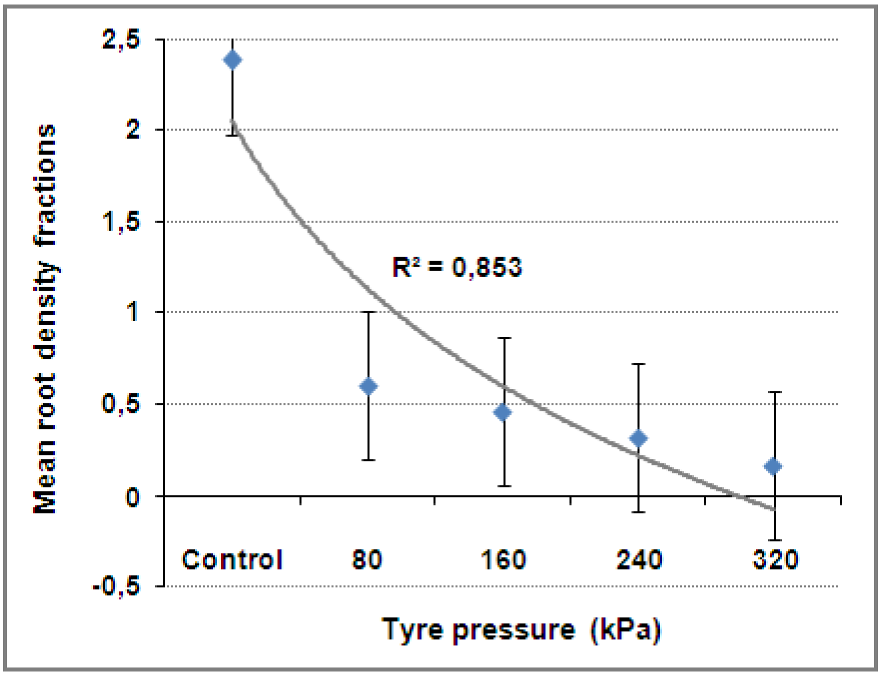


Figure 5.21 Root density fraction vs. tyre pressure for Site 1

Taylor *et al.* (1966) reported a similar curvilinear relationship between penetrometer soil strength and percentage of cotton taproots penetrating through cores of four soils. In a study by Greacen & Gerard (unpublished study reported in Greacen & Sands 1980) on the effects of soil strength on frequency of rooting of radiata pine, the authors also found a similar relationship as in this study.

The main reason for the large reduction in the root fraction percentage between the control and the areas under the tracks is that under the tracks the roots are limited to shallow depths, whereas in the control there is major root development at much larger depth (Fig. 5.22).

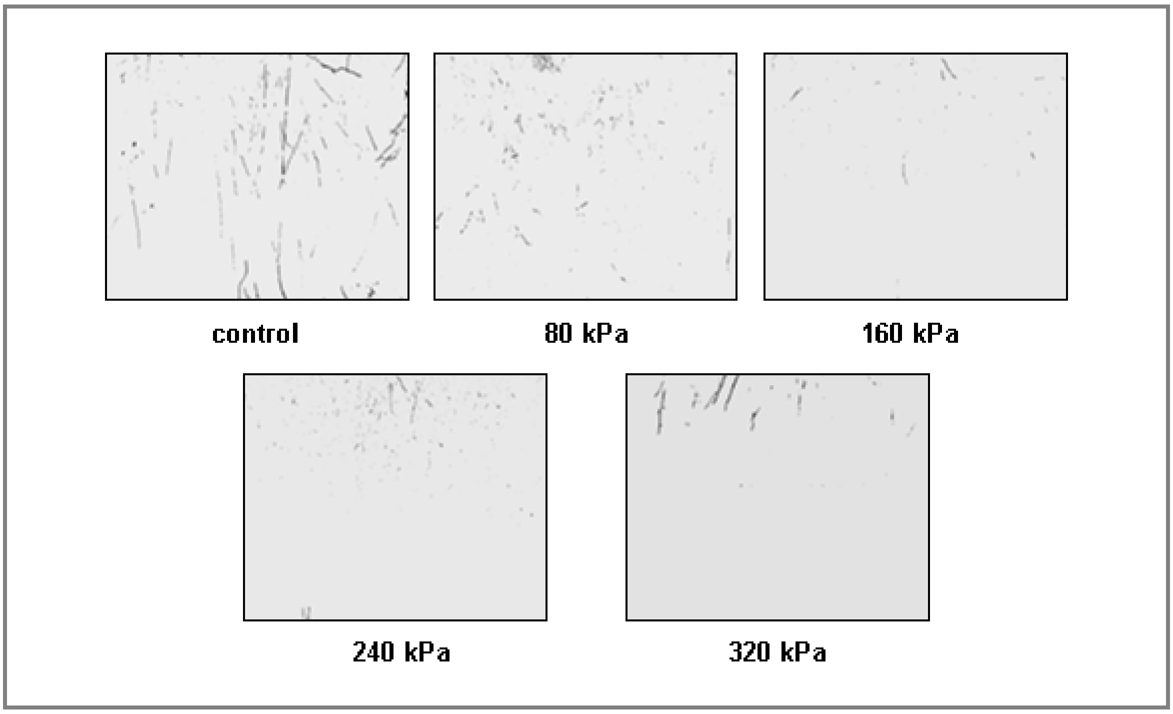


Figure 5.22 ImageJ images of root density distributions for Site 1

Site 2

A general linear decrease in root density fraction occurs with increased tyre pressure at Site 2 (Fig. 5.23). The differences between the control and the four tyre pressures are statistically significant (Table 5.1). The value for the control was similar to that for Site 1. The values at 80 and 160 kPa tyre pressures were much higher than for Site 1. The differences between 80 kPa and 160 kPa and between 160 kPa and 240 kPa (and 320 kPa) were large. The statistically significant differences between the root density fractions for the different tyre pressures were 80 kPa>160 kPa>320 kPa>240 kPa (note the reverse order of the latter two). The decrease between the control and 80 kPa is more gradual and not as big as with Site 1.

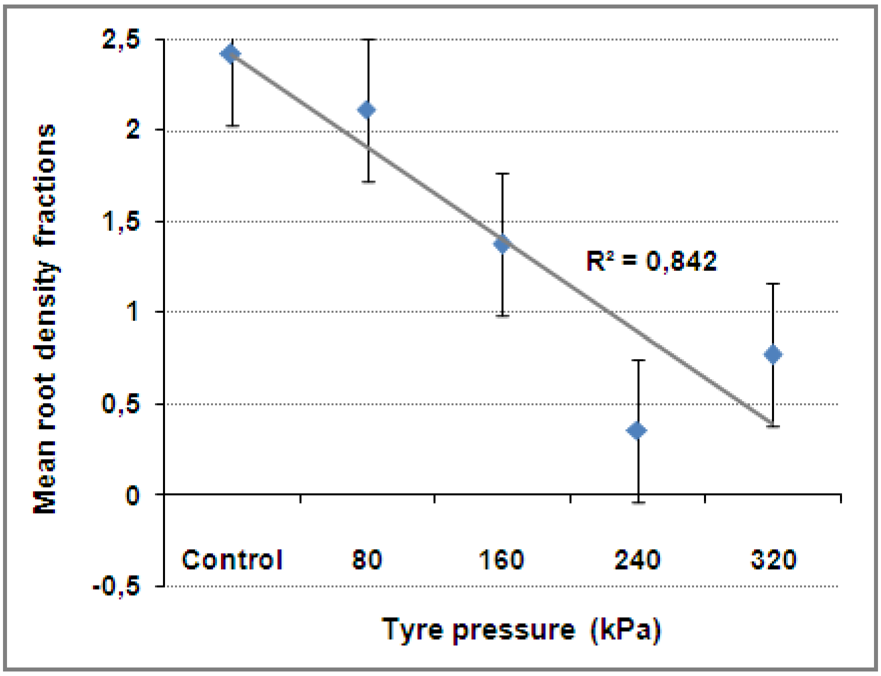


Figure 5.23 Root density fraction vs. tyre pressure Site 2

The best fit line for Site 2 is a linear relationship from the control right through to 320 kPa tyre pressure (Fig. 5.23). The points are positioned much closer to the calculated line, in contrast to Site 1 where a curvilinear relationship exists.

The root distribution is also limited to the top part of the soil profile (Fig. 5.24), but less so than in the case of Site 1.

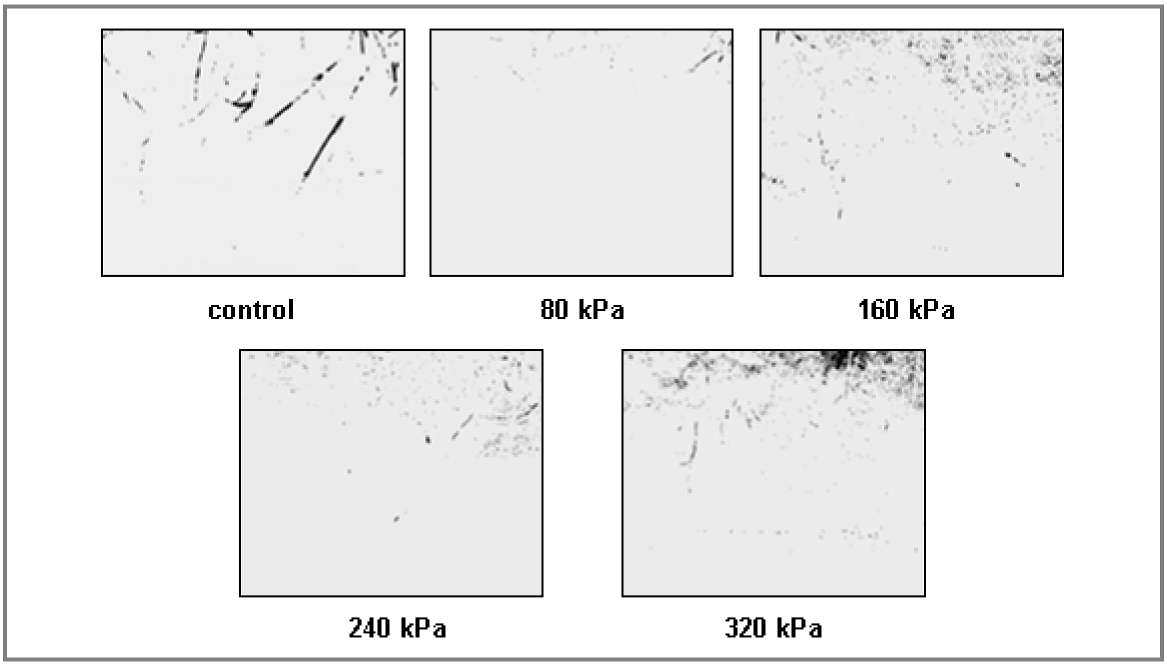


Figure 5.24 ImageJ images of root density distributions for Site 2

Site 3

A linear decrease in root density fraction occurs with Site 3, like in the case of Site 2 (Fig. 5.25). Like in the case of Sites 1 and 2, the differences between the control and all four tyre pressures are statistically highly significant. The statistically significant differences between the root density fractions for the different tyre pressures were in the order 160 kPa>80 kPa>240 kPa=320 kPa. For this soil the root density fractions for the control and at 160 kPa tyre pressure were higher than those for the controls of Sites 1 and 3. The value for 80 kPa tyre pressure was similar to those for the controls for Sites 1 and 2 and the 80 kPa value of Site 2. In contrast to the relatively high root density fractions at the two low tyre pressures, the values at the two high tyre pressures were very low, like for the two other soils.

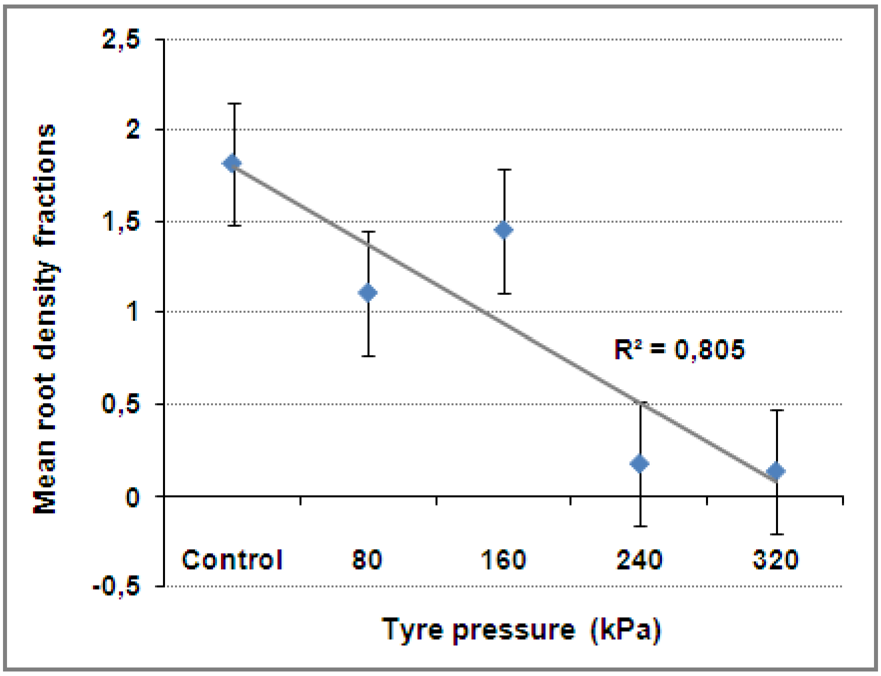


Figure 5.25 Root density fraction vs. tyre pressure for Site 3

The best fit line for Site 3 (Fig. 5.25) is also a linear relationship (due to the value at 160 kPa) as for Site 2. The regression coefficient in this case is weaker because the points are scattered wider from the calculated line. Taylor & Gardner (1963) showed a similar linear relationship as in Site 2 and 3, between root penetration and soil strength in a study of cotton seedling tap root penetration as influenced by soil water, bulk density and soil strength.

Like for Sites 1 and 2, the root distribution is also limited to the top part of the soil profile (Fig. 5.26). The very big differences between the control and lower tyre pressures on the one hand and the two higher tyre pressures on the other hand can be seen very clearly.

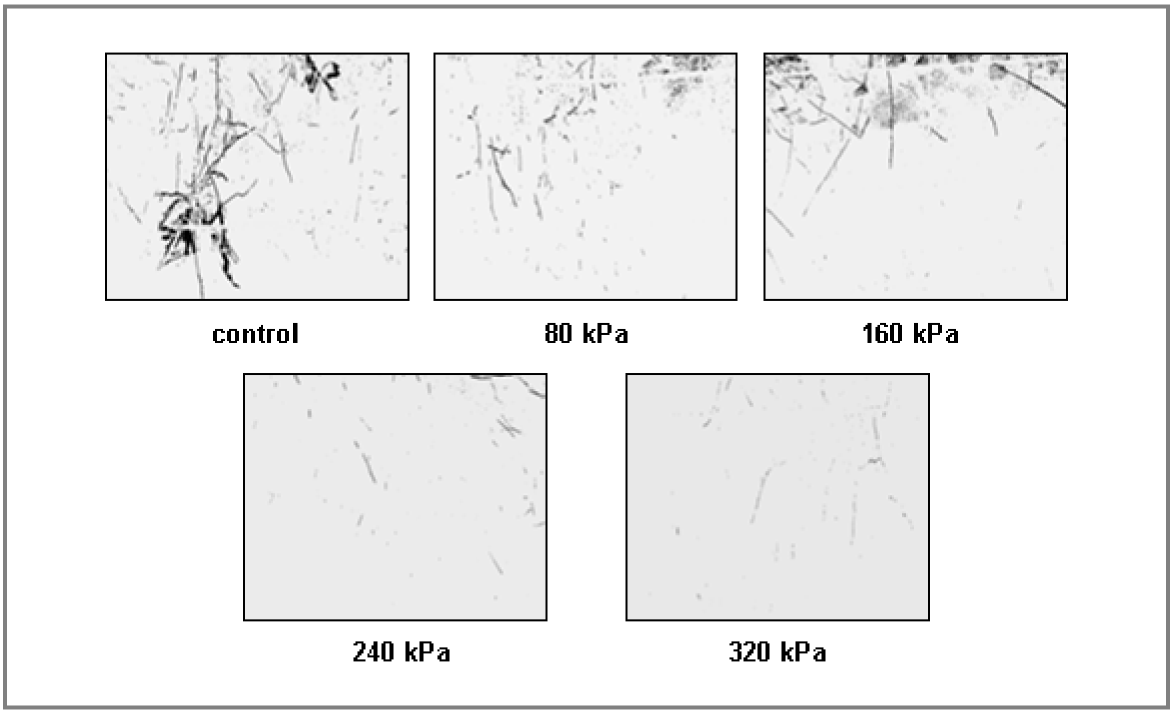


Figure 5.26 ImageJ images of root density distributions for Site 3

General

For all three soils the root density fractions for the controls were statistically significantly higher than under the tracks of all four tyre pressures. At the barren Site 1 the difference between the control and under the tracks was very big for all tyre pressures. At Sites 2 and 3, which had some vegetative cover, the effects at the two lower tyre pressures were not as damaging as at Site 1. At all three sites the two higher tyre pressures had very serious negative impacts on the root density fractions, irrespective of vegetative cover at the time of driving. These include the tyre pressure at which game drive vehicles normally operate (approximately 240 kPa). This correlates very well with the findings in Chapter 4 which indicated that the amount of soil compaction increased with increased tyre pressure.

As tyre pressure increased, the rooting depth decreased. This is clearly shown for all three sites in the profile photos (Figs. 5.22, 5.24 and 5.26), where most roots are limited to the top part of the soil profiles, most notably at the higher tyre pressures at Site 3. This correlates very well with the findings of Taylor *et al.* (1966), Bennie (1972), Burger *et al.* (1979) and Bennie & Burger (1979).

When comparing the root density fractions under the wheel tracks at all three sites during December 2010, three weeks after some rains, with the above-ground biomass at the three sites one year after the driving trials the following is seen:

- At Site 1 root densities were very low under the tracks at all four tyre pressures (Table 5.1 and Fig. 5.21). Likewise above ground vegetative growth was very poor at all tyre pressures, with large bare areas (Fig. 5.4);
- At Site 2, the root density fraction was relatively high under 80 kPa pressure, moderate at 160 kPa pressure and low at 240 and 320 kPa (Table 5.1 and Fig. 5.23). Above ground vegetative growth was clearly weaker, with larger bare areas, at 240 and 320 kPa tyre pressures than at 80 and 160 kPa (Fig. 5.11). There was thus some positive relationship between the above ground biomass and root density fraction at this site where there was more vegetative growth at the time of driving than at Site 1;
- At Site 3, where there was a fairly uniform vegetative cover at the time of driving (Fig. 5.15), there was also more vegetative growth one year after driving than at the other sites (Fig. 5.16), though in the form of dead grass. This was associated with much higher root densities at the lower tyre pressures (Table 5.1 and Fig. 5.25). However, above ground biomass was still fair at 240 and 320 kPa tyre pressure despite the lower root densities at these tyre pressures.

When looking at the average soil strength values at all three sites in the top- and subsoil, Site 1 and Site 3 had much higher soil strength values in the topsoil compared to the more sandy soil at Site 2, indicating the severe soil crusting at Site 1 and Site 3. In the subsoil the soils strength values are comparable (Chapter 4: Table 4.6, Figs. 4.5, 4.6 and 4.7). The transition of soil strength from the top- to the subsoil is very abrupt for Site 1, but for Sites 2 and 3 the transition is much more gradual. An abrupt transition in soil compaction is highly detrimental for root growth and penetration (Bennie 1972).

5.4 Conclusion

At all sites root density fraction under tracks was reduced statistically significantly at all tyre pressures, compared with the control values. Results indicated that root penetration percentage and, therefore root area distribution was reduced drastically as tyre pressure increased. This reaffirm previous research showing that higher tyre pressures cause higher sub-soil compaction than lower tyre pressures (SASTA 2001). As part of a management plan driving at low tyre pressures should be stipulated as a prerequisite when off-road guidelines are developed in cases where it is deemed impossible to forbid ORD completely. In view of the impacts found already at low pressures, especially in some situations, such as found at Site 1, the aim should be to forbid ORD, especially in vulnerable situations.

A very important conclusion of the above-mentioned trial results is the lack of recovery of above ground vegetative growth at all three trials sites, even after more than one season. An accompanying important finding is that the situation actually deteriorated with time due to increased predisposition of the soil and vegetative cover to progressive de-gradation.

The fact that roots are mostly limited to the top 15 cm of the soil profiles for all three soil sites correlates very well with the soil depth of 7 to 25 cm where severe crusting due to the vehicular traffic occurred for all soil sites (Chapter 4). This crusting has serious long lasting effects like inhibiting root growth (Laker & Vanassche 2001), germination and seedling emergence, the latter especially of small-seeded plants like grasses, and thus water- and nutrient uptake.

ORD during wet soil conditions are much more damaging and long lasting than driving off-road during dry soil conditions, but soil compaction occurs during both dry and wet soil conditions. All indications are thus that the practice of ORD is not sustainable from both a soil and biomass perspective. ORD damage due to sub-soil compaction is also much wider distributed outside and in-between the vehicle's tyres, than just below the vehicle tracks. "Controlled traffic" may be the only feasible solution for limiting damage to the soil and vegetation when driving off-road to some extent.

5.5 References

- Barley, K.P. & Greacen, E.L. (1967) Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. *Adv Agron*, 19, 1-43.
- Bekker, T.F. (2007) Efficacy of water soluble silicon for control of *Phytophtora cinnamomi* root rot of avocado. MSc thesis. Faculty of Natural and Agricultural Sciences, University of Pretoria.
- Bennie, A.T.P. (1972) 'n Ondersoek na sekere aspekte van grondsterkte in gronde van die manganoserie. MSc(Agric) thesis, Universiteit van die Oranje Vrystaat, Bloemfontein.

- Bennie, A.T.P. & Burger, R.d.T. (1979) Grondverdigting onder besproeiing op die Vaalharts besproeiingskema. Volume II: Die invloed van grondverdigting op die grond-plant sisteem. Dept. Grondkunde, Verslag, 79/2, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Bennie, A.T.P., Krynauw, G.N. (1985) Causes, adverse effects and control of soil compaction. *S Afr J Plant Soil*, 2, 109-114.
- Bohm, W. (1979) Methods of studying root systems. Volume 33. Springer-Verlag. Berlin, Heidelberg, New York.
- Bristow, K.L. (1988) The role of mulch and its architecture in modifying soil temperature. *Aust J Soil Res*,20, 269-281.
- Burger, R.d.T., Bennie, A.T.P., Botha, F.J.P. & du Preez, C.C. (1979) Grondverdigting onder besproeiing op die Vaalharts besproeiingskema. Volume I: Samevattende verslag, 79/1. Dept. Grondkunde, Universiteit van die Oranje Vrystaat, Bloemfontein, pp. 140.
- Du Preez, C.C., Bennie, A.T.P., Burger, R.d.T. (1979) Grondverdigting onder besproeiing op die Vaalharts besproeiingskema. Volume 3: Die oorsake en bekamping van verdigting van sanderige besproeiingsgronde, verslag 79/3. Departement Grondkunde, Universiteit van die Oranje Vrystaat, Bloemfontein.
- Du Preez, C.C., Bennie, A.T.P., Burger, R.d.T. (1981) Invloed van implementverkeer en besproeiing op grondverdigting te Vaalharts. *Agrochemophysica*, 13, 7-12.
- Greacen, E.L. & Sands, R. (1980) Compaction of forest soils: a review. *Aust J Soil Res*, 18, 163-189.
- Grunow, J.O. (1977) Dry matter production: grass layer. Savanna Ecosystem Project, Nylsvlei. Primary Producers Group.
- Hillel, D. (1998) Environmental Soil Physics, Academic Press, London.
- Hillel, D. & Gardner, W.R. (1969) Steady infiltration into crust-topped profiles. *Soil Sci*,108, 137-142.
- Laker, M.C. & Vanassche, F.M.G. (2001) Alleviation of soil crusting in a citrus orchard by means of a coal-derived humic product. Programme and Extended Abstracts, Joint Congr 2001, Pretoria January 2001, 265-266.
- Levy, G.J. & Rapp, I. (1999) Polymer effects on surface mechanical strength of a crusting loessial soil. *Aust J Soil Res*,37, 91-101.
- Martino, D.L. & Shaykewich, C.F. (1993) Root penetration profiles of wheat and barley as affected by soil penetration resistance in field conditions. *Can J Soil Sci*, 74, 193-200.

- McIntyre, D.S. (1958) Soil splash and the formation of surface crusts by raindrop impact. *Soil Sci*,85, 185-189.
- Mills, A.J. & Fey, M.V. (2004). Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. *S Afr J Plant Soil*, 21/5, 388-398.
- Plaza-Bonilla, D., Cantero-Martínez, C., Álvaro-Fuentes, J. & Castel, J.L. (2012) Low-cost image analysis method to quantify root surface area. Poster Session. International conference of agricultural engineering, July 8-12. Valencia, Spain.
- Rasband, W. (2011). ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, 1997-2011, (accessed: 2011) http://imagej.nih.gov/ij/.
- Schneider, C.A., Rasband, W.S., Eliceiri, K.W. (2012) NIH Image to ImageJ: 25 years of image analysis. *Nat Methods*, 9, 671-675.
- Shainberg, I. & Levy, G.J. (1994) Organic polymers and soil sealing in cultivated soils. *Soil Sci*,158, 267-273.
- Shainberg, I. & Singer, M.J. (1985) Effect of electrolytic concentration on the hydraulic properties of depositional crust. *Soil Sci Soc Am J*,49, 1260-1263.
- South African Sugar Technologist's Association (SASTA) (2001) Soil compaction work-shop proceedings, August 2001. CD-ROM. Mt Edgecombe, Durban.
- Taylor, H.M. & Gardner, H.R. (1963) Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. *Soil Sci*, 96, 153-156.
- Taylor, H.M., Roberson, G.M. & Parker, J.J. Jr (1966). Soil strength-root penetration relations for medium- to coarse-textured soil materials. *Soil Sci*, 102/1, 18-22.
- Unger, P.W. & Kaspar, T.C. (1994) Soil compaction and root growth: a review. *Agron J*, 86/5, 759-766.
- Van der Merwe, L. (2004) Guidelines for off-road driving in the private concessions of the Kruger National Park. Concessions Operations Manual, KNP.

SECTION C
EVALUATION OF TOURIST PERCEPTIONS AND POTENTIAL IMPACT THEREOF ON ESCALATING OFF-ROAD DRIVING

CHAPTER 6
INTRODUCTION AND REVIEW OF LITERATURE ON THE IMPACTS OF TOURISTS' PERCEPTIONS, EXPECTATIONS AND ATTITUDES ON THE ENVIRONMENT

6.1 Introduction

When considering the impacts of tourists on the natural environment it is not the number of tourists as such that counts, but the impacts that those tourists can have on the environment and the quality of the experience of other tourists (Morin *et al.* 1997). Game drive vehicles driving off-road to see certain species of animals is an activity in which tourists participate and which can have negative impacts on the environment. This activity is relatively new, but is an accepted way of showing tourists the 'Big Five' at close range in Africa's and South Africa's National Parks and Private Game Reserves (Bhandari 1998; Nortjé 2005).

It has been observed during game drive activities that there exists much ignorance amongst tourists regarding the negative environmental impacts of certain activities (Nortjé 2005). Studies on the physical impacts of off-road driving (ORD) on the natural environment has been referred to in Chapter 1, but no studies have apparently previously been done in South Africa or elsewhere in Africa and the rest of the world on how tourists' perceptions, expectations and attitudes influence the demand for and frequency of ORD.

This chapter will therefore focus on published studies with regards to tourists' perceptions of their impacts on the environment in general. Because people's perceptions influence their expectations and attitudes, and attitudes influence people's behaviour, all of these factors are discussed. Attention is also given to the identification of appropriate research methodologies, with special reference to the use of Likert-type scales as a rating scale in a visitor questionnaire.

6.2 Review of Literature

As the demand for outdoor recreation activities and tourist numbers in protected areas increase, protected area managers will need to develop policies which guide or restrict potentially harmful types of activities, such as off-road driving, in order to protect the natural resources of the area (Hornback & Eagels 1999). Proponents of eco-tourism often assume that their activities are environmentally friendly (Roe *et al.* 1997). This assumption is made because eco-tourism groups tend to be usually small and the tourists are interested in aspects of the environment (Roe *et al.* 1997). It is, therefore, assumed that these tourists respect the environment.

The fact that tourists have chosen an expensive wildlife-based holiday does not necessarily mean that they care about the long-term impacts of their visits. It is also noted that the environmental and social impacts of eco-tourism may be more significant than mass tourism, as eco-tourism usually occurs in pristine, undisturbed environments that are often ecologically fragile (Cochrane 1994). The *per capita* impact of eco-tourism can therefore be more than for mass tourism. Mass tourism is generally defined as the visit or travel to a destination with large numbers of people at any one time, whereas ecotourism involves smaller numbers of people (Wikipedia 2013a).

Various different definitions of eco-tourism exist and are currently in use, with the following definitions just a few of these:

- "Responsible travel to natural areas that conserves the environment and improves the well-being of local people" (TIES 1990);
- "Visits to national parks and other natural areas with the aim of viewing and enjoying the plants and animals as well as any indigenous culture" (Boo 1990);
- "An enlightening nature travel experience that contributes to the conservation of the ecosystem while respecting the integrity of host communities" (Cater & Lowman 1994);
- "Responsible travel to natural areas which conserves the environment and improves the welfare of local people" (Lindberg & Hawkins 1993);
- "Tourism that involves travelling to relatively undisturbed or uncontaminated natural areas with the specific objective of studying, admiring and enjoying the scenery and its wild plants and animals as well as any cultural aspects (both past and present) found in these areas" (Ceballos-Lascuráin 1993);

- "Tourism which is based upon relatively undisturbed natural environments, is non-degrading, is subject to an adequate management regime and is a direct contributor to the continued protection and management of the protected area used" (Valentine 1991);
- "Tourism that is environmentally sensitive" (Muloin 1991);
- "Purposeful travel that creates an understanding of cultural and natural history, while safeguarding the integrity of the ecosystem and producing economic benefits that encourage conservation" (Ryel & Grasse 1991);
- "Low impact nature tourism which contributes to the maintenance of species and habitats either directly through a contribution to conservation and/or indirectly by providing revenue to the local community sufficient for people to value, and therefore protect, their wildlife heritage area as source of income" (Goodwin 1996);
- "Ecologically sustainable tourism that fosters environmental and cultural understanding, appreciation and conservation" (Ecotourism Association of Australia 1992);
- "Ecotourism is nature-based tourism that involves education and interpretation of the natural environment and is managed to be ecologically sustainable" (Allcock *et al.* 1994; Tickell 1994);
- "Ecotourism is one of the forms of tourism developed in countries with natural and cultural potential of a universal value" (Cristureanu 2006).

Several definitions as mentioned above exist for eco-tourism, but eco-tourism has become widely known and understood as a generic term describing tourism that has as its primary purpose the interaction with nature and that it incorporates a desire to minimize negative impacts on the environment (Orams 1995). Inherent in the term is the assumption that local communities should benefit from tourism and will contribute to the conservation of the natural environment in the process (Goodwin 1996).

No definition of eco-tourism excludes the fact that the environment must sustain the tourists' recreational activities. "Sustain", meaning that the environment must not degrade beyond the point of recovery while continuing to allow for tourists' recreational activities. All definitions also stress that it must take place in natural areas. According to the Oxford Dictionary of Environment and Conservation (2001), a natural area is described as "an area identified as having significant or unique natural heritage features, with boundaries based upon the distribution of wildlife and of natural features rather than administrative borders". The most important part of the eco-tourism definitions indicate that it must be environmentally and culturally sensitive (meaning it must also respect the cultural historical/archaeological features of a natural area), and must directly benefit the environment both naturally and culturally (Goodwin 1996).

The following principles of eco-tourism should be adhered to (Sâmbotin *et al.* 2011):

- Focus should be on experiencing natural areas in ways that lead to greater understanding and appreciation of the natural area;
- Each activity/experience should integrate better understanding of natural areas;
- Each activity/experience should represent best practice for ecologically sustainable tourism;
- It must pro-actively contribute to the conservation of the natural area;
- It must provide sustainable contributions to local communities;
- It must be sensitive to and involve indigenous cultures in the management of eco-tourism;
- It must consistently meet customer/tourists' expectation;
- Marketing of the natural area should be accurate and lead to realistic expectation.

6.2.1 Tourists' perceptions

Visitors' perceptions were studied amongst others in the Valley of Butterflies protected area, Rhodes Island, Greece. In this study Spanou *et al.* (2012) pointed out the importance of visitor management for sustainable development of protected areas, as the presence of tourists may cause negative impacts on the wildlife and vegetation. The authors recognize that the perceptions and impacts of visitors are critically important for the decision-making and planning purposes. The study recorded the effects of perceptions of visitors on their impacts on the environment in this protected area. The study indicated that more education by means of more information for visitors to this protected area about the area's ecological and environmental values was needed. The study also concluded that not only should future visitors or tourists be informed and educated about the environmental value of this area, but the protection of this area could only be achieved through a combined effort of environmental management, education and integrated marketing of the special qualities of this area.

Priskin (2003) studied tourist perceptions of habitat degradation by Coastal Nature-based recreation in Western Australia. Results of this study indicated that nature-based tourists are aware of environmental impacts associated with certain activities, but to variable extents. Generally, visitors perceived these activities to be less harmful than they really are. This study found that demographic profiles of age, origin and level of education of visitors had more effect on perceptions than gender or income group. The study showed that individuals with higher levels of education, perceived impacts from most activities more harmful than less educated visitors (Priskin 2003). Higher level of education has been linked with higher environmental awareness (Lothian 2002). Impacts should be rated closer to the reality, and here higher levels of education plays a major role and tend to give an evaluation of impacts closer to the reality of the impact.

Hillery *et al.* (2001) found similar results as Noe *et al.* (1997) in a study of tourists' perceptions of environmental impact at 10 sites in central Australia. Tourists' perception of impact varied in degree. The majority identified relevant environmental threats (tourism, introduced species, etc.), while others suggested management options to address vehicle track spreading, which was a major impact identified Hillery *et al.* (2001). In general, environmental conditions were rated lower at sites suffering serious impacts, indicating that some tourists' have the ability to distinguish between sites with different vulnerabilities to impacts.

Hillery *et al.* (2001) pointed to the fact that previous studies by Cole (1987, 1989), Cole & Landres (1996), and Liddle (1975, 1988) showed that a growth in tourist use has led to an increase in negative environmental impacts for many types of impacts, including soil compaction, campsite proliferation and erosion, and plant damage. Previous studies on perceptions of the environmental impacts have often concluded that tourists are not very perceptive of their own effects on the visited natural areas, or that what they do notice are primarily the direct impacts of other tourists (Hillery *et al.* 2001). These findings indicate the danger of an egocentric (selfish) attitude by tourists towards environmental conservation

6.2.2 Tourists' attitudes

There are several publications in which information is given regarding findings on general attitudes of tourists to practices causing degradation versus their own egocentric wishes/ preferences to participate in such practices.

Probably the most important finding of the study by Priskin (2003) is that visitors are generally aware of impacts associated with their activities, but it does not mean that they will act in accordance with their opinions. Tourists may say that a specific activity is harmful to the environment, but that perception does not necessarily lead to responsible behaviour (Priskin 2003). Mitchell (1989) and Mihalić (2000) have shown that there is often a weak relationship between what people say and how they will act. However, the general tendency is that tourists, who are concerned about their impacts on the environment, are also those who would display more environmental friendly behaviour (Mitchell 1989; Mihalić 2000).

A study comparing tourists from three different nationalities in Turkey by Baysan (2001), found that differences in "environmental awareness" were more strongly associated with differences in nationality, than with educational levels and occupations. Some nationalities, like Germans, were more environmentally aware than for instance Russian and Turkish tourists. There were also national differences between their willingness to "pay" for environmental protection. The study of Baysan (2001) further shows that if the attitudes and environmental awareness of tourists in different market segments and nationalities are known, it is more likely that a balance between the environment and tourist satisfaction can be achieved. It shows that nationality should be taken into account when developing marketing strategies which seek to achieve such a balance.

Park users' and tourists' tolerance of impacts on the environment varies Noe *et al.* (1997). The study, carried out in three National Parks in the United States, found that there are different degrees of acceptability and unacceptability of negative environmental impacts between different tourists. There are also margins of relative differences between different groups of tourists in the way that they respond to specific impacts on the environment. What is also important is that some of the respondents showed "no tolerance" to any degree of impact for situations such as littering, erosion, development, and traffic congestion.

According to Ivy *et al*. (1998), cited in Papageorgiou (2001), environmental awareness is crucial to produce a proper attitude towards the environment. The study by Spanou *et al*. (2012) showed that a lack of knowledge of the protected area reduced the probability that visitors were satisfied by their experience. Environmental education and improved information with regards to degradation caused by nature-based activities are therefore crucial to change their perceptions in order to create a positive attitude towards the environment, as the study by Priskin (2003) indicated. Hillery *et al.* (2001) stated: "In one sense, tourists to natural areas present a potential paradox. They see tourism as a threat, and yet they want to be able to visit such natural areas". They stated that future research should try focus on the quantification of responses to specific environmental issues.

In China, a study was conducted to analyse the relationship between environmental attitudes and behaviour of tourists in Natural Heritage Sites (Qi *et al.* 2008). The study showed that the environmental attitudes of tourists can be divided into four categories namely environmental affection, environmental responsibility, environmental knowledge and environmental morality. Environmental responsibility reflects tourists' attitudes towards environmental protection against tourism exploitation and development. Results showed that there is a relationship between various dimensions of environmental attitudes and behaviour. Environmental affection and knowledge had significant and positive influences on environmental behaviour of tourists. This finding is important as it indicates that education could work in changing tourists' attitudes and behaviour towards their impacts on the environment. Environmental morality (Definition: "An ecological conscience or moral that reflects a commitment and responsibility toward the environment, including plants and animals, as well as present and future generations of people, oriented toward human societies living in harmony with the natural world on which they depend for survival and well being", EIONET GEMET Thesaurus) also had a significant influence.

A study of the awareness and knowledge of skiers from three different countries, conducted in the Canadian Rockies (Hudson & Ritchie 2001), found a general lack of knowledge among skiers about environmental issues pertaining to skiing. However, skiers stated they would be more inclined to visit a resort that is environmentally responsible. So, knowledge is not the most important in people's attitude towards the environment, but environmental awareness is. Results of the study also showed a strong correlation between level of income and level of environmental conscience. This indicates that higher income people are also the group of people with a higher environmental awareness, which again lead to better behaviour towards the environment.

In a study of tourists' attitudes towards the environmental, social and managerial attributes of The Serengeti National Park in Tanzania, the tourists reported a high degree of satisfaction with most aspects of their trip (Kaltenborn *et al.* 2011). Yet, the current tourists are concerned about possible future changes that could alter the visitor environment and idealized images of the African wild lands. This indicates that these tourists may be more concerned about other tourists' impacts than their own. Basic environmental attitudes (degrees of ecocentrism) influence attitudes toward management of the park. Tourists expressing a high degree of ecocentrism are on the one hand more likely to support management actions aimed at controlling tourism activities, access and impacts. On the other hand they also express a stronger interest in experiencing nature, wilderness and local culture. These attitudes contradict each other as the tourists that say that they care for the environment are also those that most want to experience all the activities that could harm the environment. Since they are more likely to support conservation and be more opposed to exploitive and consumptive resource use, they will probably be more likely to be more receptive to information aimed at influencing visitor behaviour in environmentally friendly directions (Kaltenborn *et al.* 2011).

It is often the finding in tourism studies that visitors are quite content with the current conditions and they do not perceive much environmental impact from their own level of activity, but they are concerned about future changes (Mowforth & Munt 2005). These findings agree well with the above-mentioned study results of Kaltenborn *et al.* (2011). Akama (1996) showed that tourists were mainly concerned with aspects that would make their experience better. This means that if a specific tourist's activity is perceived to be negative on the environment but contributes to a better experience by the tourists, they could support the activity. These results correlate well with the findings of Mowforth & Munt 2005; Kalteborn *et al*. 2011).

Tourists' attitudes towards biodiversity, its economic value and the tourists' awareness for biodiversity conservation were studied by Martin-Lopez *et al.* (2007), in the Donana National and Natural Park, SW Spain. What were specifically important were the tourists' attitudes and behaviour towards animal species, but also vegetation. The results indicated a strong correlation between individual tourists' attitudes towards particular species of animals, and their related willingness to pay for their conservation. The study showed that tourists were more interested in animals than plants. The results showed that when people feel or experience a connection or relationship (biophilic factor) between them and the specific species, they are more willing to pay for its conservation.

The perceptions of two groups of visitors regarding specific park-related issues were measured in a study in Vikos-Aoos National Park (Papageorgiou 2001). The results suggest a superficial (artificial, insincere) knowledge of certain concepts. In other words the visitors have a general knowledge but not specialized knowledge with regards to Park regulations and the impacts of visitor activities. Thus knowledge-raising efforts would be required for establishing a positive attitude for resource conservation.

6.2.3 Tourists' travel and "other" motivations

Identifying travel motivations of different tourists visiting a specific protected area can be very useful in strategic planning of services and activities provided by the protected area hosting to the tourists (Beh & Bruyere 2007). Motives, positive or negative, are the result of a combination of perspectives, social influences and expectations and it is important to look at how these factors influence motives.

Onyeanusi (1986) stated that tourists to the Masai Mara National Reserve in Kenya are not only interested in the abundance and quality of the wildlife, but also in the natural state of the landscape. He mentioned that off-road driving tracks created by uncontrolled driving in the Reserve constitute a management problem, not because it destroys the natural state of the Reserve, but because the negative aesthetic impact of the tracks can be seen as a problem that creates a negative reaction in tourists.

Market segmentation is essential for the effective marketing of a tourism product or destination (Saayman & Slabbert 2004). Benefits of market segmentation as pointed out by Saayman & Slabbert (2004) include:

- Long-term relationships can be formed with tourists who are brand loyal (Nickels & Wood 1997);
- Segmentation can help guide the proper allocation and use of marketing resources (Strydom *et al.* 2000; Semenik 2000);
- The marketing message can be very specific;
- Long-term growth can be secured by understanding each tourist market as an individual group of tourists with their distinct cultural make-up (Reisinger & Turner 1998).

In order to adequately address tourists' needs it is important to understand the motivation of different kinds of visitors. This was studied in three Kenyan National Reserves by Beh & Bruyere (2007). Understanding of tourists' motivations will help in drafting a sustainable tourism strategy. A principle component analysis of the visitors revealed eight different motivation factors, and three distinct visitor segments. The three segments included: Escapists, learners and spiritualists. Understanding the differences between these visitor segments will help management to better provide alternative activities and services to tourists. However, each reserve is unique and a collaborative effort is necessary to identify the reserve-specific approaches available to meet the goal of delivering a service to tourists which will satisfy those (Beh & Bruyere 2007).

The study by Beh & Bruyere (2007) concluded that when deciding to develop any new tourism-based activities, it should be done in consultation with the local communities and stakeholders, in order to ensure that the proposed activities are culturally and socially acceptable. But what if the local communities' main focus is money? Then it creates a management problem. Simply because tourists have a specific motivation is not enough reason to create new tourist activities. Those new activities should be culturally, economically and ecologically acceptable. The study also recommended that training of the ranger corps and guides is essential since they are the front line in educating tourists about the environment and sustainable management of the reserves. The development of a competent and knowledgeable reserve staff through formal training exercises has proven useful in other international protected areas (Jacobsen & Robles 1992; Negi, 1997; Roche 2010, pers. comm).

Currently, the ecological integrity, naturalness and attractiveness of the Amboseli and Mara conservation areas in Kenya are being damaged by tourist use (Roselyne & Urmilla 2009). They emphasized the need for strict management of eco-tourism activities to ensure that eco-tourisms' negative impacts on the environment are minimal. They also emphasized the need for managers of eco-tourism in protected areas to develop regional or reserve-specific strategies and to use an integrated approach in directing and controlling socio-cultural and environmental impacts. They also stressed that eco-tourism planners should collaborate with all role players for sustainable development to be successful.

In a study in Kenya on the influence of western environmental values on nature-based tourism, it was concluded that policy and institutional mechanisms need to be put in place which encourage local participation in the design, implementation and management of tourism activities (Akama 1996). It also suggests that education alone will not solve the problem of environmental impacts by tourism, but that it must be combined with regulations which can be enforced. Local communities should be empowered to decide what forms of tourism activities and developments should be allowed in their respective communities, taking into consideration the potential negative impacts of some activities, including eventual negative economic impacts (Akama 1996).

An important result of the study by Akama (1996) was that tourists, operators and regulators had similar concerns with what they perceived to be high numbers of tourists and vehicles in the Mara and Amboseli reserves. I would have expected them to be different. For example, I would expect that tourists would not like high numbers, whereas operators would like to do more business and thus prefer higher numbers. Regulators would be expected to prefer the highest possible numbers that are not harmful.

6.2.4 Tourists' behaviour

Visitor behaviour is the end-product of a complex interaction of the above-mentioned factors of perspectives, social influences, motives, perceptions and attitudes. In practice, this means that if your perspectives are negative, behaviour will be negative, and if your perspectives are positive, the end product or behaviour will also be positive.

Muthee (1992) investigated the behaviour of tourists when watching the large predators in the Masai Mara National Reserve. Certain regulations were distributed to all tourists when entering the Reserve in an attempt to control visitor behaviour in the Reserve. Violation of the regulations was recorded. Infringements of these regulations carry a large fine, although rarely applied. Results from watching visitors during game drives indicated that regulations were observed to varying degrees. Out of a total of 251 records, tourists observed all regulations in only 17 cases (6.8%). This means that regulations were not observed in over 90% of cases. Three of the regulations broken most often were, spending too much time at an animal sighting, driving too close to the animals and driving off-road. Results also showed that when officers of the Animal and Habitat Protection Unit, AHPU, were present at these incidents, it influenced the behaviour of the tourists. In cases where the unit was present, there were no incidences of the above-mentioned regulation breakages.

The above-mentioned results could point to the fact that tourists to this Reserve only agree with regulations which protect the environment when they are watched by law enforcing officials and feared being penalized. When not watched they do not care about breaking the rules. It suggests that the environmental morality of these surveyed tourists is in question. It has serious consequences for environmental protection if these tourists represent most tourists to wildlife protected areas. It also points to possible discrepancies between what tourists may say and how they are prepared to act. Again it becomes clear that there is a tendency that tourists to natural protected areas are egocentric, and their actions or behaviour do not agree with their opinions with regards to conservation of the environment.

Testing visitor perceptions on the roles of tour guides in educating visitors by means of interpreting and modelling environmentally appropriate behaviours, has indicated that visitors rated five of the six roles determined for tour guides high in importance (Randall & Rollins 2009). They rated the role of communication low in importance. The five roles which received high importance were instrumental, social, interaction, motivator of responsible behaviour, and environmental interpreter. Variability in importance ratings for each of these dimensions suggests that some individuals would not place high importance on these roles, suggesting that market segmentation should be explored in future studies to determine which segments desires each of the tour guides roles. The reason why "communication" as a role is not that important is not well understood, but the results indicated to the fact that tour guides could play a very important role in communicating important conservation messages - especially as motivator of responsible behaviour and interpreter of environmental issues - to tourists (Randall & Rollins 2009).

In their study of Hervey Bay, Coastal Queensland, in Australia, Peake *et al.* (2009) focused on the effectiveness of conservation messages and education by tour guides to tourists, in addressing tourists' perceptions and changing their behaviour with regards to the environment. Results in this study pointed to a three-level effect: a) individual characteristics such as the age and sex of the respondent, b) impact of conservation-related information from the guide which acts as stimulus to c) visitor empowerment. Point c) is the most crucial level of visitor influence (Peake *et al.* 2009). The process basically involves the guide suggesting positive conservation action that translates into a feeling of responsibility by the visitor, and eventually higher levels of satisfaction. All of the above-mentioned factors drive effective communication and education of conservation messages.

6.2.5 Indicators and standards for visitor impacts/Carrying-capacity

Morin *et al.* (1997) conducted a study where they defined indicators and standards for recreation impacts in Nuyts Wilderness, Walpole-Nornalup National Park, Western Australia. Visitors were satisfied with their most recent visit during the study period.

Tourists visiting Nuyts were more concerned about biophysical rather than social impacts. Litter was a sensitive issue for all visitors. Other issues which visitors experienced as negative were vegetation loss and damage to trees. Erosion was also a concern. Visitors were supportive of a broad range of management actions, from education through closure of areas and other limits on use. The fact that the visitors were concerned about biophysical impacts is reassuring. But, because of the results of the above-mentioned research where the egocentric nature of tourists were pointed out, tourism operators must be careful in thinking that tourists really do care about their own impacts on the environment.

The study by Morin *et al.* (1997) identified impacts and visitors' preferences regarding the level of impact and mitigating management actions. The study also provided indicators and standards potentially relevant to other Parks. Similar indicators and standards are also needed for other forms of recreational use, like off-road driving. Monitoring recreation impacts eventually needs placing in a broader monitoring program directed towards ecological sustainability. Morin *et al.* (1997) further found that recreation monitoring alone is insufficient, given that impacts acceptable to visitors may not be ecologically sustainable in the longer term. The authors found that research is needed to determine visitor tolerances towards management actions. For example, it is generally assumed that educational strategies in natural environments will be widely supported, while strategies based on limiting use, may be opposed. If the latter is the case, then again it points to possible visitor egocentrism in supporting their recreation enjoyment at the cost of the environment. Surveys should be conducted to determine visitor acceptance towards various management actions.

To develop a planning framework which includes and balances the aspects of recreation, conservation and economic benefits to the local communities is difficult. Papageorgiou & Brotherton (1999) conducted a study in the Vikos-Aoos National Park, in Greece attempting to develop such a management planning framework. The application of the planning framework to Vikos-Aoos Park represents a first attempt to account for the social aspects of Park management. By applying the concept of carrying capacity, i.e. social,- ecological and economic sustainability to the planning framework, by zonation of the specific protected area, and spreading of the visitors' impact to other less used zones could help park managers to alleviate pressure on the heavily used zones, and building education and information services away from sensitive spots. This could spread visitor pressure across the Park and allow for an increase in visitor numbers up to a level where economic targets are fulfilled.

To be able to implement the above-mentioned planning framework, it is essential to gain a thorough knowledge about visitors' impacts on the biological systems, population sizes of target animal species, and bird fauna, and the level of concern, Park visitors have for various aspects of the resource and social setting (Papageorgiou & Brotherton 1999).

Papageorgiou (2001) tried to develop a draft management framework based on regulatory and behavioural strategies and suggests education as a tool to achieve conservation objectives. Currently, the management of human-wildlife interactions is dominated by regulatory strategies, but considerable potential exists for environmental education to enhance knowledge and achieve a change in attitudes with regards to human impacts on the environment. A combination of regulation and education should be the best tool for managing environmental impacts. This study of Papageorgiou (2001) proposed such a framework for conservation based on both approaches.

Hornback & Eagles (1999) determined guidelines for public use measurement and reporting at parks and protected areas, and came up with the following major uses of tourist' visitation data:

- General management
- Natural Resource protection
- Maintenance operations
- Visitor services and protection

This study suggests that without specific tourist information with regards to their environmental beliefs, perceptions, and attitudes, the sustainable management of protected areas is not possible.

Spenceley (2005) developed a Sustainability Nature-Based Assessment Toolkit, SUNTAT, for assessing environmental factors which contribute to sustainable tourism for South Africa. The toolkit does not assess tourism enterprises as "sustainable" or "unsustainable", but rather appreciates the complexity of sustainable development as a goal which tourism should strive to achieve (Spenceley 2005). Tourism enterprises need information in order to develop environmental "Best-Practice". Information in this regard can be obtained from literature like, "Responsible tourism manual in South Africa" (Spenceley 2003), and International sources such as "Conservation International - Tour operator initiative: a practical guide to good practise" (Sweeting & Sweeting 2003). It must be emphasized that in order for tourism to be sustainable, the ecological, economic as well as cultural aspects of sustainability must be adhered too.

By using the toolkit, researchers may now go beyond just defining sustainable tourism, and begin to measure its characteristics in a reliable and comparable manner. By developing a database of economic, environmental and social benchmarks relevant to sustainability, the SUNTAT may be used as a mechanism for the tourism industry to develop baseline standards and improve the level of performance by tourism enterprises (Spenceley 2005).

A new concept of management frameworks for sustainable tourism came to the author's attention, recently. One such framework, known as "The limits of acceptable change", LAC, deals with recreational carrying capacity, i.e. how much use can or should an area be allowed to tolerate (McCool 1996)? The framework sets measurable standards for managing recreation in natural areas. It provides a process for deciding what environmental and social conditions are acceptable and identifies management actions to achieve these conditions. The key focus is "how much change is acceptable?"

LAC was developed by USDA Forest Service's researchers to manage increasing levels of recreational use in wilderness areas and associated environmental consequences (McCool 1996). It was developed because the prevalent approach at that time, biophysical carrying capacity had no ability to set limits. But, LAC derived standards have been implemented in a comparatively small number of mainly wilderness situations in the USA. Interest in application is growing, particularly in Australia and New Zealand (although not fully implemented). LAC was therefore developed for people's impacts at places like picnic sites, white water rafting etc.

The underlying principles of the "The limits of acceptable change", LAC, are, as concluded from the literature of McCool (1996), Krumpe & Stokes (1994), and Stankey *et al.* (1984):

- That degradation of the natural environment in recreational areas due to human impact is inevitable and thus must be accepted as a given,
- That there is a limit beyond which degradation of the environment due to this human-induced degradation is not acceptable - the question is who determines this limit for a specific case? Degradation beyond this limit cannot be tolerated and the state of the environment must be arrested when it is in this condition. There does not seem to be

any attention regarding a pre-permissible rate of degradation towards the reaching of this point?

But McCool (1996) says the following: "research has shown that many problems of recreational use were a function not so much of numbers of people, but their behaviour". With regards to LAC a very important flaw which is not addressed in the concept could be identified. The flaw relates to the fact that LAC does not take into account the very important concept of "resilience" (the potential/ability to recover to the original state) or "sustainability". The importance of resilience has already been discussed in pervious chapters in this thesis. In certain situations by the time the fourth point in the LAC logic process according to Cole (1987) is reached, the damage can already be irreversible or will take very long to recover.

6.2.6 Likert-type scales as a scale of measurement in visitor's questionnaire

"A Likert-scale is a psychometric scale commonly involved in research that employs questionnaires" (Wikipedia 2013b). It is the most widely used approach to scaling responses in survey research, such that the term is often used interchangeably with "rating scale", or more accurately, the "Likert-type scale", even though the two are not synonymous. The scale is named after its inventor, Rensis Likert (Likert 1932).

"Likert's scale involved a scale proper, which emerges from collective responses to a set of items (usually eight or more). When responding to a Likert questionnaire item, respondents specify their level of agreement or disagreement on a symmetric agree/ disagree scale for a series of statements. Thus, the range captures the intensity of their feelings for a given item. All items are considered to be parallel instruments" (Wikipedia 2013b).

Likert-type scales are used to quantify results and obtain shades of perceptions. Choices or categories of responses usually range from strongly disagree to strongly agree (Simon, 2011). Likert-type scales are assumed to have equal units as the categories move from most negative to most positive. This allows measurement of attitudes, beliefs, and perceptions, and provides a means of quantifying the data (Simon 2011).

Because the above-mentioned research indicated that in general the differences in tourist's perceptions and attitudes can be related to differences in nationality, age groups and income levels, it is very important to include in any questionnaire focused on tourists to a protected area, the demographic profiles, and motives for visiting a specific area (Saayman & Slabbert 2004). The preferred leisure activities and motives of tourists for visiting the Kruger National Park for example include game viewing, travel and reading, viewing of wildlife, enjoying nature and the wilderness experience (Saayman & Slabbert 2004).

6.3 Conclusion

The place to start addressing the issues of increasing demands for outdoor recreation, including demands for off-road driving, is with a detailed and methodical understanding of tourists' attitudes. Research has shown that environmental attitudes and knowledge about one's own negative environmental impacts are critical in mitigating such impacts. Understanding tourists' views, perceptions and attitudes towards the environment and especially their own impacts on the environment can only come from a well-planned scientifically designed tourist survey and questionnaire. Attitude is everything, and if the attitudes of tourists can be changed, their behaviour could also be changed.

Tourists' attitudes towards the environment influence their behaviour directly, albeit positive or negative. The common-sense mitigating approach will then be to change visitors' attitudes towards the environment and their impacts on it. This can only be done through education programs, appropriate regulation and positive communication of conservation messages, as the literature review indicated. Because perceptions have been formed over long periods of time and people's previous experiences, any good education program should attempt to change people's attitudes, and eventually change the tourists' perceptions with regards to their impacts on the environment. The literature indicated that this approach could be successful.

Results of the literature review indicated that tourists in general have a superficial understanding of the natural environment and their impacts on it. But they do understand negative impacts when they can see it. Results also indicated to a general lack of knowledge towards the environment and impacts on the environment. This general lack of knowledge is because of ignorance. An educational program focussed on training and educating the guide's corps, but also the tourists should go far in changing perceptions, and eventually demands for certain recreation activities, and thus the negative impacts of them.

A very important conclusion coming out of the literature review is that discrepancies/ contradictions between what tourists say and how they are prepared to act exist for most studies. Tourists say that they care about negative impacts on the environment, but when they need to choose whether these impacts should be controlled, they acted differently. Tourists also are egoistically orientated and tend to care about the impacts of other tourists (instead of their own) on the environment which could influence their own recreational activities in the future. Hillery *et al.* (2001) stated it clearly: "In one sense, tourists to natural areas present a potential paradox. They see tourism as a threat, and yet they want to be able to visit such natural areas".

Sufficient standards and indicators of environmental impacts by tourists' activities should be developed for each individual protected area. The idea should be to find a balance between tourists' impacts and the conservation of the natural resources - ecological, cultural and social sustainability. Therefore, all role-players need to be involved in the development of sustainable Park-specific management plans, i.e. local population, tourism operator, government as well as the tourists. A questionnaire using Likert-type scales as tool for measuring tourists' perceptions and attitudes, and for quantifying them together with tourists demographics were shown to be sufficient.

6.4 References

- Akama, J.S. (1996) Western environmental values and nature-based tourism in Kenya, *Tourism Manage*, 17/8, 567-574.
- Allcock, A., Jones, B., Lane, S. & Grant, J. (1994) *National ecotourism strategy*. Commonwealth Department of Tourism. Australia Government Publishing Service, Canberra.
- Baysan, S. (2001) Perceptions of the environmental impacts of tourism: a comparative study of the attitudes of German, Russian and Turkish tourists in Kemer, Antalya. *Tourism Geogr*, 3/2, 218-235.
- Beh, A. & Bruyere, B.L. (2007) Segmentation by visitor motivation in three Kenyan National Reserves. *Tourism Manage*, 28, 1464-1471.
- Bhandari, M. (1998) Assessing the impact of off-road driving on the Masai Mara National Reserve and adjoining areas, Kenya. International Institute for Aerospace and Earth Sciences (ITC), The Netherlands.
- Boo, E. (1990) Eco-tourism: the potentials and pitfalls. Vol. I & II World Wildlife Fund, Washington D.C.

- Cater, E., & Lowman, G. (Eds.) (1994) Eco-tourism: a sustainable option? John Wiley & Sons Ltd, Chichester, England.
- Ceballos-Lascuráin, H. (1993) Eco-tourism as a worldwide phenomenon. In: *Eco-tourism: a guide for planners and managers* (ed: Lindberg, K. & and Hawkins, D.E.). The Ecotourism Society, North Bennington, Vermont. 12-14.
- Cochrane, J. (1994) Ecotourism surveys. Expedition Advisory Centre, Royal Geographical Society, London.
- Cole, D.N. (1987) Research on soil and vegetation in wilderness: a state-of-knowledge review. Issues, state-of-knowledge, future directions; *PNat Wildn Res Conf*. General Technical Report INT-220. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah, 135-177.
- Cole, D.N. (1989) Recreation ecology: what we know, what geographers can contribute. *Prof Geogr*, 41/2, 143-148.
- Cole, D.N. & Landres, P. B. (1996) Threats to wilderness ecosystems: impacts and research needs. *Ecol Appl*, 6/1, 168-184.
- Cristureanu, C. (2006) Strategies and transactions into the international tourism. C. H. Beck Publishing House, Bucharest, pp. 163.
- Ecotourism Association of Australia (1992) Newsletter, 1, pp. 2.
- EIONET GEMET Thesaurus (2013). Environmental ethics: (accessed: 29th March 2013) http://www.eionet.europa.eu/gemet/concept?ns=1&cp=2818.
- Goodwin, H.J. (1996) In pursuit of ecotourism. *Biodivers Conserv*,5, 277-291.
- Hillery, M., Nancarrow, B., Griffin, G. & Syme, G. (2001) Tourist perception of environmental impact. *Ann Tourism Res*, 28/4, 853-867.
- Hornback, K.E. & Eagles, P.F.J. (1999) Guidelines for public use measurement and reporting at parks and protected areas. IUCN, Gland, Switserland and Cambridge, UK. iv 90+ pp.
- Hudson, S. & Ritchie, B. (2001) Cross-cultural tourist behaviour: an analysis of tourist attitudes towards the environment. *J Trav Tourism Market*, 10/2, 1-22.
- Ivy, T.G.C., Lee, C.K.E & Chuan, G.K. (1998) A survey of environmental knowledge, attitudes and behaviour of students in Singapore. *Int Res Geogr Environ Educ*, 7, 181-202.
- Jacobsen, S.K. & Robles, R. (1992) Ecotourism, sustainable development, and conservation education: development of a tour guide training program in Tortuguero, Costa Rica. *Environ Manage*, 16/6, 701-713.

- Kaltenborn, B.P., Nyahongo, J.W. & Kideghesho, J.R. (2011) The attitudes of tourists towards the environmental, social and managerial attributes of Serengeti National Park, Tanzania. *Trop Conserv Sci*, 4/2, 132-148.
- Krumpe, E.E. & Stokes, G.L. (1994) Application of the limits of acceptable change planning process in United States Forest Service Wilderness Management. In: *Proceedings, 5th World Wilderness Congress Symposium on International Wilderness Allocation, Management and Research*, September 1993. Tromsø, Norway. International Wilderness Leadership Foundation, Fort Collins, Colorado, pp. 8.
- Liddle, M.J. (1975) A selective review of the ecological effects of human trampling on natural ecosystems. *Biol Conserv*, 7, 17-36.
- Liddle, M.J. (1988) *Recreation and the environment: the ecology of recreation impacts*. Section 2, Vegetation and Wear (AES Working Paper 1/89). Australian Environmental Studies, Griffith University, Brisbane, Australia.
- Likert, R. (1932) A technique for the measurement of attitudes. *Arch Psychol*, 140, 1-55.
- Lindberg, K. & Hawkins, D.E. (Eds.) (1993) Eco-tourism: a guide for planners and managers. The Ecotourism Society, North Bennington, Vermont.
- Lothian, A. (1994) Australian attitudes towards the environment. *Aust J Environ Manag*, 9/1, 45-61.
- Martin-Lopez, B., Montes, C. & Benyas, J. (2007) The non-economic motives behind the willingness to pay for biodiversity conservation. *Biol Conserv*, 139, 67-82.
- McCool, S.F. (1996) Limits of acceptable change: a framework for managing national protected areas — experiences from the United States. Paper presented at Workshop on Impact management in Marine Parks sponsored by Maritime Institute of Malaysia, August 13th- 14th, 1996, Kuala Lumpur, Malaysia.
- Mihalić, T. (2000) Environmental management of a tourist destination: a factor of tourism competitiveness. *Tourism Manage*, 21, 65-78.
- Mitchell, B. (1989) Geography and resource analysis. Longman Scientific and Technical, London, pp. 399.
- Morin, S.L., Moore, S.A. & Schmidt, W. (1997) Defining indicators and standards for recreation impacts in Nuyts Wilderness, Walpole-Nornalup National Park, Western Australia. *CALMScience*, 2/3, 247-266.
- Mowforth, M. & Munt, I. (2005) Tourism and sustainability: development and new tourism in the Third World. New York: Routledge, pp. 338.

- Muloin, S. (1991) Wilderness access for persons with a disability: a discussion. In: *Ecotourism incorporating the global classroom* (ed: Weiler, B.). *1991 Int Conf Pap*. Bureau of Tourism Research. Canberra, Australia. 20-25
- Muthee, L.W. (1992) Ecological impacts of tourist use of habitats and pressure-point animal species. In: *Tourist attitudes and use impacts in Masai Mara National Reserve* (ed: Gakahu, C.G.). Wildlife Conservation International, Nairobi. 18-38.
- Negi, S.S. (1997) Forestry in India: research, extension, research and education, Vol 1. New Delhi, India. MD Publications, Ltd.
- Nickels, W.G. & Wood, M.B. (1997) Marketing: relationships, quality, value. New York: Worth.
- Noe, F.P., Hammit, W.E. & Bixler, R.D. (1997) Park use perceptions of resource and use impacts under varied situations in three national parks. *J Environ Manage*, 49, 323-336.
- Nortjé, G.P. (2005) The impacts of off-road driving and other concessionaire activities on physical soil degradation. MPhil thesis, Centre for Wildlife management, University of Pretoria.
- Onyeanusi, A.E. (1986) Measurement of impact of tourist off-road driving on grasslands in Masai Mara National Reserve, Kenya: a simulation approach. *Environ Conserv*, 13/4, 325-329.
- Orams, M. (1995) Towards a more desirable form of ecotourism. *Tourism Manage*, 16, 3-8.
- Oxford Dictionary of Environment & Conservation (2001) Chris Park. Oxford University Press.
- Papageorgiou, K. (2001) A combined park management framework based on regulatory and behavioural strategies: use of visitors' knowledge to assess effectiveness. *Environ Manage*, 28/1, 61-73.
- Papageorgiou, K. & Brotherton, I. (1999) A management planning framework based on ecological, perceptual and economic carrying capacity: the case study of Vikos-Aoos National Park, Greece. *J Environ Manage*, 56, 271-284.
- Peake, S., Innes, P. & Dyer, P. (2009) Ecotourism and conservation: factors influencing effective conservation messages. *J Sustain Tour*, 17/1, 107-127.
- Priskin, J. (2003) Tourist perception of degradation caused by coastal nature-based recreation. *Environ Manage*, 32/2,189-204.
- Qi, Q., Zhang, J. & Yang, Y. (2008) *An analysis of the relationship between environmental attitudes and behaviour intentions of tourists in natural heritage sites: a case*

study of tourists in Jiuzhaigou National Park. Department of Land Resources and Tourism Science, Nanjing University.

- Randall, C. & Rollins, R.B. (2009) Visitor perceptions of the role of tour guides in natural areas. *J Sustain Tour*, 17/3, 357-374.
- Reisinger, Y. & Turner, L. (1998) Cross differences in tourism: a strategy for tourism marketers. *J Trav Tourism Market*, 7, 79-106.
- Roe, D., Williams, N.L. & Dalal-Clayton, B. (1997) Take only photographs, leave only footprints: the environmental impacts of wildlife tourism. IIED Wildlife and Development Series, 10. Environmental Planning Group, International Institute for Environment and Development. London.
- Roselyne, N.O. & Urmilla, B. (2009) Sustainable eco-tourism management in Kenya. *Ethiopian J Environ Stud Manag*, 2/1, 57-65.
- Ryel, R. & Grasse, T. (1991) Marketing ecotourism: attracting the elusive ecotourist. In: *Nature tourism: managing for the environment* (ed: Whelan, T.). Island Press, Washington DC.
- Saayman, M. & Slabbert, E. (2004) A profile of tourists visiting the Kruger National Park. *Koedoe*, 47/1, p 108.
- Sâmbotin, D., Sâmbotin, A., Pătrăşcoiu, M., Coroian, A. & Mercel, I.I. (2011) Ecotourism: a model of sustainable development of tourism means. *Sci Pap*, 13/4, 221-226.
- Semenik, R.J. (2000) Promotion and integrated marketing communications. Thomson Learning, Canada.
- Simon, M.K. (2011) Dissertation and scholarly research: recipes for success. Dissertation Success, LLC. Seattle, WA.
- Spanou, S., Tsegenidi, K. & Georgiadis, Th. (2012) Perception of visitors' environmental impacts of ecotourism: a case study in the valley of butterflies protected area, Rhodes Island, Greece. *Int J Environ Res*,6/1, 245-258.
- Spenceley, A. (2003) Managing sustainable nature-based tourism in southern Africa: a practical assessment tool. Unpublished PhD thesis, University of Greenwich. Available at www.anna.speceley.co.uk.
- Spenceley, A. (2005) Nature-based tourism and environmental sustainability in South Africa. *J Sustain Tour*, 13/2, 136-170.
- Stankey, G.H., McCool, S.F. & Stokes, G.L. (1984) Limits of acceptable change: a new framework for managing the Bob Marshall Wilderness. *Western Wildlands*, 10/3, 33-37.

- Strydom, J.W., Cant, M.C. & Jooste, C.J. (2000) Marketing management. Juta, Cape Town.
- Sweeting, J.E.N. & Sweeting, A.R. (2003) A practical guide to good practice: managing environmental and social issues in the accommodations sector. The Center for Environmental Leadership in Business / Tour operators' initiative for sustainable tourism development.
- Tickel, C. (1994) Foreward. In: *Ecotourism: a sustainable option?* (ed: Cater, E. & Lowman, G.). John Wiley & Sons. Brisbane. ix-x.
- The International Ecotourism Society (TIES) (1990) Eco-tourism: (accessed 15th January 2013) http://www.ecotourism.org/what-is-ecotourism.
- Valentine, P.S. (1991) Eco-tourism and Nature Conservation: a definition with some recent developments in Micronesia. In: *Ecotourism incorporating the global classroom* (ed: Weiler, B.). *1991 Inter Conf Pap*. Bureau of Tourism Research. Canberra, Australia, pp. 4-9.
- Wikipedia, The Free Encyclopedia (2013a) Ecotourism: (accessed 10th March 2013) http://en.wikipedia.org/wiki/Ecotourism.
- Wikipedia, The Free Encyclopedia (2013b) Likert-scale: (accessed 5th March 2013) http://en.wikipedia.org/wiki/Likert_scale.

CHAPTER 7
EVALUATION OF PERCEPTIONS OF VISITORS TO THE MAKULEKE CONTRACTUAL PARK REGARDING OFF-ROAD DRIVING

Nortjé, van Hoven & Laker (May 2013),
revised article submitted for publication in Environmental Management (Springer)

7.1 Introduction

In this study at Pafuri Camp in the Makuleke Contractual Park (MCP), off-road driving (ORD) has been found to be associated with a range of negative impacts as shown in Chapters 3, 4 and 5 and Nortjé *et al.* (2012). Negative impacts include soil erosion, soil surface crusting, soil compaction, vegetation damage and disturbance of wildlife (Bhandari 1999; Nortjé *et al.* 2012; Buckley & Pannel 1990; Coppock 1982). Even low-frequency ORD (one vehicle pass) can be damaging, as the first pass over the soil surface produces the most compaction.

Repetitive ORD prevents the soil and natural environment from recovering and over time the damage can be permanent. On this basis, ORD is extremely damaging. These problems are more widespread than people realise, as most, if not all private nature reserves and even National Parks in South Africa allow ORD in order to attract tourists and, thus, enhance economic returns (Nortjé 2005). It has also been observed that ORD is sometimes instigated by tourists demanding ORD to see certain animal species at close quarters (Nortjé 2005; Muthee 1992).

Although ORD has probably been going on for decades, the practice of the activity has never been officialised in South Africa until recently. That only happened in 2000 with the commercialization program of the South African National Parks (SANParks) when commercial concessions were granted in the parks and concession holders received permission to conduct ORD in their areas. Since then, the practice grew exponentially. This coincided with the exponential growth in eco-tourism or nature-based tourism to remote and wildlife rich places elsewhere in Africa, and increased exercising of ORD in those areas (Bhandari 1998; Onyeanusi 1986; Muthee 1992). The perception is that these tourists need to see and, therefore, demand a sighting of the so called 'Big Five', namely elephant, buffalo, rhino, lion and leopard, at close range. This is the primary cause of the introduction and escalation of ORD.

Tourism operators stress that they operate in a business sector where they compete for high-paying eco-tourists to visit their specific conservation areas; therefore, they need to fulfil the needs and requirements of their guests or clients (Bonham-Whetham 2010, pers. comm). Otherwise, the clients will just make use of other operators or go to other game reserves or concession areas which conduct ORD. The result will be that those who do not engage in it will lose their business (Naylor 2012, pers. comm). In some cases prospective tourists are lured by advertisements in the media and on the internet that promise them close range experience with the 'Big Five'.

Personal experience at Pafuri Camp with regards to the above-mentioned situation is that eco-tourists to Pafuri Camp are to a large extent unaware and not well informed by the tourism operator and the media. Because the tourists do not have all the facts they do not realise that due to participating in and/or demanding an activity like ORD, they may be contributing to serious damage to the environment. Another factor is that some game drive guides are pressured by management and by some guests to drive off-road for certain animals, no matter what the possible negative impacts may be. Such situations have been observed (Nortjé *et al.* 2012). It has also been observed during game drives that there is tremendous lack of knowledge among tourists regarding the negative environmental impacts of certain activities.

The first objective of the study reported here was to collect data on the perceptions and knowledge of eco-tourists visiting the Pafuri Camp of the MCP regarding environmental issues related to ORD. A second objective was to study their attitude regarding environmental issues related to ORD. It is argued that visitors to Pafuri Camp can mainly be classified as eco-tourists, with all of the related characteristics of environmental awareness, eco-centric attitudes towards the natural environment, environmental affection and knowledge. It is postulated that they are as a consequence tourists which could be positively influenced by education on their impacts on the environment, e.g. by ORD.

The study was conducted in this area because of its management's willingness to participate in it.

7.2 Methodology

7.2.1 Questionnaire

Data collection

Data were collected by means of a structured five page visitor questionnaire (Appendix E). The questionnaire was only available in English as experience with visitors to this protected area has indicated that the majority of tourists were well versed in English. The questionnaire consisted of five sections:

- The first section focused on demographics, including age, gender, nationality, occupation, income, number of visits and time of year of the visits, after Moore *et al.* (2008);
- The second section involved questions on tourists' motives for visiting this area. The scale used was a 3-point Likert scale with 1 corresponding to 'not important' and 3 corresponding to 'very important';
- The third section involved questions on tourists' views on selected environmental and tourism issues. The scale used here was a 5-point Likert scale with 1 corresponding to 'strongly disagree' and 5 corresponding to 'strongly agree';
- The fourth section was divided into two sub-sections as follows: Sub-section A involved questions on tourists' views on issues related to ORD in protected areas - the scale used was again a 5-point Likert scale where 1 corresponding to 'strongly disagree' and 5 to 'strongly agree'; Sub-section B involved specific questions with regards to the tourists' experience of ORD at Pafuri - the scale used was a simple two option scale, namely 1=yes and 2=no;
- The last section involved questions with regards to tourists' perceptions of Pafuri Camp as an environmentally friendly destination, more specifically, their experience of specific activities at Pafuri. Again a 5-point Likert scale was used with 1 corresponding to 'not at all satisfied' and 5 corresponding to 'very satisfied'. It is acknowledged that this method is subjective; however, it provided a framework for evaluating how visitor perceptions of the natural environment influence the practice and impact of ORD.

Tourists were surveyed during their visit at the park. **All** visitors were approached and questionnaires handed out to them without consideration of any of their characteristics, time of day, or behaviour (Priskin 2003). Visitors completed the questionnaires during their stay (before or after brunch or before or after dinner). The survey was conducted over a four months period during winter (June-July) and spring (August-September) 2011. This period was selected because these months represented the peak visitor periods in

2009 and 2010, with isolated peaks in April and December (refer to Fig. 3.2). Behe & Bruyere (2007) also did their survey during a peak time of tourists visit. Most ORD also occurred during the period June to September (Fig. 3.2). ORD incidence levels are a function of visitor numbers and relatively low rainfall (Figs. 2.3 and 3.2). Foreign visitors to the area are generally sparse during the summer months in the area, due to the hot conditions (Fig. 3.2).

A total of 112 questionnaires were administered during the four month period. All 112 were completed and were usable and valid, thus constituting a 100% return. All visitors willingly agreed to complete the questionnaire. Answers were codified and inserted into a database (Excel spreadsheet) and then were statistically analysed with the use of SPSS version 19.0 2007 programme for statistics.

7.3 Results and Discussion

7.3.1 Tourists' demographic profiles

The tourists' demographic profiles were included in this questionnaire as literature showed that it is important to do this (van der Merwe & Saayman 2008; Saayman & Slabbert 2004; Peake *et al.* 2009). The literature study in Chapter 6 also indicated that in general differences in tourist's perceptions and attitudes can be related to differences in nationality, age groups, and income levels (Saayman & Slabbert 2004; van der Merwe & Saayman 2008).

The ages of persons who completed questionnaires in this study ranged from 12 to over 60 years old. Persons in older age groups constituted the largest proportion of the tourists, with a total of 42.9% of visitors being 60 years and older (Fig. 7.1). With the age group 50-59, representing 15.2% of the tourists, it means that 58.1% of the tourists were 50 years and older. This fits in with the finding that about 50% of respondents were retired people (discussed later). In the younger age groups representation increased with increasing age, as could probably be expected, with the age group 12-19 making up 1.8%, the age group 20-29 making up 9.8% and the age group 30-39 representing 18.8%. Surprisingly, the contribution by the age group 40-49 years decreased sharply, compared with the 30-39 years age group to only 11.6%.

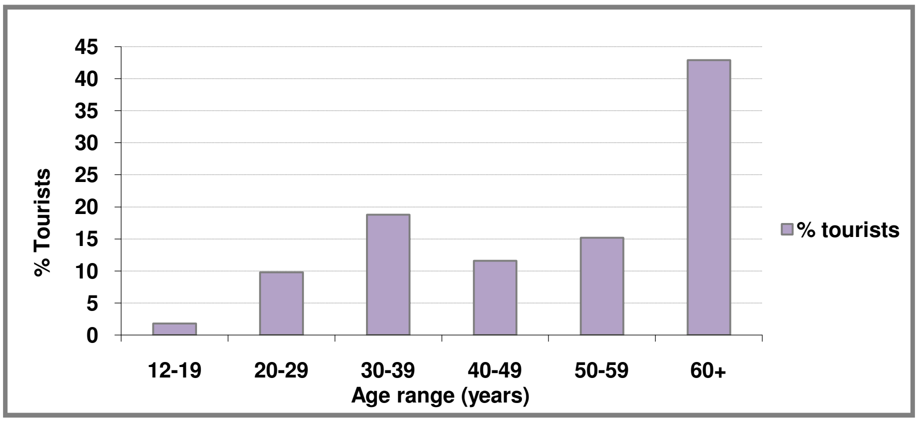


Figure 7.1 Age distribution of Pafuri tourists

A large majority of the visitors (62.5%) are in the occupation category 'professional' and 'managerial' or were in it before retirement. The 37.5% of respondents in the category 'other' include persons in retirement or already retired from a wide variety of occupations (Fig. 7.2). About half (49.5%) of the respondents were retired persons.

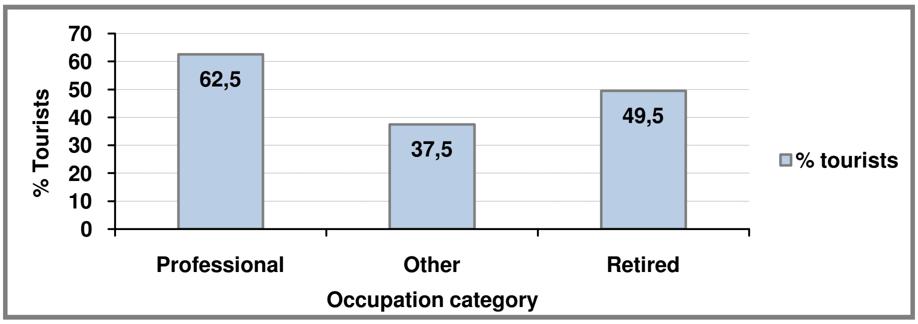


Figure 7.2 Occupation distributions of Pafuri tourists

In the 'income' category, it was decided that it would be better not to ask for specific income ranges, but rather use the following categories on order to get a basic idea of their income levels: self paid holiday, family gift, work and other. Asking the respondents to answer these questions would be much less intrusive and make them keener to complete this question. 71.4% of respondents indicated that they paid themselves for their visit to the park (Table 7.1). This could be mainly related to the fact that 49.5% were retired and 62.5% are currently or were previously managers or professional people with higher income levels.

Table 7.1 Who pays for this holiday?

Who pays for this holiday?	Number of tourists (%)
Own holiday	71.4
Family gift	0.9
Work	23.2
Other	4.5

The results on respondents' demographics therefore indicated that Pafuri Camp is mainly visited by retired, professional/managerial people. It can be expected that these are well-informed people. Well-informed meaning in this context in relation to the environment in general and tourists impacts specifically. The literature study in Chapter 6 indicated that "environmental awareness" is well correlated with higher levels of education (Lothian 1994; Priskin 2003). Therefore, it can be deduced that the majority of visitors to Pafuri Camp are "environmentally aware".

81.3% of respondents were first time visitors to Pafuri Camp (Fig. 7.3). Tourists probably tend to visit different areas during successive visits to game parks. However, in this case an important contributing factor is probably that this concession and camp opened only in 2001 and was previously relatively unknown in the market. From July 2011 there was suddenly a sharp increase in visitor numbers compared with the relatively static 2009 and 2010 (Fig. 3.2). The fact that 18.8% indicated that they were second and more time visitors (Fig. 7.3), points to the fact that tourists are coming back to Pafuri within a short space of time and are possibly satisfied with the area and its activities. Van der Merwe & Saayman (2008) found that people are getting attached to a specific "brand" that they like, as in the case of The Kruger National Park (KNP) and are therefore classified as "regular" visitors. This explains why visitors are coming back to a specific destination or are "repeat" visitors in the case of Pafuri Camp.

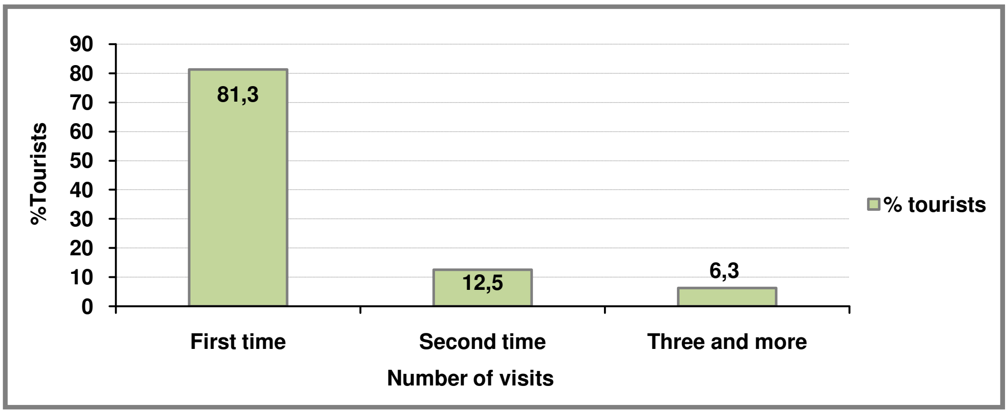


Figure 7.3 Visitor frequency distribution to Pafuri

The majority of respondents indicated that they would prefer to visit Pafuri Camp during July (28.6%). Respondents indicating that they would prefer visits during June or August (both 17.9%) were the second most common group (Fig. 7.4). Visitors who preferred to come during September (16.1%) and October (14.3%) were the third and fourth most common groups, whereas the fifth and six most common groups were those tourists preferring to visit during January (9%) and May (4.5%).

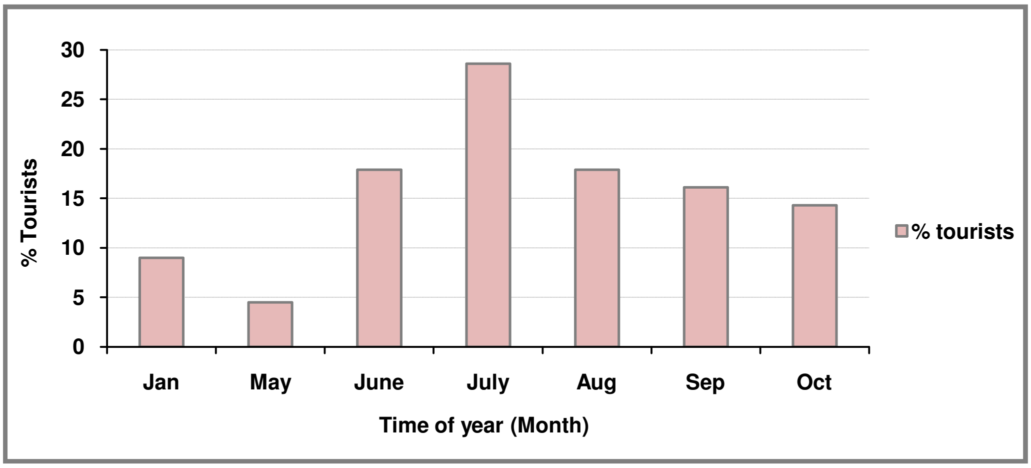


Figure 7.4 Tourists preferred time of year visit

It should be noted that these indicated preferences do not agree with the actual facts regarding visitor numbers depicted in Fig. 3.2, especially with regards to the peaks in December (2010 and 2011) and in April (2010) or March (2011). Pafuri Camp introduced a system of special discount prices for local tourists during weekends and school holidays in the summer months. This system caused visitors to come during periods other than those that they would prefer.

When looking at climate, June, July and August are favourable months, with pleasant temperatures and low rainfall. June and July fall within the winter holiday period in South Africa and June to August the summer holiday period for visitors from the northern hemisphere. June, July and August as peak visiting period seems to be the trend with most Southern and East African parks and reserves (Onyeanusi 1986; Bhandari 1989).

From a soil conservation perspective, the above-mentioned results are positive in the sense that most tourists visit the area during the dry season (June-September), when the soil is less susceptible to crusting and sub-soil compaction than during the wet season. However, it must be kept in mind that results of the other part of this study show that serious damage to soils and vegetation also occurs under dry soil conditions (refer to Chapter 4).

7.3.2 Tourists' motives for visiting Pafuri Camp/MCP

The responses of respondents regarding their reasons for visiting Pafuri Camp are summarised in Table 7.2.

Table 7.2 Tourists' motivations for visiting Pafuri Camp

Reasons for visit	% of respondents		
	Very important	Somewhat important	Not important
Gain new knowledge	51.8	41.1	7.1
Outdoor activities	88.2	10.0	1.8
Nostalgia	10.1	22.9	67.0
Novelty	31.5	37.0	31.5
Escape & relaxation	49.1	31.8	19.1
Photography	41.7	41.7	16.7
Wilderness experience	87.4	9.9	2.7
Seeing predators	53.2	32.4	14.4
Explore new locations	66.1	27.5	6.4
Socializing	17.3	41.8	40.9

The following categories were indicated to be very important motives for most visitors: 'outdoor activities', as in game drives and game-walks (88.2%); and 'wilderness experience' (87.4%). Reasons that were very important for a moderate number of visitors include: 'exploring new locations' (66.1%); 'gaining new knowledge' of the environmental, ecological and historical aspects (51.8%); 'seeing the major predators' at close range, including by means of ORD (53.2%); 'escape and relaxation' (49.1%) and 'photography' (41.7%).

Reasons that were very important for only a small number of visitors include: 'nostalgia' (10.1%), 'novelty' (31.5%) and 'socializing' (17.3%). These findings correspond well with those of van der Merwe & Saayman (2008). However, some major differences were also found between the findings in this study and those of van der Merwe & Saayman (2008), most importantly the following:

- Outdoor activities and wilderness were rated **very** high in this study. In contrast, nature was rated quite moderate and activities **very** low in the study by van der Merwe & Saayman (2008);
- Escape was rated very moderate in this study, but **very** high (>80%) the study of van der Merwe & Saayman (2008);
- Nostalgia was rated **very** low in this study, but second highest (nearly 70%) in the study of van der Merwe & Saayman (2008).

It was mentioned in Chapter 6 that van der Merwe & Saayman (2008) included some wildlife aspects erroneously in their nostalgia factor, which may explain some of the above-mentioned differences.

These results indicate that the majority of tourists visiting Pafuri Camp enjoy the outdoors, and would like to take part in activities which bring them in closer contact with the wildlife and nature. These data correspond very well with the results of the study by Onyeanusi (1986). On the negative side, this may also mean that they would be willing to take part in any activities that would contribute to satisfying their needs, even ORD. The fact that more than two thirds (68.7%) of the respondents were willing to make definite statements (positive or negative) regarding the question whether eco-tourism has negative impacts, is somewhat alarming in view of the fact that less than one third (32.1%) disagreed or strongly disagreed with the statement that 'most eco-tourists have poor knowledge and grasp of ecological facts'. In other words, quite a number took definite standpoints purely on "gut feelings" or perceptions. This is in contrast to findings by Priskin (2003).

A principle component analysis of the visitors revealed that the 10 different motivation factors (Table 7.2) grouped the visitors into three distinct visitor segments. The Scree plot indicated the latter as three component factors (Table 7.3). The three segments or component factors in this study were grouped as follows: Factor 1, 'wildlife/nature';

Factor 2, 'relaxation/get-away' and Factor 3, 'seeing the major predators/socializing'. The motives of tourists visiting Pafuri Camp are thus very specific and well defined (Table 7.3).

Table 7.3 Component Matrix

Motivation factors		Component factors			
		Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
2.9	Explore new locations	.693	.239	-.043	-.268
2.7	Wilderness experience	.580	-.250	-.287	-.014
2.2	Outdoor activities: game drives, game walks, etc.	.567	-.401	-.155	.449
2.1	Expand/gain new knowledge on various environmental, ecological, historical, etc., aspects	.544	-.168	.053	-.376
2.4	Novelty (uniqueness)	.489	.307	-.261	-.296
2.3	Nostalgia (reminiscence)	.308	.665	.073	.302
2.5	Escape and relaxation	.320	.618	-.269	.317
2.8	Seeing the major predators (lion, leopard, cheetah), at close range by means of off-road driving	.469	-.205	.658	-.226
2.10	Socializing	-.009	.593	.606	.038
2.6	Photography	.394	-.388	.365	.509

Extraction Method: Principal Component Analysis
a. 4 components extracted

Factor 4 was rejected but 'photography' was grouped under Factor 1. The reason for rejecting the component Factor 4 and regrouping 'photography' under component Factor 1 is because it is something like 'activities', since it has fair correlations with 'photography' and 'outdoor activities'. 'Seeing the major predators' and 'socializing' was grouped together because it was reasoned that the most important part of socializing after game drives was talking and discussing sightings or close sightings of the major predators (Nortjé 2009-2012, pers. obs).

Component Factor 2 (relaxation/get-away) was strongly positively correlated with 'nostalgia', 'escape and relaxation' and 'socializing', which is logical. Very noteworthy it was negatively correlated with most other 'Motivation factors'. It was most strongly **negatively** correlated with "physical" motivation factors, like 'outdoor activities' and 'photography'. This component factor was also negatively correlated with 'wilderness experience', 'gaining new knowledge' on environmental and related aspects, and even 'seeing the major predators' at close range.

It seems as if there is a group of eco-tourists that can basically be described as "passive tourists". They are possibly the ones with the least negative impacts on the environment, since they seem the least likely to demand activities like ORD, game walks, etc. Van der Merwe & Saayman (2008) found that 'nostalgia' had weak negative correlations with **all** other 'Motivation factors', with the strongest against 'nature' and that 'escape' had a weak negative correlation with 'activities'. These findings by van der Merwe & Saayman (2008) are more strongly supported by the above-mentioned findings.

7.3.3 Tourists' environmental views

In this section of the survey where the respondents' perceptions on general environmental and tourism issues were tested (Fig. 7.5), the majority of respondents 'agreed' or 'strongly agreed' with the following statements: 'the present generation should ensure the environment in eco-tourism areas is maintained for future generations' (100%); 'eco-tourists have a responsibility to acquire correct knowledge of ecological facts, in order to do correctly what they can, to protect the environment' (90.2%); 'negative impacts of eco-tourism on the environment are aggravated by the actions and demands of eco-tourists with poor knowledge and grasp of ecological facts' (70.5%); and 'negative impacts of eco-tourism on the environment are aggravated by the actions of irresponsible eco-tourism operators who offer environmentally harmful packages to ill-informed eco-tourists' (60.9%).

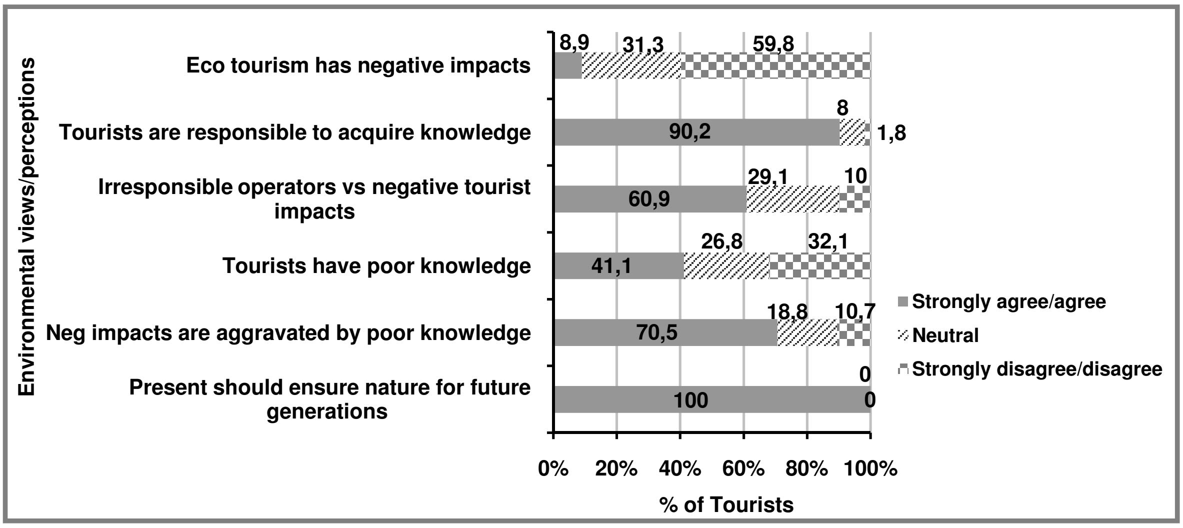


Figure 7.5 Tourists' Environmental views/perceptions

A majority of respondents (59.8%) disagreed with the statement that 'eco-tourism has negative impacts on the environment'. Almost one third (31.3%) of respondents, were neutral and, thus, felt uncertain regarding this statement. Only 8.9% of respondents 'agreed' or 'strongly agreed' that eco-tourism has negative impacts on the environment.

Most alarming, in view of this, is that such a large proportion was of the opinion that eco-tourism does not have negative impacts, without actually knowing whether this is the case. In response to the statement that 'most eco-tourists have poor knowledge and grasp of ecological facts', a significant proportion (26.8%) of the respondents was neutral, possibly because they felt uncertain.

The above-mentioned results could indicate that a significant percentage of the tourists visiting Pafuri Camp are environmentally unaware. However, this would be in contradiction of what was found in Section 7.3.1 where the visitors to Pafuri were found to be mostly educated and thus assumed as "environmentally aware". The latter assumption may thus be incorrect. Ivy *et al.* (1998), cited in Papageorgiou (2001), pointed out that environmental awareness is crucial to produce a proper attitude towards the environment. The above findings regarding visitors to Pafuri camp may thus indicate that it could be difficult to create a proper attitude amongst tourists towards the environment.

7.3.4 Tourists' general views with regards to ORD

Visitor's perceptions with regards to the environmental impacts of ORD in general differed widely (Table 7.4). Hillery *et al.* (2001) found similar results with the evaluation of tourists' perceptions of their environmental impact. The statements, with regards to the perceptions of tourists to ORD, showed that on most questions, where the negative impact of ORD was stressed, the respondents agreed. Onyeanusi (1986) also showed that visitors perceived ORD vehicle tracks to have negative impacts.

Table 7.4 Tourists' general ORD perceptions

ORD perceptions	% of respondents		
	Strongly agree/agree	Neutral	Strongly disagree/disagree
ORD has no negative impacts	11.0	17.4	71.6
ORD causes compaction	61.8	26.4	11.8
ORD causes erosion	52.7	32.1	15.2
Benefits of ORD>damage by ORD	27.9	28.8	43.2
ORD has negative impact on wildlife	38.0	28.7	33.3
ORD does not cause vegetation damage	11.7	11.7	76.6
ORD damage takes long to recover	57.1	22.3	20.5

The majority of respondents agreed that ORD has 'negative impacts' on the environment in the form of causing:

- vegetation damage (76.6%),
- negative impacts on the environment (71.6%),
- soil compaction (61.8%), and
- soil erosion (52.7%).

The responses, regarding 'negative impacts' and 'vegetation damage', were clear-cut, but for 'soil compaction' and 'soil erosion' less so. In the case of soil compaction, 26.4% were neutral and for soil erosion 32.1%, indicated uncertainty, probably due to a lack of knowledge. It is generally found that people have very little knowledge about soils and their role in the environment (Laker 2012, pers. comm). The majority (57.1%) were also of the opinion that damage caused by ORD takes long to recover, but 20.5% disagreed with this opinion and 22.3% remained neutral. Respondents were strongly divided regarding whether ORD has negative impacts on wildlife and whether the benefits of ORD outweigh damage caused by it.

The finding regarding soil erosion is in agreement with the finding by Noe *et al.* (1997) who indicated that tourists visiting different National Parks in the United States rate soil erosion only as "slightly unacceptable".

7.3.5 Tourists' experiences and personal preferences and attitudes with regards to ORD

In total, 72.3% of respondents experienced ORD at Pafuri Camp, with more than two thirds (67.9%) having had previous experience of ORD (Table 7.5). It is noteworthy that, in contrast to the sub-section on ORD in general, in this sub-section respondents expressed definite opinions in terms of 'agree' or 'disagree'. Virtually no respondents remained neutral or undecided.

Table 7.5 Tourists' perceptions of ORD at Pafuri

Perceptions of off-road driving at Pafuri	% of respondents		
	Yes	No	Do not know
Experienced ORD at Pafuri	72.3	27.7	0.0
Was ORD explained before the incident?	45.8	54.2	0.0
Did the ORD generate negative emotions in you?	13.6	86.4	0.0
Are you attracted to areas where ORD is practised	45.8	51.4	2.8
Soil & vegetation recovers after ORD	76.4	20.0	3.6
ORD should be allowed for people who never saw certain animals	56.3	40.2	3.6
Any previous experience of ORD	67.9	31.3	0.9

With regards to their own experience of ORD at Pafuri Camp and their personal attitudes towards ORD, their responses clearly contradict their above-mentioned perceptions for ORD in general. In the general section the majority of respondents indicated that they believe that ORD has several negative impacts on the environment and that damage caused, could take long to recover. Yet, in this section on their own experiences and personal attitudes:

- For no less than 86.4% of the respondents, their off-road experience did not stir any negative emotions in them.
- No less than 56.3% were of the opinion that ORD should be allowed in order to accommodate specific tourists and situations.
- Nearly half (almost 46%) of respondents are attracted to areas where ORD is practised.
- More than three quarters (76.4%) were of the opinion that soil and vegetation recover after ORD.

Thus, results with regards to the tourist's views on ORD indicate wide disparities and contradictions between their views and attitude towards ORD in general, and their attitude when it comes to their personal participation in it.

It seems that a great majority of the respondents understand that ORD has negative environmental impacts, in general, and on vegetation in particular. A majority also acknowledge damage to soil and that damage caused by ORD takes long to recover. The moment it involves them personally they make a complete turnaround, with significant numbers indicating that ORD should be allowed for certain purposes and/or that they personally would prefer visiting areas where ORD is offered. These findings concur with literature which shows tourists shared the beliefs that the environment should be protected, but are not really always willing to act accordingly, also indicating that there is a clear contradiction in terms with regards to what tourists know and how they are prepared to act (Tartaglia 2009; Hillery *et al.* 2001; Dalton *et al.* 2008).

Either they simply do not care and/or they are egocentric, wanting to have the experiences that ORD offer, although they overall believe that it will cause damage that will take long to recover. If this was representative of eco-tourists in general, then typical human nature of egocentrism comes to the fore: "We know it is bad, but want to experience it". The implication of this is that if a tourism operator would unilaterally decide not to do ORD because they care for the environment they would go out of business (Laker 2013, pers. comm).

The following statement by Hillery *et al.* (2001) is key support to the finding in this study regarding visitors believing that something like ORD is harmful, but yet their egocentric human attitude causing them to prefer to do it: "In one sense, tourists to natural areas present a potential paradox. They see tourism as a threat, and yet they want to be able to visit such natural areas".

Priskin (2003) indicated that visitors are generally aware of impacts associated with their activities, but it does not mean that they will act in accordance with their opinions. Tourists may say that a specific activity is harmful to the environment, but that perception does not necessarily lead to responsible behaviour (Priskin 2003). Mitchell (1989) and Mihalić (2000) have shown that there is often a weak relationship between what people believe and say and how they will act.

The findings of this section of the questionnaire again supports the earlier conclusion in this study that education and the creation of environmental awareness alone will not lead to responsible demands and actions by tourists regarding conservation in wildlife areas. Regulatory measures will also have to be put in place and effectively enforced.

7.4 Development of a Conceptual Framework for Sustainable Management of Wildlife Parks and Reserves

Understanding tourists' environmental beliefs, expectations, motivations and perceptions on the one hand, their attitudes and behaviour on the other hand and the inter-relationship between these are critically important when developing a conceptual framework for a sustainable tourism and conservation management plan (Fig. 7.6).

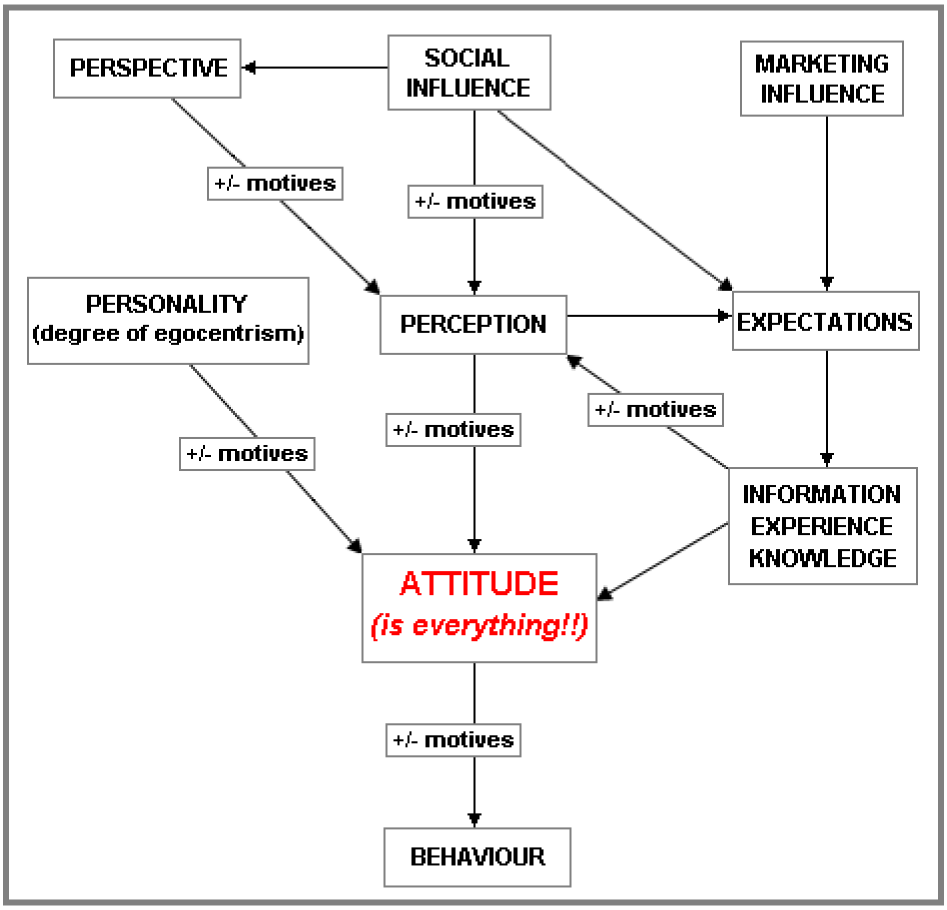


Figure 7.6 Proposed conceptual framework depicting driving forces for tourist behaviour

Based on the findings of the study reported here, the conceptual framework outlined in Fig. 7.6 was specifically developed for the situation in wildlife parks and reserves in Africa and South Africa in particular. The discussion that follows should be seen and interpreted with this framework in mind. Information required as inputs in this conceptual framework can only be obtained from proven methods of data collection, like well-designed visitor questionnaires with built in checks and balances.

In Africa and South Africa there are the so-called game reserves/game parks, where the primary focus is wildlife (including birds) and the accompanying supporting ecosystems (Laker 2013, pers. comm). Together with these is a high degree of biodiversity. Scenery is secondary and the kinds of driving forces and activities characteristic of North American and European reserves, for example scenery, special features, boating, camping, picnicking, hiking, riding, fishing and mountaineering, are of frivolous interest or do not exist. The situation in the game parks/reserves of Africa, including South Africa, is therefore totally different to that in the USA and Europe. It should be kept in mind that there are also other types of wilderness reserves in Africa/South Africa where wildlife are of minor or no interest.

The first thing most people think about when going to the KNP in South Africa, or the Serengeti and Masai Mara in Tanzania and Kenya respectively, is the 'Big Five' or millions of wildebeests and zebras.

Furthermore, people think about a wide variety of beautiful wild animals, also interesting and beautiful birds. In South Africa we have a large variety of large trees. Only a few of the South African and African game parks have such beautiful scenery to compete with the wildlife. The game parks in Africa have a totally different dynamics than the other kinds of parks in the USA and Europe. In Africa it is all about "hunting" with the eyes, binoculars, camera and video camera. It is a challenge to find a specific animal or bird, and is about finding the "important" things like the 'Big Five', or rare animals like cheetah and wild dogs.

The problem comes when tour operators or concession holders in these wildlife rich game parks lure foreign and rich South African tourists with the promise of seeing these animals at close range. Then activities like ORD become involved. What follows is a serious conflict between the interests of the natural environment and the demands of tourists (Nortjé 2005). In such scenario it is not as easy as in the case of the parks which are based on scenery, to prioritize the tourists' wishes and what they see as acceptable in order to satisfy their needs. Concepts like sustainability and resilience are now becoming very important and tour operators, concession holders, guides, tourists, and decision makers must understand them.

Tourism activities like ORD are inherently linked to the well-being of the natural environment, of which soil and climate are the basic foundations, thus making soil the most important natural physical-biological resource (Laker 2013, pers. comm). Loss of the attributes that make a region or concession attractive to tourists can economically compromise the tourism and conservation industries in that region and detract from the livelihoods of people who depend on them.

Sustainability is the concept that dictates that growth and development must take place and be maintained over time, within the limits set by natural ecosystems (Smyth & Dumanski 1993). Sustainable means, endure. It shows that we must have a long-term rather than a short-term approach with our activities on planet earth. In laymen's language it means that we must utilize our natural resources in such a way that we do not destroy, neither degrade it. This approach is required for all production-systems including ORD.

It is for the above reasons that an International Working Group on Sustainable Land-use came into being in 1991 (Smyth & Dumanski 1993). According to this group, land-use must be managed according to the following requirements to be sustainable:

- Maintain, if possible, the biological productivity;
- Decrease the risk, to ensure greater security;
- Maintain the quality of the natural resources;
- Maintain the economic viability;
- Ensure social viability.

No protected area can operate in isolation and for this reason it is essential to collaborate with local communities and other interested and affected parties in determining economic and ecological needs and priorities. It is particularly relevant where local communities as in the case with the Makuleke Community, want to make the biggest amount of money or achieve maximum benefit from such a venture. Any sustainable management strategy focussing on the three essential ingredients of sustainability - the environment, the tourists and the local communities should include somehow in the strategy a way of the local communities to understand the importance of sustainability.

The following definition of sustainable eco-tourism is suggested here: "Because eco-tourism implies visits to fragile, pristine and undisturbed natural environments, the goal should be sustainable eco-tourism, where a balance between the tourism impact and environmental recovery exists, with emphasis on natural resource protection. This implies that if any activity, like ORD is not sustainable, the activity should be terminated".

One of the "new" management frameworks for sustainable tourism, known as the "limits of acceptable change" (LAC), has been developed for use in the USA. It is for the reasons mentioned above not applicable to game parks/reserves where wildlife viewing is the primary activity and can therefore not be applied in such African protected areas.

Probably two of the greatest flaws in the LAC concept are:

- Under the 11 pillars of LAC, no mention is made of "resilience" (the potential/ability to recover to the original state) or "sustainability". In Africa and South Africa these two concepts are the cornerstones of environmental protection;
- The 11 pillars of LAC concentrate on actions and activities that make recreational areas less attractive to tourists and less pleasant for them to visit, with attention to environmental damage occupying a secondary position. In other words they are more anthorpologically (human) than ecologically oriented. Thus the potential danger of egocentrism over-riding ecocentrism is increased.

The latter is also evident from the underlying principles of the "limit of acceptable change" (LAC) conceptual framework, which are, according to McCool (1996):

- That degradation of the natural environment in recreational areas due to human impact is inevitable and must thus be accepted as a given;
- That there is a limit beyond which degradation of the environment due to this human-induced degradation is not acceptable. Degradation beyond this limit cannot be tolerated and the state of the environment must be arrested when it is in this condition. A key question and comment regarding this principle naturally comes to the fore: Who determines this limit for each specific case? Furthermore, there does not seem to be any attention regarding a permissible rate of degradation towards the reaching of this point.

In practice the above-mentioned principles mean that no "substantial" limitations are put on tourists until their activities have degraded the environment to the lowest acceptable level. Future tourists are then severely limited in order to prevent any further degradation. This means a much weaker experience by future tourists because of the fact that their predecessors were not limited. Again, nowhere is "recovery" mentioned, just mention of limiting further degradation. These sounds much like "compensation" for damage already done.

The whole spirit which is reflected in LAC, is one of "egocentrism" - "we know that we are degrading the environment, but we want to have the experiences. Others should be satisfied with much less in future". It was shown in the present study that **no** ORD is acceptable and the first time driving off-road is the most damaging one (Nortjé *et al.* 2012). It is not sustainable and when talking about resilience it is over very long time periods (Nortjé *et al.* 2012). "*Soil resilience*, is the ability of a soil to approach its original state following utilization thereof and which resulted in loss of productivity due to chemical, physical and/or biological degradation" (Nortjé 2005). There is thus no space for allowing ORD to a so-called "limit of acceptable change".

With regards to the tourists' views and perceptions on ORD in general and also specifically at Pafuri Camp, the results mean that strong legal measures by government and strict rules by SANParks will have to be put in place and enforced to curb this. Factual proofs, based on scientifically researched data, such as those that have been collected in the other part of this study are required to alert government and SANParks of the potential dangers of ORD and enable them to put appropriate laws and rules in place. Such data should also be used to convince tourists and tourism operators of the potential long term negative implications for future tourists and for tourism operators by means of a strong campaign of educating eco-tourists and tourism operators.

Game guides could play a major role in communicating these important messages (Peake *et al.* 2009; Randall & Collins 2009). Findings by Ballantyne *et al.* (2009) suggest that when tourists are included as conservation partners in the conservation management of a protected area, and conservation messages are communicated to them on a regular basis, they are very receptive to messages which include restrictions on specific tourist activities, especially with regards to activities which may have negative impacts on the environment.

Spenceley (2005) identified certain environmental factors which are "compatible" or "essential" with sustainable nature-based tourism in Transfrontier Conservation Areas (TFCA's). A few of Spenceley's important "essential" factors related to the present study are: management that incorporates ecological and conservation principles, sustainable levels of natural resource use, a balance between the need for conservation and the economic need for tourism and environmental mitigation plans designed to deal with negative environmental impacts from tourism.

Environmental factors which are "incompatible" with sustainable nature-based tourism and related to ORD are: use of non-renewable resources that exceeds the rate at which replacement of the resource can be created, the renewable resources (soil) are used at a rate higher than their regeneration rates, disappearance of fragile plant and animal species because of tourism disturbance, negative impacts on plant germination, establishment and growth due to tourism disturbance and possible changes in the behaviour of wild animals due to tourism disturbance.

Martin-Lopez *et al.* (2007) found in a study of tourists' attitudes towards biodiversity, its economic value and the tourists' awareness for biodiversity conservation in the Donana National and Natural Park (SW Spain), a strong correlation between individual tourists' attitudes towards particular species of animals, and their related willingness to pay for their conservation. The study showed that tourists were more interested in animals than plants. The results showed that when people feel or experience a connection or relationship (biophilic factor) between them and the specific species, they are more willing to pay for its conservation.

The author's personal experience is that this is true. Research projects involving one or more of the 'Big Five' animal species have a much better chance of being approved than less important or less cute animal species (Nortjé 2008, pers. obs). The biophillic factor influences the tourists' attitude towards certain animal species (Martin-Lopez *et al.* 2007). That may be the reason why people or tourists are not keen in paying for conserving the plants and soil. They do not have a relationship with these very important ecological factors (Nortjé 2008, pers.obs). This is a very important finding and points to the fact that people need to be educated about these other important ecological factors in order to connect people with the less "cute" ecological factors. Results of this study also indicated that scientific considerations are relatively much less important than anthropomorphic ("the idea that non-human animals have human-like feelings and behaviours" — people tend to feel a relationship with the animals), in determining both the human attitudes towards species and the willingness-to pay to support biodiversity conservation.

A management strategy which caters for the needs of different visitors should be able to satisfy a greater number of visitors with less pressure on the sensitive zones. For example a strategy could cater for bird watchers, fauna and flora visitors, and include education in all of them. Walking trials could be an excellent alternative to game drives and ORD for watching and studying fauna and flora and for bird watching (Nortjé 2013, pers. obs). It is also very important to realize that the maximum sustainable use level, set by ecological criteria, may be lower than what the tourism operator and local communities' desire from an economic viewpoint, but must be respected if nature viewed in a long-term perspective is to be protected and if the resource base is to remain profitable. This statement states that tourists and even tourism operators may want to stretch the ecological boundaries because of egocentric satisfaction and economic benefits, but the reality of impacts on the environment should be respected.

The argument set in the introduction that visitors to Pafuri Camp can mainly be classified as eco-tourists, with all of the related characteristics of environmental awareness, ecocentric attitudes towards the natural environment, environmental affection and knowledge is true only for some of the above-mentioned attributes. It has been shown that there are two different ideas with regards to the visitors' "environmental awareness". They are also shown not to be ecocentric, but they are egocentric in the sense that they want their own way at the costs of the environment. Although it would be tough to positively influence them through education on their impacts, i.e. ORD on the environment, education should form part of the management plan.

7.5 References

- Ballantyne, R., Packer, J. & Hughes, K. (2009) Tourists' support for conservation messages and sustainable management practises in wildlife tourism experiences. *Tourism Manage*, 30, 658-664.
- Behe, A. & Bruyere B.L. (2007) Segmentation by visitor motivation in three Kenyan national reserves. *Tourism Manage*, 28, 1464-1471.
- Bhandari, M. (1998) Assessing the impact of off-road driving on the Masai Mara National Reserve and adjoining areas, Kenya. International Institute for Aerospace and Earth Sciences (ITC), The Netherlands.
- Bhandari, M. (1999) Tourism raised problems in Masai Mara National Park, Narok, Kenya. APEC, Nepal.
- Buckley, R. & Pannel, J. (1990) Environmental impacts of tourism and recreation in national parks and conservation reserves. *J Tourism Stud*, 1/1, 24-32.
- Coppock, J.T. (1982) Tourism and Conservation. *Tourism Manage,* December 1982.
- Dalton, G.J., Lockington, D.A. & Baldock, T.E. (2008) A survey of tourist's attitudes to renewable energy supply in Australian hotel accommodation. *Renewable Energy*, 33, 2174-2185.

- Hillery, M., Nancarrow, B., Griffin, G. & Syme, G. (2001) Tourist perception of environmental impact. *Ann Tourism Res*, 28/4, 853-867.
- Ivy, T.G.C., Lee, C.K.E. & Chuan, G.K. (1998) A survey of environmental knowledge, attitudes and behaviour of students in Singapore. *Int Res Geogr Environ Educ*, 7, 181-202.
- Lothian, A. (1994) Australian attitudes towards the environment. *Aust J Environ Manag*, 9/1, 45-61.
- Martin-Lopez, B., Montes, C. & Benyas, J. (2007) The non-economic motives behind the willingness to pay for biodiversity conservation. *Biol Conserv*, 139, 67-82.
- McCool, S.F. (1996) Limits of acceptable change: a framework for managing national protected areas — experiences from the United States. Paper presented at Workshop on Impact management in Marine Parks sponsored by Maritime Institute of Malaysia, August 13th- 14th, 1996, Kuala Lumpur, Malaysia.
- Mihalić, T. (2000) Environmental management of a tourist destination: a factor of tourism competitiveness. *Tourism Manage*, 21, 65-78.
- Mitchell, B. (1989) Geography and resource analysis. Longman Scientific and Technical, London. pp. 399.
- Moore, S.A., Crilley, G., Darcy, S., Griffin, T., Taplin, R., Tonge, J., Wegner, A & Smith, A. (2008) Designing and testing a park-based visitor survey. Sustainable Tourism - CRC.
- Muthee, L.W. (1992) Ecological impacts of tourist use of habitats and pressure-point animal species. In: *Tourist attitudes and use impacts in Masai Mara National Reserve* (ed: Gakahu, C.G.). Wildlife Conservation International, Nairobi. pp. 18-38.
- Noe, F.P., Hammitt, W.E. & Bixler, R.D. (1997) Park user perceptions of resource and use impacts under varied situations in three National Parks. *Environ Manage*, 49, 323-336.
- Nortjé, G.P. (2005) The impacts of off-road driving and other concessionaire activities on physical soil degradation. Unpublished MSc Thesis, Centre for Wildlife Management, University of Pretoria.
- Nortjé, G.P., van Hoven, W. & Laker, M.C. (2012) Factors affecting the impact of off-road driving on soils in an area in the Kruger National Park, South Africa. *Environ Manage*, 50/6, 1164-1176.
- Onyeanusi, A.E. (1986) Measurement of impact of tourist off-road driving on grass-lands in Masai Mara National Reserve, Kenya: a simulation approach. *Environ Conserv*, 13/4, 325-329.

- Papageorgiou, K. (2001) A combined park management framework based on regulatory and behavioural strategies: use of visitors' knowledge to assess effectiveness. *Environ Manage*, 28/1, 61-73.
- Peake, S., Innes, P. & Dyer, P. (2009) Ecotourism and Conservation: factors influencing effective conservation messages. *J Sustain Tour*,17/1, 107-127.
- Priskin, J. (2003) Tourist perception of degradation caused by coastal nature-based recreation. *Environ Manage*, 32/2, 189-204.
- Randall, C. & Rollins, R.B. (2009) Visitor perceptions of the role of tour guides in natural areas. *J Sustain Tour*, 17/3, 357-374.
- Saayman, M. & Slabbert, E. (2004) A profile of tourists visiting the Kruger National Park. *Koedoe*, 47/1, pp. 108.
- Smyth, A.J. & Dumanski, J. (1993) *FESLM: An international framework for evaluating sustainable land management*. World Soil Resources. Report of the Land and Water Development Division Food and Agriculture Organization of the United Nations.
- Spenceley, A. (2005) Nature-based tourism and environmental sustainability in South Africa. *J Sustain Tour*, 13/2, 136-170.
- Tartaglia, S. (2009) Comparison of tourists' environmental beliefs and environmental behaviour. Department of Tourism and Environment, Brock University. Niagara Falls, Ontario.
- Van der Merwe, P. & Saayman, M. (2008) Travel motivations of tourists visiting Kruger National Park. *Koedoe*, 50/1, 154-159.

SECTION D
CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Off-road driving is not an ecologically sustainable practice and should therefore not be allowed. A significant area in the flood plains is impacted by ORD, and statistically significant impacts of ORD on soil crusting and sub-soil compaction were found. Most damage occurred during the first vehicle pass. Wet soils are much more prone to vehicle damage than dry soils, although both are affected. The trend of increased ORD incidence during wet periods is therefore alarming. The effects of ORD are not just confined to a strip under the wheel tracks, but much wider due to a large lateral effect to both sides of the vehicle tracks. This lateral effect at both the outside of the vehicle tracks and in between the vehicle tracks increases the total area compacted.

Tyre pressure is an important factor, with serious negative impacts on root development found at pressures of 240 kPa and higher at all three sites. At Site 1 serious impacts were found even at low tyre pressures. Vegetation recovery from wheel impact is poor, even after more than one rain season. Guidelines of recovery after 20-30 mm rain (Appendix A) are thus actually irrelevant. Vegetation degradation worsens over time due to predisposition to further damage. The vehicle tracks acted as rills into which water is channelled, therefore predisposing the soil to erosion.

Comparing the effects of animals walking in paths with the vehicle impacts revealed some large differences in impact. Apart from the fact that the animals only caused a soil crust and do not cause high sub-surface compaction, the animal paths' crusts also do not give soil strength values close to or greater than 5 000 kPa. Sometimes it was even much lower than that. Animal paths' effects are also more vertical than lateral. With the vehicle tyres there is a totally different result, especially at higher tyre pressures (240 and 320 kPa), thus emphasizing the large and non-sustainable impacts of vehicle traffic.

Tourists have a superficial understanding of both the natural environment and environmental conservation, which mean that they have a general lack of knowledge towards the environments and their impacts on it. This general lack of knowledge is because of ignorance. With regards to their perceptions regarding ORD, discrepancies/ contradictions exist between what tourists say and how they are prepared to act, exist for most studies. Tourists say that they care about negative impacts on the environment, but when they need to choose whether these impacts should be controlled, they acted differently. Tourists in this study are egocentric, in the sense that they don't like to practise what they preach. This is especially true with regards to their views on ORD.

8.2 Recommendations

Because ORD, even for small distances has been proven as a non-sustainable practice it should not be allowed. It creates a vicious circle, leading to sub-soil compaction and soil crusting, induced drought, inhibiting seed germination and seedling emergence, no grass cover, no animals, no predators, no tourists, and no income.

Fewer vehicle passes caused less compaction than more vehicle passes on the same tracks, but most compaction occurred during the first pass. Thus, driving in the same tracks more than once is less damaging than driving once on different tracks. "Controlled traffic" could solve this problem and should be considered when developing management strategies for off-road driving in wildlife protected areas. ORD monitoring should continue as this constitutes some control over the activity. Hot-spots of ORD, i.e. high incidence areas, of ORD shift continually, and monitoring combined with a detailed soil map of the area can help in managing ORD while spreading visitors' impact to less sensitive parts of the area.

Another approach which could ease visitors' impact on the environment through ORD includes redesigning the current road network so that roads pass through areas where wild animals are most likely to be seen at close range and without having to leave the roads. The current road network is very old and was not initially developed with game viewing in mind (Appendix A). This better planned road network would traverse through the most important areas (hotspots) of animal sightings, while taking the pressure off of creating new tracks by driving off-road. An expanded or redesigned road network would be beneficial in the following three ways: 1) reducing pressure on the existing road network, 2) reducing pressure on the environment through ORD, and 3) improve wildlife sightings.

Lower tyre pressures should be considered when driving off-road for any purpose. No driving on wet soil should be considered, although it has been proven that ORD vehicles also cause soil compaction on dry soils. No new developments (lodges, hotels, etc.) with permission for ORD in their concessions should be allowed in this specific area as this would just increase the pressure on the area through more tourists and more demands for ORD. All soils are susceptible to soil crusting and sub-soil compaction by ORD to varying degrees, but certain areas and soils are more susceptible than others, and should therefore be avoided. These areas and soils include the following:

- Ramsar pans
- Vlei areas
- Soils with Prismacutanic B-horizons (so-called "sodic" sites)
- Silt-loam soils and soils with high fine sand + silt contents
- Sandy soils with less than 15% clay content
- Barren areas with no grass cover

An educational program focused on training and educating the guide corps as well as the tourists would go far in changing tourists' perceptions, and eventually demands for ORD and its negative impacts. But, education of tourists alone would not solve the problem. Strong legal measures by government and strict rules by South African National Parks (SANParks) will have to be put in place and enforced to control these tourism impacts. Factual proofs, based on scientifically researched data, such as those that have been collected in the other part of this study are required to alert government and SANParks of the potential dangers of ORD and enable them to put appropriate laws and rules in place. Such data should also be used to convince tourists and tourism operators of the potential long term negative implications for future tourists and for tourism operators by means of a strong campaign of educating eco-tourists and tourism operators.

Sufficient standards and indicators of environmental impacts by tourists' activities should be developed for each individual protected area. The idea should be to find a balance between tourists' impacts and the conservation of the natural resources — ecological, cultural and social sustainability. Concepts like, resilience should form an integral part in any tourism management strategy. Therefore all role-players need to be involved in the development of sustainable park — specific management plans, i.e. local population, tourism operator, government as well as the tourists.

The finding that tourists were more interested in animals than plants and soils is a very important finding and points to the fact that people need to be educated about these other important ecological factors specifically-, in order to connect people with the less "cute" ecological factors. A management strategy which caters for the needs of different visitors should be able to satisfy a greater number of visitors with less pressure on the sensitive zones.

APPENDICES

APPENDIX A
Makuleke - Off-Road Driving Policy

Given the pressures of commercial ecotourism operation within the South African lowveld and the belief that it is possible to engage in off-road driving without suffering major environmental impact, Wilderness Safaris, The Outpost and Ecotraining have decided to take up the right as expressed in their respective contracts with the Makuleke CPA to engage in limited off-road driving in the Makuleke Contractual Park (MCP). This contractual right was voluntarily suspended by all three parties in 2005 pending a better understanding of the area.

This is a draft document and considered dynamic. We anticipate adapting the approach based on the findings of various monitoring efforts and also as we encounter specific obstacles or challenges.

1) What is the aim?

To improve the quality (and in some instances quantity) of predator sightings (lion, leopard, cheetah, wild dog) in the Makuleke Contractual Park (MCP) in order to bolster the sustainability of the commercial operation and thus the viability of the three-way partnership between community, state and private sector and the continued conservation status of the land. Specifically we seek to i) prolong the length of predator sightings, ii) ensure that more vehicles are able to benefit from such sightings, iii) improve photographic opportunities for guests and iv) be able to access sightings that were previously not available to road-based viewing. The aim is not to engage in uncontrolled off-road driving in order to achieve this, but rather to promulgate a series of strictly controlled protocols that allow improved sightings as a result of very limited off-road access and which do not impact on the environment in an unsustainable way. It is our intention that this policy sets a new standard for off-road driving that can be exported elsewhere in South Africa.

An example of where this practice might be employed is where a lion pride is encountered on Rhino Boma Road in the early morning. The first vehicle has a good sighting but as the sun climbs the lions move off the road into the shade of some mopane scrub. The second vehicle is unable to see the lions and no vehicles in the afternoon are able to see the lions. The lions are lying within 50m of the road and could easily be seen if the view were not obscured by the mopane. Under the guidelines presented here the vehicle could move as little as 20-30m off road getting a better angle view on the lions from the other side of the mopane.

In addition to strictly controlled and regulated off-roading events, we believe, bearing in mind that the current network was never designed with game viewing in mind, that an expanded road network within the MCP would be beneficial in a number of ways (i.e. reducing pressure on existing network, improving sightings etc). We also believe that the viability of the area would be greatly improved and the pressure on existing roads greatly reduced if appropriately converted vehicles access the road network of the KNP south of the Luvuvhu and made regular use of Thulamela.

Included in this document is a map featuring proposed roads (...) as well as the existing road network south of the Luvuvhu (...) which should be regularly utilized by the concessionaires.

Principles:

- The decision to test the sustainability of off-road driving will be for a trial period of no less than two years, subject to frequent internal monitoring and an independent evaluation during this trial period by an external expert (Mr Gerhard Nortjé, PhD study). The cost of this evaluation shall be borne by Wilderness Safaris and the researcher in his personal capacity. According to SANParks/KNP, the current indications are that, when properly managed, there seems to be no permanent negative impact due to off-road driving. This view is apparently supported by the Section Rangers, as well as the above-mentioned researcher, Mr Gerhard Nortjé (Final report to KNP available on request). Off-road driving is currently permitted in at least six of the seven private concessions.
- Wilderness Safaris, The Outpost and Ecotraining undertake to review the off-road driving policy before the two year trial period is complete if it is determined that the adverse impacts are of an unacceptable level. This determination will be guided by the findings of the independent researcher, Gerhard Nortjé, and a decision will be taken in consultation with the other concessionaires.
- This two year trial period will begin on 10 October 2008, following an initial assessment of the area on 1-5 October 2008 by Mr Nortjé. Quarterly reports are expected from Mr Nortjé as well as a final report following the two year trial period. At this point a decision will be taken by the concessionaires whether or not to continue or to suspend the practice of off-road driving in the Makuleke Contractual Park (MCP).
- Off-road driving is prohibited on certain sensitive sites which are considered to be vulnerable to impact such as the Ramsar pans (...), dry riverbeds such as the Limpopo River, any sodic site, any damp seepline and in the landscape type known as Makuleke Sandy Bushveld characterised by red sandy soils.
- In addition, off-road driving is expressing prohibited from taking place from the tar road (H1-9) within the MCP regardless of habitat type or sighting.
- All Concessionaires (Pafuri Camp, The Outpost, Ecotraining) and their employees must comply with the guidelines set out below.

- The usual game drive standards continue to apply insofar as only two vehicles being allowed in each sighting at any one time, and only one vehicle moving at a time and so on.
- The Concessionaires will maintain a register and record on a daily basis each off-road driving event that occurs, including all relevant details of the event (...). These individual concessionaire registers will be consolidated on a monthly basis. Failure to maintain the register will be cause for terminating any individual's permission to drive off-road and will be liable to financial penalty in that individual's personal capacity. Repeated transgressions are regarded as a dismissible offence and all guides operating in the MCP will sign adherence to the protocols.
- This register will be made available on a quarterly basis (or on request if more regularly) to KNP and the Makuleke JMB for their records and for independent monitoring.
- Under no circumstances is the off-road driving permitted in the MCP to be of a level undertaken in any of the private reserves on the KNP boundary such as the Sabi-Sand or Timbavati. Rather, within the MCP, we anticipate a far more conservative model based on that permitted in Zimbabwe national parks where vehicles are permitted to leave the road in order to gain a better view of animals in close proximity to it, but are not permitted to drive off road on the scale conducted in South Africa in general.

Guidelines:

- Off-road driving may only be undertaken in the event of a confirmed sighting of lion, leopard, wild dog, cheetah and white rhino.
- A confirmed sighting constitutes a visual of the animal in question, undisputed audio thereof or visual of an animal (kudu, nyala, and impala) repeatedly alarm calling in a manner that unequivocally indicates the presence of a predator. Alarm calls of species such as francolins or squirrels, tracks of predators (even drag marks), vultures and other signs do not constitute a confirmed sighting. Where necessary, visual must first be obtained on foot before proceeding by vehicle. This can be achieved in a way that does not disturb the animal and which allows a return to the area in a vehicle in the event of such a confirmed sighting.
- Species such as elephant and buffalo should be viewed from the road or on foot and no off-road driving should take place to view these species.
- Under no circumstances may vehicles leave the road for species other than those listed here, charismatic or not. Leaving the road is not a right that a paying guest can insist on in order to achieve a better sighting or photograph of species such as zebra.
- Off-road driving will be limited to **300 m** either side of existing tracks and roads in the MCP as listed under 'Specific' on the following page. Animals that move beyond this during hunting events or merely in the course of locomotion may not be followed beyond this limit. This is also applicable in circumstances where a large carcass with attendant predators or a den site might lie at more than 100 m from the road.

- Vehicles driving off-road **should under most circumstances** follow in the tracks of another vehicle and should avoid damage to any vegetation wherever possible. Where only one route is possible then the same set of tracks can be followed.
- Off-road driving is not permitted on sodic patches/duplex soils, on Ramsar site pans, dry riverbeds, damp seeplines, or in the red soils characteristic of Makuleke Sandy Bushveld evident on roads such as Lanner Drive and Caracal Link, in any area where gradient is suggestive of potential erosion problems or in wet conditions at any site.
- Off-road driving is not permitted in wet conditions. A period of 24 hours must pass following rainfall of 25 mm.
- Any off-road damage to be repaired as soon on the same or following day as is safe and practical (compaction reversed, ruts erased, tracks raked out of sandy soils etc).

APPENDIX B

Makuleke Elders' Questionnaire

16th January 2012

Number of elders?

- 6 elders.

Names of elders

- Ndlayi Ester Mngomnulu, Mammy Dumazi, Maria Baloyi, Anna Chauke, Sarah Baloyi and Suzani Manganyi

When removed from the Makuleke area?

- In 1969.

Exact positions of villages where they stayed, historical sites, cultivated fields/ lands, kraals, settlements

- Indicated on map (Fig. 2.17). They used to live in, and around, the Luvuvhu and Limpopo flood plains. Villages were on *koppies* surrounding pans and the flood plains. They did not farm inside the pans.

Did they cultivate on the first terrace in the river beds (Dundee Soil form)?

- No. They were afraid of hippos and flood waters.

What farming practises did they practise?

- They ploughed (maximum 25 cm deep). They also used to fish in the rivers.

How did they mange farming during flood and drought periods?

- During flood times they used to move their lands north to higher elevation areas. During drought they farmed close to the rivers.

What crops did they cultivate and when?

- Crops cultivated were maize, beans, pumpkins, okra, watermelons, sorghum, peanuts, Bambara groundnuts (grown underneath the soil), millet and sweet cane. The crops were planted during October/November and harvested toward the end of February/April. Temporary log houses were erected in the fields during planting and cultivation times, because they were afraid of lions. They were not afraid of the other animals.

What equipment did they use to plough and what kind of plough did they use?

- Donkey-drawn hand turn-plough (Fig. 2.18). No tractors were used. No oxen were used because, in 1938, there was an outbreak of the 'foot and mouth' disease in

Zimbabwe, which killed all oxen (cattle) in the Pafuri area, and the Kruger authorities banned all domestic cattle from the area. All livestock were killed and burned. They controlled weeds with pick-axes.

How big was the cultivated areas and what type of shape were they?

- The size of lands close to the rivers was very small (40 m x 40 m). The cultivated lands were between 1 and 2 hectares in size, with more or less squared shape. They cut some trees to make these lands, but left some trees in the middle of these cultivated fields for rest and shade.

Were the flood plains cover with grass or any other vegetation or were they devoid of any soil cover?

- There was lots of grass during summer months in the Luvuvhu flood plains, but they were devoid of any vegetation during the dry months.

Extrainformation

- **Explain the existence of the small ridges on the flood plains along the Luvuvhu River.**
  - No small ridges existed in the flood plains, except for termite mounds. The terrain was flat. Termite mounds were also beneath the soil. Only termites and frogs occurred. They used to plough them open when preparing the land. They think it was the floods that caused these small ridges.
- **Explain the road network, the traffic and other infrastructure in the area**
  - The shop owners were driving their trucks towards Crook's Corner and Fernando's shop. Only one road existed from south towards the east, to Crook's Corner. Only this road was used for traffic, including KNP rangers. One-track paths were used to draw cards/slays with harvested crops to sell at the shop.
- **Kraals and dangers from wild animals**
  - They had wooden kraals with no wires. They kept many donkeys in kraals. From 5 o'clock in the afternoon until before dark, the lions used to try to kill the donkeys. They used to burn fire wood to try to keep away the lions. Elephants also used to raid the crops. That is why the pumpkins were put on the roofs of houses.
- **What did they trade?**
  - They used to trade animal bones for bananas. The white people wanted it.

APPENDIX C

Table C.1 ORD register, front page

Off-Road Driving Register											
PAFURI CONCESSION, KNP				**Year:**		**Month:**				Page 01	front
Day of month											
Time											
GPS coordinate from road (entrance + exit)	S E	S E	S E	S E	S E	S E	S E	S E	S E	S E	S E
GPS coordinate at sighting	S E	S E	S E	S E	S E	S E	S E	S E	S E	S E	S E
Distance (m)											
Direction travelled											
Weather conditions											
Temp. (°C)											
Sighting / Reason for ORD											
Vegetation type											
Topography											
Soil type											
Soil (wet / dry?)	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry	wet / dry
Slope length (m)											
Slope (%)	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30	< 7 7 - 15 15 - 20 20 - 25 25 - 30 > 30

Table C.1 ORD register, back page

Off-Road Driving Register											
PAFURI CONCESSION, KNP				**Year:**		**Month:**				Page 01 back	
Day of month											
Time											
How many times were ORD's prevented?											
Visual damage <u>before</u> ORD (soil / vegetation)											
Visual damage <u>after</u> ORD (soil / vegetation)											
Fires?	no / yes	no / yes	no / yes	no / yes	no / yes	no / yes	no / yes	no / yes	no / yes	no / yes	no / yes
Crossed a river / a spruit / a drainage line?	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line	no / yes river spruit drainage line
Total persons per vehicle											
Number of foreigners											
Number of SA tourists											
Number of vehicles per sighting											
Tyre make											
Tyre size											
Tyre pressure											
General remarks											

APPENDIX D

Statistical Data

Table D.1a Compare mean compaction across number of passes at tyre pressure 80 kPa

Soil type	Condition	Depth	Compaction						ANOVA	Bonferroni multiple comparisons between the 3 passes		
			1 Pass		2 Passes		3 Passes					
			Mean	S. D.	Mean	S. D.	Mean	S. D.		1 vs 2	1 vs 3	2 vs 3
1	**Dry**	0 - 5	1623.68	858.25	1519.44	506.33	2267.90	602.32	.147			
		6 - 15	4236.25	574.33	2689.17	991.69	2923.39	575.26	.035*	.061 **	.089 **	1.000
		16 - 25			3422.50	1276.43	3827.08	1282.76	.801			
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4554.17	633.13	4245.83	396.99	4683.33	314.11	.281			
	Wet	0 - 5	1691.67	870.21	2092.87	500.41	2172.69	663.57	.457			
		6 - 15	3130.17	1472.32	2416.63	259.98	3098.41	521.38	.583			
		16 - 25	3398.95	290.21	3808.80	626.95	3981.00	1528.77	.807			
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4491.67	318.85	4556.17	685.94	4543.67	596.56	.978			
2	**Dry**	0 - 5	639.90	552.80	518.70	383.96	717.00	458.51	.766			
		6 -15	1957.77	431.09	2229.18	630.14	2503.65	760.41	.342			
		16 - 25	2829.85	584.71	3178.01	890.01	3101.73	452.05	.646			
		26 - 35	2900.87	684.67	2344.62	334.85	2782.43	487.73	.235			
		36 - 50	2113.68	456.90	1884.11	323.21	2116.82	585.87	.668			
		Max	3472.67	569.58	3622.83	624.77	3599.83	345.21	.869			
	Wet	0 - 5	895.17	440.57	1374.38	434.45	1880.63	493.65	.007*	.268	.006 *	.223
		6 -15	3639.25	1020.43	3779.00	514.96	4189.00	649.25	.512			
		16 - 25	3693.10	165.32	3986.23	688.00			.612			
		26 - 35	3828.70	174.94	3557.72	1111.96			.767			
		36 - 50	3076.63	1444.81	2150.00	1647.56			.611			
		Max	4114.50	972.94	4695.83	206.41	4887.50	136.70	.087**	.309	.107	1.000
3	**Dry**	0 - 5	850.26	692.38	1087.82	780.68	772.43	574.25	.715			
		6 -15	4138.30	558.20	3597.56	1145.33	3775.55	1142.61	.691			
		16 - 25			2862.88	1858.44	2613.70	438.74	.969			
		26 - 35			2940.83	855.36	4132.47	535.32	.091**			
		36 - 50										
		Max	4616.50	373.10	4610.17	294.41	4812.17	241.15	.453			
	Wet	0 - 5	620.83	254.63	561.67	184.00	664.17	365.48	.817			
		6 -15	2148.84	293.99	2017.71	640.00	1945.63	625.04	.809			
		16 - 25			2882.23	1095.11	1829.17	473.78	.366			
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		Max	4541.67	356.60	4333.33	501.67	4004.17	345.12	.103			

*Significant at the 5% level **Significant at the 10% level

Table D.1b Compare mean compaction across number of passes at tyre pressure 160 kPa

Soil type	Condition	Depth	Compaction						ANOVA	Bonferroni multiple comparisons between the 3 passes		
			1 Pass		2 Passes		3 Passes					
			Mean	S. D.	Mean	S. D.	Mean	S. D.		1 vs 2	1 vs 3	2 vs 3
1	**Dry**	0 - 5	1726.32	413.15	1860.40	282.07	1625.28	574.89	.658			
		6 - 15	3296.85	969.66	3381.39	812.37	3889.93	707.87	.549			
		16 - 25	3643.75	8.84	3176.56	143.63			.012*		*	
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4595.83	464.332	4627.00	528.13	4450.00	550.45	.820			
	Wet	0 - 5	1883.73	339.58	1925.68	580.08	1886.53	489.29	.986			
		6 - 15	3807.28	726.16	3384.37	525.91	3763.33	735.45	.765			
		16 - 25	There are fewer than two groups for dependent variable avg16-25									
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4687.50	413.45	4304.17	714.74	4377.00	477.27	.459			
2	**Dry**	0 - 5	803.23	718.38	656.57	589.54	837.37	683.23	.884			
		6 -15	2216.10	312.05	2328.07	778.84	2527.23	1033.59	.804			
		16 - 25	2880.34	645.83	3122.07	694.06	3287.58	579.12	.616			
		26 - 35	2745.06	809.69	3292.13	374.14	3134.78	387.10	.281			
		36 - 50	2245.01	595.06	2516.24	514.00	2505.03	505.08	.665			
		Max	4091.33	752.45	3997.50	483.71	4212.33	686.85	.850			
	Wet	0 - 5	728.73	285.37	1017.50	571.29	1360.42	346.14	.060	.755	.059**	.531
		6 -15	3663.85	336.21	3534.82	510.97	3659.88	600.38	.877			
		16 - 25	3893.75	411.89	3561.25	427.89	3492.50	362.55	.556			
		26 - 35	3818.75	164.40	4064.10	690.24	3900.00	823.78	.912			
		36 - 50	2063.33	174.42	2340.27	890.45	2285.00	1286.93	.944			
		Max	4725.00	200.62	4687.50	188.91	4508.33	489.30	.483			
3	**Dry**	0 - 5	297.90	238.28	385.37	399.47	449.53	648.95	.851			
		6 -15	3035.90	1064.83	3496.06	880.95	2287.94	708.41	.145			
		16 - 25	2858.90	675.66	3796.07	947.25	2485.44	515.06	.076**	.321	1.000	.084 **
		26 - 35	3154.23	450.86	4037.77	429.97	3431.71	619.95	.142			
		36 - 50	3703.20	560.44			4134.95	551.61	.519			
		Max	4747.50	180.75	4660.17	507.03	4776.83	274.00	.836			
	Wet	0 - 5	720.83	398.01	1093.33	665.32	1143.33	344.15	.293			
		6 -15	2421.25	782.80	2665.00	1065.21	2933.96	367.39	.547			
		16 - 25	3886.25	581.60	3029.17	632.71	2841.25	730.09	.320			
		26 - 35	3968.75	309.36	3914.58	723.77	3496.25	5.30	.645			
		Max	4412.50	324.71	4558.33	318.85	4216.67	550.15	.378			

*Significant at the 5% level **Significant at the 10% level

Table D.1c Compare mean compaction across number of passes at tyre pressure 240 kPa

Soil type	Condition	Depth	Compaction						ANOVA	Bonferroni multiple comparisons between the 3 passes		
			1 Pass		2 Passes		3 Passes					
			Mean	S. D.	Mean	S. D.	Mean	S. D.		1 vs 2	1 vs 3	2 vs 3
1	Dry	0 - 5	1883.90	320.96	1772.52	610.47	1721.67	538.81	.852			
		6 - 15	4787.50	229.81	4546.87	570.10	4231.67	357.96	.389			
		16 - 25	There are fewer than two groups for dependent variable avg16-25.									
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4662.50	217.23	4174.83	1024.82	4287.50	518.833	.444			
	Wet	0 - 5	2033.79	432.20	2305.00	288.11	1528.10	452.16	.013*	.767	.131	.012*
		6 - 15	3397.17	330.87	4051.57	668.02	4149.06	306.27	.258			
		16 - 25	There are fewer than two groups for dependent variable avg16-25.									
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4377.00	654.350	4733.33	245.79	3989.50	936.95	.196			
2	Dry	0 - 5	159.10	205.77	213.27	347.02	132.03	251.11	.874			
		6 -15	1487.55	499.77	1867.07	880.87	1581.33	473.72	.581			
		16 - 25	2150.07	669.42	2681.45	741.88	2413.80	885.30	.506			
		26 - 35	2596.08	671.31	2994.52	612.90	2826.30	635.43	.569			
		36 - 50	2755.39	659.80	3023.67	451.07	2671.79	543.45	.536			
		Max	3891.33	586.02	3951.83	284.90	3760.17	500.08	.777			
	Wet	0 - 5	684.17	470.58	789.17	788.01	735.83	556.43	.958			
		6 -15	3103.33	914.09	3100.00	737.44	3731.06	837.33	.363			
		16 - 25	3067.00	896.91	3595.63	1317.24	3670.00	11467.0	.679			
		26 - 35	3077.50	711.19	3142.50	458.20	3336.25	457.68	.802			
		36 - 50	2814.66	765.23	2624.44	917.65	2969.78	288.71	.810			
		Max	4025.00	788.35	4375.00	608.28	4520.83	603.00	.442			
3	Dry	0 - 5	999.87	345.89	1006.57	462.57	609.03	490.41	.230			
		6 -15	4148.62	1067.47	4368.75	824.91	3858.83	998.71	.721			
		16 - 25	2764.40	686.57			2481.00	432.06	.781			
		26 - 35	2513.50	1480.66			2070.17	967.71	.878			
		36 - 50	3054.36	514.96			2982.38	1289.41	.942			
		Max	4831.17	397.46	4558.00	404.55	4820.83	279.92	.365			
	Wet	0 - 5	465.83	250.97	581.23	316.21	707.50	316.27	.391			
		6 -15	2347.33	531.92	2253.93	421.84	2740.20	462.17	.203			
		16 - 25	4526.04	645.28	3609.37	737.33	3105.63	725.46	.052**	.296	.057**	1.000
		26 - 35			3702.19	839.54	3511.81	574.31	.459			
		Max	4675.00	581.16	4420.83	269.45	4350.00	399.69	.419			

*Significant at the 5% level **Significant at the 10% level

Table D.1d Compare mean compaction across number of passes at tyre pressure 320 kPa

Soil type	Condition	Depth	Compaction						ANOVA	Bonferroni multiple comparisons between the 3 passes		
			1 Pass		2 Passes		3 Passes					
			Mean	S. D.	Mean	S. D.	Mean	S. D.		1 vs 2	1 vs 3	2 vs 3
1	**Dry**	0 - 5	1697.83	291.74	1696.92	377.78	1541.67	177.95	.582			
		6 -15	3115.00	296.99	3757.50	934.47	2481.61	772.01	.304			
		16 - 25	There are fewer than two groups for dependent variable avg16-25.									
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4677.00	339.21	4395.83	421.43	4175.00	363.66	.101			
	Wet	0 - 5	1569.77	284.30	1652.50	353.31	1606.67	462.95	.929			
		6 -15	3241.39	230.92	3428.74	316.92	4033.06	685.72	.070**	1.000	.091**	.210
		16 - 25	There are fewer than two groups for dependent variable avg16-25									
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4541.67	466.55	4554.17	181.26	4562.50	365.98	.995			
2	**Dry**	0 - 5	461.60	402.04	320.73	382.00	486.17	387.74	.736			
		6 -15	2379.55	656.69	2393.32	782.26	2672.92	642.58	.718			
		16 - 25	3290.73	895.68	3382.58	901.14	3576.63	320.66	.802			
		26 - 35	3184.26	720.97	3042.30	286.72	3496.00	589.13	.502			
		36 - 50	2472.47	327.17	2352.92	153.37	2759.79	676.55	.415			
		Max	3989.33	613.86	4006.17	685.70	4201.67	454.32	.791			
	Wet	0 - 5	1807.50	542.83	1551.23	425.89	1561.46	227.99	.504			
		6 -15	3896.67	594.07	4028.94	409.35	4539.17	285.58	.139			
		16 - 25	4086.23	104.54	4012.50	643.22			.507			
		26 - 35	4585.42	55.98	4465.92	484.25			.762			
		36 - 50	There are fewer than two groups for dependent variable avg36-50.									
		Max	4858.33	147.20	4629.17	402.62	4495.83	514.15	.289			
3	**Dry**	0 - 5	670.73	726.57	739.83	560.65	760.33	569.66	.967			
		6 -15	3011.36	1137.69	3467.03	1153.49	3270.40	882.10	.780			
		16 - 25	2484.70	838.57	2600.80	542.72	2449.70	470.93	.932			
		26 - 35	2291.44	690.50	1632.73	660.03	1938.07	678.28	.376			
		36 - 50	2500.36	635.15	2409.07	476.99	2909.24	831.21	.481			
		Max	4639.50	548.75	4835.17	201.98	4845.50	192.06	.541			
	Wet	0 - 5	597.50	278.20	731.67	407.22	630.00	187.48	.733			
		6 -15	2567.32	448.39	2777.59	681.92	2621.70	271.96	.753			
		16 - 25	4540.63	366.77	3505.83	1687.74	3454.07	1663.94	.481			
		26 - 35	There are fewer than two groups for dependent variable avg26-35.									
		Max	4654.17	321.10	4693.67	251.78	4362.50	444.06	.231			

*Significant at the 5% level **Significant at the 10% level

Table D.2a Comparison of threshold values at tyre pressure 80 kPa, dry conditions

Soil type	Depth	Horizontal distance	Mean	S. D.	ANOVA
1	0 - 5	On	1337.92	1011.93	
		25 cm	2105.47	306.68	.277
		50 cm	1855.56	369.44	
		1 m	2374.36	537.51	.192
		1.5 m	2361.67	292.16	.168
		2 m	2411.97	230.78	.148
	6 - 15	On	3792.50	236.88	
		25 cm			
		50 cm			
		1 m	4087.50	901.56	.698
		1.5 m	3941.67	906.93	.842
		2 m	3738.70	.	.883
2	0 - 5	On	510.80	711.54	
		25 cm	1223.60	641.77	.340
		50 cm	1190.00	1173.80	.466
		1 m	1429.17	524.44	.222
		1.5 m	1380.00	947.52	.319
		2 m	1452.50	109.60	
	6 - 15	On	1729.03	206.75	
		25 cm	4571.50	.	.007*
		50 cm	4010.40	101.68	.001*
		1 m	3740.00	.	.014*
		1.5 m	3258.75	885.65	.053**
		2 m	3408.75	1108.39	.069**
	16 - 25	On	2443.23	377.72	
		25 cm			
		50 cm	2667.85	184.77	.506
		1 m	3187.50	.	.230
		1.5 m	2486.25	917.47	.944
		2 m	1836.25	408.35	.185
	26 - 35	On	2642.80	590.40	
		25 cm			
		50 cm	1879.37	174.94	.188
		1 m	1581.67	.	.260
		1.5 m	1907.50	182.67	.201
		2 m	1669.17	243.95	.124

*Significant at the 5% level **Significant at the 10% level

Table D.2b Comparison of threshold values at tyre pressure 160 kPa, dry conditions

Soil type	Depth	Horizontal distance	Mean	S. D.	ANOVA
1	0 - 5	On	1630.00	494.798	
		25 cm	1937.36	546.984	.510
		50 cm	1905.36	320.625	.464
		1 m	2541.96	156.022	.038*
		1.5 m	1396.53	463.776	.583
		2 m	1893.30	522.703	.561
	6 - 15	On	3982.50	.	
		25 cm			
		50 cm	3769.44	.	.464
		1 m			
		1.5 m			
		2 m	4775.00	.	.
2	0 - 5	On	1184.07	910.27	
		25 cm	1060.00	565.69	.878
		50 cm	1838.63	669.81	.455
		1 m	888.70	224.44	.697
		1.5 m	2071.20	319.90	.294
		2 m	837.50	781.35	.692
	6 - 15	On	1729.03	206.75	
		25 cm	4571.50	.	.007*
		50 cm	4010.40	101.68	.001*
		1 m	3740.00	.	.014*
		1.5 m	3258.75	885.65	.053**
		2 m	3408.75	1108.39	.069**
	16 - 25	On	2443.23	377.722	
		25 cm			
		50 cm	1879.37	174.94	.506
		1 m	3187.50		.230
		1.5 m	2486.25	917.47	.944
		2 m	1836.25	408.35	.185
	26 - 35	On	2129.85	859.06	
		25 cm			
		50 cm	3135.00		.515
		1 m			
		1.5 m			
		2 m	2561.60		.752

*Significant at the 5% level **Significant at the 10% level

Table D.2c Comparison of threshold values at tyre pressure 240 kPa, dry conditions

Soil type	Depth	Horizontal distance	Mean	S. D.	ANOVA
1	0 - 5	On			
		25 cm			
		50 cm			
		1 m			
		1.5 m			
		2 m			
	6 - 15	On			
		25 cm			
		50 cm			
		1 m			
		1.5 m			
		2 m			
2	0 - 5	On	105.80	111.03	
		25 cm	650.00	480.83	.134
		50 cm	847.50	342.95	.034*
		1 m	640.00	424.26	.111
		1.5 m	207.50	293.45	.603
		2 m	42.50	60.10	.527
	6 - 15	On	1358.17	501.84	
		25 cm	4441.67	789.60	.012*
		50 cm	4350.00	565.69	.008*
		1 m	3360.60	1103.94	.063**
		1.5 m	3172.35	753.28	.045*
		2 m	2163.75	1210.92	.356
	16 - 25	On	1953.23	468.34	
		25 cm			
		50 cm			
		1 m	3471.25	47.73	.023*
		1.5 m	4271.20		.050*
		2 m	2758.75	2229.15	.558
	26 - 35	On	2321.93	497.93	
		25 cm			
		50 cm			
		1 m	1965.40	655.82	.533
		1.5 m	2952.47	.	.387
		2 m	2960.00	1612.20	.541

*Significant at the 5% level **Significant at the 10% level

Table D.2d Comparison of threshold values at tyre pressure 320 kPa, dry conditions

Soil type	Depth	Horizontal distance	Mean	S. D.	ANOVA
1	0 - 5	On	1635.00	346.74	
		25 cm	2216.28	658.04	.247
		50 cm	1687.40	824.61	.924
		1 m	1845.42	464.78	.564
		1.5 m	1143.33	295.90	.135
		2 m	1385.80	429.59	.478
	6 - 15	On	3115.00	296.99	
		25 cm			
		50 cm	4775.00	141.42	.019*
		1 m	3631.25	.	.391
		1.5 m	4106.11	439.07	.072**
		2 m	3585.42	144.37	.182
2	0 - 5	On	423.33	353.46	
		25 cm	1342.40	130.96	.043*
		50 cm	1651.20	305.75	.028*
		1 m	1542.50	753.07	.100
		1.5 m	1430.00	360.62	.053**
		2 m	2166.20	1058.96	.067
	6 - 15	On	2421.47	517.20	
		25 cm	4656.00		.065**
		50 cm	4500.00		.074**
		1 m	4337.50		.085**
		1.5 m	4066.67	1001.73	.086**
		2 m			
	16 - 25	On			
		25 cm			
		50 cm			
		1 m			
		1.5 m			
		2 m			
	26 - 35	On			
		25 cm			
		50 cm			
		1 m			
		1.5 m			
		2 m			

*Significant at the 5% level **Significant at the 10% level

Table D.3 Coefficients of variation

			1 Pass			2 Passes			3 Passes		
Soil type	**Condition**	**Depth**	**Mean**	**S. D.**	**Coefficient of Variation**	**Mean**	**S. D.**	**Coefficient of Variation**	**Mean**	**S. D.**	**Coefficient of Variation**
1	**Dry**	0 - 5	1818.87	497.35	27.34	1808.03	513.90	28.42	1974.12	581.04	29.43
		6 - 15	3675.82	874.21	23.78	3189.54	720.88	22.60	3013.45	1079.70	35.83
		16 - 25	3524.60	1041.06	29.54	2887.24	767.64	26.59	2612.07	801.19	30.67
		26 - 35	3608.54	878.11	24.33	3808.75	22.98	0.60	2737.50		
		Max	3437.00	1194.64	34.76	4370.79	575.24	13.16	4223.38	727.61	17.23
	Wet	0 - 5	1872.44	461.64	24.65	1769.23	466.12	26.35	1807.30	578.13	31.99
		6 - 15	3282.28	826.59	25.18	3293.35	754.78	22.92	3091.88	701.52	22.69
		16 - 25	4033.08	797.84	19.78	4027.08	358.07	8.89	3325.00	281.74	8.47
		26 - 35	4233.33								
		Max	4422.38	589.05	13.32	4385.42	563.42	12.85	4466.67	520.90	11.66
2	**Dry**	0 - 5	633.25	626.22	98.89	887.46	649.02	73.13	734.47	655.89	89.30
		6 - 15	3068.64	1073.20	34.97	2900.61	1225.21	42.24	2918.09	908.22	31.12
		16 - 25	3668.50	794.49	21.66	3113.67	1167.32	37.49	3463.26	777.15	22.44
		26 - 35	3351.92	664.86	19.84	3124.55	820.08	26.25	3266.73	679.26	20.79
		Max	4573.84	563.93	12.33	4269.58	866.56	20.30	4253.96	653.11	15.35
	Wet	0 - 5	928.74	491.40	52.91	1022.60	516.60	50.52	1133.07	571.42	50.43
		6 - 15	3414.45	923.71	27.05	3558.81	757.09	21.27	3368.90	733.05	21.76
		16 - 25	3190.05	1174.51	36.82	3565.94	985.09	27.62	3546.13	866.10	24.42
		26 - 35	2765.71	1569.65	56.75	2840.00	824.67	29.04	3601.40	640.36	17.78
		Max	4418.75	637.43	14.43	4384.37	610.28	13.92	4505.21	464.97	10.32
3	**Dry**	0 - 5	1329.25	634.34	47.72	1079.77	513.76	47.58	1099.05	691.17	62.89
		6 - 15	3780.29	890.41	23.55	3915.77	816.84	20.86	3384.63	1094.40	32.33
		16 - 25	2584.60	615.64	23.82	2738.64	710.58	25.95	2191.71	968.70	44.20
		26 - 35	3014.89	769.46	25.52	2807.37	1108.57	39.49	2498.29	886.43	35.48
		Max	4768.81	376.25	7.89	4838.79	365.73	7.56	4744.04	488.24	10.29
	Wet	0 - 5	641.88	328.34	51.15	681.04	480.53	70.56	582.50	324.53	55.71
		6 - 15	2316.28	765.81	33.06	2338.22	865.86	37.03	1983.59	719.99	36.30
		16 - 25	3404.48	1150.87	33.80	3050.22	1543.37	50.60	3090.22	1371.76	44.39
		26 - 35	4228.10	304.59	7.20	3186.82	1304.72	40.94	3405.79	1555.26	45.67
		Max	4575.00	503.84	11.01	4322.92	498.04	11.52	4610.42	360.40	7.82

Table D.4 Animal paths vs. controls

Site	Condition	Depth	In/Next	Mean	Std Dev	p-value
1	**Wet**	Avg 0 - 5	in path	1536.77	728.85	
			next to path	1168.83	1015.73	0.465
		Avg 6 - 25	in path			
			next to path	3149.72	1176.38	-
		Avg 26 - 35	in path			
			next to path	2300.00	537.40	-
		Max	in path	4437.40	859.79	
			next to path	3785.00	784.54	0.175
	Dry	Avg 0 - 5	in path	1534.32	532.14	
			next to path	812.40	395.75	0.047*
		Avg 6 - 25	in path	3185.32	366.60	
			next to path	2243.77	803.52	0.076**
		Avg 26 - 35	in path	3200.55	270.40	
			next to path	2061.87	323.53	0.021*
		Max	in path	4392.40	314.74	
			next to path	3287.40	991.23	0.116
2	**Wet**	Avg 0 - 5	in path	1308.00	296.29	
			next to path	556.00	335.84	<0.0001*
		Avg 6 - 25	in path	3114.42	563.33	
			next to path	2029.48	553.09	0.001*
		Avg 26 - 35	in path	-	-	
			next to path	-	-	
		Max	in path	4240.00	602.56	
			next to path	4192.50	540.33	0.940
	Dry	Avg 0 - 5	in path	1355.96	464.69	
			next to path	497.92	444.20	0.047
		Avg 6 - 25	in path	2968.01	966.76	
			next to path	2762.38	1026.35	0.917
		Avg 26 - 35	in path	1568.05	285.47	
			next to path	1610.00	602.34	0.773
		Max	in path	4855.00	109.55	
			next to path	4670.00	417.36	1.000
3	**Wet**	Avg 0 - 5	in path	2368.47	195.92	
			next to path	1890.60	591.79	0.221
		Avg 6 - 25	in path	3508.44	450.49	
			next to path	3152.10	418.14	0.157
		Avg 26 - 35	in path	-	-	
			next to path	-	-	-
		Max	in path	4769.80	181.59	
			next to path	4556.25	187.50	0.085**
	Dry	Avg 0 - 5	in path	1390.77	473.86	
			next to path	2021.75	534.65	0.117
		Avg 6 - 25	in path	-	-	
			next to path	3134.54	434.30	-
		Avg 26 - 35	in path	-	-	
			next to path	-	-	-
		Max	in path	3660.00	973.17	
			next to path	4490.00	310.54	0.075**

*Significant at the 5% level **Significant at the 10% level

Table D.5a Animal paths vs. ORD at 80 kPa

Site	Condition	Depth	On/In	Mean	Std Dev	p-value
1	**Wet**	Avg 0 - 5	on ORD track	2172.69	663.57	
			in path	2368.47	195.92	.662
		Avg 6 - 15	on ORD track	3098.41	521.39	
			in path	3508.44	450.49	.143
		Avg 16 - 25	on ORD track	3981.00	1528.76	
			in path	-	-	-
		Max	on ORD track	4543.67	596.56	
			in path	4769.80	181.59	.972
	Dry	Avg 0 - 5	on ORD track	2267.90	602.32	
			in path	1390.77	473.86	.030*
		Avg 6 - 15	on ORD track	2923.39	575.26	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4683.33	314.11	
			in path	3660.00	973.17	.030*
2	**Wet**	Avg 0 - 5	on ORD track	1880.62	493.65	
			in path	1536.77	728.85	.792
		Avg 6 - 15	on ORD track	4189.00	649.24	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4887.50	136.70	
			in path	4437.40	859.79	.305
	Dry	Avg 0 - 5	on ORD track	717.00	458.51	
			in path	1534.32	532.14	.030*
		Avg 6 - 15	on ORD track	2503.65	760.41	
			in path	3185.32	366.60	.247
		Avg 16 - 25	on ORD track	3101.73	452.05	
			in path	3362.15	612.85	.537
		Max	on ORD track	3599.83	345.21	
			in path	4392.40	314.74	.009*
3	**Wet**	Avg 0 - 5	on ORD track	664.17	365.48	
			in path	1308.00	296.29	.005*
		Avg 6 - 15	on ORD track	1945.62	625.03	
			in path	3114.42	563.33	.002*
		Avg 16 - 25	on ORD track	1829.17	473.78	
			in path	3822.92	1293.42	.200
		Max	on ORD track	4004.17	345.11	
			in path	4240.00	602.56	.155
	Dry	Avg 0 - 5	on ORD track	772.43	574.25	
			in path	1355.96	464.69	.126
		Avg 6 - 15	on ORD track	3775.55	1142.61	
			in path	2968.01	966.76	.247
		Avg 16 - 25	on ORD track	2613.70	438.74	
			in path	1907.45	864.73	.229
		Max	on ORD track	4812.17	241.15	
			in path	4855.00	109.54	.662

*Significant at the 5% level **Significant at the 10% level

Table D.5b Animal paths vs. ORD at 160 kPa

Site	Condition	Depth	On/In	Mean	Std Dev	p-value
1	**Wet**	Avg 0 - 5	on ORD track	1886.53	489.29	
			in path	2368.47	195.92	.126
		Avg 6 - 15	on ORD track	3763.33	735.45	
			in path	3508.44	450.49	.400
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4377.00	477.27	
			in path	4769.80	181.59	.139
	Dry	Avg 0 - 5	on ORD track	1625.28	574.89	
			in path	1390.77	473.86	.537
		Avg 6 - 15	on ORD track	3889.93	707.87	
			in path	-		-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4450.00	550.45	
			in path	3660.00	973.17	.069**
2	**Wet**	Avg 0 - 5	on ORD track	1360.42	346.14	
			in path	1536.77	728.84	.537
		Avg 6 - 15	on ORD track	3659.88	600.38	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4508.33	489.30	
			in path	4437.40	859.79	.931
	Dry	Avg 0 - 5	on ORD track	837.37	683.23	
			in path	1534.32	532.14	.177
		Avg 6 - 15	on ORD track	2527.23	1033.58	
			in path	3185.32	366.60	.177
		Avg 16 - 25	on ORD track	3287.58	579.12	
			in path	3362.15	612.85	.841
		Max	on ORD track	4212.33	686.85	
			in path	4392.40	314.74	.755
3	**Wet**	Avg 0 - 5	on ORD track	1143.33	344.15	
			in path	1308.00	296.29	.352
		Avg 6 - 15	on ORD track	2933.96	367.39	
			in path	3114.42	563.33	.635
		Avg 16 - 25	on ORD track	2841.25	730.09	
			in path	3822.92	1293.42	.667
		Max	on ORD track	4216.67	550.15	
			in path	4240.00	602.56	.813
	Dry	Avg 0 - 5	on ORD track	449.53	648.95	
			in path	1355.96	464.69	.052**
		Avg 6 - 15	on ORD track	2287.94	708.41	
			in path	2968.01	966.76	.421
		Avg 16 - 25	on ORD track	2485.44	515.06	
			in path	1907.45	864.73	.413
		Max	on ORD track	4776.83	274.00	
			in path	4855.00	109.54	.792

*Significant at the 5% level **Significant at the 10% level

Table D.5c Animal paths vs. ORD at 240 kPa

Site	Condition	Depth	On/In	Mean	Std Dev	p-value
1	**Wet**	Avg 0 - 5	on ORD track	1528.10	452.16	
			in path	2368.47	195.91	.017*
		Avg 6 - 15	on ORD track	4149.06	306.27	
			in path	3508.44	450.49	.400
		Avg 16 - 25	on ORD track	-	-	
			in path	-	-	
		Max	on ORD track	3989.50	936.95	
			in path	4769.80	181.59	.310
	Dry	Avg 0 - 5	on ORD track	1721.67	538.81	
			in path	1390.77	473.86	.429
		Avg 6 - 15	on ORD track	4231.67	357.96	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4287.50	518.83	
			in path	3660.00	973.17	.329
2	**Wet**	Avg 0 - 5	on ORD track	735.83	556.43	
			in path	1536.77	728.84	.126
		Avg 6 - 15	on ORD track	3731.06	837.33	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4520.83	603.00	
			in path	4437.40	859.79	.894
	Dry	Avg 0 - 5	on ORD track	132.03	251.11	
			in path	1534.32	532.14	.004*
		Avg 6 - 15	on ORD track	1581.33	473.72	
			in path	3185.32	366.60	.004*
		Avg 16 - 25	on ORD track	2413.80	885.30	
			in path	3362.15	612.85	.082**
		Max	on ORD track	3760.17	500.08	
			in path	4392.40	314.74	.113
3	**Wet**	Avg 0 - 5	on ORD track	707.50	316.27	
			in path	1308.00	296.29	.005*
		Avg 6 - 15	on ORD track	2740.21	462.17	
			in path	3114.42	563.33	.313
		Avg 16 - 25	on ORD track	3105.62	725.46	
			in path	3822.92	1293.42	.533
		Max	on ORD track	4350.00	399.69	
			in path	4240.00	602.56	.896
	Dry	Avg 0 - 5	on ORD track	609.03	490.41	
			in path	1355.96	464.69	.052**
		Avg 6 - 15	on ORD track	3858.83	998.71	
			in path	2968.01	966.76	.247
		Avg 16 - 25	on ORD track	2481.00	432.06	
			in path	1907.45	864.73	.343
		Max	on ORD track	4820.83	279.92	
			in path	4855.00	109.54	.697

*Significant at the 5% level **Significant at the 10% level

Table D.5d Animal paths vs. ORD at 320 kPa

Site	Condition	Depth	On/In	Mean	Std Dev	p-value
1	**Wet**	Avg 0 - 5	on ORD track	1606.67	462.95	
			in path	2368.47	195.91	.004*
		Avg 6 - 15	on ORD track	4033.06	685.72	
			in path	3508.44	450.49	.629
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4562.50	365.98	
			in path	4769.80	181.59	.227
	Dry	Avg 0 - 5	on ORD track	1541.67	177.95	
			in path	1390.77	473.86	.792
		Avg 6 - 15	on ORD track	2481.61	772.01	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4175.00	363.66	
			in path	3660.00	973.17	.537
2	**Wet**	Avg 0 - 5	on ORD track	1561.46	227.99	
			in path	1536.77	728.85	.662
		Avg 6 - 15	on ORD track	4539.17	285.57	
			in path	-	-	-
		Avg 16 - 25	on ORD track			
			in path			
		Max	on ORD track	4495.83	514.15	
			in path	4437.40	859.79	.931
	Dry	Avg 0 - 5	on ORD track	486.17	387.74	
			in path	1534.32	532.14	.017*
		Avg 6 - 15	on ORD track	2672.92	642.58	
			in path	3185.32	366.60	.177
		Avg 16 - 25	on ORD track	3576.63	320.66	
			in path	3362.15	612.85	.429
		Max	on ORD track	4201.67	454.32	
			in path	4392.40	314.74	.305
3	**Wet**	Avg 0 - 5	on ORD track	630.00	187.48	
			in path	1308.00	296.29	<.0001*
		Avg 6 - 15	on ORD track	2621.70	271.96	
			in path	3114.42	563.33	.147
		Avg 16 - 25	on ORD track	3454.07	1663.93	
			in path	3822.92	1293.42	1.000
		Max	on ORD track	4362.50	444.06	
			in path	4240.00	602.56	.652
	Dry	Avg 0 - 5	on ORD track	760.33	569.66	
			in path	1355.96	464.69	.082**
		Avg 6 - 15	on ORD track	3270.40	882.10	
			in path	2968.01	966.76	.662
		Avg 16 - 25	on ORD track	2449.70	470.93	
			in path	1907.45	864.73	.476
		Max	on ORD track	4845.50	192.06	
			in path	4855.00	109.54	.890

*Significant at the 5% level **Significant at the 10% level

APPENDIX E

Tourism Questionnaire

May 2011

Centre for Wildlife Management,
Department of Animal & Wildlife Sciences
University of Pretoria

Dear visitor,

I am a PhD Student in Wildlife Management from the University of Pretoria, South Africa.

As part of my research study on "The impact of off-road driving on soils and ecosystems", I am doing a survey to determine the views and perceptions of eco-tourists on relevant environmental issues and off-road driving in particular. Demands and pressures by eco-tourists for off-road driving are important factors promoting off-road driving in Game Parks and Reserves. In order to develop appropriate, effective guidelines for sustainable management of off-road driving in our very important protected areas in South Africa, it is extremely important to gain information regarding the views and opinions of eco-tourists regarding related matters.

A large enough data pool is needed, so as to draw informed, scientifically acceptable conclusions. These will be used in combination with quantitative data on the influence of off-road driving on soils and ecosystems, collected by means of field measurements and experimentation.

Your views and perceptions are extremely important to me and I ask you to share your experience, evaluations, and opinions with regards to the questions included in this questionnaire. The survey is anonymous, and the collected information will be used only for research purposes.

For your convenience, to all questions only one answer is required. It should not take more than 15 minutes of your time.

Thank you for your cooperation,
Gerhard Nortjé

IMPORTANT NOTE:
Do not complete this questionnaire if you have already completed <u>this same</u> questionnaire before, since it may skew statistical analysis of the data

******

Section 1
DEMOGRAPHICS (coded)

- **Age** (mark with X)

12 to 19	(1)	20 to 29	(2)	30 to 39	(3)
40 to 49	(4)	50 to 59	(5)	60+ years	(6)

- **Gender** (mark with X)

Female	(1)	Male	(2)

- **Nationality**

(mark the correct country with X)

South Africa	(1)	France	(2)	Germany	(3)
UK	(4)	USA	(5)		

(if **not one of** the above, specify which country in the appropriate continent)

Africa	(6)	Asia	(9)
Europe	(7)	Oceania	(10)
South America	(8)	North America	(11)
other	(12)		

- **Occupation** (mark with X or specify for other)

professional	(1)	managerial	(2)	other (specify)	(3)

- **Who is paying for this visit?** (mark with X or specify for other)
Note: It would be valuable if you complete this part, but you may opt to skip it if it is too sensitive

own holiday	(1)	family gift	(2)	work invitation	(3)
other (specify)	(4)				

- **Time of the year** (mark with X; if applicable, mark as many as fitting)

January	(1)	February	(2)	March	(3)	April	(4)
May	(5)	June	(6)	July	(7)	August	(8)
September	(9)	October	(10)	November	(11)	December	(12)

- **Number of visits to Pafuri** (mark with X)

first time	(1)	second time	(2)	3^{rd} or more times	(3)

******

Section 2
MOTIVES

Indicate the importance of different motives for your visit to Pafuri.
Mark with X in the appropriate blocks.

Motive	Level of importance		
	(1) **Not important**	(2) **Somewhat Important**	(3) **Very important**
Expand/gain new knowledge on various environmental, ecological, historical, etc., aspects			
Outdoor activities: game drives, game walks, etc.			
Nostalgia (reminiscence)			
Novelty (uniqueness)			
Escape and relaxation			
Photography			
Wilderness experience			
Seeing the major predators (lion, leopard, cheetah), at close range by means of off-road driving			
Explore new locations			
Socializing			

******

Section 3

YOUR VIEWS ON SELECTED ENVIRONMENTAL AND TOURISM ISSUES

Give your views on the following general environmental and tourism issues.
Mark with X in the appropriate blocks.

Issue	(1) **Strongly disagree**	(2) **Disagree**	(3) **Neutral**	(4) **Agree**	(5) **Strongly agree**
The present generation should ensure that the environment in ecotourism areas is maintained for future generations					
Negative impacts of eco-tourism on the environment are aggravated by the actions and demands of eco-tourists with poor knowledge and grasp of ecological facts					
Most eco-tourists have poor knowledge and grasp of ecological facts					
Negative impacts of eco-tourism on the environment are aggravated by the actions of irresponsible eco-tourism operators who offer environmentally harmful packages to ill-informed eco-tourists					
Eco-tourists have a responsibility to acquire correct knowledge of ecological facts in order to do correctly what they can to protect the environment					
Eco-tourism has negative impacts on the environment					

——******——

Section 4
YOUR VIEWS ON ISSUES RELATED TO OFF-ROAD DRIVING FOR THE PURPOSE OF OBTAINING CLOSE VIEWS OF SPECIAL WILDLIFE SPECIES IN ECO-TOURISM AREAS

(Off-road driving refers to random driving off regularly used tarred, gravel or dirt roads)

A. Give your views on the following general issues related to off-road driving in eco-tourism areas. Mark with X in the appropriate blocks.

Issue	(1) Strongly disagree	(2) Disagree	(3) Neutral	(4) Agree	(5) Strongly agree
Off-road driving has no negative impacts on the environment					
Off-road driving causes soil compaction					
Off-road driving causes soil erosion					
The benefits that tourists get by off-road driving exceed the possible damage caused to the environment					
Off-road driving has a negative effect on wildlife in general and on their behaviour specifically					
Off-road driving does not cause vegetation damage					
Possible damage caused by off-road driving takes very long to rehabilitate naturally					

B. Give your personal opinions on the following points regarding off-road driving at Pafuri and off-road driving as draw-card for visiting eco-tourism areas. Mark with X in the appropriate blocks.

Issue	(1) Yes	(2) No
Did you experience off-road driving during your stay at Pafuri?		
Was off-road driving explained to you before you went off-road?		
Did the off-road driving generate negative emotions in you?		
As tourist, are you attracted to an area where off-road driving is practised?		
Do you believe that soil and vegetation recovers after off-road driving?		
Do you believe that off-road driving should be allowed to accommodate people who have never seen certain wild animals at close range?		
Do you have any previous experience of off-road driving?		

******

Section 5
RATING OF PAFURI CAMP AS ENVIRONMENTALLY FRIENDLY DESTINATION
(satisfaction with this destination)

How did you experience the facilities and activities offered at Pafuri, with regards to their environmental friendliness?
Mark with X in the appropriate blocks.

Facility/Activity	**Degree of satisfaction**				
	(1) **Not at all satisfied**	(2) **Slightly dissatisfied**	(3) **Neutral**	(4) **Moderately satisfied**	(5) **Very satisfied**
Management of vehicle traffic					
Tour guide's knowledge of the natural environment					
Care taken by guides during off-road driving incidents					
Environmental friendliness of all activities offered by the Concession					
Management of natural environment					
Limiting destruction of the landscape					

******

THANK YOU

APPENDIX F

An Overview on Off-Road Driving within the Ecotourism Sector

This document is an overview points and findings related to Off-Road Driving in the Ecotourism Sector

Walter Ralph Jubber

April 2011

Introduction:

This document discusses view points and the aspects of off-road driving, in particular my own. Over the years within the commercial ecotourism operation, off road driving has become a normal practised game viewing tool. It has served as a way of:

- Habituating predators, thus allowing more relaxed and longer predator sightings.
- Increasing predator sightings for guests.
- Allowing guests a greater opportunity of close viewing, in particular for photography.

Due to the pressures exerted on the industry, off road driving has become a prerequisite, instead of an optional. Reasons being:

- Guests wanting to see the big charismatic species: Lion, Leopard, Rhino, Wild Dog, Cheetah, Elephant, Buffalo, etc.
- Commercial operations ensuring or guaranteeing high profile species to guests staying within the reserve or area of operation.
- Pressures exerted by tour agents, to ensure their guests get to see high profile species.

The reality is that foreign guests have saved up large sums of money, in order to live a dream of coming to Africa and having the opportunity of viewing some of the unusual animal species found on the African continent. In some instances this is the only time and once in a lifetime opportunity that they may see these species. Due to this we as ecotourism operators have accepted the need to show our guests these high profile species, thus ensuring a steady flow of commerce which would sustain our operation and conservation of African species. Happy guests and agents, equals a steady flow of occupancies, which ensures a steady flow of finance and ultimately this results in a steady flow of commerce going into conservation, hence funding conservation practices[1]. I however feel that the grey areas arise between what is deemed ethical or unethical off road driving and how far these lines are pushed. Questions like:

- How far is too far?
- If we can off road 200 or 300m, why not more?

- What is pressurising the species we watching?
- What harm is being done to saplings if driven over, if seen springing back up?
- Which species shouldn't be viewed off road?
- Should vehicles enter and exit on the same tracks?
- Does off road driving really have a negative impact on the environment?
- What is deemed as a sensitive area?

Hopefully within this document I explain some of the viewpoints which have arisen, and things I have experienced and noted in accordance to off road driving, and what I deem as ethical off road driving. As said before this is based on my experiences and understandings, and most of this is based on my time spent in the ecotourism industry, within commercial operations conducting off road driving and those not. I have also spent the last three years working with and aiding Gerhard Nortjé (soil scientist) in an off road study, analysing the impacts of off road driving and thus determining or evaluating how to limit the negative effects and impacts of off road driving.

Ethics involved with Off Road Driving

As discussed above the reality is that most commercial operators will commence with off road driving and it will be done. However there needs to be an understanding of off road driving ethics. Today's traveller is becoming more involved with carbon footprints, carbon sinks, etc, and they have become more aware of eco-sensitivity. For more guests are now questioning why, how come, what damage is being caused, how this is prevented, etc. And this is being more conscious due to the green movement and different thought processes arising.

Working with a hunting operator in Namibia, off road driving was not a question of increasing the guests photographic viewing opportunity, but was to get around, due to limited road networks, but also predominantly to get into the area where the animal was shot to load it and take it back to be skinned and the meat to be stripped and distributed to the community.

However in the case of the photographic tourism industry this needs to be looked at slightly differently, we off road to get the guest into a better vantage point to take the photograph of the species, documenting that they have seen this high profile species, and this has become a very important aspect of the digital age. It is not only good enough to have a photograph, but the digital photography age, allows guests to compare their photographs with their friends, families and fellow guests, a development of photographic competition.

So due to pressure on the guide and the camp or lodge, guides will search for the species and once located the decision is made to off road or not. The radio call will be made, thus allowing and ensuring that the other guides and their guests in the vicinity are also privileged enough to view this species. The question is, is this so wrong? My honest answer is no, however when the misconduct and the eco-sensitivity of the area and species is not taken into account, this is where things need to be re-assessed.

Working within the Makuleke Contract Park for Wilderness Adventures, Pafuri Camp, the decision was made to start off road driving in the concession (2008), but a strict guideline would be implemented and that a PhD study (Gerhard Nortjé) on the impacts would be undertaken. An off road driving code of conduct policy was put in place[2]; which was peer reviewed by those operating within the Contract Park. The policy was put in place and the decision was made to undertake off road driving.

The off road driving policy included[1]:

- Indicating which areas are deemed as less sensitive and off road driving may be undertaken and those areas which are deemed sensitive, with no off road driving allowed.
- A parameter of maximum 300m allowed off road, from any permitted road.
- Vehicles to use the same route in and out, thus limiting the impact and compaction.
- Sensitivity to the animal being viewed or/ and followed.
- Guides to complete an off road register, including, species being viewed, location, GPS co-ordinates of both the entry site and the viewing site, number of vehicles, etc.
- Off road driving only permitted for confirmed lion, leopard, wild dog, cheetah and rhino sightings within authorized off road areas.
- No off road driving allowed after rain, on wet soil conditions.

The whole principle was to improve the photographic opportunity for guests, thus enhancing their game viewing experience, and to set in place an ethos which would be deemed the most eco-sensitive way of commencing off road driving; this possibly becoming an off road protocol going forward. Agreed there is a place for off road driving and it needs to be undertaken ethically, what I deem unethical off road driving, may be seen in many eyes as a biased view, but is based on my experience and involvement over the last three years with the off road driving study in the Makuleke Contract Park.

What I deem as incorrect or unethical Off Road driving:

- Any form of unnecessary pressure exerted on a hunting predator or species, in order to get in close, thus disturbing or preventing natural behaviour.
- Insensitivity to the species being watched, getting too close, causing visual distress in the species being observed, to ensure a photograph.
- Crashing through vegetation, instead of simply going around, with the belief of it saving time and that the brush will recover.
- Off road driving for exceptionally long distances. Is this off road driving, or the creation of a new road?
- By multiple vehicles off road driving at various entry points, next too or around the site of entry, thus causing a larger surface of compaction. Same entry point should be used. Compaction isn't only initiated on the vehicle tracks but for a meter on either side of the tracks, due to outward compaction at the site. This being quantified with penetrometer readings at test sites, where the first vehicle going off road is responsible for 54 -70% of the soil compaction and in some cases even up to 90%. Thereafter any vehicle travelling on the same off road tracks have decreasing rates of soil compaction[3].
- Off road driving for elephant and buffalo; including other commonly viewed general game species. These species should be avoided; however, in regions where there is limited road network this needs to be assessed.
- Off Road driving on soils which are more sensitive and have a slower rate of recovery, must be avoided.
- No off road driving on wet soils.

Conclusion

I have always been and will be on the side of conservation. Working for Wilderness Safaris over the last four years, the company's ethos and main focus is on community development and conservation, with ecotourism as the funding mechanism. Therefore in order for the company to make substantial revenue to assist in conservation and community development, we need to impress and give our guests the ultimate, most ethical game viewing experience possible. I have been very involved over the years in conservation and several studies, and from a guiding career have specialised in walking safaris and trails, with my main focus being guiding on foot. As with most trails guides, our view point would always be rather walk than drive and in particular off road, due to us not wanting to cross over off road vehicle tracks. Also being exposed to and seeing what I would deem insensitive or unethical off road driving my initial opinion was always rather not to commence with off road driving in the first place. However, I understand the importance and the need to create a revenue and also the pressures exerted on the industry for guests to be able to photograph and view high profile species, and in many ways this is only possible with off road driving. It is also essential, especially for the greater picture of conservation.

My opinion being is that as long as strict guidelines are followed, with the aspect of eco-sensitivity as well as, and possibly the most important aspect, the sensitivity to the species being followed or viewed be adhered to, off road driving has proven to be instrumental. The ongoing study which was started in October 2008 has proven that when off road driving is done correctly and conservation minded, with the concept of eco-sensitivity and species sensitivity being followed, that it can be done correctly [3, 4, 5].

References:

1. Nortjé, G; 2005. The Impacts of Off-Road Driving and other Concessionaire Activities on Physical Soil Degradation.
2. Roche, C; 2008. Makuleke - Off Road Driving Policy.
3. Nortjé, G; 2010. Pafuri Progress Report Jan to Nov 2010.
4. Nortjé, G; 2010. Pafuri Progress Report April to Dec 2009.
5. Jubber, W; 2010. Off Road Driving Report from Jan to April 2010.