Ecology and Utilisation of the medicinal plant *Harpagophytum procumbens* (Burch.) DC. ex Meissn. (Pedaliaceae) in southern Africa

Dissertation

Zur Erlangung des Doktorgrades

im Fachbereich Biologie der Universität Hamburg

vorgelegt von

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aus Hamburg

Hamburg 2004

Genehmigt vom
Fachbereich Biologie der
Universität Hamburg
auf Antrag von Herrn Professor Dr. N. JÜRGENS

Weitere Gutachter der Dissertation:
Herr Professor Dr. R. LIEBEREI

Tag der Disputation: 31. Januar 2003

Hamburg, den 06. Februar 2003

Universität Hamburg
Fachbereich Biologie
14/1

Professor Dr. U. Wienand
Dekan

Hamburg, den 14/01/2003

Die sprachliche Korrektheit der in englischer Sprache abgefassten Dissertation von Frau Berit Hachfeld mit dem Titel

„Ecology and utilisation of the medicinal plant Harpagophytum procumbens (Burch). DC. ex Meissn. in southern Africa"

wurde von dem Unterzeichnenden geprüft und bestätigt.

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Datum der Disputation: 31. Januar 2003

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Abbreviations

CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
comm.	Communal
CoP	Conference of the Parties
CRIAA SA-DC	Centre for Research and Action in Africa, Southern Africa Development and Consulting
DSSS	Department of Specialist Support Services
MET	Ministry of Environment and Tourism
NA	Namibia
NBRI	National Botanical Research Institute
NDCWG	National Devil's Claw Working Group
NGO	non-governmental organisation
NW-DACE	North West Department of Agriculture, Conservation and Environment in South Africa
NWFP	Non-Wood Forest Products
pers. comm.	personal communication
Private	privately owned commercial farm
SHDC Project	Sustainable Harvesting Devil's Claw Project
TL	Thusano Lefatsheng, non-governmental organisation
TRIPs	Trade Related Aspects of Intellectual Property Rights
WTO	World Trade Organisation
ZA	Zuid Africa / South Africa

Acknowledgements

Uwe Schippmann from the German Federal Agency for Nature Conservation (BfN), Bonn, set the initiative for this interesting project and supported me with a lot of enthusiasm all the way through. Norbert Jürgens from the Botanical Institute of the University of Hamburg made it possible to carry out this project as a PhD thesis in his study group.

Great support with the fieldwork came from various colleagues at the Institute of Botany and the Institute of Soil Science from University of Hamburg. In particular Andreas Petersen contributed invaluable help all through the project. Thanks also to Inge Gotzmann, Ute Schmiedel, Thorsten Becker, Carolin Mayer, Markus Müller, Pia Parolin, Mariam Ahktar-Schuster, Gisela Bertram, Hans-Jürgen Buß as well as other friends and colleagues. Thanks to my family who supported several years of field work in the Namib Desert and other parts of southern Africa.

Various people, NGOs, organisations, and ministries supported the study in Namibia and South Africa and helped with the organisation of the project:

- Carla van der Vyver, Nature Conservation, NW-Province, South Africa
- Cyril Lombard from CRIAA SA-DC, Windhoek, Namibia
- Dave Cole from CRIAA SA-DC, Windhoek, Namibia
- DCWG – Devil's Claw working Group, Namibia
- Domitilla Raimondo, NBI Cape Town, South Africa
- Elke Erb, Swakopmund, Namibia
- Elsabe Powell, Nature Conservation, N-Cape Province, South Africa
- Gerrit Matteys, Nature Conservation Upington, N-Cape Province, South Africa
- Holger Kolberg, Ministry of Environment & Tourism, Windhoek, Namibia
- John Donaldson and Andrew Skowno, NBI Cape Town, South Africa
- Marianne Strohbach, Swakopmund, Namibia
- Mr. Wittneben, Mr Knouwds, Mr. Piepmeyer, and Mr. Versveld from the Ministry of Agriculture and Rural Development, Namibia
- PRECIS Data Manager, NBI Pretoria, South Africa
- Rachel Wynberg, University of Strathclyde, Scotland
- Stefanie Schneider, former BIOTA southern Africa Namibia co-ordinator, Namibia

Data and information on the collecting locations of *Harpagophytum* specimen was kindly contributed by H.D. Ihlenfeldt from the Botanical Institute of the University of Hamburg.

Without the various people in the communal areas and private farmland of Namibia and South Africa, their great help with the search of *Harpagophytum*, their warm welcome, sharing of knowledge on and interest in the occurrence of the species, this study would not have been possible. Great thanks goes to the numerous commercial and communal farmers of both countries.

In South Africa these were:

Taeunus Botha, Pierre & Gezine Bruwer, Ampje Coetze, Duisman van Eden, John Edwards, Eiffel village, Louis & Dorette Haumann, Kobus & Hope Haumann, Karen & Manfred Kuchler, Lou & Annette Kruger, Mrs Hilda Mothoari and her colleagues of the Thago Ke Pholo-Project, Ludumane village, Gert Olivier, Nicki Oppenheimer & Anglo Gold and Johann Lensing as the manager of Tswalu, Jaco Powell, Anne Rasa, Henk Smith, Japie & Venetia Schreuder, Lou van der Walt, Hasie & Helmine Hassborck, W.I.F. Peens, Lardus van Zyl, and many others.

In Namibia these were:

Carl-Uwe & Anka Aakmann-Visher, Mr & Mrs Austermühle, Renate & Horst Austermühle, Mr & Mrs Diekmann, Peter & Anka Eichoff, Elke Erb, Harald & Birgit Förster (Okatumba Wildlife), Mrs Höpkes, W.G. Horsthemke, Munionganda Kakavango Kamuaruuma, Kautjiza Kalipuine, P. Kavezuma, Okatemba Kotjindanda, Rick Kukuni, Munionganda Kuvena, Thomas Muhendje, Rolf & Marion Ritter, Hans & Bianca Sorada, Jörg Seufert, Bimbo Tjihero, Zuvee Tjirane, Tjiunrunga & Mamacky Tuaandi, Wilkens, and many others.

1 Introduction – Biodiversity and medicinal plants

Biodiversity has received increasing attention in the scientific, political and every-day world over the past years (e.g. BARTHLOTT & WININGER 1998, CHAPIN et al. 2001, WBGU 2001). It has been recognised that biodiversity represents a limited and invaluable good that cannot be substituted by any other means. Greatest threats to biodiversity that have been identified are the loss of habitat and the worldwide increase of invasive species. Next to this, the elimination of potentially valuable medicinal plants is considerable, especially of those whose therapeutic benefit is still unknown. It is estimated that the chemical and biomedical potential has only been determined for less than 1% of the earth's higher plants, while the remaining 99% is rapidly disappearing (SHELDON, BALICK & LAIRD 1997).

The international Convention on Biodiversity (CBD), which was implemented in the year 1994, for the first time acknowledged this on a global level. The CBD was inspired by the world community's growing commitment to sustainable development that includes the conservation of biodiversity, the sustainable use of its components and the fair and equitable sharing of benefits arising from the use of genetic resources (UNEP 1998). The Convention being an internationally binding treaty, recognises that countries have the sovereign rights to exploit their own resources including the responsibility to ensure its sustainable use.

The term biodiversity goes far beyond the mere meaning of species richness in flora and fauna and has been defined by the CBD in Article 2 as follows:

"Biological diversity means the variability among living organisms from all sources including *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

Estimates of global species numbers range from 10 to 50 million or more, of which only 1.7 million have been described so far (e.g. WILSON 1992, HEYWOOD 1997, MAY 1998). Worldwide over 400,000 higher plants are known (GOVAERTS 2001, BRAMWELL 2002). Many of them are the basis for a variety of goods such as food, sweets, liqueurs, plant-based medicinals, herbal remedies, perfumes, cosmetics and so forth (LANGE 1999). Among these, approximately 50,000 taxa are used for medicinal purposes (SCHIPPMANN, LEAMAN & CUNNINGHAM 2002). In 1996, more than 440,000 tons of medicinal plants have been traded. At that time, the global market for corporate herbal medications was worth US $ 14 billion (GAIA/GRAIN 2000). The demand is estimated to be growing by 10-20% each year, meaning also an increasing demand in the exploitation of biodiversity.

Most medicinal plants originate in the south where also the highest biodiversity occurs while in the north the greatest capital exists to market medicinal products. Herbal medicine has always been used and gathered by the people to cure various ailments and diseases. In particular, for rural and poor people the richness in plant species in their areas inherits a high importance. An estimated three billion of people rely on traditional pharmaceuticals; this is 80% of the developing world (FARNSWORTH 1988). In China, 18.9% of the native plant species are used as drugs in Chinese traditional medicine (DUKE & AYENSU 1985). In South Africa, there are more than 300,000 traditional healers, and 60% of South Africans subscribe to traditional medicine (VAN WYK et al. 1997, MAYENG 1998).

The understanding of the applicability and value of medicinal plants is in most cases closely linked to the knowledge of indigenous people. Over a long period of time a very complex relationship between the indigenous people and biodiversity has developed (SHIVA 2000). Indigenous people have for centuries utilised the biodiversity of their environment. They have learned about the medicinal properties of biodiversity, how to sustainably use it and have themselves been influenced by biodiversity in their lifestyles. Often their livelihood depends on biodiversity. Thus, biodiversity is not only a matter of conservation of species or ecosystems, but is closely related to the economic survival of rural people. With the transfer of knowledge between indigenous communities and the northern world, not only new technologies have entered into and changed the lives of rural people, but also their rich knowledge has been transferred to a much larger range of persons in the northern world.

The demand in medicinal plants, the research on their medicinal properties and how these can be extracted and further processed to produce herbal remedies and pharmaceuticals, is related to the issues of intellectual property rights and traditional knowledge. Who owns the knowledge? Are the traditional users the owners or are these the companies that developed extraction methods and market the retail products? Who profits and who benefits from biodiversity? There are different approaches to these fundamental questions. One is implemented in the TRIPs agreement (Trade Related Aspects of Intellectual Property Rights) of the WTO (World Trade Organisation) in which the member countries acknowledge that intellectual property rights can be protected by the licensing of patents on products or processes. This patenting ensures exclusive user rights for the patent holder over a certain period of time. Another and more comprehensive approach was accomplished by the CBD, which acknowledges the sharing of benefits and the value of traditional knowledge explicitly in its agenda.

Parallel to an increasing demand in trade, in particular, when demand and consumption are outside the countries of origin, an increasing threat of the species in question is frequently observed (e.g. MARSHALL 1998, SCHIPPMANN 2001). Traditional management systems may then be supplanted by short-term business interests. Various examples are known where international trade has resulted in a species becoming threatened in the wild. Prominent examples are *Prunus africana,* American ginseng (*Panax quinquefolius*), and also Asian ginseng (*Panax ginseng*). Here, the strong demand led to the application of unsustainable harvesting techniques and thus to the eventual threat of extinction in the species (CUNNINGHAM & MBENKUM 1993, ROBBINS 2000, SCHIPPMANN 2001). At issue is therefore whether the demand for a resource can be functionally translated into an effective rationale for its conservation.

The international tool implemented to avoid that international trade in species creates a risk for the survival of wild populations is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). With a listing on one of the CITES Appendixes, a monitoring and regulation of such trade in a species is put in place. CITES has currently 163 member countries and 28,417 plant species are protected under the Convention (http://www.cites.org/eng/parties/index.shtml, http://www.cites.org/eng/disc/species.shtml). While in the past CITES mainly focussed on the horticultural sector of international trade, recently greater awareness is evident for the large commodity trade in medicinal plants (SCHIPPMANN 2001). Yet, currently less than 1% of the total number of CITES-listed plant species are medicinal and aromatic plants (LANGE 1999).

One example from southern Africa of an internationally traded medicinal plant species is *Harpagophytum procumbens* (thereafter referred to as *Harpagophytum*) of the Pedaliaceae family. *Harpagophytum* is an endemic plant species to southern Africa, which is traded on a commercial basis since the 1950s when its medicinal value was recognised by a German farmer in Namibia. The plant is a traditional phytomedicine of the San people in southern Africa who have utilised parts of the plant to cure various ailments for time immemorial (MATLAHARE 2002). Still today, the predominant share of the exports comes from the wild and is harvested by rural people. While the gathering of the valuable root tubers for commercial purposes remained on a limited scale for several decades, from the beginning of the 1990s a strong and rapid increase in exports was observed which reached over thousand tons in 2002. These amounts resulted in the emergence of concerns on a potential over-exploitation of the plant. In particular as no sound scientific basis was available on the resource status of *Harpagophytum* in the three major range states, Namibia, South Africa and Botswana, the impact of harvesting on the sustainability of wild populations of *Harpagophytum* was unknown. Based on these interrelations, the medicinal plant *Harpagophytum* was chosen for this study to service as good example for the analysis of the relationship between the ecology of a species, its utilisation and related socio-economic issues.

2 Aim of the study and research objectives

The understanding of the biology of a plant species becomes increasingly important when wild gathering or collection is paired with utilisation on a commercial scale. In particular when the harvesting of the valuable parts suggests a potentially detrimental effect on the survival of the plant, issues of sustainability should receive increased attention. Various examples from other medicinal plant species show that the gathering of root or bark material may pose a threat to a species, if the resource is not managed properly (e.g. *Prunus africana, Krameria lappacea*). This also applies to *Harpagophytum*, a plant species gathered for its secondary root tubers from the wild in southern Africa. In order to be able to estimate the impact that harvesting may have on the wild populations as many data as possible should be collected on the biological status and ecology of *Harpagophytum*.

Examples from other species harvested in the wild have shown that it is important to implement management tools for a commercial exploitation as soon as possible to avoid the establishment of bad harvesting practises and to initiate a proper managing of the resource while it is still abundant. Over the past years it has been more and more recognised not only by non-governmental organisations but also by governments that it is indispensable to involve also the local harvesters and traditional authorities into such management planning and their implementation (POWELL 1996). Only if rural communities see an advantage in the sustainable use of a species, management will be able to create an incentive for sustainability.

For a comprehensive approach to the understanding of the ecology and utilisaton of a commercially utilised species two major fields should be considered parallel to each other (Fig. 1). Next to the research field of the ecology and availability of the resource in the range countries, the commercial aspects of utilisation have to be analysed.

An important step towards sustainable management is the understanding of the distribution and abundance of a commercially exploited plant species. This is best done with a mapping approach that includes the documentation and analyses of ecological parameters that influence the occurrence of the plant. The most recent comprehensive publication on the distribution of the genus *Harpagophytum* was published in 1970 before the start of the large-scale commercial exploitation of the species (IHLENFELDT & HARTMANN 1970). While herbarium specimen data may offer more recent information on the occurrence of *Harpagophytum*, it cannot supply information on the abundance of the species. Therefore, in this study, a comprehensive mapping approach is followed that focuses on the assessment of both, the abundance of *Harpagophytum* and its ecological requirements.

While in humid tropical areas plants may be available and harvested throughout the year, in semi-arid and arid areas many plant species shed their leaves or follow other fugitive strategies to avoid the pressures of the dry season (e.g. VON WILLERT et al. 1992). Species in arid areas frequently have developed a geophytic growth form, surviving the dry season of the year dormant beneath the soil surface. A successful mapping of the abundance of such plant resources is naturally limited to time periods when the plant has produced green shoots. Thus, to assess the distribution and ecological parameters that determine the occurrence of a geophytic plant such as *Harpagophytum*, next to mapping, a monitoring over a series of years is useful. Only by a monitoring approach the impact of precipitation and other annual variations in abiotic, biotic and anthropogenic parameters can be estimated. In a harvested species, success in and time necessary for regeneration after harvesting can be tracked by monitoring. In this study, both, the mapping and the monitoring approach are applied.

The extent to which field studies are able to cover the entire distribution area of a species is usually limited. In *Harpagophytum*, being a plant that is distributed over the entire southern African region, it is useful to include other sources of information besides the sampling of field data. Such additional sources may be personal communications and interviews with people who are in daily contact with the respective plant. Interviews with landowners within the distribution area of *Harpagophytum* as well as interviews with land users were carried out in this study to collect complementary information to the field sampling.

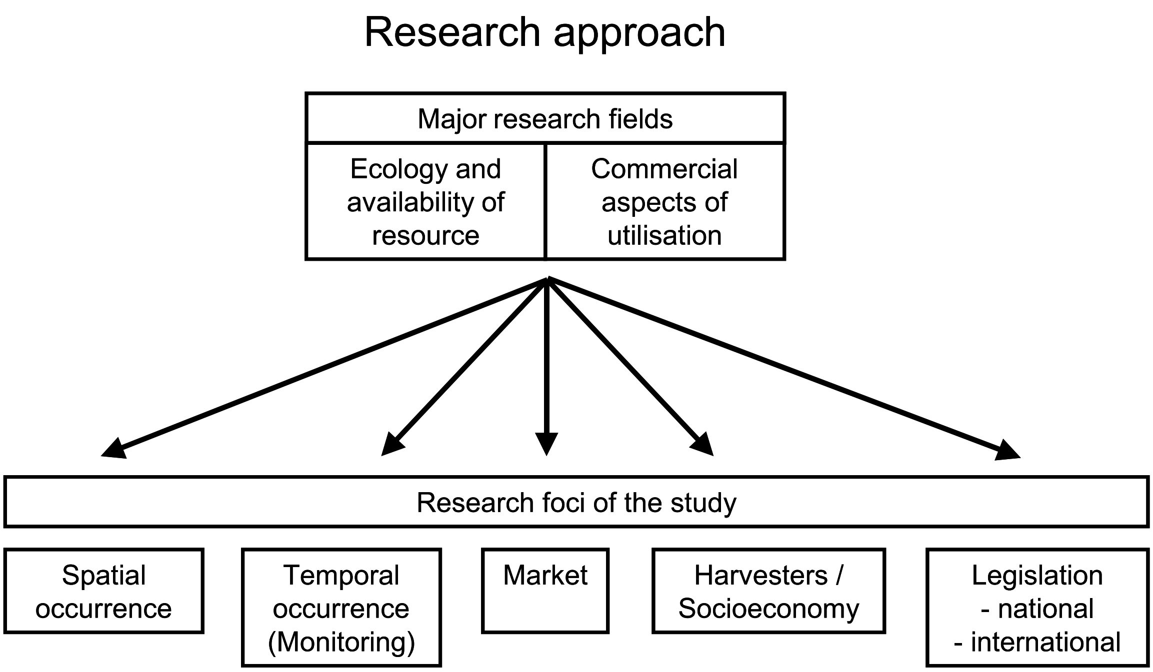


Fig. 1: Scheme of the research approach and major research foci of this study.

In general, the application of only ecological sampling is usually insufficient for an understanding of the extent and impact of commercial exploitation on a plant species. Unless the reason and the extent of the exploitation is understood it will be difficult to successfully maintain sustainability in its utilisation. The reason and extent of exploitation is driven by the demand for the resource. Therefore, data is not only needed on the mere export quantities, but also on the market structures and future tendencies of the importing countries. Therefore, in this study, next to the collecting of trade data on *Harpagophytum* also a survey on the extent of imports by German companies was conducted. The legal background that regulates the utilisation of the plant in the source countries, presents another factor that influences the extent of utilisation of *Harpagophytum* and which has been compiled in the course of this study.

Furthermore, it has to be understood why harvesters are harvesting a plant resource and why they are not involved in other income generating structures. Important is the extent of their dependency on the income generation by the gathering of the resource. Information on the harvesters of *Harpagophytum*, their socio-ecological background and the possibilities of income generation by harvesting was collected in the frame of this study.

The amalgamation of these different sources of information on the ecology and utilisation of *Harpagophytum* facilitates the study aim that is the evaluation of the extent and impact of utilisation on the long-term availability of wild populations of *Harpagophytum* in southern Africa.

The research objectives of this study can be summarised as follows:

(a) Ecology of *Harpagophytum*

- Which abiotic and biotic properties favour an occurrence of *Harpagophytum*?
- Do annual changes in precipitation amounts influence the density of *Harpagophytum*?
- How das land use impact the occurrence and abundance of *Harpagophytum*?
- Which spatial distribution pattern does *Harpagophytum* form?
- What is the potential of the generative regeneration of *Harpagophytum*?
- What is the perception of the landowners on the factors that drive the abundance of *Harpagophytum*, and do they match with the scientific findings of this study?

(b) Utilisation of *Harpagophytum*

- Which harvesting methods are applied and how do they have to be rated regarding sustainability?
- What is the current extent of the harvest in *Harpagophytum*?
- Is it possible to determine hotspots of utilisation and if so, where and why are they located in certain areas?
- What is the impact of harvesting on the abundance and population size of *Harpagophytum*? Are there areas spared from harvesting?
- How successful is regeneration in *Harpagophytum* after harvesting is dismissed over a certain time?
- What is the perception of landowners and harvesters on the resource status of *Harpagophytum*? Do they believe that the plant is decreasing in their region or do they think the plant is managed properly?
- Is *Harpagophytum* endangered by over-utilisation through harvest? And if so, what should be done to ensure a sustainable use of *Harpagophytum*?

(c) Commercial issues of *Harpagophytum*

- Who is involved in the harvesting of *Harpagophytum?* What are the incentives to become involved?
- What is the extent of trade in *Harpagophytum*? How has trade developed over the past years and how will it develop? What are the differences between the source countries?
- What is the monetary outcome for the harvesters and what are the trade chains and the prices in the three source countries?
- Are there any regulation or management tools to control harvest and export of *Harpagophytum* in the source countries? If so, how are they implemented?
- What is the perception of various stakeholders including harvesters, traders, landowners and government officials on the extent of trade and do they believe regulatory measures should be implemented?

The study is structured in the way that at first species information on *Harpagophytum* is presented, which includes a compilation of the systematics (Chapter 3), the distribution of the genus (Chapter 4), the natural environment (Chapter 5) and the socio-economic background of the utilisation of the species (Chapter 6), as well as a chapter on the pharmaceutical Harpagophyti radix (Chapter 7). A comprehensive chapter on the results of the field studies on the ecology of *Harpagophytum* (Chapter 8) follows which discusses the assessment of various abiotic, biotic and anthropogenic parameters (including the extent of harvesting) on the research sites in Namibia and South Africa. Subsequent to this, results of the monitoring approach (Chapter 9) and of the interviews (Chapter 10) are presented. A synthesis of the results of the different field approaches closes the first major research field on the ecology and availability of *Harpagophytum*. a chapter on the synthesis of the field studies (Chapter 11). While the chapters on the results of fieldwork are restricted to Namibia and South Africa or only to Namibia, the last three sections of this study deal with commercial aspects of utilisation in *Harpagophytum* in the three range states. These are harvester issues with yield and price analyses of the harvested raw material (Chapter 12), cultivation (Chapter 13), trade (Chapter 14) with trade figures, market analyses and conservation issues, and the legislation of *Harpagophytum* (Chapter 15). A final chapter integrates the results of the field studies and the commercial aspects of the utilisation of *Harpagophytum* and presents conclusions on the impact of different options of a market development on the ecology of the species and the socioeconomy of the harvesters (Chapter 16).

3 Systematics of *Harpagophytum*

3.1 Taxonomy and evolution

The genus *Harpagophytum* was formally established by DE CANDOLLE in 1845, who created this new generic name and replaced the older and invalid name *Uncaria* BURCHELL 1822 (Rubiaceae). LINDLEY in 1836 (cited in IHLENFELDT & HARTMANN 1970) was the first to place *Harpagophytum* in the family Pedaliaceae, which was followed up by later authors. The family belongs to the Lamiales and is basically an Old World family centred in the Africa south of the Sahara with a few outliers in Madagascar, India and Sri Lanka (IHLENFELDT 1994). At present, the family comprises 22 genera with approximately 90 species. The family includes several species of economic importance of which *Sesamum orientale*, an oil-yielding plant, and *Harpagophytum* can be considered to be most important (NAYAR 1976).

The first critical taxonomic study of *Harpagophytum* was undertaken by STAPF in 1895. An authoritative treatment was published by IHLENDFELDT & HARTMANN (1970), on which the following description of the genus *Harpagophytum* is based: The genus *Harpagophytum* DC. ex MEISSN. comprises perennial herbs with prostrate annual shoots, which sprout out of a succulent main root. From the main root tuber side roots develop, which are typically thickened to root tubers. The leaves are opposite, oval and entire or lobed to varying extents. The flowers are pedicellate, single and axillary with a maroon to bright pink colour. The fruit is conspicuous and gives the genus its colloquial name "Devil`s Claw": It is a woody capsule of varying size, flattened and with two strong wings on the back of each carpel taking the shape of spiny limbs or rows of spiny appendices. The seeds are numerous and are set free over a long period of time (retarded dehiscence). The genus *Harpagophytum* includes two species with two and three subspecies, which are differentiated by three diagnostic features: fruit characters, leaf characters and geographical distribution:

***Harpagophytum procumbens* (BURCH.) DC. ex MEISSN.:**

This species exhibits 50-60 seeds per capsule. The woody fruit is strongly differentiated with two double rows of spiny appendices. The spines of each row are at least three in number, often exceeding the length of the capsule and always exceeding its width to 2-3 times. The leaves are 3-5 lobed and the flowers typically have violet lobes with a light yellow throat, but sometimes they are purely yellow or purely violet (Fig. 2). The species comprises two subspecies, i.e. *H. procumbens* ssp. *procumbens* and *H. procumbens* ssp. *transvaalense,* which are differentiated by fruit size and the length and number of the spiny appendices, the size of the leaves, and the degree of lobation. The two subspecies occur in different regions of southern Africa.

***Harpagophytum zeyheri* DECNE.:**

This species comprises smaller fruits with less seeds (20-30 seeds). The wings of the woody fruit are set in two double rows with short spiny appendices on the top. The width of the wings rarely exceeds the width of the capsule. The leaves are ovate to three lobed and 30-400 mm long. The flowers likewise exhibit violet lobes with a light yellow throat or purely violet or purely yellow. The three subspecies of *Harpagophytum zeyheri, H. zeyheri* DECNE. ssp. *zeyheri, H. zeyheri* DECNE. ssp. *schiffii*, and *H. zeyheri* DECNE. ssp. *sublobatum* differ with respect to fruit size, seed number and leaf shape.

The origin of the genus is considered to be in the Northern Transvaal Province, South Africa, where the putatively most primitive forms are found today. In that region the highest number of alleles is found resulting in the highest ability in leaf and fruit forms, flower colours etc. The evolution within *Harpagophytum* is assumed to have progressed in direction to bur fruits with much elongated spiny appendices correlated with the characters retarded dehiscence and increase of seed numbers.

Both species are well stabilised, but genetic exchange between species and subspecies is still considered at the distribution limits, where the areas my overlap. Such introgressive populations do exist in northern Namibia and in northern Transvaal (IHLENFELDT & HARTMANN 1970). Further taxonomic research on the basis of genetic differences between the different species could help to determine and distinguish introgressive populations. LEVIEILLE (2002), for instance, aims at the evaluation of taxonomical differences between geographically distant populations by the use of in-vitro micro-propagated plants.

3.2 Scientific synonyms and common names

Due to historical changes of the name *Harpagophytum*, two synonyms exist: *Uncaria procumbens* BURCH. 1822 and *Harpagophytum burchellii* DECNE. A great number of common names is known for *Harpagophytum* that reflect the ethnic group and/or region where the species is utilised. Most of the names are related to the very characteristic fruits of the species such as the German and English names for *Harpagophytum* used in Namibia: "Teufelskralle" and Devil`s Claw. Whereas in many ethnic groups of Namibia the name Kamangu is used for *Harpagophytum,* in Botswana the name Grapple plant or Sengaparile is more common. Table 1 lists various common names of *Harpagophytum* that are derived from literature and personal communications.

Tab. 1: Common names of *Harpagophytum*.

Common name	Common name
Beesdubbetje	Ouklip
Devil`s claw	Rankdoring
Duiwelsclou	Sengaparile
Grapple plant	Skerpioendubbeltje
Grapple Thorn	Teufelskralle
Kanako	Toutje Tou
Kamangu	Tubercule de griffe du diable
Kloudoring	Woodspider
Sources: Watt & Breyer-Brandwijk 1962, Wenzel & Wegener 1995; various pers. comm.	

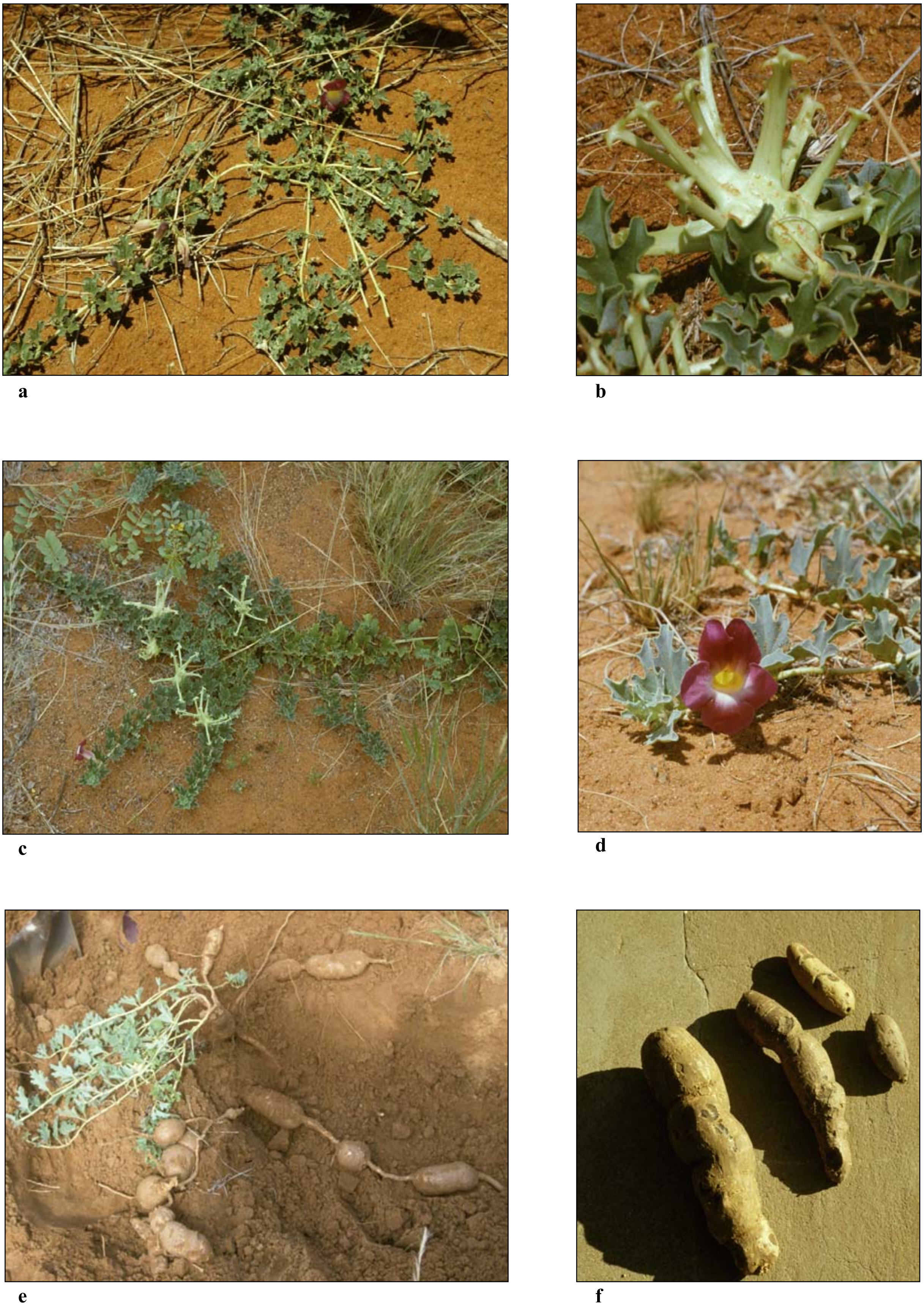


Fig. 2a: Flowering *Harpagopytum* plant, b) young immature fruit, c) fruiting *Harpagophytum* plant, d) pink tubulaire flower, e) plant with secondary root tubers, f) different sizes of secondary root tubers of *Harpagopyhtum*.

4 Distribution of *Harpagophytum*

4.1 Distribution in southern Africa

The distribution patterns of the various genera indicate a high age of the Pedaliaceae family, reaching back to a time period subsequent to the separation of South America from Africa and prior to the separation of India and Madagascar from Africa (about 100m.y.b.p., RAVEN & AXELROD 1974, IHLENFELDT 1994).

The genus *Harpagophytum* is limited to southern Africa and is distributed between the 15th-30th degree latitude in Namibia, Botswana, South Africa, and occurs to a lesser extent also in Zambia, Zimbabwe, and Mozambique (IHLENFELDT & HARTMANN 1970). The two species of *Harpagophytum*, *H. procumbens* and *H. zeyheri*, and five subspecies comprise each a predominantly distinct distribution area (Fig. 3).

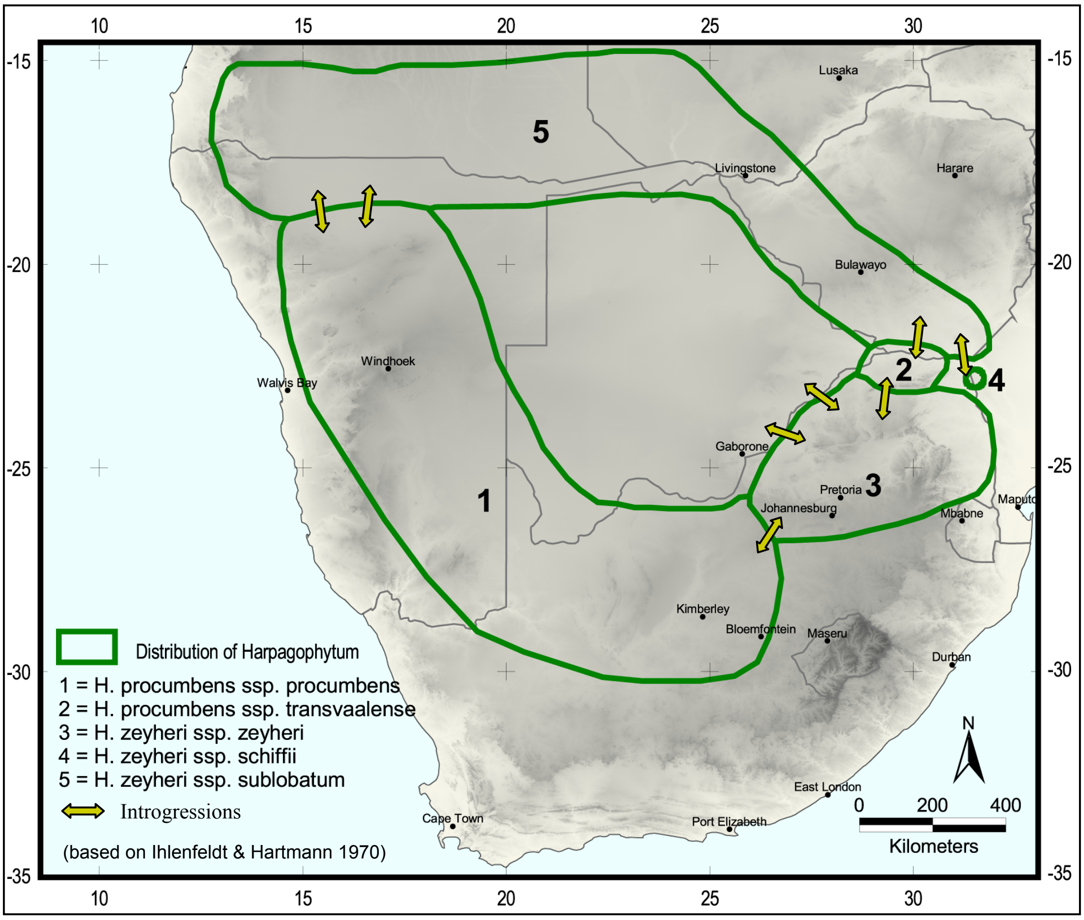


Fig. 3: Distribution of species and subspecies of *Harpagophytum* in southern Africa (after IHLENFELDT & HARTMANN 1970).

The two subspecies of *Harpagophytum procumbens* are characterised by a clearly distinct distribution area:

H. procumbens ssp. procumbens, which is the species dealt with in the following (and later referred to as *Harpagophytum* only), occurs in Namibia up to the 19th degree latitude, in southern Botswana, and in South Africa in the northern part of the Western Cape Province as well as in the North West Province south to the 30th degree latitude. Due to a lack of data, IHLENFELDT & HARTMANN (1970) drew the eastern distribution border of this subspecies in the Omaheke Region in northern Namibia and did not include

Botswana in the distribution area. Yet, from the present point of knowledge, it can be assumed that the border of the distribution area of *Harpagophytum procumbens ssp. procumbens* runs in a more northern direction and includes great parts of the Bushmanland in Namibia and also larger parts in Botswana. Most current data from herbarium specimen, i.e., the PRECIS data bank from Pretoria, South Africa, and data from the National Botanical Research Institute in Namibia, is presented in Chapter 11 together with the synthesis of personal field data.

Harpagophytum procumbens ssp. transvaalense comprises a very limited distribution area in the northern Transvaal Province of South Africa, north of the Soutpansberge, and in Zimbabwe, near the border to Transvaal.

Harpagophytum zeyheri with its three subspecies, occurs in the more humid areas of southern Africa with *H. zeyheri ssp. zeyheri* being present also in the northern Transvaal Province, south of the Soutpansberge. Here, introgressive populations of the two subspecies of *Harpagophytum procumbens* may occur in the north-eastern or the south-western border of the distribution area. *H. zeyheri ssp. schijffii* is only known from a very restricted area around the Kruger National Park in the very north eastern tip of South Africa at the border to Mozambique (Northern Transvaal Province). Introgressive populations are assumed for the other subspecies *H. zeyheri ssp. sublobatum.* The subspecies *H. zeyheri ssp. sublobatum* comprises a similar large distribution area as *H. procumbens ssp. procumbens* and touches the distribution area of the latter at the 19th degree latitude in Namibia. This subspecies is distributed in the northern and more humid parts of southern Africa from southern Angola and south-western Zambia down to the 19th degree latitude in Namibia and probably also in Botswana, as well as in the western parts of Zimbabwe. Introgressive populations may occur at all points of contact between the subspecies of *Harpagophytum*.

4.2 Distribution in National Parks

Several National parks and conservancies lie within the distribution area of the genus *Harpagophytum* in southern Africa.

In Namibia the Etosha National Park is the largest National Park situated in the northern part of Namibia. *Harpagophytum procumbens ssp. procumbens* occurs here with a patchy distribution in the southern and sandy areas of the park as documented by LE ROUX in May and April of 1975 (Strohbach, pers. comm.). No recent studies in the park have been done but the species is still evident in the parks area (Erb, pers. comm.)

Botswana houses several National Parks of which no information on the occurrence of *Harpagophytum* therein is currently available.

In South Africa the Kalahari Gemsbok Park is located right at the border to Botswana (and stretching into it) in the sandveld area, where *Harpagophytum procumbens ssp. procumbens* occurs. Personal communications indicate a frequent occurrence some decades ago, but due to drought and harvesting activities the species is claimed to be less frequent at the moment (Bezuidenhout, pers. comm.). The largest National Park in South Africa is the Kruger National Park at the north eastern tip of the country. The park lies within the distribution area of *Harpagophytum zeyheri ssp. zeyheri*, of which several collecting sites are known in the park. No information is known about the population status of the species though.

5 The natural environment of *Harpagophytum*

The natural environment of *Harpagophytum* in southern Africa is characterised by various forms of the physiography, climate, soil, geology, and the vegetation. In the following, these are broadly introduced.

5.1 Physiography

The distribution area of *Harpagophytum* stretches from the Great Escarpment areas in Namibia and South Africa to the vast plateau in the interior of South Africa and the south-west of Namibia housing the Kalahari Desert. Heights of the landscape range from 500m to 2000m above sea level. The most elevated areas with 1500-2000m above sea level are situated around the Namibian capitol Windhoek and south-west of Kuruman in the Northern Cape Province of South Africa. Landscape types range from vast plains to plains with scattered hills and Inselbergs, Kalahari dunes, hills and low mountain ranges (VAN DER MERWE 1983).

5.2 Climatic conditions

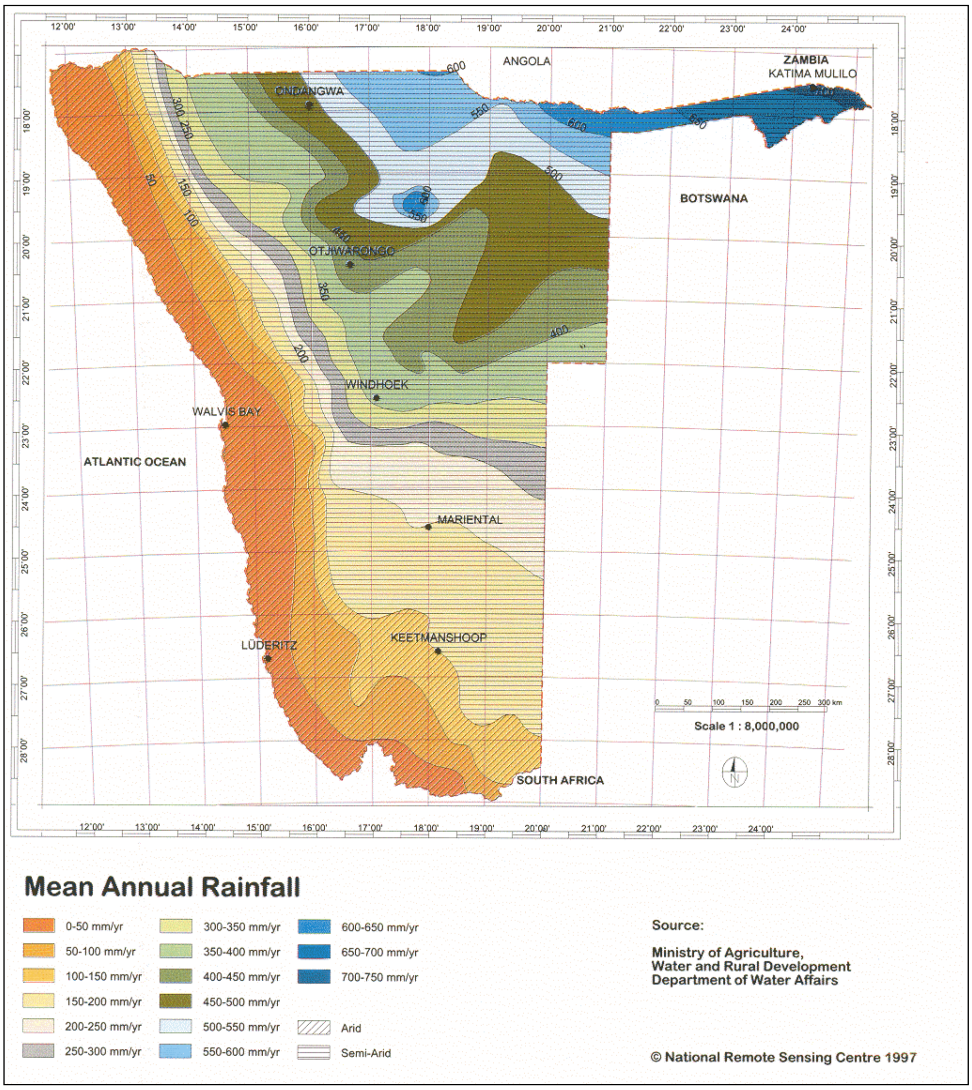
Climatic conditions in arid and semi-arid southern Africa are characterised by low annual precipitation amounts, high maximum air temperatures, low relative air humidity, and high evaporation rates. Frost during the winter month may additionally occur in some areas.

5.2.1 Precipitation

The genus *Harpagophytum* is restricted to the summer rainfall areas of southern Africa with climatic conditions stretching from arid to semi-arid and semi-humid. Rainfall quantities within the distribution area may vary between 150-500mm per year (Fig. 4). Precipitation is characterised by a highly erratic occurrence in space and time. The unpredictability of rainfall increases towards the more arid borders of the distribution area, i.e. towards the Kalahari and the Namib Desert. In some of the arid areas of the Kalahari and the Namib transition zone no rainfall may occur over a period of one to several years. Even in the case of a rainfall event, this is often highly localised and may occur in an area of few kilometres only, resulting in a small-scaled annual pattern of the vegetation.

5.2.1.1 Namibia

In Namibia, the rainfall gradient stretches from the south-west to the north-east of the country (Fig. 4, upper graph). Annual rainfall quantities within the distribution area of *Harpagophytum* range from 100 or 150mm to 500mm. The water deficit (calculated from the mean annual rainfall minus mean annual evaporation) is multiple the amount of rainfall and ranges from -3800mm to -2400mm within the distribution area of *Harpagophytum*. Frequency of rainfall is highest with an annual average of 30-40 rainfall days in the northern parts of the country, on the Windhoek Plateau between Windhoek, Okahandja, and the Gobabis area (VAN DER MERWE 1983). Rainfall frequency decreases towards the south to 10-20 rainfall days per year.



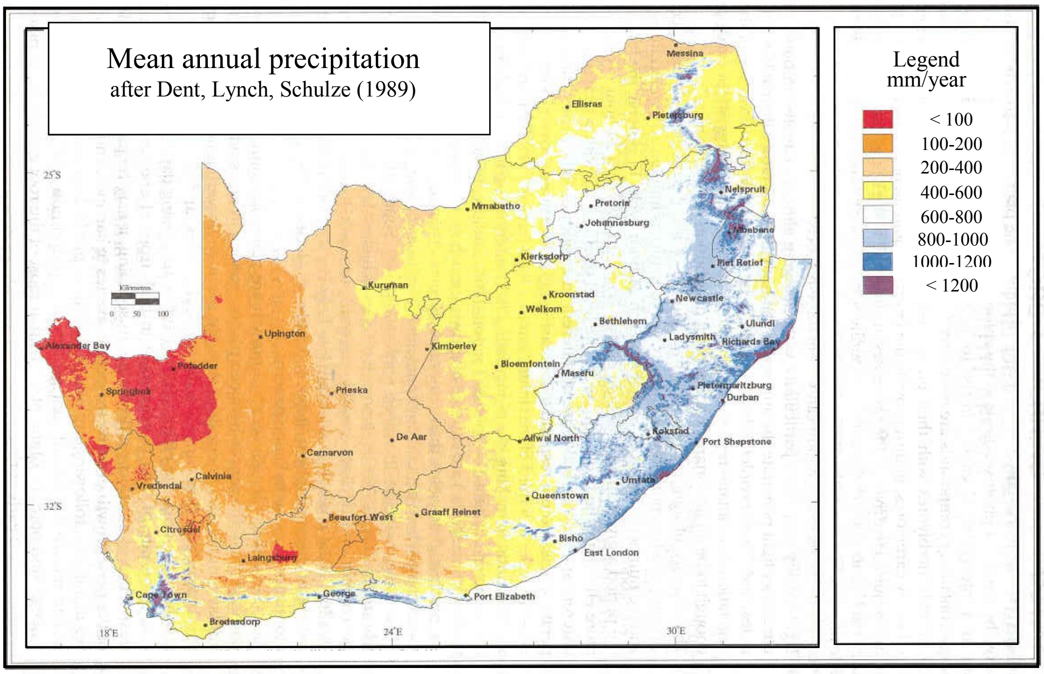


Fig. 4: Mean annual rainfall in Namibia (above) (NATIONAL REMOTE SENSING CENTRE 1997), and South Africa (below) (in TAINTON 1999).

Research sites assessed in this study on the ecology of *Harpagophytum* (Chapter 8) are located in areas with mean annual precipitation amounts of 200-250mm and 450-400mm (BARNARD 1998). The re-documentation sites (Chapter 9) are situated in areas with annual rainfall quantities between 100-150mm and 250-400mm.

5.2.1.2 South Africa

Precipitation within the distribution area of *Harpagophytum* in South Africa is characterised by a larger range stretching from 100-450(500)mm (Fig. 3, lower graph). Precipitation amounts and predictability increase from west to east and towards the south. Most of the research was conducted in low rainfall areas with 100-200mm and 200-400mm annual precipitation (LOW & REBELO 1996). Only in the eastern distribution area of *Harpagophytum,* which is however not covered by the study, higher quantities of over 400mm may occur.

5.2.2 Air temperature and relative air humidity

Other important factors to influence plant growth include the air temperature and relative humidity. Air temperature in the research areas is typically high to very high in summer and low in winter. Temperatures are highest in the lower lying areas, i.e. towards the south of Namibia and in the Kalahari basin of South Africa. Maximum temperatures are reached in the mid of summer, in January with temperatures of 37°C or more. In some areas frost may occur over a period of few days during the winter months.

Relative air humidity typically behaves contrarily to the air temperature and is lowest during midday in summer and highest at night during winter. Areas with the occurrence of *Harpagophytum* are generally characterised by a sparse to missing cloud cover, high air temperature resulting in a low relative air humidity, which accounts for high evapotranspiration rates.

5.2.3 Climatic regions

According to the system of KÖPPEN (1936) climatic regions within the distribution area of *Harpagophytum* predominantly cover the dry regions characterised by a deficiency in rainfall (B-climates). These may show a transition to true deserts (BWh climate) with annual mean temperatures above 18°C such as in the area south of Rehoboth (Namibia), or show a BS-climate indicating a transition to semi-desert conditions. Semi-desert conditions prevail for instance in the Otjozondjupa Region of Namibia as well as north and east of the town Okahandja (VAN DER MERWE 1983).

5.3 Habitat requirements of *Harpagophytum*

5.3.1 Namibia

The AEZ Programme (AGRO-ECOLOGICAL ZONE PROGRAMME) of the Ministry of Agriculture, Water and Rural Development (2001) delineates several agro ecological zones for Namibia. Following this classification, the distribution area of *Harpagophytum* covers predominantly two zones (Fig. 5), the area of the Central Plateau and of the Kalahari Sands Plateau. In parts also the Escarpment area, the Kaokoland area, and the Kalkveld area belong to the wider distribution area of *Harpagophytum*. The species may also occur in the Etosha pan.

Landform types (NATIONAL REMOTE SENSING CENTRE, NAMIBIA 1997) include

- Kalahari types, i.e. fossil sand dunes of the Kalahari, soft porous Kalahari limestone, loose sand drift of the Kalahari, hills in the Kalahari basin, and
- Landform types of the plateau, i.e. erosion forms (hills and slopes) of the Karoo rocks in the Plateau country, plateau with ridges, plateaus proper of the plateau, and highlands of the plateau country.

Although soil types may vary on a small scale, only data on the dominant soil types is available (Fig. 4, classified after ISSS, ISRIC, FAO 1998). Predominantly ferralic Arenosols (sandy, low nutrient status) characterise the soils of the Kalahari, while haplic Leptosols (shallow and rocky) are distributed in the mid and southern part of Namibia. In the mid of the country leptic-skeletic Regosols are typical which characterise non-developed soils with a high amount of rock fragments.

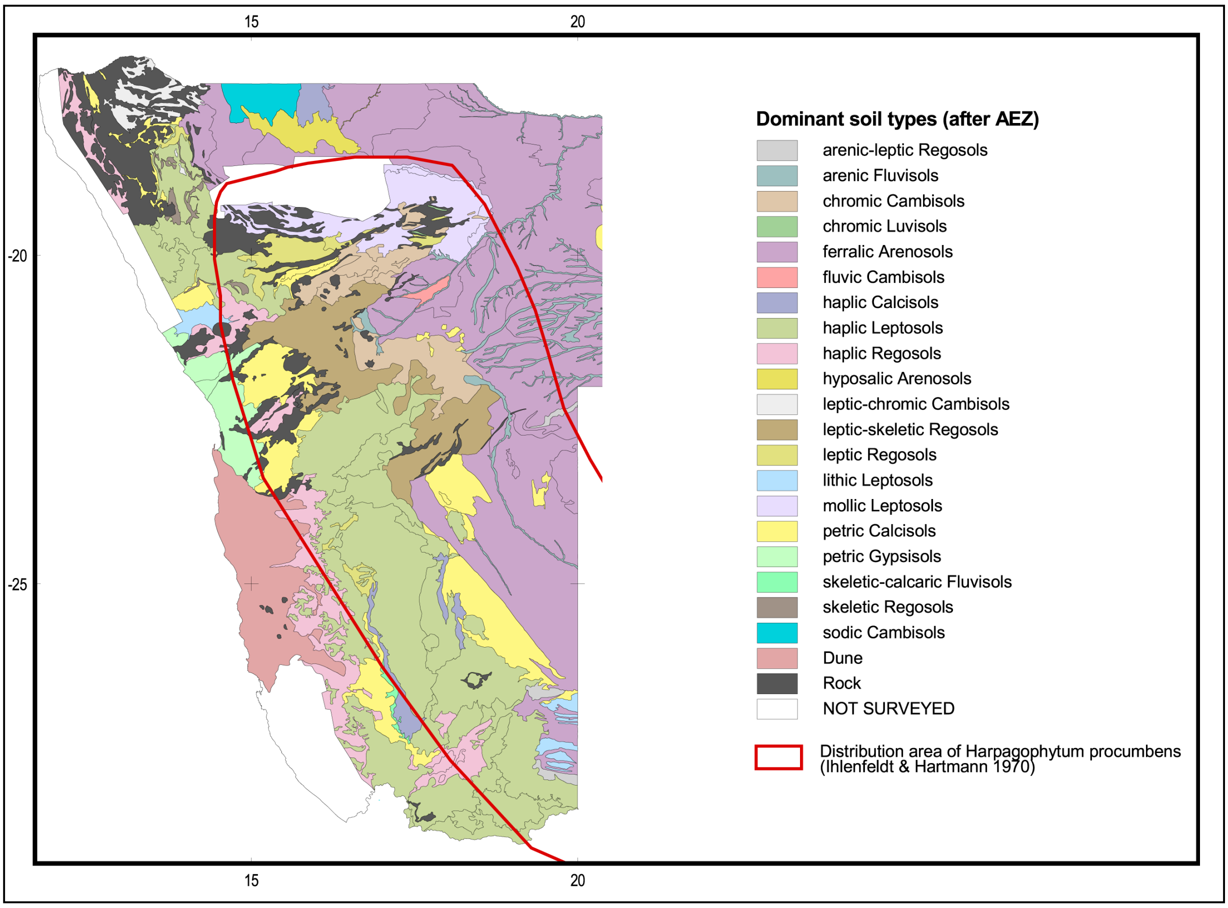


Fig. 5: Distribution area of *Harpagophytum* and dominant soil types of Namibia. Sources: AGRO-ECOLOGICAL ZONING PROGRAMME (2001), IHLENFELDT & HARTMANN (1970).

5.3.2 South Africa

Soils of South Africa are described in the Land Type Series of the ENVIRONMENTAL POTENTIAL ATLAS of 2001. In the South African part of the distribution area of *Harpagophytum* freely drained soils with a red-yellow apedal are typical. These may vary with respect to the soil depth, the occurrence of dunes, the base status, and the clay content. Other soil types within the distribution area show a plinthic catena, have prismacutanic and/or pedocutanic diagnostic horizons or Glenrosa and/or Mispah forms (regional names after SOIL CLASSIFICATION WORKING GROUP 1991) with lime being present in the entire landscape.

5.4 Vegetation

Harpagophytum procumbens ssp. procumbens has its centre of distribution in the Savanna Biome of Namibia, South Africa and Botswana. The term biome is used in the sense of RUTHERFORD & WESTFALL (1986) who follow GODMAN & PAYNE (1979) saying that "a biome is a broad ecological unit that represent a major life zone extending over a large natural area". A biome is determined by environmental conditions, especially by climate thus reflecting the climate conditions of an area.

The life form composition of the Savanna vegetation within the distribution area of *Harpagophytum* is typically a mixture of phanerophytes (tree species) and hemicryptophytes including grasses. Towards the more arid border of the distribution area of *Harpagophytum*, phanerophytes might be replaced by chamaephytes (shrubby species). Within the Savanna Biome, *Harpagophytum* occurrences range from more humid tree savannas to arid thornshrub savannas. In more degraded areas the density of phanerophytes might be strongly reduced or even missing due to over-utilisation by mankind. Typically, the plant communities are then composed of predominantly annual herbs and grasses (HACHFELD 1999).

5.4.1 Namibia

For Namibia, several classification systems related to vegetation and land use are applied.

5.4.1.1 Biome classification

IRISH (1994) presented a biome map of Namibia in which most of the distribution area of *Harpagophytum* falls into the Savanna Biome. The Nama-Karoo Biome evident in the more southern parts of the country also forms part of the wider distribution area of the species. It is characterised by the predominance of small shrubs and low rainfall quantities. No occurrence has been stated from the Desert Biome, which is dominated by therophytic life forms.

5.4.1.2 Vegetation types

The only vegetation map of Namibia available was presented as preliminary vegetation map by GIESS in 1970 and published again as third revised edition in 1998. *Harpagophytum* may occur in nine vegetation types in Namibia (Fig. 6). Yet, this map was produced on a very large scale while small-scale mosaics of the vegetation developed within these broad types.

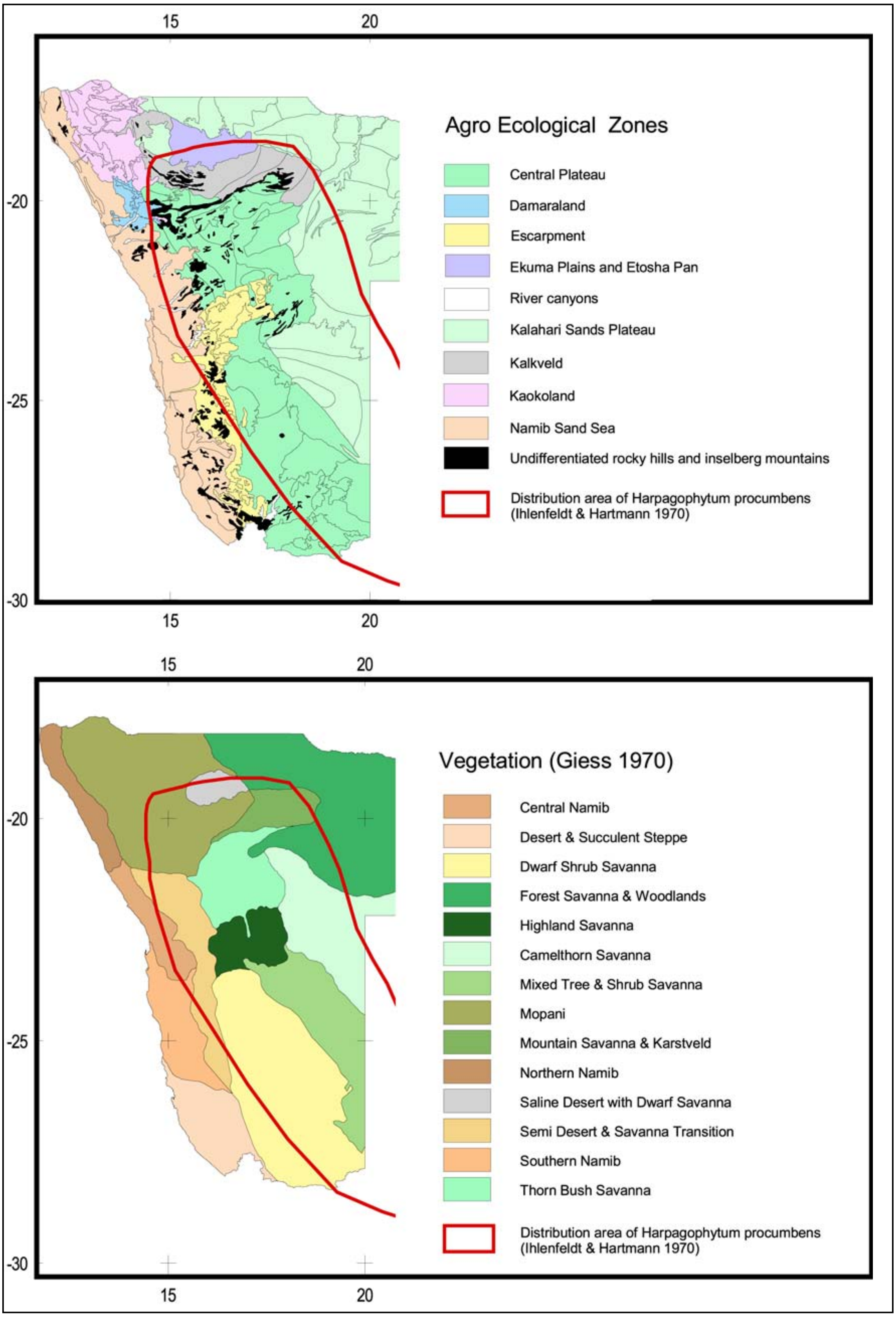


Fig. 6: Distribution area of *Harpagophytum* with the agro ecological zones (above) and vegetation types (below) of Namibia. Sources: AGRO-ECOLOGICAL ZONING PROGRAMME (2001), GIESS (1970), IHLENFELDT & HARTMANN (1970).

5.4.2 South Africa

5.4.2.1 Biome classification

Similar to Namibia, the South African distribution area of *Harpagophytum procumbens* ssp. *procumbens* as proposed by IHLENFELDT & HARTMANN (1970) is covered by the Savanna Biome. The Grassland Biome and the Nama Karoo Biome also form part of the wider distribution area of the species (Fig. 7). The Grassland Biome is characterised by species with a grassy growth form, herbs and scattered trees. *Harpagophytum* may occur in five to six vegetation types of the Savanna Biome.

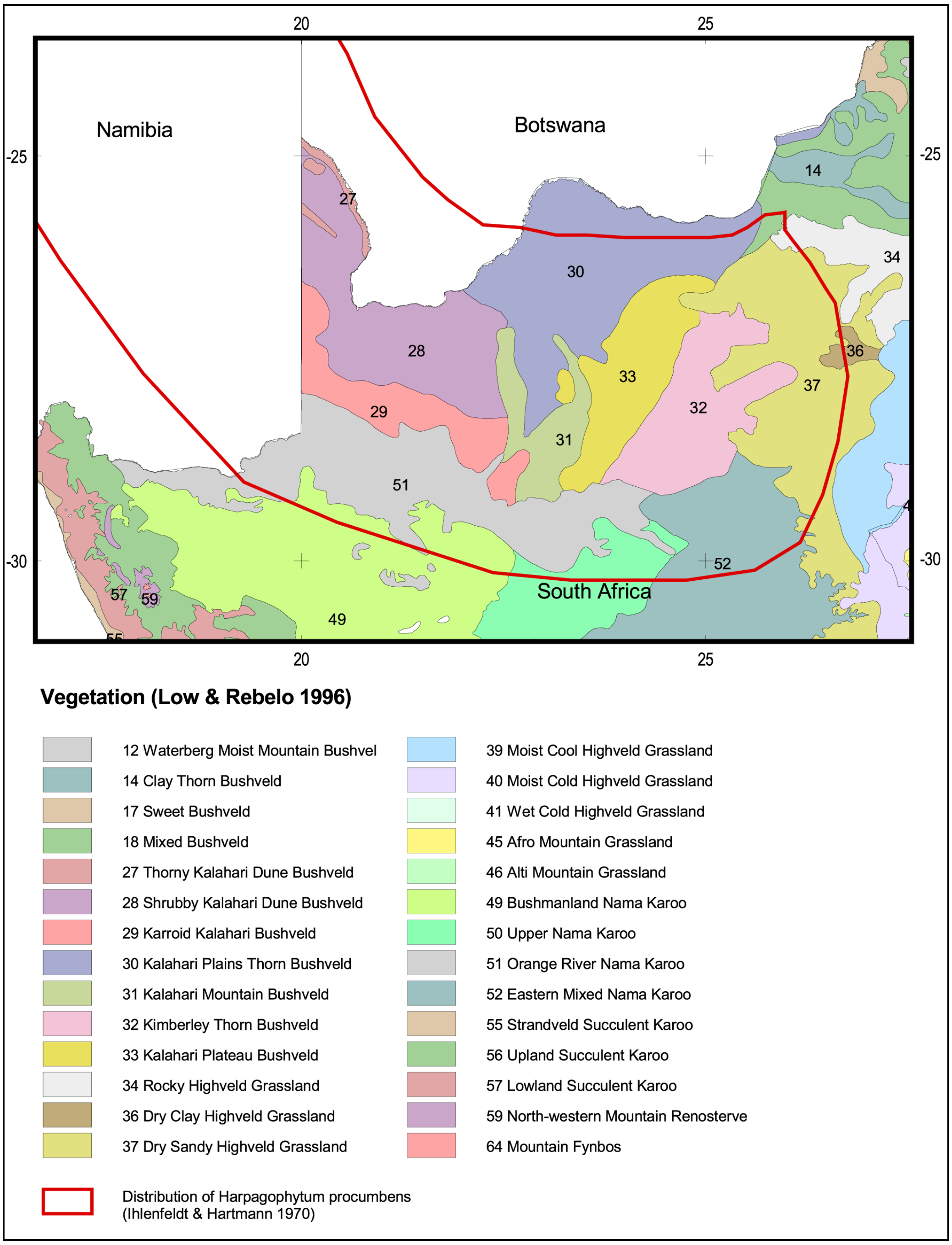


Fig. 7: Distribution area of *Harpagophytum* in the major vegetation types of South Africa. Sources: LOW & REBELO (1996), IHLENFELDT & HARTMANN (1970).

6 The socio-economy of *Harpagophytum*

Harpagophytum is a plant species that is predominantly gathered from the wild. The harvesting of the secondary root tubers of the plant in the wild is labour intensive and time consuming while the monetary outcome is in general low (Chapter 12). As land use by indigenous peoples comprises typically no income generating activities but is restricted to hunting or gathering, even at a low financial incentive, people who are desperately in the need to earn an income will become involved in the harvesting of *Harpagophytum*. The relative importance of harvesting the veld product *Harpagophytum* varies with the potential income an individual can get from other sources of income.

Most of the harvesters of *Harpagophytum* come from poor, marginalized communities with few if any other opportunities for cash income (e.g. HEATH 1999, LEITH 2000, TRAFFIC 2000).

The harvester profile of *Harpagophytum* gatherers is coherent with the statement of CUNNINGHAM (1994) saying that commercial gatherers of medicinal plant material whether for a national or international trade are in most cases poor people whose main aim is earning money and not resource management. In general and with few exceptions, prices paid to gatherers of medicinal plants are very low bearing no relation to annual sustainable off-take. While traditionally, management and monitoring of veld products has always been important to the lives of indigenous land users, this attitude may change when commercial harvesting is implemented on a larger scale. This is in particular true when people from outside the traditional user group get involved in harvesting. Then, very often in order "to make a living, commercial medicinal harvesters of plant parts therefore "mine" rather than manage these resources" (CUNNINGHAM 1994).

Closely related to this is the issue of land tenure. Rights and control over land and natural resources in areas inhabited by indigenous people is an unsolved problem of most countries inhabited by indigenous people (POWELL 1996). The land they occupy and live in as well as the resource from which they subsist is usually state property and localised in very remote areas. Due to this in many cases wild medicinal plant resources are considered open access by many non-traditional harvesters rather than a limited access of private resource. With the start of a commercial exploitation of natural resources of the resource areas, and in particular when the resource is limited or the demand is high, land tenure may cause conflicts. The situation is often – and also in *Harpagophytum* – exacerbated by individuals from outside the community who want to get a share of the common resource. Yet, conflicts may not only occur between the community and outside harvester groups, but may also arise between the communities and the government, which wishes to sustain its control over the resource (by the implementation of permit system, harvesting quotas etc.) or between two adjacent communities competing over the same resource.

Another important socio-economic aspect applicable to the harvesting of *Harpagophytum* is the gender issue. Predominantly women are involved in the harvesting of *Harpagophytum* (e.g. NTSEANE 1993). Demographic data showed for a district in Botswana that out of 329 households, 71% were female headed. These households, which are typically in particular poverty stricken are involved in the harvesting of *Harpagophytum*. A comprehensive discussion of this socio-economic topic is given in Chapter 12.

7 The drug Harpagophyti radix

The medicinal value of *Harpagophytum* has long been known by the indigenous Nama, San and Khoi peoples in southern Africa. The knowledge on the medicinal properties has also been applied by in-migrating Bantu-speaking groups who entered the wider distribution area of *Harpagophytum* between 1500 and 500 years ago (COLE 2003). Although the modalities of this integration of knowledge is not known, it is likely that it has been adopted from the San. The secondary root tubers have traditionally been used by these ethnic groups for the cure of various diseases.

The first European to recognise the medicinal potential of *Harpagophytum* was a German farmer, G.H. Mehnert, who emigrated to Namibia at the beginning of this century. After Mehnert had learnt about the various medicinal properties from the indigenous peoples in Namibia in 1907, in the 1950s he had the root tubers tested at the German University of Jena. First larger exports of *Harpagophytum* started in the year 1962 by the Namibian company Harpago (Pty) Ltd to the German company Erwin Hagen Naturheilmittel GmbH (COLE 2003).

7.1 *Harpagophytum* in Pharmacopoeias

Harpagophytum can be considered a phytomedicine following the definition of ESCOP (http://www.escop.com), meaning medicinal products which contain as active ingredients only plants, parts of plants or plant materials, or combinations thereof, whether in the crude or processed state. Such medicinal products are defined in the European Directive 65/65/EEC of 1993 (http://www.alliance-natural-health.org/docs/archive/pharma/D-Med-65-65-EEC.PDF). In general, *Harpagophytum* products are registered as herbal medicines in France and Germany or as food supplements in the United Kingdom, Netherlands, USA, and the Far East.

The official requirements for the European trade in the drug *Harpagophytum* are stated in various monographs in Europe (i.e. DEUTSCHES ARZNEIBUCH 1997, BRUCHHAUSEN et al. 1993, THE BRITISH HERBAL PHARMACOPOEIA 1990). Of these, the European Pharmacopoeia formed in 1964 and comprising currently 26 member states, can be considered one of the most important ones. Monographs listed there have the task of laying down common standards for the composition and preparation of substances used in the manufacture of medicines and by this guaranteeing their quality. The European Pharmacopoeia has the force of law and aims at the replacement of the old national pharmacopoeias (http://www.social.coe.int/en/edqm.htm). Another important reference in which applications of *Harpagophytum* are listed is the monograph of The European Scientific Cooperative on Phytotherapy (ESCOP), which is an umbrella organisation representing national phytotherapy associations across Europe and which was founded in 1989 (ESCOP 1996, http://www.escop.com). Also under the German Commission E Monographs, *Harpagophytum* has been listed in 1989 and revised in 1990. The Commission E (http://www.herbalgram.org/iherb/commissione/monographs) is a governmental regulatory agency that was established in 1978 to evaluate useful herbs and to publish monographs listing uses and side effects.

Synonyms for the drug made of *Harpagophytum* are Harpagophyti radix or Tubera harpagophyti. Up to 2003, the only species allowed and registered in the European Pharmacopoeia has been *Harpagophytum procumbens*. Only in January 2003, *Harpagophytum zeyheri* was added to the definition to cover all traded

Harpagophytum products (COLE 2003). Beforehand, an increasing number of scientist and other stakeholders had called for the inclusion also of *Harpagophytum zeyheri* in the European Pharmacopoeia (e.g. BETTI 2002, HALLBAUER 2002) claiming that with respect to quality control, conservation issues and already existing adulterations this would provide a useful tool to take the harvesting and trade pressure from *Harpagophytum procumbens*.

The drug Harpagophyti radix is defined as sliced (or cut in pieces) or pulverised dried material of the secondary root tubers. The macroscopical description requires the slices to be irregularly circular, 2-4cm to sometimes 6cm in diameter, and with a thickness of 2-5mm. Slices should have a cork reddish-brown to dark brown colour and should be longitudinally wrinkled. The drug is obtained by slicing or cutting of the fresh secondary root tubers, which are dried in the sun for about three days. Material should come from wild populations out of the range states from southern Africa, i.e. Namibia, Botswana, and South Africa. Confusions may occur with old main tubers of *Harpagophytum procumbens*, detectable at the black-brown colouring and the lack of bitter taste. Confusion may additionally occur with the very bitter tasting roots of other African plant species such as *Elephanthorriza* spec. (Mimoasaceae) and *Acanthosicyos naudinianus* (Cucurbitaceae).

Quantitative standards of the pharmacopoeias include that the drug has to be almost odourless, the taste has to be medium to extremely bitter with a little sweet component. Purity should be high with only 2% foreign matter, and a loss through drying process of at most 10% is acceptable. The requirements regarding the ash content vary: According to BRUCHHAUSEN et al. (1993) the ash content should have a maximum of 8%, whereas in the BRITISH HERBAL PHARMACOPOEIA (1990) a total ash content of not more than 22% is stated. In general, the level of active ingredients and in particular of harpagoside is used to determine the quality of the dried tubers. Extraction technologies comprise aqueous or ethanol-based methods, but can also be achieved with liquid carbon-dioxide and a cosolvent. Various patents regarding the extraction technologies have been registered (GRUENWALD 2002, Chapter 14.7).

7.2 Constituents of *Harpagophytum*

7.2.1 Constituents of *Harpagophytum procumbens*

Since the medicinal value of the secondary tubers of *Harpagophytum* has been recognised, a great number of analysis on the active constituents and their effects have been carried out (e.g. CIRCOSTA et al. 1984, COSTA DE PASQUALE et al. 1985, OCCHIUTO et al. 1985, GUILLERAULT et al. 1996). In this context, only a broad overview can be presented. An extensive list of various analyses on the pharmacology, phytochemistry and clinical use of *Harpagophytum procumbens* is given in WEGENER (1998, 2000).

Principally both, the secondary storage tubers and the main tuber comprise similar active ingredients. The difference lies in the quantity of the medicinally important constituents. According to CZYGAN & KRUGER (1977) the secondary tubers have about twice the amount of harpagoside in comparison to the main tuber. As only the secondary tubers are registered as official drug, in the following these will be dealt with.

The medicinally most important constituents of Harpagophyti radix are iridoid glycosides. Iridoids represent a typical chemical constituent evident in the entire Pedaliaceae family and are also characteristic for the order of Lamiales. Iridoids are present in various traditional herbal medicines and exhibit a wide range of bioactivity (WEGENER 2000). In the secondary tubers of *Harpagophytum* Iridoids reach a dry matter content of 2-3% in good quality material, typically ranging from 0.5-3%. The fraction of iridoid glycosides consists of predominantly harpagoside and to a lesser extent also of harpagide, procumbide and 8-para-coumaryl-harpagid. Referring to the BRUCHHAUSEN et al. (1993), at least 1% harpagoside is to be included in the dried drug, whereas the monograph of the EUROPÄISCHES ARZNEIBUCH (1997) states a content of a minimum of 1.2% harpagoside to be required. Flavone and Phenylethanolderivate should also occur. Sugars are found to about 51% composed of stachyose, raffinose, sucrose, and monosaccharides. No starch and high weight polysaccharides occur in the secondary tubers. Additionally, small amounts of triterpenes (esp. Oleanic acid), phytosterils, aromatic acids like caffeic, cinnamic, flavonoids including kaemferol and luteolin, and harpagoquinone are found (e.g. BURGER, BRAND & FERREIRA 1987, BRITISH HERBAL COMPENDIUM 1992). A number of experiments with isolated harpagoside and harpagide proved that only complete extracts show a therapeutic effect but no single constituents (e.g. EICHLER & KOCH 1970, ERDÖS et al. 1978, CIRCOSTA et al. 1984, FLEURENTIN & MORTIER 1997). Following WEGENER (1998) "the actual active constituents as well as its effective mechanisms of the Harpagophyti radix are not clear so far. It is, however, obvious that only the whole extract can ensure a good effect".

The quantity of harpagide in the dried tubers determines the quality and price of the material. CZYGAN & KRUGER (1977) state a content of 0.9-1.8g harpagoside per 100g dried tuber, whereas other sources give an amount of 0.1-3.6% (RAGUSA et al. 1984, CARLE 1988, CHRUBASIK et al. 1996). A minimum content of 1.2% harpagoside in the drug is defined by the monograph of the EUROPÄISCHES ARZNEIBUCH (1997). No correlation is evident between the size of the tubers or the age of the plant and the harpagoside content per dry weight though (TITIEMA 1986). Highest quantities of constituents are said to have accumulated in the secondary tubers in autumn (May – April) at the beginning of the dry period when the storage tubers are filled with reserves and water content is not as high as in the middle of the rainy season (BLANK 1973).

7.2.2 Constituents of *Harpagophytum zeyheri*

Generally *Harpagophytum zeyheri* inhabits the similar constituents as *H. procumbens*. Yet, differences can be found in the quantity of the medicinally valuable iridoids harpagoside and harpagide, which had been responsible for the long-term rejection to include also this species as official drug. Other authors such as CZYGAN & KRUGER (1977) are of the opposite opinion and demonstrated similar contents of harpagoside in *Harpagophytum procumbens* and *Harpagophytum zeyheri*.

The most marking difference in the composition of active ingredients between both species is the content of the iridoid 8-p-coumaroyl-harpagide (PCHG). Whereas in *H. procumbens* harpagide forms the main constituent and PCHG occurs only with 0.1%, in *Harpagophytum zeyheri* one finds a relation of 1:1 between PCHG (equals 1.8%) and harpagide. The analytical method to differentiate between both metabolite was recently published and is carried out with HPLC (High pressure liquid chromatography) methods (BAGHDIKIAN et al. 1997, EICH & WEGENER 1997, EICH, SCHMIDT & BETTI 1998). This criterion is proposed to serve as quality proof for exported material. But due to the fact that clarity on potential mixtures of both species failed in the past, it can be expected that so far changing quantities of *Harpagophytum zeyheri* have often to always been mixed with the *H. procumbens* and thus sold as Harpagophyti radix (WEGENER 1998).

7.3 Therapeutical effects of *Harpagophytum*

The medicinal uses of the official drug *Harpagophytum* (*Harpagophytum procumbens*) are numerous. One has to distinguish between pharmaceutical uses in the European market and traditional uses by different ethnic groups and.

7.3.1 Medicinal applications

Therapeutical effects are derived from the complete extract of the secondary root tubers only, whereas isolated glycosides show only little effect (e.g. FLEURENTIN & MORTIER 1997). In Europe, the *Harpagophytum* extract is recommended for painful arteriosclerosis, gastro-intestinal complains (also loss of appetite), diabetes, hepatitis, and neuralgia. Other indications include the reduction of spasmodic blood pressure, positive effects on liver, gallbladder, and kidney diseases, as well a senility. The drug has potent anti-inflammatory properties, shows analgesic and antiphlogistic effects with no notable side effects (e.g. WATT & BREYER-BRANDWIJK 1962, VOLK 1964, LANHERS et al. 1992, WENZEL & WEGENER 1995, BAGHDIKIAN et al.1997, SMITH et al. 2001).

At the beginning of the trade in *Harpagophytum* in the 1970s retail products comprised exclusively teas. It is assumed that only such infusions as herbal teas have a dyspeptic action which is probably due to the strong and intensive stimulatory bitterness of the dried tuber (WEGENER 2000). Today the range of products ranges from tea to tablets and capsules. As *Harpagophytum* is primarily trades as dried sliced tubers, processing to retail products does currently not take place in the range countries but in Europe (Chapter 14).

The application of herbal medicines and also of *Harpagophytum* has increased considerably over the past years. GRUENWALD (2002) states an increase in the percentage of prescriptions of *Harpagophytum* by physicians for the treatment of poly-arthritis as well as back and joint pains from 40% in 2000 to 60% in 2001. Currently, products of *Harpagophytum* account for approximately 74% of the treatments for rheumatism in Germany.

7.3.2 Traditional uses

In traditional medicine the secondary tubers are used for various indications such as the treatment of indigestion, as purgative, bitter tonic, febrifuge, or in the case of syphilis. External applications comprise the treatment of sores, boils, and other skin lesions including skin cancer (WATT & BREYER-BRANDWIYK 1962, VON KOENEN 1996, SMITH et al. 2001). The drug is also applied to give relief to pregnancy and birth pains (ERDÖS et al. 1978). In general, the root tubers are said to have anti-arthritic properties and to support general detoxifying remedy (BURGER 1987).

7.4 Adulterations and Confusion with other species

Due to an increase in the demand and the subsequent increase in the harvesting of *Harpagophytum*, increasingly also people not being acquainted with the detailed morphology of the plant become involved in the harvesting. Today, only a limited number of harvesters come from a traditional background and are well familiar with the appearance of the species (see Chapter 12). Next to the lack of knowledge, low prices, the need for cash money, as well as a limited resource may lead to the harvesting of other look-alike species. Adulterations in the exported drug material are reported to vary depending on the harvesting area. Some exporters claim to be able to visually detect these adulterations in dried and sliced material (Krafft, pers. comm.). Others started to use chromatography to differentiate between both species of *Harpagophytum* (Horsthemke, pers. comm.).

The main species confused with *Harpagophytum* is *Acanthosycios naudinianus*, a geophytic member of the Cucurbitaceae family, which frequently is encountered with *Harpagophytum* in the wild. Other adulterations occur with rhizomes of *Elephantorrhiza* spec. (Mimosaceae), of *Kedostris* spec. (Cucurbitaceae) and with other species of the plant families of Convolvulaceae, Asclepiadaceae, and Apocynaceae (CZYGAN et al. 1977). As for example species of the Apocynaceae are extremely toxic, analysis of *Harpagophytum* drug material with adulterations of those species had in the past let to the assumption that toxic effects in the *Harpagophytum* drug might occur (ZORN 1958). This is, however, not the case (e.g. TUNMAN & LUX 1962, ERDÖS et al. 1978, VANHAELEN et al. 1981). SCHNEIDER et al. (2001) published a paper on how to avoid adulterations of *Harpagophytum*. SCHNEIDER (2000) also produced an illustrated handbook also for this purpose.

At first glance and in particular for a harvester not acquainted with taxonomy, the habitus of *H. zeyheri ssp. sublobatum* appears very similar to that of *H. procumbens ssp procumbens* (GERMISHUIZEN 1982). Although the fruits lack conspicuous spines, and the leaves as well as the flowers are smaller, adulterations of both species occur quite frequently.

8 Ecology of *Harpagophytum*

This chapter presents results of fieldwork conducted on the ecological requirements of *Harpagophytum* in Namibia and South Africa.

8.1 Approach

Generally, regarding sustainability of medicinal plants, information is in particular required on those, harvested from the wild and traded on a commercial scale. Comprehensive knowledge should therefore be collected on the regeneration, growth, population structure, flowering and fruiting phenology or seasonality, pollinators, breeding systems, seed dispersal and so forth (CUNNINGHAM 1992, SHELDON, BALICK & LAIRD 1997). The understanding of the ecology of traded plant species is the more important the more severe the impact of harvesting is on the survival of individuals, populations or species. In general, this impact depends on the plant parts used. The global market demand for the roots of a plant such as *Harpagophytum* can for instance seriously threaten the continued existence of a species, when over harvesting occurs. Hence, a thorough understanding of the ecology of *Harpagophytum* is an important prerequisite for the success in a sustainable use and trade of the species.

This chapter analyses several ecological aspects of *Harpagophytum*, which were studied on various research sites in Namibia and South Africa. The approach is based on the knowledge that *Harpagophytum* is not evenly distributed over southern Africa, but is limited to certain parts of the subcontinent. Only in certain areas environmental conditions are suitable for the occurrence of the species.

Owing to the temporal limitation of the study and the vast distribution area of the species, a country-wide sampling of the entire distribution area of the medicinally important species could not be carried out (see Chapter 4 for the distribution of *Harpagophytum*). Therefore, spot checks were made and research focussed on the centre of the species distribution. This selection was done on the biome level, each biome being characterised by the dominance of one to few plant functional types. For *Harpagophytum*, the Savanna Biome represents the major biome within the distribution area. Biomes, where the species is only reported occasionally were not considered. Within the Savanna Biome, different land use types as well as vegetation and habitat types are represented in the study. These pinpoint investigations are relevant for describing and assessing the current distribution, density and vitality of *Harpagophytum*.

In order to achieve a more detailed understanding of the occurrence and density pattern of *Harpagophytum*, field data has been intersected with the available information on the vegetation types, land use intensities, land and soil properties. This method enables to interpolate the locally collected data over a larger region. Special focus was put on the role of land ownership for the resource availability of *Harpagophytum*. For this, communally and privately owned farmland were sampled. HOFFMAN & ASHWELL (2001) state that political as well as economic conditions differ markedly in South African commercial and communal areas. For the understanding of patterns of degradation they found a division into both types of landownership crucial. In this chapter it is tested, if parameters such as the land use intensity and the therewith closely related composition and density of the vegetation, vary with respect to the land ownership and thus influence the occurrence and density of *Harpagophytum*.

Harpagophytum being a species that has been internationally traded for several decades based on extraction of wild material, this part of the study also aims at an evaluation of the exploitation intensity and a corresponding decrease of the plant in different parts of the distribution area. The field data contributes to an interpretation of future harvesting quantities and issues of sustainability (Chapters 12, 14).

Results of the field studies on the occurrence and density of *Harpagophytum* in Namibia and South Africa are presented starting with an introduction to the applied methods and research areas (Chapter 8.2, 8.3). The occurrence of *Harpagophytum* under different land use systems and various vegetation types of both countries is discussed (Chapter 8.4) as well as the impact of environmental parameters such as the habitat type (Chapter 8.5) and soil properties (Chapter 8.6). A discussion on the role of land use (Chapter 8.7) and of the surrounding vegetation for the occurrence of *Harpagophytum* (Chapter 8.8) follows. In Chapter 8.9, the spatial patterns of *Harpagophytum* are analysed while in a subsequent chapter focus is laid on the reproductive effort and potential of the species in different parts of the distribution area (Chapter 8.10). The Chapter 8.11 discusses the utilisation of *Harpagophytum* presenting harvesting intensities as well as potential resource availabilities.

8.2 Methods

Data and information is derived from field work in Namibia and South Africa, as well as from personal communications and interviews with farmers, NGOs and other stakeholders.

In general, the highly erratic precipitation patterns (in time and space) of the research areas are responsible for a number of methodological constraints which this study similar to any other study dealing with biotic components of arid summer rainfall areas has to cope with: Ecological studies which include mapping approaches such as this study typically cover a large area while at the same time each research site is documented only once. Due to this, the quantity of rainfall which an area received or not received may influence the results of the study and may result in misinterpretations. To overcome this constraint, sample size needs to be large enough and additional information has to be collected on rainfall amounts prior to the documentation. In this study, interviews with land owners complement collected field data to properly interpret whether *Harpagophytum* is occurring or missing in an area.

8.2.1 Field campaigns

Field work was carried out in the period of February-March 2000, January-April 2001 and February-March 2002 in Namibia and South Africa. Tab. 2 in Chapter 8.3 lists the number of sites recorded in both countries.

8.2.2 The research sites

The research sites used for the documentation of *Harpagophytum* have a size of one square kilometre. Within the distribution area of *Harpagophytum*, several square kilometres were placed in various vegetation types of the Savanna Biome. Where possible, more than one square kilometre was placed on the same farm or in the same area. This was done because a larger sample size better reflects the heterogeneity of the landscape of a specific area which is a result of environmental or anthropogenic impacts. By the use of research sites of the size of one square kilometre, not only single populations or individual occurrences of *Harpagophytum* can be documented (as would be for instance in smaller plots of 100m²), but information is collected in a broader environmental context, meaning an occurrence of several populations.

The plot size of one square kilometre inherits the typical combination of different habitat types and different small-scale vegetation mosaics of the general vegetation type and biome of the area. The recording of individuals of *Harpagophytum* within the square kilometre was done using smaller documentation units, i.e. linear transect walks. In total, 24 of such linear transects were placed randomly within each square kilometre (Fig. 8). The different transects were placed so that they cover the major habitat and vegetation types present on the research site, while environmental parameters within each transect are kept as homogenous as possible. Typically, the documentation was carried out by two persons, each covering half of the research site and assessing 12 transects. Overall, on each site several kilometres were walked by each person, which contributed additional information on the occurrence of *Harpagophytum* besides the mere recording of the transects. Depending on the vegetation type and accessibility, period of time required for the documentation of the research sites covered several hours for two persons.

Each transect comprises a length of 100m and a width of 2m, on which the number of individuals of *Harpagophytum* as well as other additional parameters are documented. For a convenient application in the field, a stick of 2m length was used which was carried horizontally in front of the person walking along the transect. By this, half of its length (1m) reaches to each side of the person. All individuals of *Harpagophytum* which were covered by the range of the stick were documented to belong to the transect. This technique proved to be in particular helpful in the communal areas where interested community members accompanied and supported us with the assessment of the transects. The stick represented a helpful measure also for the people to only include those plants into the recording of the transects which did grow beneath the stick's range.

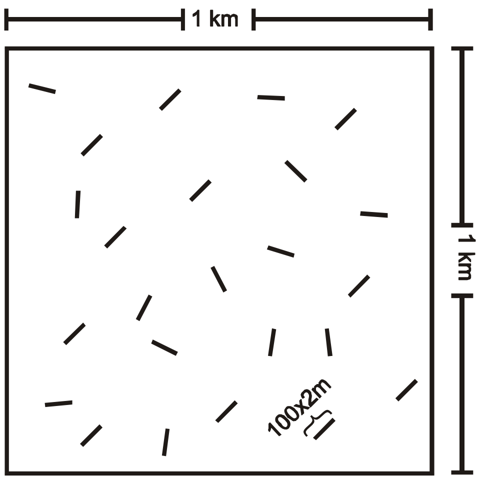


Fig. 8: Design of a 1 km² research site with 24 randomly distributed linear transects of 100*2 m.

The design and method of documentation allows the following:

- The general occurrence or lack of individuals of *Harpagophytum* is documented not only for single transects but also for a larger landscape unit.
- A scattered occurrence of single individuals of *Harpagophytum* can be determined for the research area.
- The existence and density of aggregations of *Harpagophytum* is assessed for an area larger than the transect which allows a spatial interpretation of the distribution of patches.
- Various combinations of a scattered and clumped occurrence of *Harpagophytum* can be recorded.

The method experiences a restriction when it comes to population patterns, meaning the detection of every clumped occurrence of *Harpagophytum* on the research sites. As clumped aggregations can have an extension of several $100m^2$ or only of $10m^2$, especially small clumps may not be covered by the transects. No interpretation with respect to total patch numbers/site is therefore possible by this method. The 24 transects cover a total area of 0.48% of the square kilometre, which is randomly distributed over the research site. This linear transect method has also been applied by STROHBACH (2001) for a national survey on *Harpagophytum* in Namibia.

8.2.3 The documentation sheet

Several abiotic and biotic parameters have been recognised to be possibly important for the occurrence of *Harpagophytum.* These parameters were recorded on each transect using a fixed documentation sheet (see attachment). From each 100m transect, the GPS co-ordinates of the beginning and the end of the transect were recorded. By this, re-documentations of the transects will be possible also in future.

Recorded environmental parameters are:

- Habitat type: broad categories of dune habitats and non-dune habitats were used, i.e. plain, dune base, dune slope, dune crest, interdune, roadside (disturbed plains), Omuramba (periodically flooded plains).
- Soil substrate type and soil colour were determined using the first centimetres of the upper soil layer. Soil colour was determined following a rough scale from brown, brown-yellow, brown-red, red, yellow, and yellow-red.
- Type and intensity of land use: this was determined by the grazing pressure on the vegetation. A detailed description is given together with the results in Chapter 8.7.
- Density and composition of the surrounding vegetation: the cover of different layers of the vegetation (grass, herb, shrub and tree layer) was determined. Additionally, the dominant species were recorded for each layer.
- Where appropriate, additional notes were recorded, e.g. on the distance of the research site to the next village or special disturbances.
- Parallel to every documentation an interview with the farmer or the major stakeholder of an area was carried out.

The following data on *Harpagophytum* individuals was collected for each transect:

- Above-ground plant size was determined dividing individuals according to the diameter of the prostrate shoots into small (smaller than 10cm in diameter) and large individuals (larger than 10cm in diameter). This differentiation is based on the assumed correlation between the above ground plant size, i.e. the diameter of the prostrate shoots, and the flowering intensity. It is expected that small individuals are only occasionally able to produce reproductive organs.
- To gather information on the reproductive success and ability of *Harpagophytum*, flower and fruit counts with fruits still attached to the mother plant (young fruit) and those detached from the mother plant (old fruit) of past years rainy seasons were carried out.
- The number of manmade holes was counted to quantify the harvesting intensity. A de-tailed description of the detection of harvesting holes in the field is given in Chapter 8.11.

8.2.4 Applied analytical methods

Several analytical methods were applied to the collected field data. For some analyses a categorisation of the individual numbers of *Harpagophytum* recorded on the square kilometres and on the transects was necessary:

- On the square kilometre sites overall quantities of *Harpagophytum* were categorised into five quantity classes: 0, 1-49, 50-99, 100-199 and >200 individuals/km².
- On the transects, six classes instead of individual numbers were used to analyse the spatial growth pattern of *Harpagophytum*: 0, 1-4, 5-9, 10-20, 21-50 and >50 individuals/transect.

It was defined that a clumped occurrence of *Harpagophytum* has to show at least 10 plants/transect. In the case of lower individual numbers/transect a scattered occurrence of single plants was assumed. The class sizes are based on personal observation on the occurrence of aggregations of the species in the field as well as on methodological discussions with other scientists, who also apply the differentiation between patches and non-patches (see also STROHBACH 2002)

The resource density of *Harpagophytum* prior to the impact of harvesting was calculated as potential available resource (Chapter 8.11). For this, the recorded number of plants and of digging holes were added. Then, the extent of utilisation was identified for each transect as percentage holes of the potential resource.

The calculation of the potential seed production of *Harpagophytum* plants and their contribution to the seed bank was based on field data (fruit numbers) and on data from literature on seed amounts per fruit (BLANK 1973, DE JONG 1985, TITIEMA 1986). Data of ERNST et al. (1988) on the fitness of seeds in fresh fruits of *Harpagophytum* indicate a percentage of 37% of seeds for each capsule that are not able to germinate. From this, it was concluded that the remaining 63% of the seeds of each capsule have an embryo. This percentage was used for the estimation of a *Harpagophytum* seed bank (Chapter 8.10.3).

Applied statistical methods:

As data collected in the course of the study is predominantly not normal distributed, non-parametric instead of parametric analyses were applied. In this study, this was the Spearman rank order correlation, the Kruskall-Wallis test and the Mann-Whitney U test:

- The Spearman rank order correlation tests the potential relationship between two data sets on the basis of ranks. The test was always carried out two-sided. The correlation assumes that the variables under consideration were measured on at least an ordinal (rank order) scale, that is, that the individual observations can be ranked into two ordered series (LOZAN & KAUSCH 1998). Spearman R tests the terms of proportion of variability accounted for two variables computed from ranks. The value of correlation (i.e., correlation coefficient) does not depend on the specific measurement units used.
- The Mann-Whitney U test is a nonparametric alternative to the t-test for independent samples. It assumes that the variable under consideration was measured on at least an ordinal (rank order) scale. The interpretation of the test is essentially identical to the interpretation of the result of a t-test for independent samples, except that the computed U test is based on rank sums rather than on means. The U test is the most powerful (or sensitive) nonparametric alternative to the t-test for independent samples. With sample sizes larger than 20, the sample distribution of the U statistic rapidly approaches the normal distribution. Then, U statistic is accompanied by a z value (normal distribution variation value), and the respective p value, which is then used and listed.
- The Kruskal-Wallis ANOVA by ranks test is a single factor variance analyses (KÖHLER, SCHACHTEL, VOLESKE 1995). It assesses the hypothesis that the different samples in the comparison were drawn from the same distribution or from distributions with the same median. It is assumed that the variable under consideration is continuous and that it was measured on at least an ordinal (rank order) scale.

8.3 Research areas

Field research was carried out in two of the three major range countries, Namibia and South Africa. Botswana was not included in the study even though harvesting does take place in the country. Due to delays in the permit issuing process, it was decided to rather intensify the studies in Namibia and South Africa. Nevertheless, besides results of the field studies an evaluation of the harvest of, trade in and legislation of *Harpagophytum* is included in the study (Chapters 12-15).

Tab. 2: Number of research sites documented in Namibia and South Africa in 2000-2002.

Country / year	2000	2001	2002	Total
Namibia				50
Communal	5	12	-	17
Private	11	22	-	33
South Africa				46
Communal	3	2	6	11
Private	9	9	17	35

Over the past three rainy seasons (2000, 2001, 2002) a total of 96 research sites was documented in Namibia and South Africa. Listed in Tab. 2 is the number of sites assessed in Namibia and South Africa differentiated into sites on privately and communally owned land. Approximately the same number of sites was assessed in Namibia (50 sites) and South Africa (46 sites). In both countries more square kilometres were documented in private farmland than in communal areas, i.e. 17 sites were visited and recorded in communal areas of Namibia and 11 sites in South Africa.

8.3.1 Regions and districts

Prior to the selection of the major research areas, intensive discussion took place with important stakeholders involved in the research on *Harpagophytum* in both countries

In Namibia, most important partner was CRIAA SA-DC. The NGO is part of the National Devil's Claw Working Group (DCWG). With the DCWG it was decided to concentrate field sampling on selected areas rather than widely scattered over the entire country. As research had been done in the areas of the Otjozondjupa- and Windhoek Region in the previous year and most harvesting activities have been reported from this area, further research was conducted in these two regions (Tab. 3, Fig. 9).

In South Africa the selection of the major research areas was discussed with the Nature Conservation Offices of the Northern Cape Province and the North-West Province (Tab. 3, Fig. 10).

Tab. 3: Number of research sites in different countries, regions, districts and provinces.

Country	Region / Province	District	Number of sites
Namibia	Kunene	Opuwo	1
	Otjozondjupa	Okahandja	8
		Otjiwarongo	15
		Okakarara	9
	Omaheke	Gobabis,	2
		Otjinene	3
	Khomas	Windhoek	8
	Hardap	Rehoboth	4
South Africa	Northern Cape	Gordonia	8
		Kuruman	8
	North West	Vryburg	2

In Namibia, a total of 50 square kilometres was documented covering five regions of the country (Fig. 9). Of these, 17 sites were placed in communal areas, i.e. in the Otjozondjupa, Omaheke, Hardap and Kunene Region. Two sites were placed in the refugee camp of Osire in the district of Okahandja.

In South Africa, *Harpagophytum* was documented on a total of 46 square kilometres in the Northern Cape and in the North West Province (Fig. 10). Ten of the eleven communal sites are located in a very large communally owned area of the North West Province. No other larger communally owned areas were included in the study.

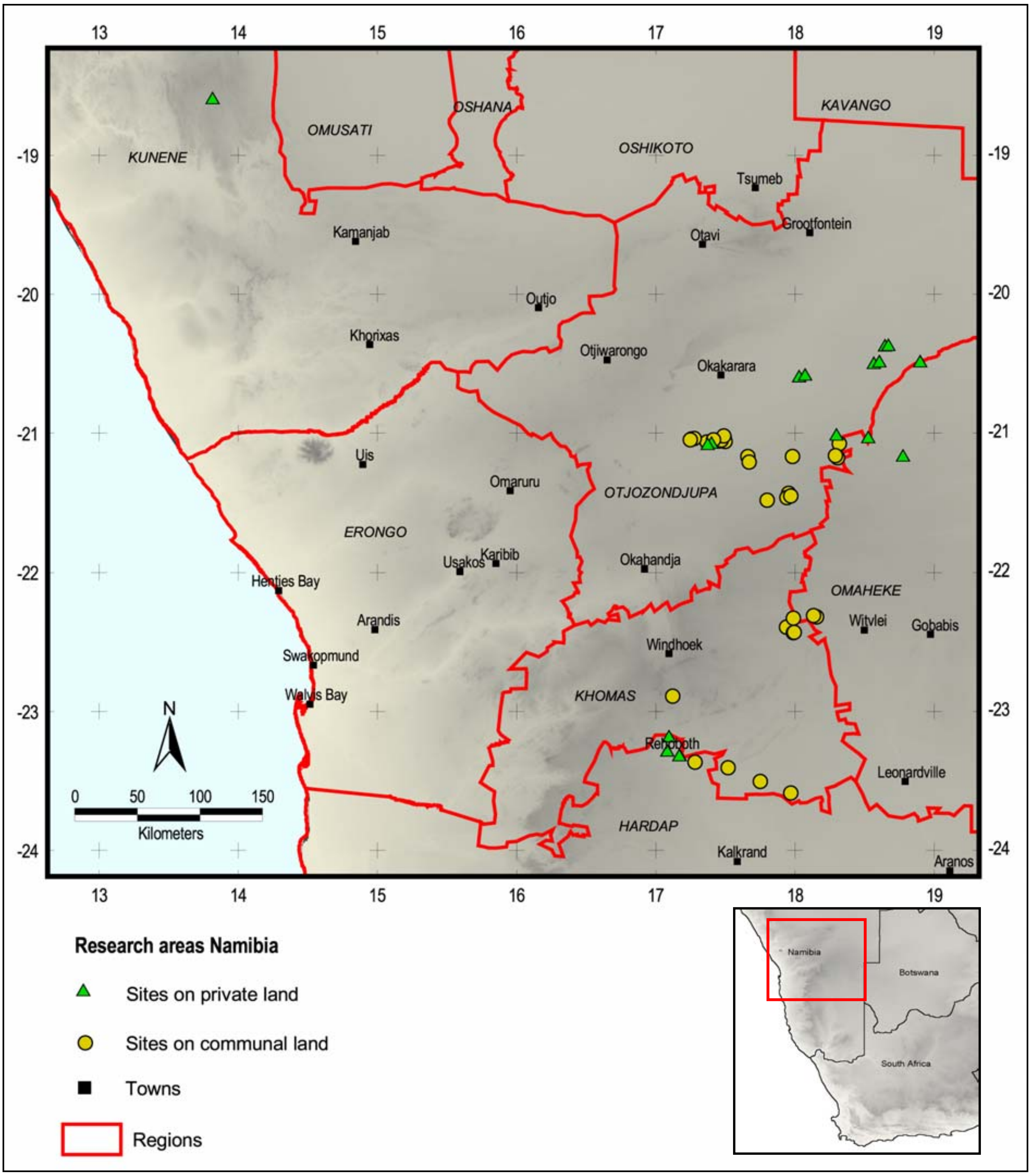


Fig. 9: Location of research sites in communal and private land of Namibia.

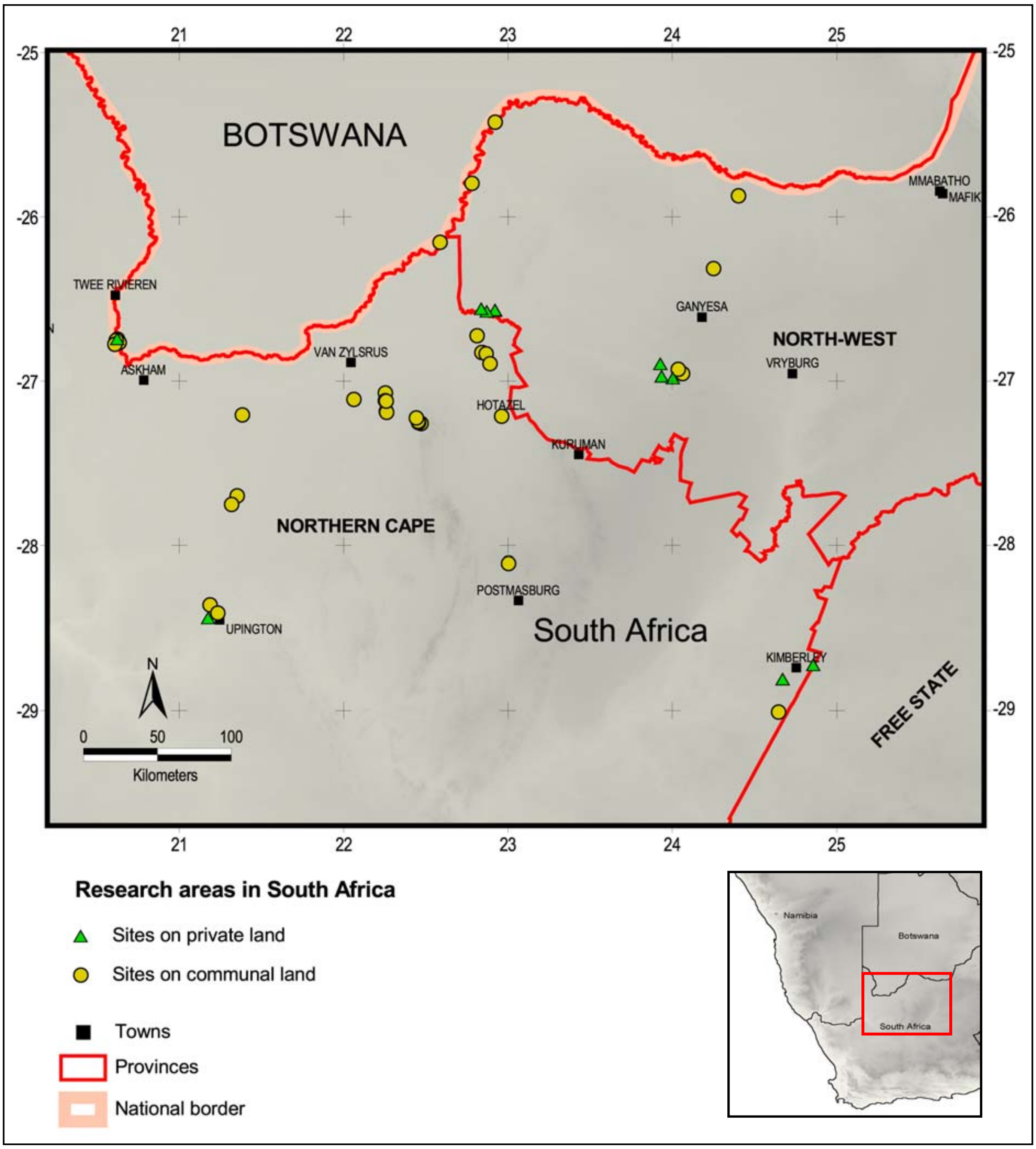


Fig. 10: Location of research sites in communal and private land of South Africa.

8.4 Occurence and frequency of *Harpagophytum*

The distribution and frequency of a species is limited by various environmental factors. Next to primary ecological parameters such as light, temperature, water, and nutrients, indirect factors such as climate, relief, and soil play a major role. Disturbance and land use through human activities can also have an enormous direct or indirect impact on the distribution and thus occurrence of a species. Plant species have a specific range of tolerance with respect to single environmental parameters, of which a minimum as well as a maximum poses a limitation to its growth and occurrence (e.g. LARCHER 1980, DIERSCHKE 1994). In particular in arid regions vegetation patterns are often characterised by a patchy distribution and abundance of plant species as well as vegetation units (e.g. WALKER & NOY-MEIR 1982, PATTEN & ELLIS 1995). Because arid areas are characterised by a great variability of precipitation in time and space, the availability of water is of crucial importance to species and can control their distribution (BORNKAMM & KEHL 1989). Next to precipitation, water availability is closely related to soil texture and topographic relief. In the following, the occurrence of *Harpagophytum* in southern Africa is analysed with respect to land ownership and the herewith related land use systems and vegetation types.

8.4.1 Occurrence under different land use

Two major land use types or systems of land ownership were sampled in the course of the study. That is private commercial farmland which is owned and the access to the land is controlled by one family or a limited number of persons and communal land which is typically owned by the state and utilised by rural communities with open or semi-open access depending on the role of the traditional chiefs and the community. It is assumed that different land tenure systems vary in their impact on the occurrence and density of *Harpagophytum*. This impact may be induced by several factors such as land use type, stocking rate, grazing intensity, vegetation condition and composition. This chapter focuses on individual numbers of *Harpagophytum* in both types of land ownership. Detailed analyses of the possibly underlying factors are discussed in the following chapters.

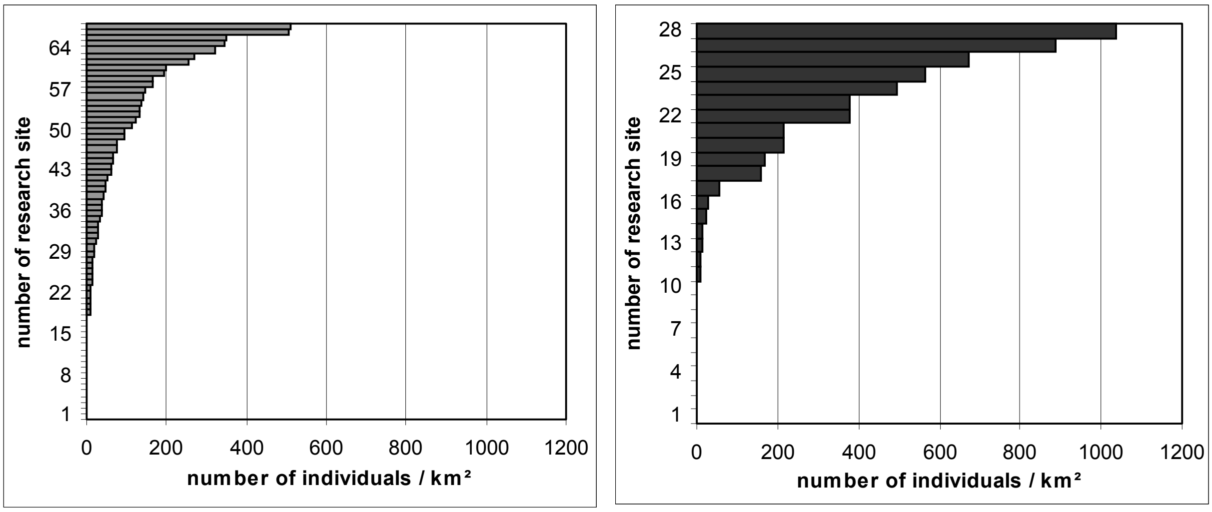
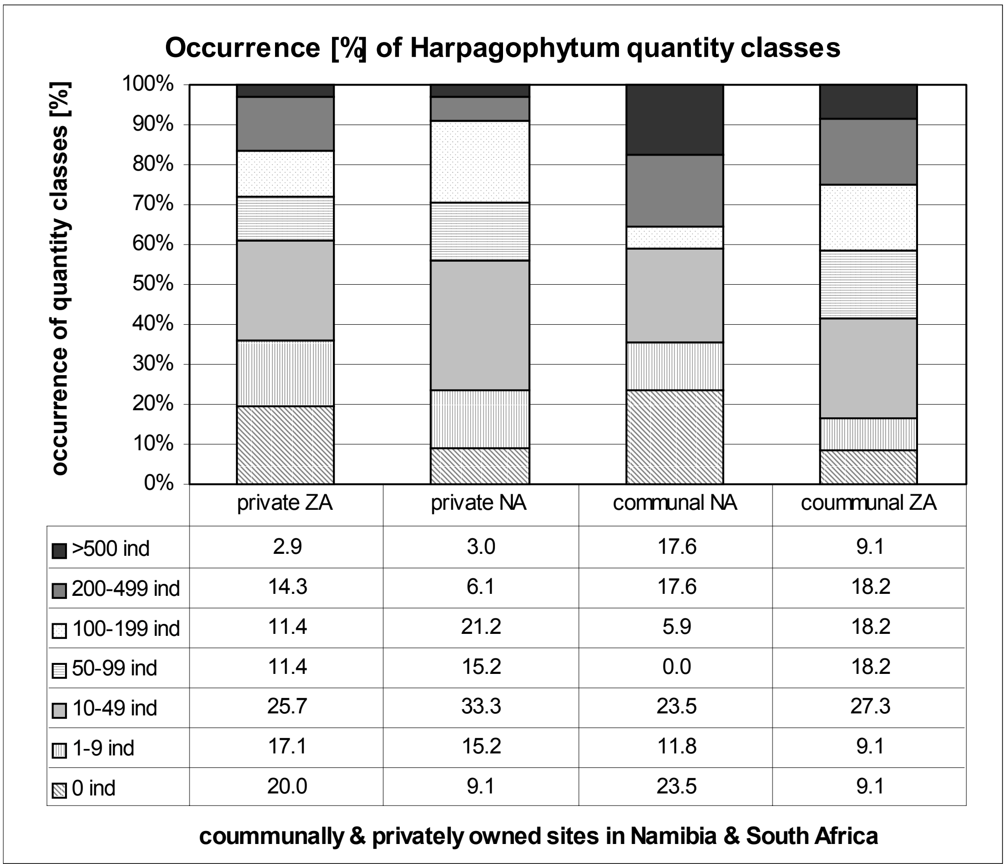


Fig. 11: Number of individuals of *Harpagophytum* recorded on 1km² on private farmland (left, n=68km²) and on communal land (right, n=28 km²) of Namibia and South Africa.

A general overview over the resource distirbution of *Harpagophytum* in both types of land ownership gives Figure 11. Here, the square kilometre sites – each represented by one row – are sorted in order of increasing individual numbers. This broad comparison of individual numbers of *Harpagophytum* in communally and privately owned areas of Namibia and South Africa indicates that the plant is not restricted to either land use type, but the greates resource occurs in the communal areas. Whereas on private (commercial) farmland the maximum number of plants counted was approximately 500 plants/km², in the communal areas more than twice the amount was found. Low individual numbers of less than 100 plants/km² were recorded on more research sites on the private farmland. Under both land tenure systems research sites were included in the study on which no individuals of *Harpagophytum* grew.



	private ZA	private NA	communal NA	coummunal ZA
>500 ind	2.9	3.0	17.6	9.1
200-499 ind	14.3	6.1	17.6	18.2
100-199 ind	11.4	21.2	5.9	18.2
50-99 ind	11.4	15.2	0.0	18.2
10-49 ind	25.7	33.3	23.5	27.3
1-9 ind	17.1	15.2	11.8	9.1
0 ind	20.0	9.1	23.5	9.1

Fig. 12: Percentage of occurrence of different quantity classes of *Harpagophytum* individuals on one square kilometre in communal areas and private farmland of Namibia (NA) and South Africa (ZA).

For a more detailed analysis, the numbers of *Harpagophytum* individuals were grouped into seven quantity classes (0, 1-9, 10-49, 50-99, 100-199, 200-499, >500 individuals/km²). In the next graph (Figure 12) the percentage of occurrence of the seven quantity classes on each square kilometre is presented for both countries and land use systems separately.

Although *Harpagophytum* was more frequently missing on communal than on private farmland in Namibia, the plant is not in general less frequent in Namibian communal areas. Instead, this result rather reflects a methodological weakness with respect to the choice of research sites. Whereas in communal areas, especially in Namibia (Okakarara Region), the square kilometres were often placed randomly, on private farmland we often relied on the farmers' choice of the research areas. The areas in which we then placed the square kilometres were typically areas where the farmer had seen the plant before.

On several sites on privately owned farmland *Harpagophytum* numbers are restricted to medium quantities of 10-49 individuals/km². In particular in Namibia, on one third of the research sites (33.3%) plant numbers were counted in this quantity class. Generally, low to missing individual numbers (quantity classes 0, 1-9, 10-49 individuals/km²) occurred at 40-60% of the sites irrespective of country and land use system. In the communal areas of South Africa the quantity classes with low species numbers were found least frequent.

In communal areas more sites showed high plant densities (>200 individuals/km²). This is in particular evident for Namibia, where this quantity class occurred on almost one third of the sites (35.2%) of which 17.6% more than 500 individuals were counted. In South Africa such high individual numbers occurred less frequent, i.e. on less than one third of all sites (27.3%) plant quantities of more than 200 individuals/km² were recorded and the highest quantity class (>500 individuals/km²) was found on only 9.1% of all sites.

8.4.2 Occurrence in different vegetation types

For the analyses of the occurrence and frequency of *Harpagophytum* in the various vegetation types within the distribution area of the species, the classification system of GIESS (1970) and of LOW & REBELO (1996) was applied. These were introduced in Chapter 5.

8.4.2.1 Namibia

Based on the vegetation map of GIESS (1970), six of nine vegetation types of the Savanna Biome, for which an occurrence of *Harpagophytum* can be expected, were sampled. A table in the attachment gives a description of the different vegetation types within the distribution area of *Harpagophytum* together with the number of square kilometres documented in each vegetation type. Table 4 below lists as short summary the number and percentages of research sites located in the different vegetation types and land use systems of Namibia. As broad vegetation types differ between communal and private farmland no direct comparison of both is possible with respect to *Harpagophytum* frequencies. Maps with the different densities of *Harpagophytum* in relation to the vegetation types are presented at the end of this chapter (Fig. 18, 19) for communal and private land of Namibia and South Africa.

Tab. 4: Number & percentage of research sites located in the different vegetation types (after GIESS 1970) of Namibia.

Vegetation type	Communal area	Private farmland	Communal area [%]	Private farmland [%]
Mopane Savanna	1	-	5.9	-
Thornbush Savanna	2	18	11.8	54.5
Highland Savanna	-	5	-	15.2
Tree Savanna & Woodland	5	-	29.4	-
Camelthorn Savanna	5	6	29.4	18.2
Mixed Tree & Shrub Savanna	4	4	23.5	12.1

Total individul number of *Harpagophytum* per research site was used to determine the species' dominance on various vegetation types (Fig. 13). The greatest overall resource of *Harpagophytum* on private farmland of Namibia was recorded for the Highland Savanna (median 74.0 plants/km²) and the Camelthorn Savanna (median 71.5 plants/km²). In the Thornbush Savanna (median 42.5 plants/km²) only few sites with high plant quantities occurred and in general lower quantities were counted. The Mixed Tree and Shrub Savanna experienced the lowest resource availability.

In the communal areas the largest range of *Harpaogphytum* quantities occurred on sites in the Camelthorn Savanna (median 11 plants/km², range from 0-885 plants/km²), but highest resource potential was found in the Mixed Tree and Shrub Savanna with a median of 377 plants/km².

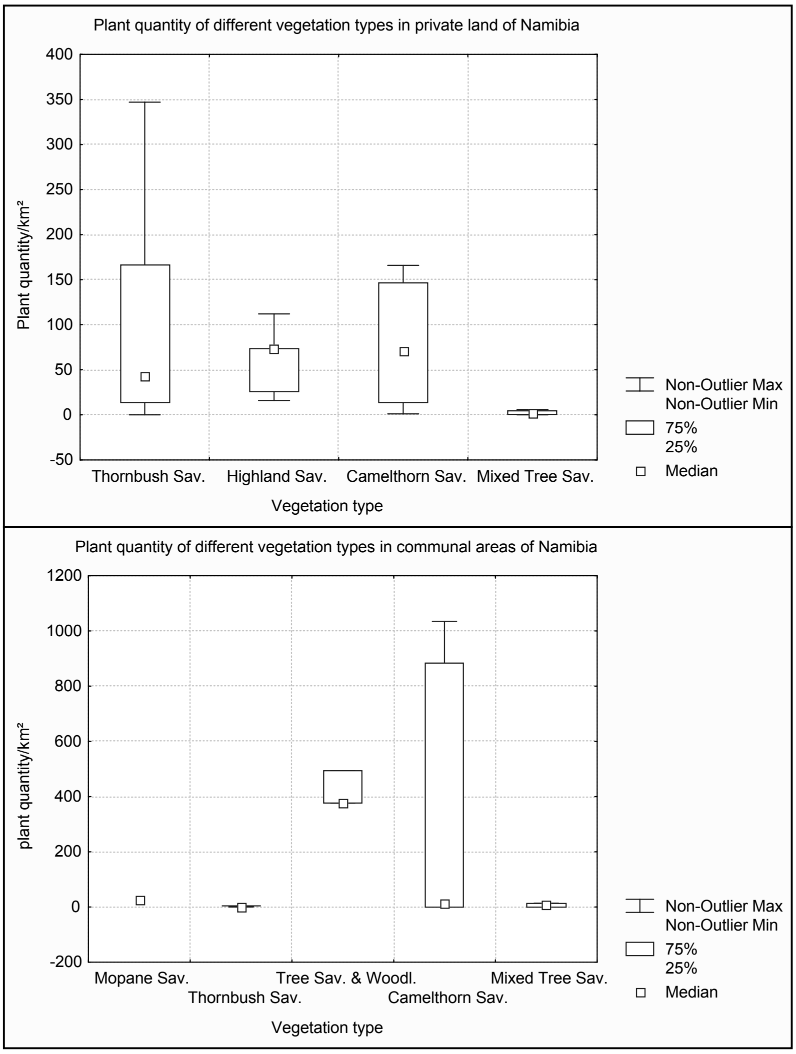


Fig. 13: Box-Whisker plots of plant quantities of *Harpagophytum* in different vegetation types on private and communal land of Namibia.

In the following, the distribution of *Harpagophytum* quantities on the research sites of the different vegetation types is discussed and related to rainfall quantities.

Mopane Savanna

Only one square kilometre was documented in the Mopane Savanna of Kaokoland in the northwest of Namibia. Rainfall in this part of the country is 300-400mm/year (BARNARD 1998). The vegetation of the Mopane Savanna is characterised by the Mopane tree, *Colophospermum mopane*, which forms an open or, if rainfall is sufficient, a dense and almost forest-like savanna. Mopane grows as a shrub towards the western border of the savanna or as medium to large trees in its eastern and more humid parts, which is where the research site is located. This site was directed to us by nearby living Himba who have known this site for a long time. On the site 27 individuals of *Harpagophytum* were recorded, yet *Harpagophytum* does not occur regularly and in dense patches in this area. Harvesting does only take place for private and traditional use. Due to missing replicates no interpretation with respect to variations of the resource can be drawn.

Thornbush Savanna

The Thornbush Savanna of Namibia forms the typical vegetation type of the central regions of Namibia. Dominant trees and shrubs are *Acacia* species and other thorn shrubs which occur in assemblages of varying size imbedded in a grassland matrix (Fig. 14). Mean annual rainfall in the research area of this vegetation type is 350-450mm (BARNARD 1998).

A total of 20 sites was recorded in the Thornbush Savanna with the majority of sites (18 sites) situated on private farmland. Only two sites are located on state land on a large refugee camp which has been erected ten years ago. This Osire refugee camp is surrounded by private farmland and is – while very limited in size – inhabited by 20.000 refugees. Interviews with farm owners hint towards a severe harvesting impact by the refugees on the surrounding farmland. To detect this impact several square kilometres were placed in the direct vicinity to the refugee camp.

Tab. 5: 1km²-sites in quantity classes of *Harpagophytum* in the Thornbush Savanna, differentiated in private and state land (refugee camp).

Quantity classes on 1km²	Private farmland	Refugee camp
0 ind	1	1
1-9 ind	2	1
10-49 ind	6	-
50-99 ind	2	-
100-199 ind	4	-
200-499 ind	1	-
>500 ind	1	-

Fig. 14: Thornbush Savanna vegetation.

In the Thornbush Savanna, all quantity classes of *Harpagophytum* are represented on the sites documented (Tab. 5, Fig. 18). No clear trend with respect to an overall resource amount could be distinguished, but on most sites medium quantities with 10-199 individuals/km² were recorded. A large resource (>200 individuals/km²) was only found on two sites on private farmland, whereas in the Osire refugee camp only on one site few individuals (quantity class 1-9 individuals/km²) were counted.

Highland Savanna

The Highland Savanna of Namibia occurs in the Khomas Hochland and the Windhoek Bergland areas (Fig. 13, Fig. 18). The vegetation is characterised by various *Acacia* species (*Acacia hereroensis*, *A. reficiens*, *A. hebeclada*) and a varying grass and herb layer which depends on rainfall. Mean annual rainfall is 300-400mm (BARNARD 1998). All five research sites are located on private farmland.

Harpagophytum occurs with a similar density in the Highland Savanna as in the Thornbush Savanna with medium quantities of 10-199 individuals/km² (Tab. 6, quantity classes 10-49, 50-99, 100-199 individuals/km²). Neither sites without any plants or very few individuals (1-9 individuals/km²) nor sites with >200 individuals were found.

Tab. 6: 1km²-sites in quantity classes of *Harpagophytum* in the Highland Savanna.

Quantity classes on 1km²	Communal area
0 ind	0
1-9 ind	0
10-49 ind	0
50-99 ind	0
100-199 ind	1
200-499 ind	3
>500 ind	1

Tree Savanna and Woodland

According to the distribution map of IHLENFELDT & HARTMANN (1970) the Tree Savanna and Woodland is the northernmost vegetation type in which this *Harpagophytum* subspecies occurs. Further to the north *H. zeyheri* is growing. The Tree Savanna and Woodland is characterised by large trees such as *Lonchocarpus nelsii* (Fabaceae) and *Terminalia sericea* (Combretaceae). Typically the substrate is sandy and of white, yellow or red colour. Mean annual rainfall is higher than in the other vegetation types with quantities of 400-500mm/year (BARNARD 1998). The five sites of this vegetation type are situated on communal farmland, in the Okakarara Region.

In this vegetation type the highest quantities of *Harpagophytum* were found (Tab. 7). None of the five sites exhibited <100 individuals/km². More often 200-499 individuals were recorded with a maximum of 672 plants/km². These results are the more impressive as in this area also the highest impact of harvesting of *Harpagophytum* exists. On all documented sites harvesting took place to a varying extent.

Tab. 7: 1km²-sites in quantity classes of *Harpagophytum* in the Tree Savanna and Woodland.

Quantity classes on 1km²	Communal area
0 ind	0
1-9 ind	0
10-49 ind	0
50-99 ind	0
100-199 ind	1
200-499 ind	3
>500 ind	1

Camelthorn Savanna

The Camelthorn Savanna forms the greatest part of the Central Kalahari in Namibia. It is dominated by the Camelthorn tree, *Acacia erioloba* (Fabaceae), and other common shrubs such *as Acacia mellifera*, *Grewia flava* (Tiliaceae). Woodland patches with *Terminalia sericea* (Combretaceae) may occur within this vegetation type. Mean annual rainfall is 350-450mm (BARNARD 1998), but may vary considerable between its southern and northern parts. Next to the Thornbush Savanna it is one of the best documented vegetation types in this study. Approximately the same number of research sites is located on communal (five sites) and private farmland (six sites).

Tab. 8: 1km²-sites in quantity classes of *Harpagophytum* in the Camelthorn Savanna.

Quantity classes on 1km²	Private farmland	Communal area
0 ind	0	2
1-9 ind	1	0
10-49 ind	2	1
50-99 ind	1	0
100-199 ind	2	0
200-499 ind	0	0
>500 ind	0	2

Whereas on private farmland a medium resource of *Harpagophytum* was recorded with quantities of <200 individuals/km² (quantity classes 1-9, 10-49, 50-99, 100-199 individuals/km²), in the communal areas no clear trend was found. On two sites very large resource quantities with 885 and 1035 individuals (quantity class >500 individuals/km²) were counted, while on two other sites no plants occurred (Tab. 8). These are located in the northern extension of the vegetation type near the Tree Savanna and Woodland vegetation type (Fig. 18).

Mixed Tree and Shrub Savanna

The Mixed Tree and Shrub Savanna covers the area of the southern Kalahari characterised by a series of longitudinal red sand dunes, dune valleys and pans. The typical vegetation comprises *Acacia haematoxylon* (Fabaceae)*, A. erioloba, A. reficiens, Boscia foetida* (Capparaceae) and perennial grasses (Fig. 15). Within the distribution area of *Harpagophytum* the Mixed Tree and Shrub Savanna experiences the lowest annual rainfall with 200-300mm (BARNARD 1998). Seven square kilometres represent this vegetation type of which three sites are located on private and four sites on communal farmland.

Plant quantities recorded were low irrespective of the land use system (Tab. 9, Fig.e 18). Maximum number of individuals found was 14 individuals/km². The research sites in the communal area are situated near the town of Rehoboth, where strong harvesting activities took place in the 1970s and 1980s. In Chapter 10, it will be shown that the low number of plants found in this areas today is most probably due to overharvesting of the species.

Tab. 9: 1km²-sites in quantity classes of *Harpagophytum* in the Mixed Tree and Shrub Savanna.

Quantity classes on 1km²	Private farmland	Communal area
0 ind	2	1
1-9 ind	2	1
10-49 ind	0	2
50-99 ind	0	0
100-199 ind	0	0
200-499 ind	0	0
>500 ind	0	0

Fig. 15: Mixed Tree and Shrub Savanna with dunes and single large *Acacia erioloba* trees.

In summary, out of six vegetation types sampled in this study, the largest resource of *Harpagophytum* occurred in the communal areas of the Tree Savanna and Woodland. This vegetation type experiences also the highest rainfall amounts of the research area. In the other vegetation types and mostly irrespective of the land use type species numbers were either spread over the entire range of quantity classes (Thornshrub Savanna, Camelthorn Savanna) or medium individual numbers were recorded (Highland Savanna). The smallest resource of *Harpagophytum* was found in the Mixed Tree and Shrub Savanna, which is at the same time the area with the lowest rainfall.

8.4.2.2 South Africa

In South Africa, all vegetation types of the Savanna Biome (after LOW & REBELO 1996) were sampled in the course of the study with at least three research sites. Main focus of the research was put on two dominant vegetation types, the Shrubby Kalahari Dune Bushveld and the Kalahari Plains Thorn Bushveld. A Table in the attachment gives a description of the different vegetation types within the distribution area of *Harpagophytum* and lists the number of square kilometres documented in each. Table 10 below gives a broad overview over the number and percentage of research sites located in the different vegetation types and land use systems of South Africa. As vegetation types differ between communal and private farmland no direct comparison of both was possible. A map showing the *Harpagophytum* quantities on the research sites of the vegetation types is presented at the end of this chapter (Fig. 19).

Tab. 10: Number & percentage of research sites located in the different vegetation types (after LOW & REBELO 1996) of South Africa.

Vegetation type	**Communal area**	**Private farmland**	**Communal area [%]**	**Private farmland [%]**
Shrubby Kalahari Dune Bushveld	1	14	9.1	40.0
Karoid Kalahari Bushveld	1	2	9.1	5.7
Kalahari Plains Thorn Bushveld	5	12	45.5	34.3
Kalahari Mountain Bushveld	-	4	-	11.4
Kimberley Thorn Bushveld	2	1	18.2	2.9
Kalahari Plateau Bushveld	2	2	18.2	5.7

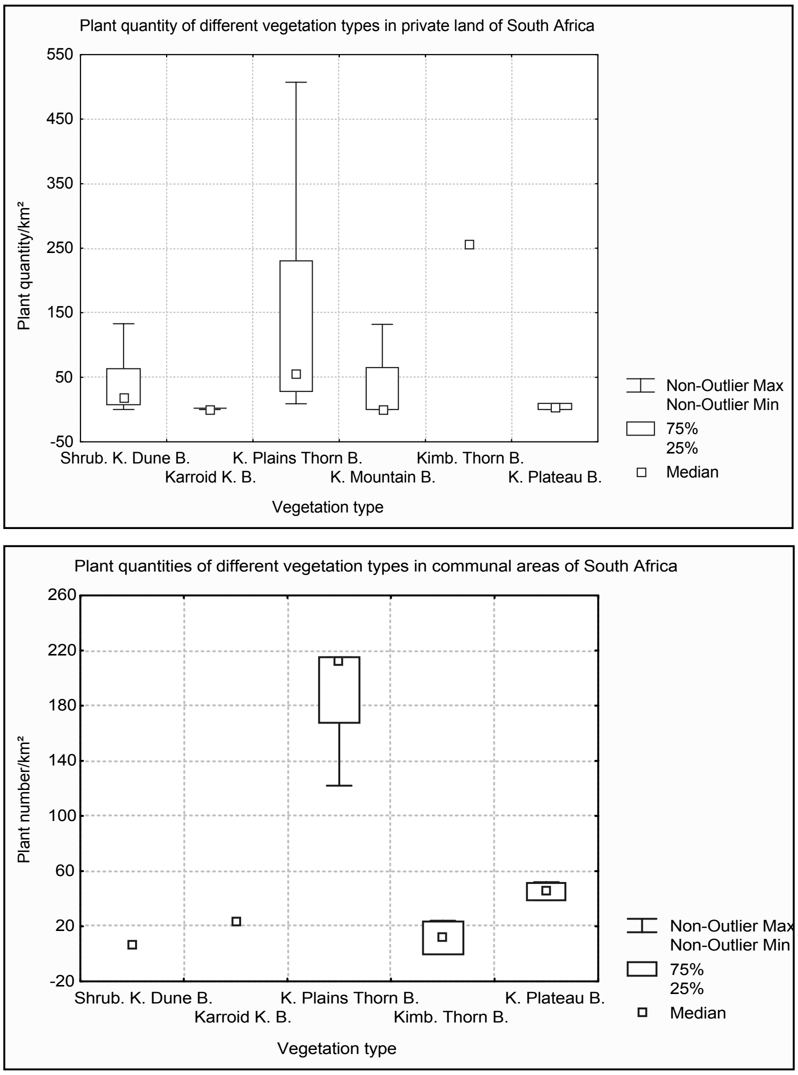


Fig. 16: Box-Whisker plots of plant quantities of *Harpagophytum* in different vegetation types in private and communal land of South Africa.

Only three vegetation types (Shrubby Kalahari Dune Bushveld, Kalahari Plains Thorn Bushveld, Kalahari Mountain Bushveld) are represented with more than two research sites on private farmland. Highest resource availability was found for the Kalahari Plains Thorn Bushveld, where not only the highest median (56 plants/km²) but also the greatest range of quantities of *Harpagophytum* occurred on the research sites (Figure 15). In the other two vegetation types partly also higher densities were recorded, which however, did not result in an increase of the median.

Also in the communal areas of South Africa the largest resource of *Harpagophytum* occurred in the Kalahari Plains Thorn Bushveld with a mean of 213 individuals on one square kilometre (Fig. 16). In the other vegetation types only one or two research sites were assessed restricting any conclusions on resource quantities. In the following, the sampled vegetation types are discussed with respect to the resource availability of *Harpagophytum*.

Shrubby Kalahari Dune Bushveld

A large percentage of research sites in South Africa is located in the Shrubby Kalahari Dune Bushveld. This vegetation type is characterised by the occurrence of dunes of varying height and interdunes of varying width with deep aeolian sandy substrates. Typically, the dunes are vegetated with scattered shrubs, few trees and a well developed grass layer after sufficient rainfall. Medium rainfall quantities are 200mm/year (LOW & REBELO 1996). Most of the area belongs to privately owned farmland and thus from a total of 15 sites only one site is situated on a communally managed farm.

Table 11 and Figure 19 indicate that the majority of sites exhibited a low resource of *Harpagophytum* (quantity classes 1-9, 10-49 individuals/km²). Only on two sites >100 individuals were recorded with a maximum of 268 plants/km². These were located in the very east of the vegetation type near the Kalahari Plains Thorn Bushveld with higher annual precipitation amounts (Fig. 4). Due to a high grazing pressure the vegetation layer of the communally managed farm was scattered and only seven plants were found. No harvesting of the species takes place on the research sites. Details on the impact of grazing, the surrounding vegetation etc. are discussed in Chapters 9.7 and 9.8.

Tab. 11: 1km^2-sites in quantity classes of *Harpagophytum* in the Shrubby Kalahari Dune Bushveld

Quantity classes on 1km²	Private farmland	Communal land
0 ind	0	0
1-9 ind	4	1
10-49 ind	5	0
50-99 ind	1	0
100-199 ind	1	0
200-499 ind	1	0
>500 ind	0	0

Karoid Kalahari Bushveld

The Karoid Kalahari Bushveld occurs in the area around the town of Upington and is characterised by flat gravel plains and a shallow substrate. The vegetation type borders the Nama Karoo Biome, for which no occurrence of *Harpagophytum* is reported. The low mean annual rainfall with 175mm/year is responsible for the sparse vegetation cover, a missing tree layer and a sparse grass layer. Two sites are placed on a farm near Upington, the third site is situated in the municipal area of the town. This site is not managed, but used as an open access area for grazing and harvesting of *Harpagophytum* by some inhabitants of Upington.

No *Harpagophytum* was found on both research sites on the farm, where the soil was sandy but very shallow. On the municipal site a total of 24 individuals was recorded next to a number of harvesting holes. Irrespective of the impact of harvesting, this site only houses a limited number of individuals, no dense and large patches of the species occurred in this vegetation type and on this substrate.

Kalahari Plains Thorn Bushveld

The Kalahari Plains Thorn Bushveld is characterised by deep and sandy to loamy substrates with a typically well developed tree layer. The shrub layer is in general moderate, while the density of the grass layer may vary annually depending on rainfall quantities (Figure 3). Mean annual rainfall is 300mm/year (LOW & REBELO 1996). The Kalahari Plains Thorn Bushveld stretches from the Northern Cape Province to the NW-Province. Here, the largest number of research sites is located (Fig. 19). Twelve sites are situated on private farmland and five site are placed in communal areas in the NW-Province.

Tab. 12: 1km²-sites in quantity classes of *Harpagophytum* in the Kalahari Plains Thorn Bushveld.

Quantity classes on 1km²	Private farmland	Communal land
0 ind	0	0
1-9 ind	1	0
10-49 ind	3	0
50-99 ind	2	0
100-199 ind	2	2
200-499 ind	2	2
>500 ind	1	1

For South Africa, the Kalahari Plains Thorn Bushveld represents the vegetation type with the largest resource of *Harpagophytum* (Tab. 12, Fig. 19). In particular on communal farmland in the NW-Province on each site >100 individuals/km² was recorded. Harvesting takes place on both, communal and partly also on private land, but on communal land the harvesting impact is much higher and harvesting activities are better organised. On private farmland, the entire range of quantity classes was found for this vegetation type ranging from 1-9 individuals to a maximum of 507 plants/km². Low plant numbers occurred in particular near the border to Botswana.

Kalahari Mountain Bushveld

All research sites within this vegetation type are located on a large game farm (farm Tswalu, Figure 16) in the Northern Cape Province. Mean annual rainfall in this area is approximately 350mm/year, but rainfall is very erratic (LOW & REBELO 1996). The substrate of the hilly or undulated landscape is typically shallow. The vegetation of the farm is characterised by thorn shrubs, single trees of *Acacia erioloba* (Fabaceae) and other species and a dense grass cover (due to good rainfall in the year of observation).

Out of four sites documented on the farm, only on one site individuals of *Harpagophytum* were found. This site was located next to an old but still inhabited farmhouse where a former grazing impact was still visible. *Harpagophytum* grew in a large and dense patch around the old household. Transects in the direct vicinity to the house showed the greatest number of individuals. In total 132 plants were recorded on the square kilometre.

Fig. 17: Kalahari Mountain Bushveld vegetation on the farm Tswalu, N-Cape Province, South Africa.

Kimberley Thorn Bushveld

The Kimberley Thorn Bushveld is located in the south-east corner of the research area (Figure 18) and receives the highest rainfall of the research area. The vegetation type is characterised by deep loamy to sandy substrates and an open savanna vegetation (LOW & REBELO 1996). Three square kilometres were documented in this vegetation type near the town of Kimberley. Two research sites were assigned to communal land and belong to municipal property outside town (semi-open access). On one site cattle grazing takes place on a very low intensity level. The other site was situated adjacent to a townhouse complex and to private farmland. No utilisation of this area was visible. The third square kilometre was documented on private farmland next to an agricultural field.

On the private farmland a dense patch of *Harpagophytum* was found where >200 individuals/ km² were recorded. In contrast, on the municipal sites none respectively only 32 plants were counted (quantity class 10-49 individuals/km²). No signs of a utilisation of the species were visible.

Kalahari Plateau Bushveld

All research sites within the Kalahari Plateau Bushveld are located in the NW-Province, near the border to the Kalahari Plains Thorn Bushveld (Figure 18). Two sites were documented on a private farm adjacent to a large communal area where also the other two sites of this vegetation type were sampled. Annual rainfall in this area ranges from 250-450mm/year (LOW & REBELO 1996). The vegetation is composed of a bushveld which can vary in density.

Tab. 13: 1km²-sites in quantity classes of *Harpagophytum* in the Kalahari Plateau Bushveld.

Quantity classes on 1km²	Private farmland	Communal land
0 ind	1	0
1-9 ind	1	0
10-49 ind	0	1
50-99 ind	0	1
100-199 ind	0	0
200-499 ind	0	0
>500 ind	0	0

Table 13 indicates that very low quantities of *Harpagophytum* were recorded on both sites of the private farmland (quantity classes 0, 1-9 individuals/km²). In the communal area, where harvesting of the species does take place medium quantity classes (10-49, 50-99 individuals/km²) were found.

Summarizing, for the resource status of *Harpagophytum* it can be concluded that generally total individual numbers are lower than in the vegetation types investigated in Namibia. Medium quantities of the species were found in most of the sampled vegetation types. The greatest resource occurs on communal as well as on private farmland of the Kalahari Plain Thorn Bushveld in the area around Kuruman at the border of the Northern Cape to the NW-Province.

8.4.3 Summary and conclusions on the occurrence of *Harpagophytum*

The occurrence of *Harpagophytum* varies with respect to the surrounding vegetation and land use. A comparatively higher resource availability of *Harpagophytum* occurred in the sampled Namibian vegetation types in comparison to South African sites. In Namibia, the density of *Harpagophytum* on the research sites correlated with the rainfall gradient. The highest resource density was evident for the communal areas of the northern most research area with the highest annual rainfall quantities (Tree Savanna and Woodland), whereas the lowest individual numbers occurred in the most dry and southern parts of the country (Mixed Tree and Shrub Savanna). In contrast, in South Africa, a relationship between the occurrence of *Harpagophytum* and precipitation was not explicitly evident. Instead, the greatest resource of *Harpagophytum* was documented in the Kalahari Plains Thorn Bushveld for both, communal areas and private farmland. This area receives medium annual rainfall quantities in contrast to the Kimberley Thorn Bushveld, where irrespective of higher rainfall amounts only few patches of the species were recorded. Generally, at least medium amounts of the species were documented for all vegetation types sampled in the course of the study. Summarizing, the results suggest that precipitation does not solely account for differences in the occurrence of *Harpagophytum*. Instead, in areas with higher rainfall quantities additional factors such as competition and small scale variation in other abiotic factors may influence the occurrence of *Harpagophytum*. These will be discussed in the following chapters.

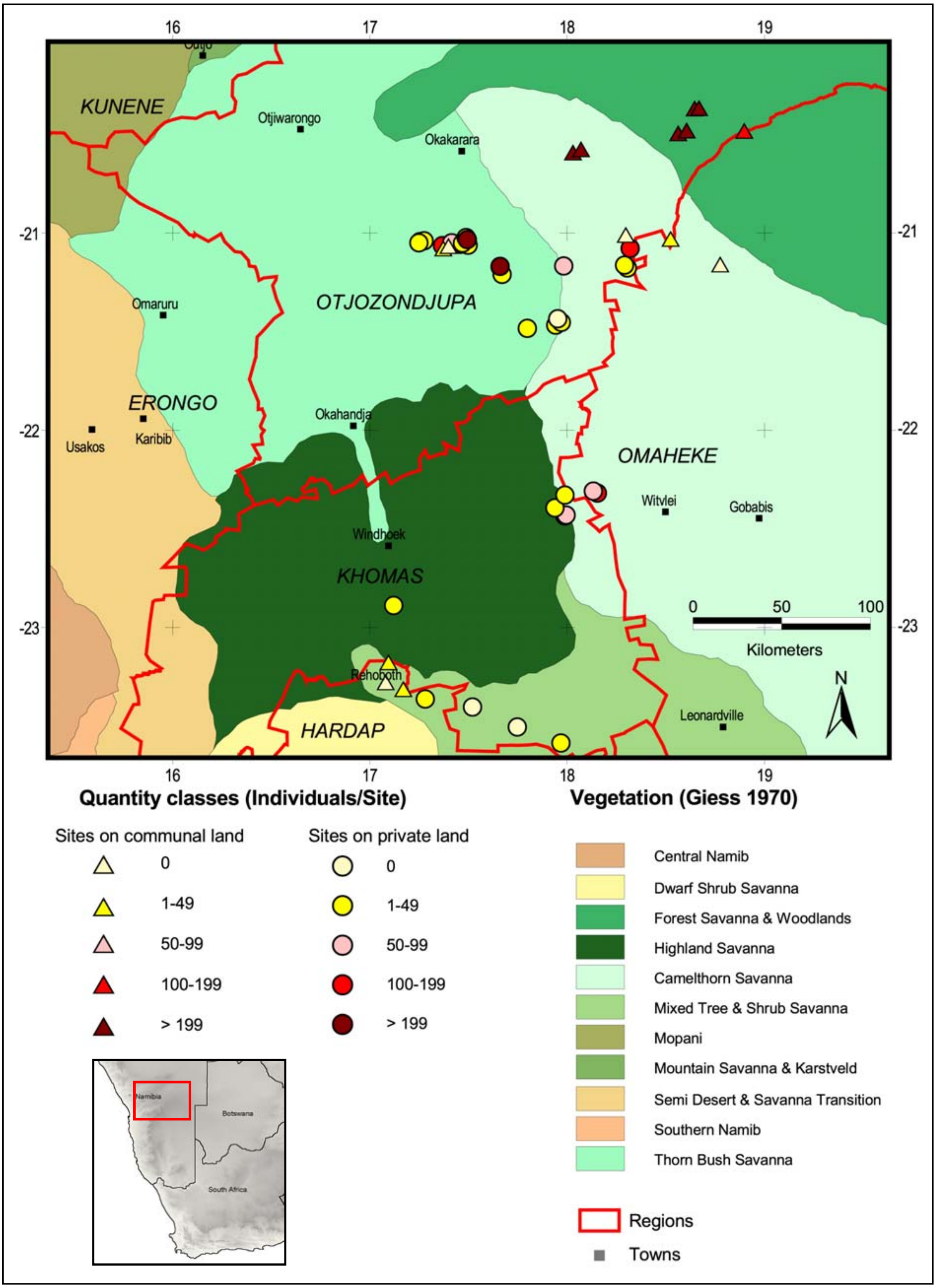


Fig. 18: Map of research sites in different vegetation types of Namibia differentiated into quantity classes per square kilometre. Map Source: GIESS (1970), AGRO-ECOLOGICAL ZONING PROGRAMME (2001).

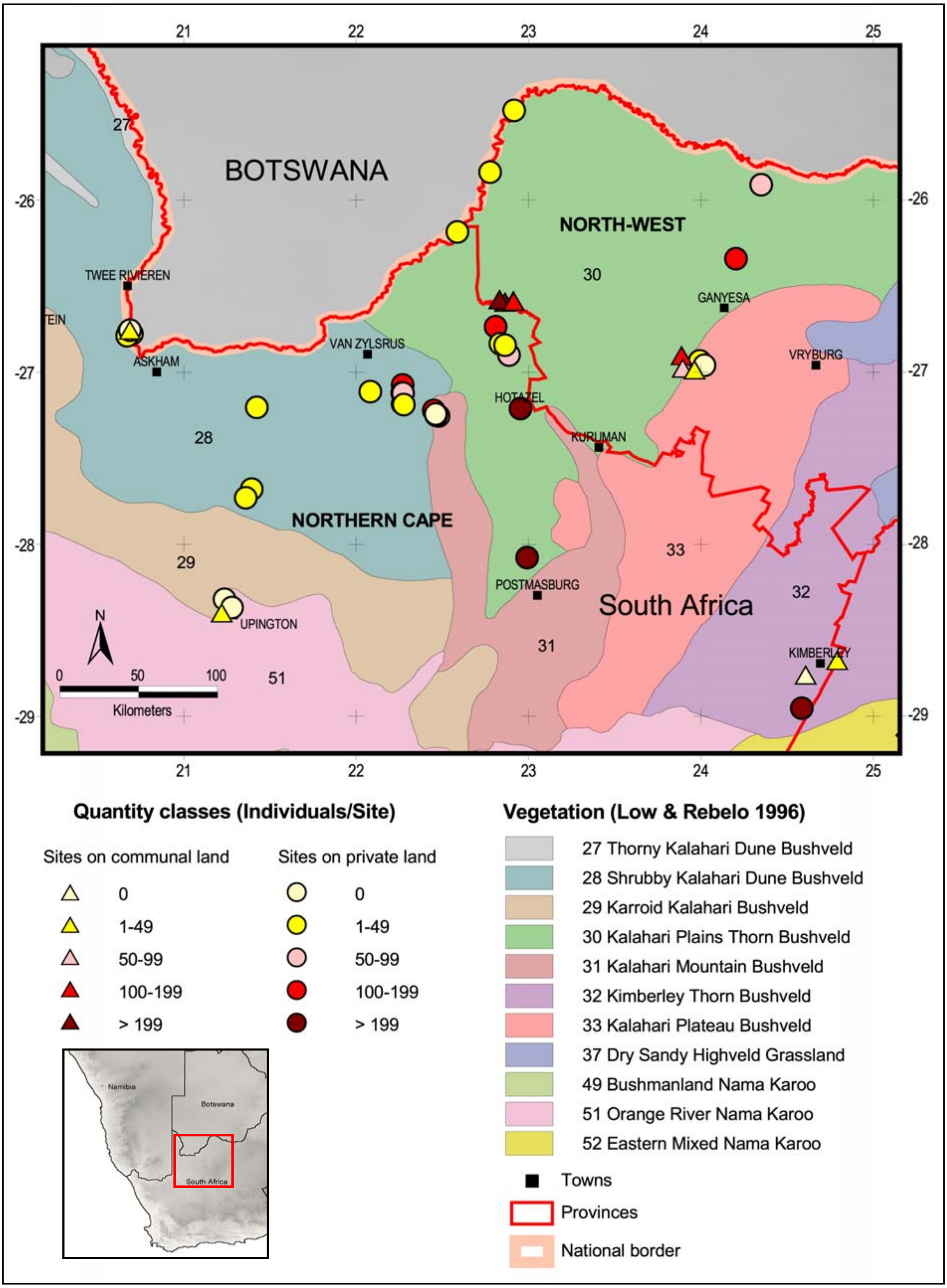


Fig. 19: Map of research sites in different vegetation types of South Africa differentiated into quantity classes per square kilometre. Map Source: LOW & REBELO (1996).

8.5 The impact of the habitat on *Harpagophytum*

Different habitat types can be expected to have different historical attributes (e.g. previous disturbance levels through land use) and different vegetation attributes. Vegetation attributes such as species composition or species richness may affect historical attributes or they may themselves be affected by the habitat type and/or the history (AARSEN 2001). Various studies led to definitions of habitats and corresponding plant strategies, which, however often follow conflicting views (e.g. GRIME 1979, HUSTON 1994). For geophytes such as *Harpagophytum*, the habitat, in which the species is able to permanently establish itself, should offer properties, which suffice the plant individual needs (to refill its large reserves of water and biomass) for at least a short period within the growing season. Typically, in arid and semi arid areas the most important abiotic habitat characters are the soil water storage capacity, evaporation rates and soil nutrient properties. Also historical components such as former or current impact of land use may influence the quality of a habitat for plant growth. In *Harpagophytum*, several studies report an occurrence of the species in sandy areas of the Kalahari (e.g. IHLENFELDT & HARTMANN 1970, TAYLOR & MOSS 1982, KGATHI 1988). Yet, few studies offer more comprehensive information on detailed habitat preferences. BLANK (1973) for instance, suggests that *Harpagophytum* favours depressions in fossil dunes, alluvial and/or overgrazed plains. For the Etosha National Park in Namibia, it is reported that ten times more *Harpagophytum* individuals occur in areas previously cleared as a firebreak than on adjacent areas 5m away from the firebreak, where the grass cover is much more dense (NOTT 1986).

8.5.1 *Harpagophytum* density in different habitat types

A total of seven habitat types were sampled in the course of the study (Tab. 14). As plains represent the major habitat type of the research areas, fieldwork focussed on these. Dune areas comprising habitat types such as dune base, dune crest and dune slope were predominantly sampled in the private farmland of South Africa, while the sampling of Omuramba plains (periodically flooded plains) was restricted to the communal areas of Namibia. Roadsides were only assessed on private Namibian farmland.

Tab. 14: Number of transects recorded in different habitat types of Namibia and South Africa.

Habitat	Namibia		South Africa	
	Private farmland	Communal areas	Private farmland	Communal areas
Dune base	11	7	62	9
Dune crest	–	5	26	1
Dune slope	5	15	47	15
Interdune	4	1	72	11
Omuramba	–	12	–	–
Plain	599	294	459	208
Roadside	11	–	–	–

8.5.1.1 Namibia

Analyses of the resource potential of *Harpagophytum* in different habitat types of Namibia were carried out on two levels of detail: Next to total counts of individuals of *Harpagophytum* on the transects also total potential number of individuals were used, meaning the sum of individuals and of digging holes (Fig. 20). By this, sites, where previous harvesting activities resulted in reduced resource availability, are evaluated by their resource potential and not only by the individuals visible in the field.

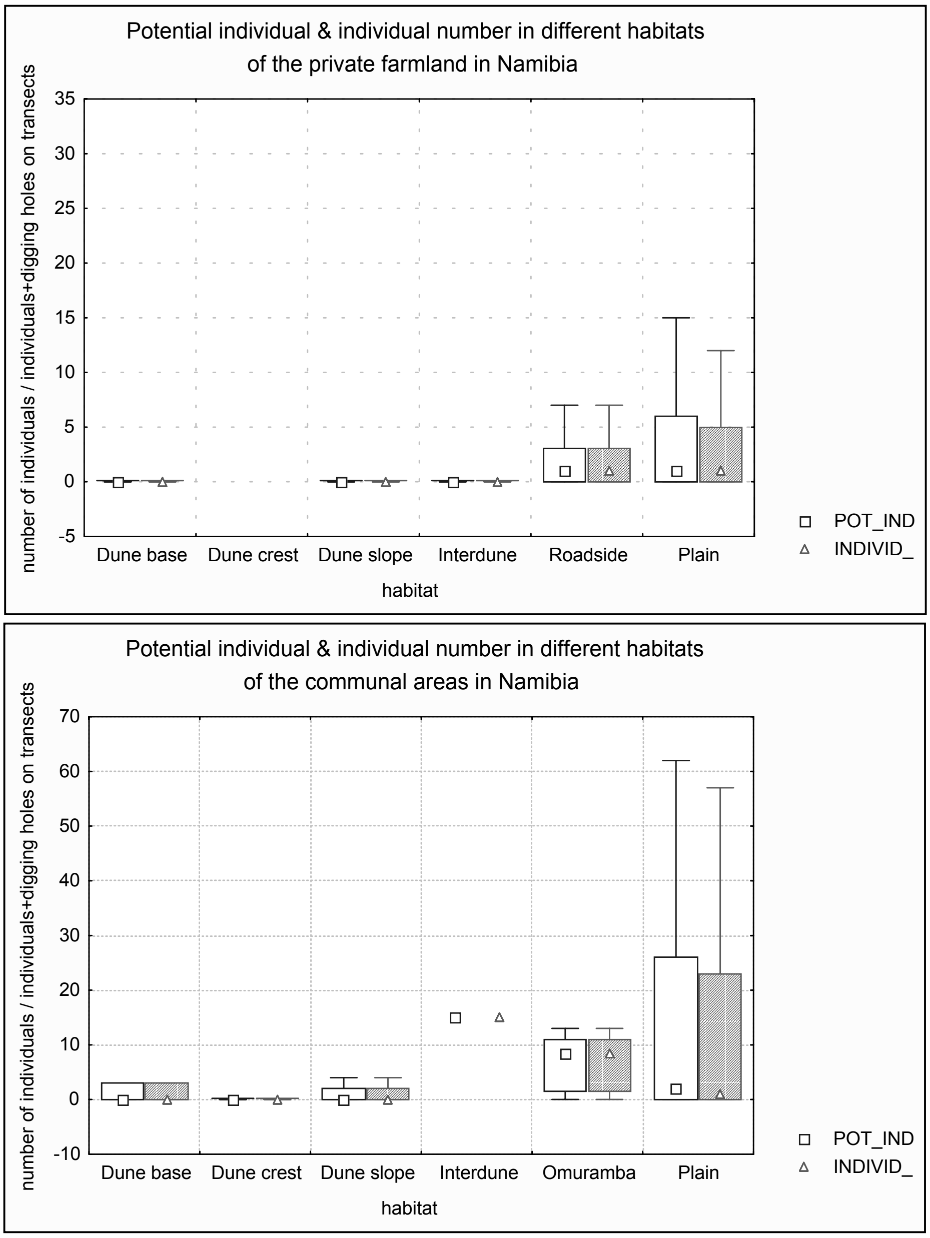


Fig. 20: Number of potential individuals (POT_IND, individuals and holes) and of individuals (INDIVID_) in different habitats of private and communal land in Namibia.

Private farmland of Namibia

Plains and roadsides form the major habitats for the occurrence of *Harpagophytum*. No significant difference in the resource density is evident between the number of living plants in the field and their potential number. On dune habitats (dune base, dune slope and interdune) *Harpagophytum* was missing. Individual densities on plains were predominantly restricted to 0-6 individuals/transect. In the case of patches of *Harpagophytum* (defined as quantities of >10 individuals/transect), these were typically restricted to plain habitats.

Communal areas of Namibia

In the communal areas of Namibia, the occurrence of *Harpagophytum* is not exclusively linked to plain habitats, even though they represent the habitat type with the greatest range of resource densities. Omurambas (periodically flooded areas) are characterised by a higher median. Only one transect was documented in an interdune with 15 individuals of *Harpagophytum*. On dune base and dune slope habitats, single individuals were found, but numbers were limited to 2-5 individuals/transect. No plants occurred on dune crests.

To test the significance of differences in individual numbers on different habitat types, the Mann-Whitney-U-Test was applied (Tab. 15). As data was tested to be not normal distributed, no t-test could be used. In the case of low sample sizes (e.g. dune crest sites), the test was automatically corrected by the applied program and a more conservative probability (p) was calculated. When the sample size of both variables was too low, no test was carried out leading to some empty boxes in parts of the table. Sample sizes of the different habitat types are listed above (Tab. 14).

Tab. 15: P-values of a Mann-Whitney-U-Test of habitat types and the number of individuals of *Harpagophytum* recorded on transects in Namibia.

Private farmland Namibia					
Habitat type	p Dune base	p Dune slope	p Interdune	p Plain	p Roadside
Dune base	–			0.0376**	0.0286**
Dune slope		–		0.0376**	0.0286**
Interdune			–	0.0628	0.0470**
Plain	0.0376**	0.0376**	0.0628	–	0.8770
Roadside	0.0286**	0.0286**	0.0470**	0.8770	–
Communal areas Namibia					
Habitat type	p Dune base	p Dune crest	p Dune slope	p Omuramba	p Plain
Dune base	–	0.2677	0.7780	0.1179	0.3928
Dune crest	0.2677	–	0.1418	0.0061***	0.0424**
Dune slope	0.7780	0.1418	–	0.0037***	0.0977
Omuramba	0.1179	0.0061***	0.0037***		0.5304
Plain	0.3928	0.0424**	0.0977	0.5304	–
***= highly significant (p<0.01). **= significant (0.01<p<0.05)					

In general, a considerably higher individual density was recorded for communal in comparison to private land (see Chapter 8.9) with patches of *Harpagophytum* with >10 individuals/transect being present on more habitat types, i.e. on plains, Omurambas, the interdune site, and occasionally on the dune base (extremes, not shown in the graph). Only on plain habitats the potential resource availability, calculated from the amalgamation of plant and digging hole quantities, differed from the living plant resources.

8.5.1.2 South Africa

The potential number of individuals of *Harpagophytum* as well as the number of living individuals recorded on private South African farmland, was highest on plain habitats and lowest on dune crests and dune slopes (Fig. 21).

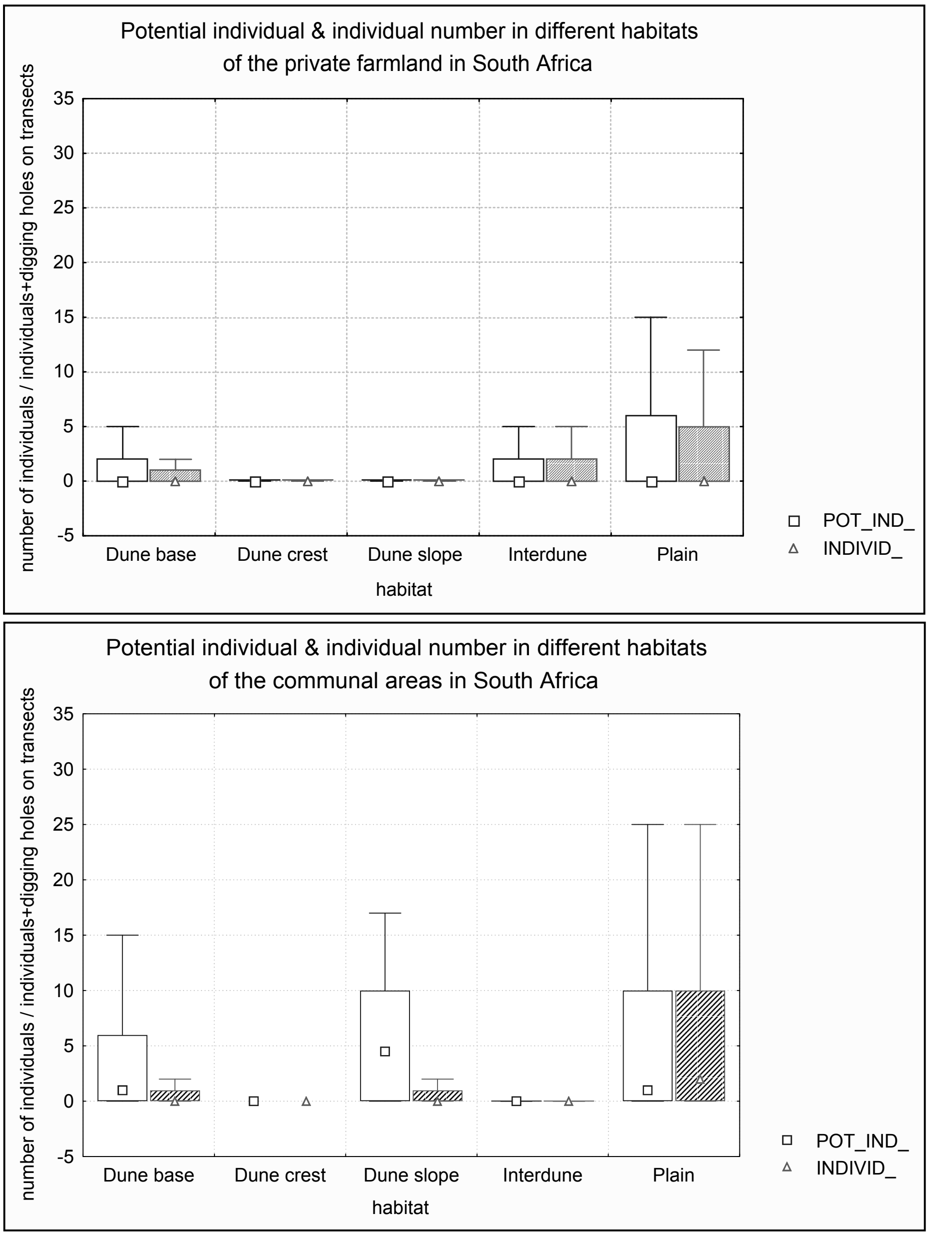


Fig. 21: Number of potential individuals (POT_IND, individuals & holes) and of individuals in different habitats (INDIVID_) of the private and communal land in South Africa.

Private farmland of South Africa

Differences between both quantities of *Harpagophytum* existed in the habitat types dune base and plain indicating that on these harvesting takes place. In general, individual numbers stay low irrespective of the habitat type. This is indicated by the zero values of the medians. Patches of *Harpagophytum* (>10 individuals/transect) only occurred on plain habitats on private farmland.

Communal areas of South Africa

For the communal areas of South Africa, the impact of utilisation is momentous for the dune base and dune slope (Fig. 21): A low resource availability is suggested when only living individuals of *Harpagophytum* are considered, while the potential resource proves the existence of a formerly higher abundance of the species on these habitats. This is in particular evident in the differences of the dune slope medians. Data indicates that patches of *Harpagophytum* (>10 individual/transect) may have occurred on the dune base and dune slope as well as on plain habitats. Whereas resource and potential resource density on plain habitats is similar to the potential resource of the dune slope, the median of the latter is considerably higher. No *Harpagophytum* plants were recorded in the other two dune habitats, the dune crests and the interdunes. Resource density in general, is higher than on private farmland but lower than in Namibian communal areas (see Chapter 8.9 for details on the resource distribution of *Harpagophytum*).

The Mann-Whitney-U-Test (Tab. 16) elucidates the results of the Box-Whisker plots. For the private farmland of South Africa on dune habitat types, a significant difference in individual numbers of *Harpagophytum* is only evident between the dune slopes and the dune base. Due to the low to missing resource of *Harpagophytum* on the dune crests and the dune slopes, a significant difference was found for both habitat types with the interdune and plain habitat. Interdune and dune base show a similar resource density and therefore do not differ significantly.

In the communal areas of South Africa, the resource density based on the living individual numbers in the field is very low except for the plain habitats. Therefore, significant differences are evident only for habitat types in comparison to the plain habitat but not within the other types.

Tab. 16: P-values of a Mann-Whitney-U-Test of habitat types and number of individuals of *Harpagophytum* recorded on transects in South Africa.

Private farmland South Africa					
Habitat type	p Dune base	p Dune crest	p Dune slope	p Interdune	p Plain
Dune base	-	0.1016	0.0049**	0.7094	0.0109**
Dune crest	0.1016	-	0.4402	0.0469**	0.0011***
Dune slope	0.0049**	0.4402	-	0.0013***	0.0000***
Interdune	0.7094	0.0469**	0.0013***	-	0.7094
Plain	0.0109**	0.0011***	0.0000***	0.7094	-
Communal areas South Africa					
Habitat type	p Dune base	p Dune crest	p Dune slope	p Interdune	p Plain
Dune base	-	-	0.9762	0.3233	0.0308**
Dune slope	0.9762	-	-	0.1772	0.0059***
Interdune	0.3233	-	0.1772	-	0.0011***
Plain	0.0308**	-	0.0059***	0.0011***	-
***= highly significant (p<0.01). **= significant (0.01<p<0.05)					

8.5.2 Summary and conclusions on the impact of the habitat on *Harpagophytum*

The habitat type plays an important role for the occurrence and density of *Harpagophytum*. Data analyses prove that the species shows a distinct preference for plain habitats. Plains may either be characterised only by their geomorphology (non-undulated plains) or by the impact of soil properties, land use (heavily grazed Omuramba habitat) or other man-made disturbances (roadside habitat). The category plain habitat comprises a number of various smaller habitat fractions, which together form a mosaic of small-scale habitat types. The finding that *Harpagophytum* patches are most prominent in this habitat type category has therefore to be differentiated with respect to other environmental parameters such as the composition and density of the vegetation and soil parameters (Chapters 8.6, 8.8). Except for the private farmland of South Africa, it was found that *Harpagophytum* also favours dune base habitats, and partially dune slopes. However, it was observed that steep dune slopes and upper parts of the slopes do not represent suitable habitats for *Harpagophytum*. Instead, the species typically grows on the lower slopes adjacent to the dune base. From the finding that dune crests and upper dune slopes are not suitable for the establishment of *Harpagophytum* plants it can be concluded that both habitat types house ecologically unfavourable conditions for the species. It has been observed that in a dune landscape dune crests and upper slopes typically show a scarce vegetation cover, which leaves the upper substrate layer (sand) unstable and easily susceptible to wind erosion. This finding is supported by HOFFMAN & ASHWELL (2001) who state that for the Northern Cape Province of South Africa where several sites were sampled, wind erosion is the most prominent type of erosion. Such environmental conditions make it difficult for a geophytic and slow growing plant like *Harpagophytum* to survive. The upper dune slopes and dune crests being susceptible to soil erosion are furthermore characterised by a more rapid evaporation of soil water and hence present less favourable habitats for seed deposition, seed germination and seedling establishment also in *Harpagophytum*. More detailed analyses of the role of soil properties for *Harpagophytum* are presented in the next chapter and in Chapter 10.

8.6 The impact of soil properties on *Harpagophytum*

Next to precipitation and habitat type, the soil is of great importance for the composition of the vegetation in arid and semi-arid areas. The substrate next to the typically low rainfall amounts has a significant impact on the evolvement of specific species compositions (e.g. ANDERSEN 1996). Not only the soil depths, but also chemical and physical soil parameters such as the grain size distribution, influence the ecological properties of a site. In arid and semi-arid areas, sandy substrates offer more favourable conditions for plant growth than substrates with a high percentage of silt and loam (WALTER 1962, SCHOLZ 1963). Because of the high and rapid evaporation of soils in arid regions, the soil surface of silt substrate may produce a thin crusting layer that prevents infiltration and promotes run-off in particular after typical heavy summer rainfall events. Contrarily, in sandy soils these problems usually do not occur (except for the case of biological crusting on the soil surface). Due to more coarse grain sizes and larger pores in sandy soils a more rapid evaporation is evident for the upper soil layers soils, which prevents soil water in the lower soil layers to rise to the soil surface and to also evaporate.

8.6.1 Physical soil properties

Soils occurring within the distribution area of *Harpagophytum* are mainly classified as Arenosols, and Regosols (after ISSS, ISRIC, FAO 1998). For each transect, soil substrate type and soil colour was determined (Fig. 22):

Only two broad types of soil substrates were distinguished for transects with *Harpagophytum*, i.e. sand and loamy sand. As no transects were recorded in pans or outcrop areas, no high clay or stone contents were sampled. On private farmland of Namibia and in communal areas of South Africa a similar number of transects was documented on a substrate composed of sand and loamy sand, while in the other two research areas most transects inhabited a sand substrate. Although slightly more individuals/transect were recorded on sand substrate in comparison to loamy sand substrate, the low medians indicate that this difference is not significant.

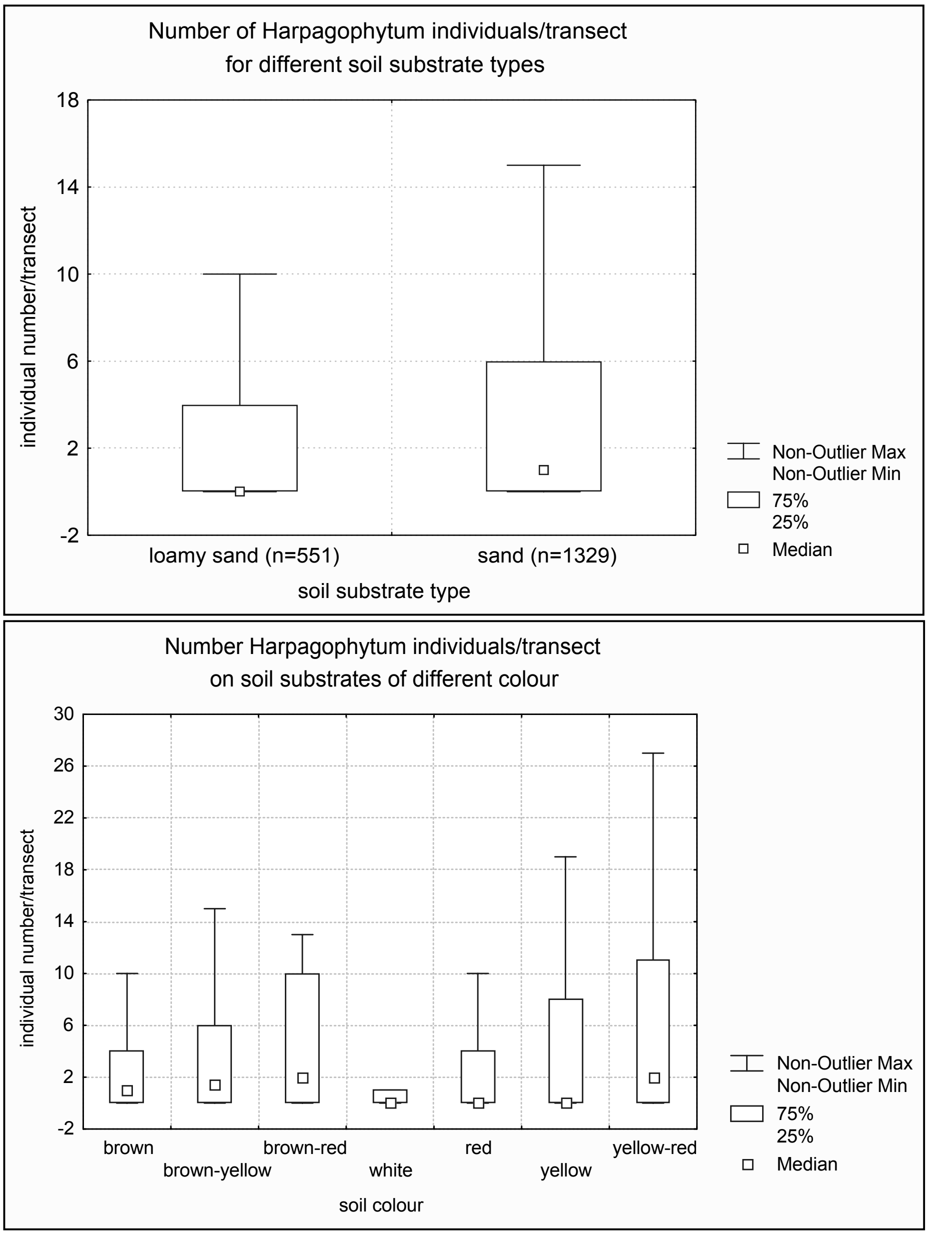


Fig. 22: Number of *Harpagophytum* individuals per transect for different soil substrates (upper graph) and soil colours (lower graph).

Harpagophytum may occur on soil substrates of all colours. Due to the low sample sizes for soils with a white and brown hue in colour (brown, brown- yellow, brown-red), ranges of individual numbers appear as great as for the red, yellow and yellow-red soils which were documented more frequently. From these, slightly higher individual numbers of *Harpagophytum* were counted on yellow-red substrates. This is indicated by the larger range and by the higher median. On brown-red soils *Harpagophytum* occurs with a similar density, but fewer transects inhabit greater individual numbers, i.e. the non-outlier maximum is lower than on soils of a yellow-red colour.

8.6.2 Chemical soil properties

No soil samples for laboratory analysis were taken in the course of the study. Detailed data on the pH value and the electric conductivity is, however, available for one private farm in the Northern Cape Province of South Africa (PETERSEN & GRÖNGRÖFT in press). The farm is characterised by a linear dune landscape with dunes of 5-12m in height and interdunes of a width ranging from 30-50m. Two square kilometres were documented on the dune habitats, in the same area as the data collecting of PETERSEN & GRÖNGRÖFT was carried out.

Data of PETERSEN & GRÖNGRÖFT (in press) on the pH values (in H_2O) of the upper soil layer (0-10cm) indicates a lack of large pH variations between the different dune habitats (Fig. 23). The pH values for the three habitat types vary between neutral to slightly acid values. Greatest variability was found in the interdune where also the vegetation experiences the greatest potential variation in its composition and density. Electrical conductivity of the upper soil layer is very low and ranges from 30-70µS/cm for all habitat types (Petersen, pers. comm..). This result makes clear that no significant differences in the salt content of the soils are evident for the different habitats that may have an impact on the occurrence of *Harpagophytum*.

With the use of the distribution of *Harpagophytum* densities on the habitat types of the two square kilometres on the farm, it was tried to delineate a relationship between pH values and individual numbers (Fig. 24). A low median for plant numbers was found for the four habitat types, but widest ranges occurred in the interdune habitat. Also on the dune base and the lower dune slope occasionally 1-2 individuals of *Harpagophytum* were documented, indicated by the extremes in the graph. No plants were recorded on the dune crest, for which also the lowest, slightly acid pH values were measured. However, due the low sample size for this habitat type, no significant relationship between the lack of individuals of *Harpagophytum* and a lower pH value can be concluded. The great variability of pH values in the interdune habitat reflects the variety of different micro-habitats within the interdunes.

On the farm, interdunes may be composed of dense *Rhigozum trichotomum* (Bignoniaceae) stands, of open *Dicoma capensis* (Asteraceae) or *Hermannia tomentosa* (Sterculiaceae) patches or of a grass matrix of varying density. Individuals of *Harpagophytum* were only found where annual grasses (predominantly *Schmidtia kalahariensis*) occurred with a cover of less than 20% or occasionally also within open *Dicoma capensis* patches. No significant differences in the pH values of the different subtypes of interdunes were found by PETERSEN & GRÖNGRÖFT (in press), but interdunes with *Rhigozum trichotomum* patches often show underlying calcrete within the first 2m below soil surface.

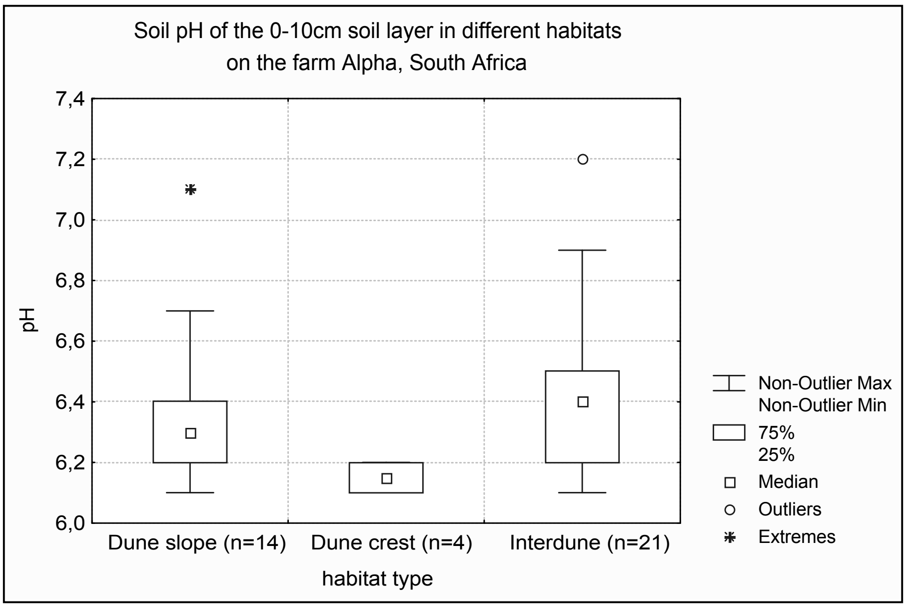


Fig. 23: Soil pH (H_2O) of upper soil layer (0-10cm) for three habitat types on the farm Alpha in South Africa. Source: PETERSEN & GRÖNGRÖFT, in press).

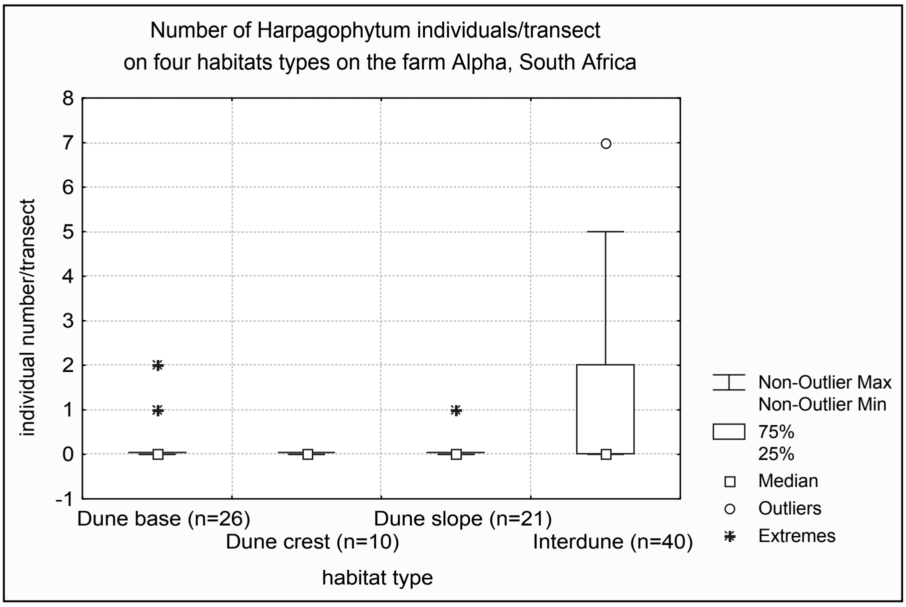


Fig. 24: Number of *Harpagophytum* individuals/transect for four habitat types on two square kilometres on the farm Alpha, South Africa.

8.6.3 Summary and conclusions on the impact of soil properties on *Harpagophytum*

Variation in soil moisture availability may be one of the most important causes of spatial heterogeneity in plant communities of arid land ecosystems (EVENARI et al. 1971). Soil moisture content is related to the type of habitat and soil substrate or grain size distribution, respectively. Analyses indicate that *Harpagophytum* may predominantly occur on sand substrates with a varying loamy component. A slightly higher, but not significant individual density was recorded for sand substrates in contrast to loamy sand substrate. Furthermore, *Harpagophytum* may grow on soils of varying colours. Lowest resource density was evident for white soil substrates. Irrespective of the fact that red soils were sampled most frequently, the number of individuals counted in this soil colour type was limited. Slightly higher individual numbers were recorded on yellow-red and brown-red soils.

Data of PETERSEN & GRÖNGRÖFT (in press) contribute information on the chemical soil properties of different habitat types on a farm in the Kalahari. Low differences in soil pH and electrical conductivity of the upper soil layer make clear that chemical soil properties do not account for differences in the occurrence of *Harpagophytum* in the different habitat types. Variations in individual numbers of *Harpagophytum* were greatest in the interdunes where also greatest variations in the pH values occurred. From this it is concluded that not interdunes in general represent favourable habitats for *Harpagophytum*, but that small-scale changes in soil features, which result in a specific composition of the vegetation account for differences in the species density. SCHNEIDER et al. (2001) report slightly lower pH-values of pH 5.5-6.0 for a site with yellow-red sand substrate in the Kalahari dune landscape near Maltahöhe, Namibia, where dense patches of *Harpagophytum* occur. For another research site in the more eastern part of the Kalahari (Kuruman. South Africa) with a red substrate and partly higher clay contents, the authors found higher values of pH 7.1 and pH 7.7. This area receives high rainfall amounts of 200-300mm. From this it may be concluded that pH values ranging from slightly acid to neutral or mildly alkaline do not have an impact on the occurrence of *Harpagophytum*. Also VEENENDAAL (1984) did not find much variation in the nutrient content of soil samples from two villages in Botswana.

IHLENFELDT & HARTMANN (1970) also claim that *Harpagophytum* predominantly occurs on deep sands, red sands or loamy brown sands. TAYLOR & MOSS (1982) state a preference of *Harpagophytum* for red Kalahari sand, but found that the species may also grow in other sand types as well as calcrete soils. Also personal observations from Kimberley, South Africa, indicate that individuals of *Harpagophytum* may grow on substrate with underlying calcrete in 5-10cm depth. VOLK & LEIPPERT (1971) found that *Harpagophytum* favours none or slightly calcareous, neutral to slightly acid soils of hills and fragment free, shallow soils of depressions. Results from a questionnaire distributed on commercial Namibian farms support the results of this study as most farmers found that *Harpagophytum* only grows on red sandy soils, and to a very low extent also in clay pans and on white sandy soils (NOTT 1986).

8.7 The impact of land use on *Harpagophytum*

Land use in the more arid areas of southern Africa is typically characterised by livestock farming on natural vegetation (range land) instead of crop-farming. In general, the low annual precipitation does not allow crop-farming on a large scale (ANDERSEN 1996). In South Africa, over 80% of the land is range land and raising livestock forms the dominant form of land use. Cropland covers only up to 10% of the research areas in the NW-Province, South Africa (HOFFMAN & ASHWELL 2001). The occurrence of *Harpagophytum* is limited to these areas where land use is dominated by game, cattle, sheep and goat farming. Land use intensity of these areas may vary strongly with respect to environmental conditions (e.g. precipitation, soil) and is strongly influenced by the person or community utilising an area. In South Africa, the unpredictable and low rainfall within Kalahari allows predominantly small-stock farming, but game farming has considerably increased over the past years (ANDERSEN 1996). Land degradation in semi-arid environments such as Namibia is commonly ascribed to inappropriate "traditional" land tenure and land use systems together with a growth in population and sedentarization. Among others, these factors are stated to lead to a detrimental utilisation of natural resources and thus a depletion of grazing resources, an increase of soil erosion and bush encroachment. (RHODE 1997, SEELY et al. 1995, HOFFMAN & ASHWELL 2001). It is generally taken as a fact that communally owned areas in particular experience a more intensive level of overgrazing and degradation than privately owned farmland (e.g. ARCHER et al. 1989, POWELL 1996). Many studies concentrate on the impact of grazing on both land use types (e.g. SKARPE 1986, PERKINS 1996, MOLEELE & PERKINS 1998, HARRISON & SHACKELTON 1999, HOFFMAN & ASHWELL 2001). For the Kalahari, already LEISTNER (1967) and ACOCKS (1975) stated the susceptibility of the Kalahari to overuse by herbivores. ACOCKS regarded the scattered grass layer together with the loose sandy substrate to be extremely vulnerable to grazing. The development of bare active dunes in certain areas has even been attributed to severe disturbances by overgrazing (WIGGS et al. 1994).

For the occurrence and density of *Harpagophytum*, it is assumed that severe grazing pressure may have both, a supporting and a restrictive component. Firstly, some of the major threats *Harpagophytum* plants have to face comprise grazing, trampling and harvesting of the roots by livestock and game. This is especially true for the dry period of the year as well as for low-rainfall years when little other fodder is available for the animals (VOLK 1964). Animals might then dig up the main tubers for additional water supply. The newly emerged shoots, which are regularly grazed are avoided by the animals once the clawed fruits begin to form. Even though the main tubers are able to sprout fresh shoots after being grazed back, it can be assumed that continuous grazing will finally lead to a limited production of new fruit and seed and thus reduces the capability of a natural generative regeneration of the populations. Secondly, besides this negative effect of grazing on individuals of *Harpagophytum*, also positive effects of comparatively high land use intensities are stated. That is that *Harpagophytum* is suspected to be a species, which increases parallel to an increase of the grazing impact on the vegetation (e.g. BLANK 1973). In the 1970s, *Harpagophytum* was even considered a weed in Namibia and farmers were encouraged to extinct the plant. This attitude was based on the experience that (a) the fruits of the plants – formed like a claw – get caught in the throat of calves leading to starvation, if the claw is not removed in time, (b) the fruits get entangled to the fur of sheep and reduce the value of the latter, or (c) the long creeping shoots of *Harpagophytum* are non-digestible and can cause severe illnesses especially for cattle and horses (HACHFELD 1999). Several farmers reported that next to other indicators, the conditions of the veld is determined by the occurrence or lack of *Harpagophytum*. In the case of a dense growth of the species they claim a bad condition of the veld due to long-term overgrazing, which results in a vegetation composition dominated by grasses of low grazing value.

This chapter analyses the impact of land use on *Harpagophytum* using the veld condition with the grazing intensity as an indirect indicator. The term veld condition combines a loss of vegetation cover and a change in plant species composition due to grazing practises (HOFFMAN & ASHWELL 2001). Veld condition is generally difficult to define, not easy to assess and is a matter of perception (ROUX 1990 in HOFFMAN & ASHWELL 2001). Several methods have been developed to measure the impact of grazing and these are still subject to discussions (e.g. DU TOIT 1995, FUHLENDORF & SMEINS 1999). What they typically have in common is the intensive involvement of manpower.

For this study, the assignment of grazing intensity classes was considered a useful tool for the detection of different grazing intensities in the field. The derivation of different grazing intensity classes follows HOFFMAN & ASHWELL (2001) and is based on the status of the vegetation (composition and density) and on the visual determination of trampling and faeces quantities in the field. As the vegetation is subject to rainfall variations and to small-scale variations in soil parameters, the grazing classes naturally suffer certain subjectivity. Only a limited number of intensity classes were used to reduce pseudo-class forming by subjective categorisation to a minimum.

Five grazing intensity classes were used, which were defined as

Grazing intensity class 0	no grazing impact visible
Grazing intensity class 1	weak/low grazing impact visible
Grazing intensity class 2	medium grazing impact visible
Grazing intensity class 3	strong grazing impact visible
Grazing intensity class 4	very strong grazing impact visible

Each transect was assigned to one grazing intensity class. To determine the grazing intensity class several parameters were evaluated such as the surrounding vegetation, its species composition and cover on the transect as well as in the wider area of the research site. In particular the quantitative relationship between annual and perennial grasses, the occurrence and dominance of indicator species for overgrazing and the status of the herb layer were taken into consideration. Observations of the trampling intensity by life stock were added as well as interviews with the landowners on their grazing system and stocking rates.

8.7.1 Frequency of different grazing intensity classes

Table 17 lists the number of research sites and transects documented in the four grazing intensity classes:

- On private farmland of Namibia, grazing intensity was moderate and no areas with a strong to very strong grazing impact (classes 3 & 4) were sampled. Instead, most sites reflect a medium grazing intensity, i.e. 23 sites and 405 transects were documented in the grazing intensity class 2.
- In the communal areas of Namibia, a different tendency was found. Here, frequently a medium to strong harvesting impact was evident and the majority of sites were placed in such areas. Transects on which no grazing impact occurred were not assessed.
- In South Africa, on both, private farmland and communal areas, all grazing intensity classes were covered by the study. Whereas on private farmland most sites and transects showed a medium grazing impact (class 2), in the communal areas the highest number of sites was documented in areas with a strong grazing impact (class 3).

Tab. 17: Frequency of different grazing intensity classes on communal and private land of Namibia and South Africa.

Grazing intensity class // Research area	Grazing class 0	Grazing class 1	Grazing class 2	Grazing class 3	Grazing class 4
Namibia – private farmland					
No. sites	8	9	23	–	–
No. transects	10	215	405	–	–
Namibia – communal area					
No. sites	–	2	7	11	3
No. transects	–	38	101	128	67
South Africa – private farmland					
No. sites	3	7	15	11	6
No. transects	48	147	195	152	128
South Africa – communal area					
No. sites	1	3	2	5	2
No. transects	24	68	32	82	46

8.7.2 Resource status and grazing intensity

For the analyses of the relationship between the occurrence of different *Harpagophytum* densities and the grazing intensity, quantities of *Harpagophytum* were divided into six quantity classes (0, 1-4, 5-9, 10-20, 21-50, >50 individuals/transect). It was proposed that a number of >10 individuals indicates the occurrence of a patch of *Harpagophytum* while lower quantities resemble a scattered occurrence of single individuals. The percentual occurrence of quantity classes at different grazing intensities is presented in Figure 25:

Private farmland of Namibia (Fig. 25a):

Grazing intensities on the research sites were low (classes 0-2). Signs of overgrazing were not found. A scattered occurrence of single individuals of *Harpagophytum* (quantity classes 1-4, 5-9 individuals/transect) was recorded for all three grazing classes. Patches with >10 individuals were restricted to a low to medium grazing intensity. No patches occurred where no grazing was evident. Very high individual numbers and dense patches with >50 individuals/transect were only documented under medium grazing intensities (class 2).

Communal areas of Namibia (Fig. 25b):

The impact by grazing ranged greatly between the sites. Transects with low individual numbers and a scattered occurrence of *Harpagophytum* occurred at all grazing classes with a clear focus on transects with low grazing intensities. Patches of *Harpagophytum* dominated where the grazing impact on the vegetation was high (grazing intensity classes 3, 4). Especially under a strong, but not very strong grazing intensity, a large resource density was evident with half of the transects inhabited by >21 individuals. Also quantities of >50 individuals were restricted to 10% (class 4) and 20% (class 3) of all sites. Under both grazing intensities the percentage of transects on which no individuals of *Harpagophytum* occurred was very low.

a) b) c) d)

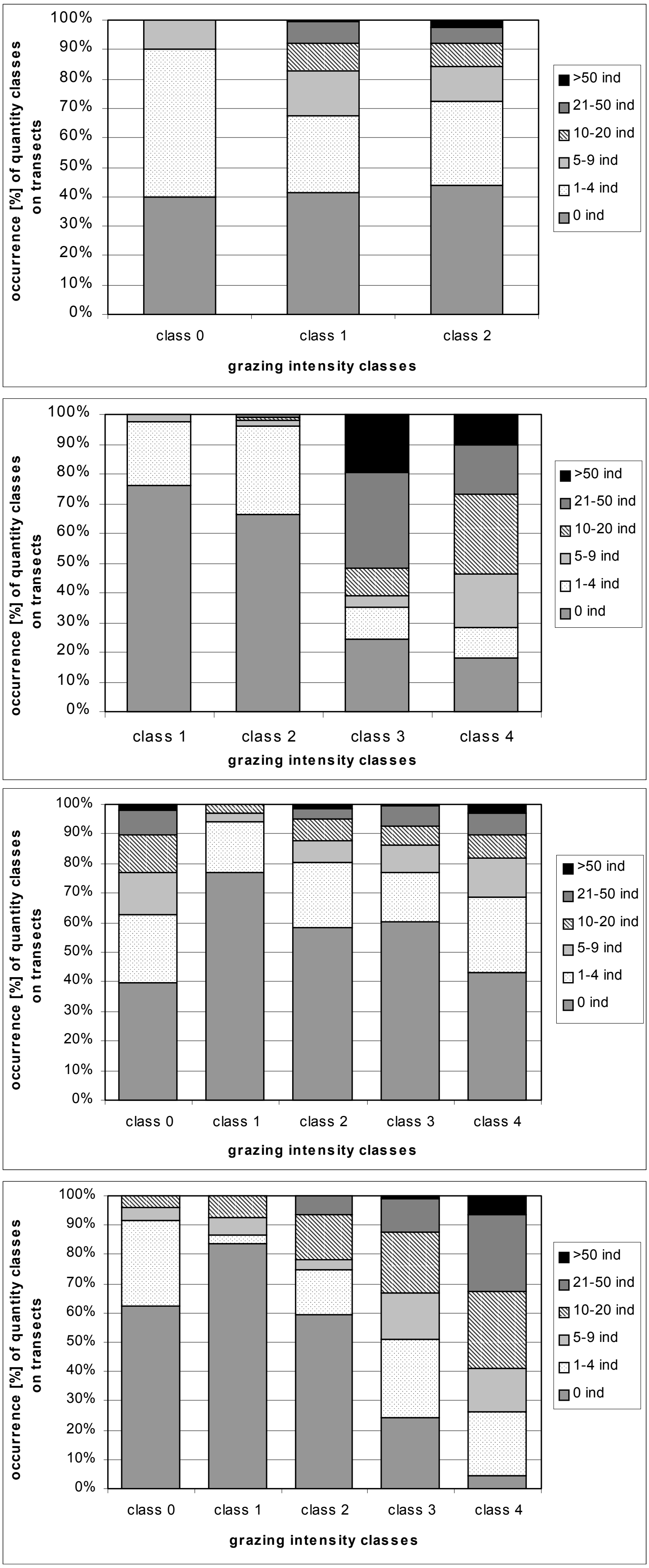


Fig. 25: Occurrence of *Harpagophytum* quantity classes in four grazing classes in a) private farmland, b) communal areas of Namibia and c) private farmland, d) communal areas of South Africa.

Private farmland in South Africa (Fig. 25c):

All grazing intensity classes occurred. Single *Harpagophytum* individuals (quantity classes 1-4, 5-9 individuals/transect) as well as a patchy occurrence (>10 individuals) is evident for all grazing intensities. Resource density was highest at either no grazing or a very strong grazing intensity. Such sites were documented in the municipal areas of Upington and near Kimberley in the N-Cape Province (South Africa). There, no grazing but other anthropogenic disturbances lead to the disturbance of the vegetation by other means than livestock farming, which also favoured the development of dense populations. The frequency of very high individual numbers with >21 individuals resembles the findings on the private farmland of Namibia, where also on a maximum of 10% of the transects such quantities were recorded.

Communal areas of South Africa (Fig. 25d):

A similar but less strong correlation between high resource densities and grazing intensity was found in comparison to the communal areas of Namibia. Again, patches as well as a scattered occurrence of single individuals occurred under all grazing intensities. However, only under the impact of strong to very strong grazing (grazing intensity classes 3, 4) very dense patches of *Harpagophytum* with >50 individuals/transect were documented. In contrast to the communal areas of Namibia, the highest percentage of transects with >21 individuals and >50 individuals were found at a very strong grazing intensity. On more than three quarters of the transects with a vegetation experiencing such a strong influence of grazing, *Harpagophytum* individuals were recorded. In the grazing intensity class 4, plants were counted on even more than 90% of all transects. Of these, on more than half of the transects patches with >10 individuals were recorded. Similar to the communal areas of Namibia, in both grazing classes rarely no plants were counted.

Table 18 summarises the results of the visually interpreted relationship between the grazing intensity and the *Harpagophytum* density on the transects. For the correlation, no quantity classes of *Harpagophytum* were used, but original field data with individual numbers/transect. The Spearman rank order correlation proves that except for the private farmland of Namibia, a significant correlation exists between high grazing intensity and high density of *Harpagophytum*. For the private farmland of South Africa, the correlation is very weak with a low r_s value. It can thus be concluded that the higher the grazing intensity of an area, the higher is the expected density of *Harpagophytum*.

Tab. 18: Spearman rank order correlation (2-sided) of different grazing intensity classes and individual numbers of *Harpagophytum* on transects of 100*2m.

Country		N	r_s	t(N-2)	p-level
Namibia	Private farmland	630	-0.0108	-0.2711	0.7864
	Communal areas	334	0.5735	12.7547	0.0000***
South Africa	Private farmland	670	0.1366	3.5642	0.0004***
	Communal areas	227	0.5698	10.4015	0.0000***
***= highly significant (p< 0.01)					

8.7.3 Summary and Conclusions on the impact of land use on *Harpagophytum*

The grazing intensity was used as an indicator for the impact of livestock on the composition and density of the vegetation. Grazing intensity on the research sites was assessed using five different grazing intensity classes (class 0-4). The results indicate a divergent importance of the four grazing intensity classes for the privately and communally owned areas of Namibia and South Africa. On private farmland a higher number of sites and transects were documented which experienced a comparatively lower grazing pressure than the communal areas.

Data analyses prove that *Harpagophytum* may principally occur at all grazing intensities. Yet, the density of the resource varies with respect to the grazing pressure on the surrounding vegetation and thus also on *Harpagophytum*. A highly significant correlation was found between the number of individuals of *Harpagophytum* and the grazing intensity for all research areas except the private farmland of Namibia. This is due to the lack of high grazing pressures on these research sites. In the communal areas of both countries the species was recorded on almost 80% of the transects under a strong and on over 80% under a very strong grazing pressure. Single individuals grow widely spaced from each other (quantity classes 1-4, 5-9 individuals/ transect) under all grazing intensities and in all research areas. In contrast, patches of *Harpagophytum* with >10 individuals/transect tend to occur under a higher grazing pressure on the vegetation. This is particularly true for the communal areas of both countries. I.e., in Namibian communal areas on up to 60% of the transects patches of *Harpagophytum* were recorded in highly to extremely grazed areas. In South African communal areas only at a very strong grazing pressure such a large percentage of transects showed a patchy occurrence of *Harpagophytum*. In general, very dense populations (>50 individuals/transect) were typically limited to areas with a very strong grazing pressure.

It can finally be concluded that land use, here characterised by the grazing intensity, does play an important role for the occurrence and resource status of *Harpagophytum* in southern Africa. This impact is reflected in particular in changes of the density not only of *Harpagophytum* but also of the surrounding vegetation. The results support the assumption from the beginning of this chapter that *Harpagophytum* may be a plant increasing with an increase in grazing pressure. This correspondence is, however, not valid for the general occurrence of the species but is limited for its growth in assemblages of several to many individuals. Furthermore, one must consider potentially negative effects of trampling and grazing on the regeneration and reproductive potential of adult individuals and positive effects of it on seed dispersal and thus the regeneration of populations. Both have not explicitly been analysed in this study. For forage plants, for instance, it is generally accepted that in addition to the direct effect of herbivory, density of forage plants decrease due to scarcity of seeds (MILTON & DEAN 1993). In the Karoo, grazing reduced the growth and maturation of seedlings of forage species (MILTON 1995). It is also expected but awaits further research that the nutrient status of the substrate that is influenced by livestock and game as well, will have an impact on the growth and regeneration of *Harpagophytum*.

8.8 The impact of the vegetation on *Harpagophytum*

Plant species populations experience various regulations by inter-specific competition as well as by limitations through abiotic parameters. Only if species manage to overcome or avoid competition, they are able to survive. Successful co-existence may for instance be reached when different layers for the above-ground as well as the below-ground organs are used in order to avoid spatial competition for soil water, soil nutrients or light (e.g. DIERßEN 1990). In particular temporal competition plays an important role in arid and semi-arid environments with unpredictable summer rainfall. Plant species with below-ground storage tubers such as *Harpagophytum,* are able to quickly response to rare rain events and to re-sprout before ephemeral species of other life forms have germinated and established themselves. As *Harpagophytum* is able to form dense mats on the ground, the growth of other plant individuals in the near vicinity may be suppressed. The geophytic life form of *Harpagophytum* does, however, not pose an advantage in the case of rare and single rainfall events. Fresh shoots may wither in the cause of a following rainless month and only after another sufficient rainfall, new shoots emerge (Hachfeld, pers. observation). Under such conditions, plant species are much more competitive which are able to keep their shoots alive also over a number of rainless weeks.

Generally, *Harpagophytum*, in its growth potential and ability to form dense patches, is strongly influenced by the surrounding vegetation. Already ESDORN (1963) stated a tendency of *Harpagophytum* to be a ruderal plant like other genera in Pedaliaceae (i.e. *Rogeria*). Also BLANK (1973) claimed a restriction of *Harpagophytum* to over-stocked areas and disturbed habitats indicating that the specific composition and density of the vegetation of these habitats supports its establishment and occurrence.

This chapter discusses the relationship between the density and composition of the vegetation and the resource status of *Harpagophytum*. This relationship is analysed using different layers of the vegetation instead of the vegetation cover in general for this not homogenous and consists of a strongly varying dominance of different life forms.

8.8.1 Role of vegetation layers for the occurrence of *Harpagophytum*

The various layers of the vegetation differ with respect to their role for the occurrence and density of *Harpagophytum*. Due to its growth form and rooting system, it can be assumed that *Harpagophytum* experiences a direct competition with grasses and possibly also with herbs and small shrubs. Contrarily, trees, having a deep rooting system, exploit soil water and nutrient reserves in deeper soil layers. Ephemeral growth forms which root in the upper soil layer, may compete with *Harpagophytum* about water and nutrients of the soil. In the following, this hypothesis is tested for the four research areas using a two-sided rank correlation (Spearman rank order correlation). A potential relationship between the cover of different vegetation layers and individual counts of *Harpagophytum* per single transect are tested (Tab. 19):

For the research sites on private farmland of Namibia and South Africa, the results support only partly the postulated hypothesis:

- A weak but highly significant positive relationship between the herb cover and the resource density of *Harpagophytum* indicates an increase in *Harpagophytum* densities parallel to an increase of the herb cover.

- In contrast, for the grass cover a weak but highly significant negative correlation with *Harpagophytum* counts was found, which supports the hypothesis that a dense grass cover restricts the occurrence of *Harpagophytum*.

For the communal areas of both countries, results differ slightly:

- In Namibian communal areas, a weak and highly significant positive relationship between *Harpagophytum* densities and the herb cover was evident. For the grass cover this negative relationship was considerably stronger and highly significant. An increase of individuals of *Harpagophytum* was positively correlated to a decrease of the tree cover.
- For the South African communal areas, only the weak negative relationship between the grass cover and *Harpagophytum* quantities accounts for the above made hypothesis. The positive relationship of the density of *Harpagophytum* with the density of the shrub cover can however not be explained by this.

Tab. 19: Spearman rank order correlation (2-sided) of quantity of *Harpagophytum*/ transect in Namibia and South Africa with cover of herb-, grass-, shrub-, and tree layer**.**

Research area	**Vegetation layer**	**No. transects**	**Correlation coefficient (r_s)**	**p**
Namibia				
Private farmland	Herb cover	630	0.1982	0.0000***
	Grass cover	616	-0.1234	0.0021***
	Shrub cover	616	-0.0606	0.1328
	Tree cover	630	-0.1187	0.0028***
Communal areas	Herb cover	334	0.1649	0.0025***
	Grass cover	334	-0.5952	0.0000***
	Shrub cover	334	0.0441	0.4216
	Tree cover	334	-0.3812	0.0000***
South Africa				
Private farmland	Herb cover	644	0.1766	0.0000***
	Grass cover	649	-0.1135	0.0038***
	Shrub cover	643	-0.0444	0.2609
	Tree cover	658	0.0090	0.8182
Communal areas	Herb cover	214	-0.0791	0.2490
	Grass cover	213	-0.2861	0.0000***
	Shrub cover	214	0.2525	0.0002***
	Tree cover	214	0.1281	0.0613
***= highly significant (p<0.01)				

Generally, the results give proof to the above raised hyptothesis that grasses play a competitive role for the occurrence of *Harpagophytum*. A dense herb layer does, in contrast, not limit the growth of *Harpagophytum*, but seems to be an indicator for favourable environmental conditions also for the occurrence of *Harpagophytum*.

8.8.2 Grazing intensity and grass cover

The type of grazing, its patterns and intensity may have a strong influence on the vegetation (see Chapter 8.7). This influence varies with respect to rainfall, substrate and geomorphology. As *Harpagophytum* showed to be in particular sensitive to grass competition (see above subchapter), the cover of the grass layer was used for further analyses. Also, grasses are valuable indicators for the impact of grazing on the vegetation. Especially, the composition and density of the grass layer varies with respect to the grazing type and its intensity.

The two-sided Spearman rank order correlation (Tab. 20) tests this assumed relationship between the grazing intensity classes and the grass cover on the transects. Except for the private farmland of Namibia, a highly significant negative correlation between both variables was found. This was in particular strong for the communal areas of both countries indicating that heavily overgrazed areas are characterised by a lack or a low cover of annual and perennial grasses.

Tab. 20: Spearman rank order correlation (2-sided) of grazing intensity and grass cover on transects for communal and private land of Namibia and South Africa.

Research area		**No. of transects**	**Correlation coefficient (r)**	**p**
Namibia	Private farmland	616	0.0074	0.8537
	Communal areas	334	-0.6874	0.0000***
South Africa	Private farmland	649	-0.1929	0.0000***
	Communal areas	213	-0.5881	0.0000***
***= highly significant (p<0.01)				

The relationship between the grazing impact and the grass cover is shown for all research areas together (Fig. 26). For this, the grass cover was divided into eleven grass cover classes, ranging from 0%, over 1-10%, 11-20% etc. to 91-100% grass cover/transect. The same grazing intensity classes were used as in Chapter 8.7 (grazing intensity classes 0-4).

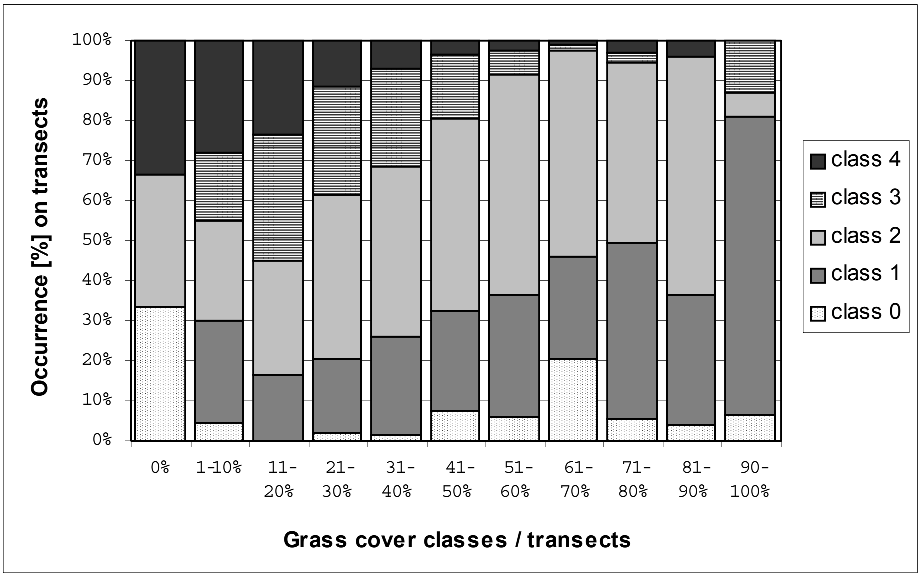


Fig. 26: Relationship between grazing intensity classes and different grass cover classes. Shown is the percentage of occurrence on transects of all research areas.

The graph (Fig. 26) indicates that

- Low to medium grazing intensities (class 1, 2) occur irrespective of the grass cover.
- Low grazing intensities (class 1) were in particular evident at a grass cover of more than 70%.
- The percentage of a high grazing pressure increases with a decrease of the grass cover.
- A strong to very strong grazing intensity (class 3, 4) is predominantly restricted to an open grass matrix. More than half the transects with such a strong to very strong grazing impact were characterised by a low grass density of only 11-20%.
- Yet, even under a high grazing pressure a dense grass cover may develop. This was generally the case when only few species dominated the composition of the grass layer. Typically, these were annual grass species, indicating overgrazing such as *Schmidtia kalahariensis*. In some areas this species reached up to 92% cover.
- Very strong grazing intensities (class 4) were predominantly associated with low grass cover classes. In areas where the grass cover stayed low with 0-20% (grass cover classes 0%, 1-10%, 11-20%), very often a very high impact of grazing was evident.

8.8.3 Grass cover and resource status of *Harpagophytum*

To analyse the relationship between different grass cover classes and the resource status of *Harpagophytum*, the grass cover of single transects was assigned to one of eleven grass cover classes (Fig. 27). Five quantity classes of *Harpagophytum* (quantity classes 0, 1-9, 10-20, 21-50, >50 individuals/transect) were assigned to these cover classes. As defined earlier, it was distinguished between patches and a scattered growth of single *Harpagophytum* plants.

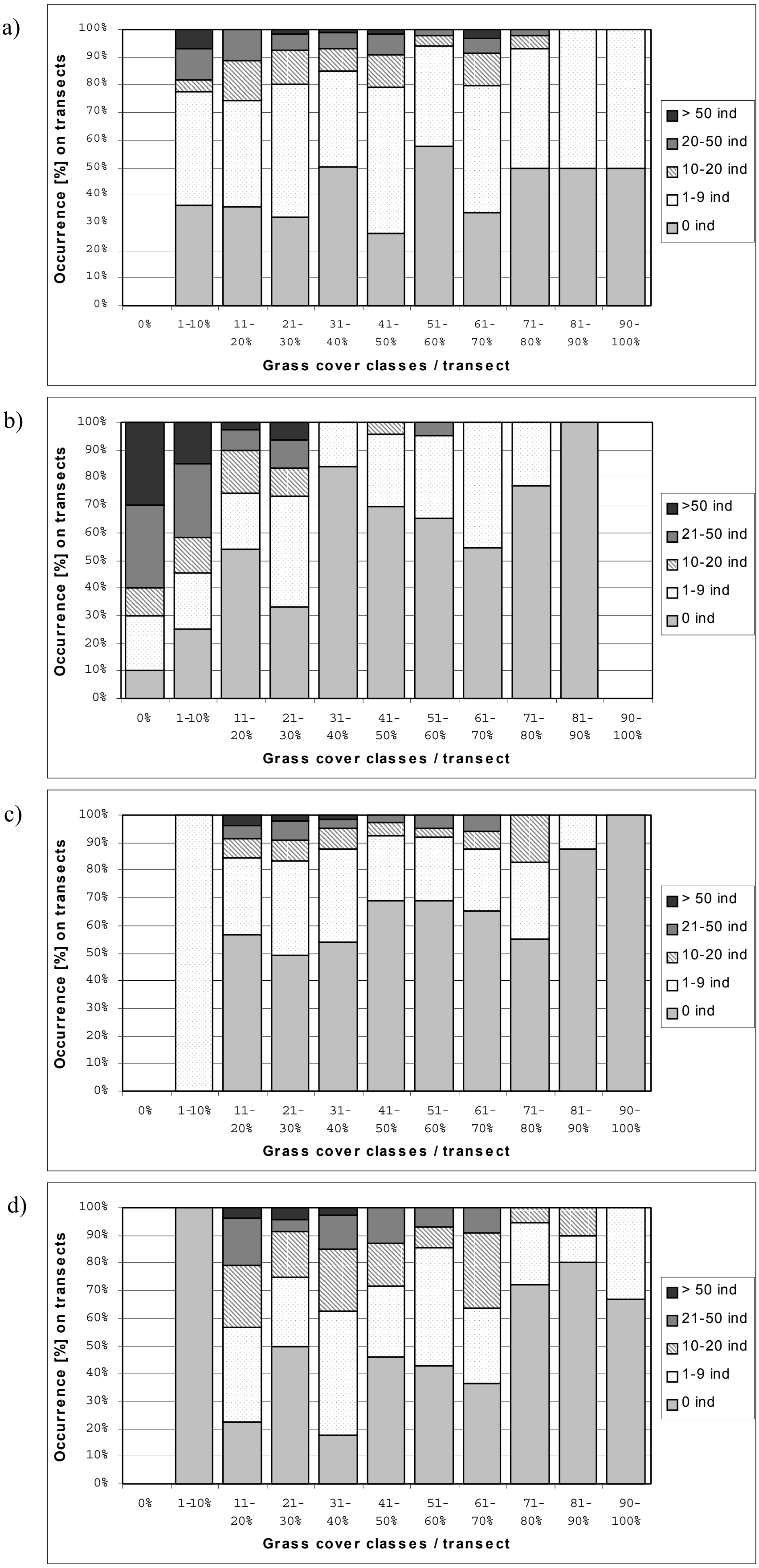


Fig. 27: Occurrence [%] of density classes of *Harpagophytum* at different grass cover classes in a) private and b) communal land of Namibia and c) private and d) communal land of South Africa.

Private farmland of Namibia (Fig. 27a):

- A scattered occurrence of single individuals of *Harpagophytum* is not dependent on the grass cover density: At least for 30% of all transects of each grass cover class 1-9 individuals were found.
- A low grass cover does not necessarily guarantee the occurrence of *Harpagophytum* as for all grass cover classes transects without any individuals occur.
- Patches with >10 individuals/transect occur up to a maximum grass cover of 80%. Patches predominantly occur in a grass matrix of less than 50% cover. Higher population densities (>21 individuals/transect) are rare irrespective of the grass cover. Only at an open grass cover with less than 10% cover, on 21% of the transects this quantity was documented.

Communal areas of Namibia (Fig. 27b):

- *Harpagophytum* grows in a scattered pattern of single individuals at a great range of grass cover values (0-80%).
- A lack of individuals of *Harpagophytum* is not related to a certain grass cover, but occurs irrespective of it. Yet, the percentage of transects without any *Harpagophytum* individuals increased when the grass covered more than 40% of the ground.
- Patches were predominantly restricted to grass cover values of less than 40%. When the grass cover was below 10%, more than half of the transects showed such high quantities. Populations of *Harpagophytum* were most dense (>50 individuals/transects) at a missing or very open grass cover of a maximum of 30%.

Private farmland of South Africa (Fig. 27c):

- Single individuals of *Harpagophytum* grow at a wide range of cover classes (1-90%).
- Patches with >10 individuals/transect occur less frequently in comparison to Namibia. Only on up to 18% of the transects in the grass cover classes between 11-80% patches of *Harpagophytum* were found. Higher quantities of >50 individuals occurred only when grasses covered less than 40% of the ground.

Communal areas of South Africa (Fig. 27d):

- A scattered occurrence of *Harpagophytum* is evident at grass cover values of >10% cover.
- A lack of the species occurs irrespective of the grass cover, but is most frequent in the cover classes above 70%.
- Patches of *Harpagophytum* are not necessarily restricted to a low grass cover. Also at a grass cover of 81-90%, partly 10-20 individuals/transect were recorded. Individual numbers of >50 were restricted to grass cover values of 11-40%.

8.8.4 Accompanying plant species

For each transect, other species of the various vegetation layers encountered along the transects were documented. No detailed documentation with respect to the cover of single plant species was carried out. As plant species were recorded following their dominance on the transects, an interpretation of their role with respect to the occurrence of *Harpagophytum* is possible. For this, only those transects, for which patches (>10 individuals/transects) were recorded, were used to determine the frequency of accompanying species in the grass, herb and shrub layer. Compiling was carried out for Namibia and South Africa separately, as partly species composition varied strongly between the study sites (Tab. 21).

Tab. 21: Species of the grass, herb and shrub layer that typically accompany patches of *Harpagophytum*.

South Africa (n= 131 transects)				**Namibia (n=198 transects)**			
Species	**Plant family**	**No. sites**	**% sites**	**Species**	**Plant family**	**No. sites**	**% sites**
Grasses							
Eragrostis spp.	Poaceae	53	40.5	Eragrostis spp.	Poaceae	95	48.0
Aristida spp.	Poaceae	30	22.9	Stipagrostis uniplumis	Poaceae	61	30.8
Schmidtia spp.	Poaceae	29	22.1	Aristida spp.	Poaceae	42	21.2
Stipagrostis uniplumis	Poaceae	20	15,3	Stipagrostis spp.	Poaceae	41	20.7
				Rhynchelytrum spp.	Poaceae	24	12.1
				Schmidtia spp.	Poaceae	10	5.1
Herbs (annual & perennial)							
Cassia italica	Fabaceae	17	21.4	Indigofera spp.	Fabaceae	86	43.4
Cucurbitaceae	Cucurbitaceae	16	12.2	Tylosema esculentum	Fabaceae	53	26.8
Indigofera spp.	Fabaceae	16	12.2	Cucurbiticaea	Cucurbitaceae	32	16.2
Elephanthorriza elephantina	Fabaceae	11	8.4	Geigeria spp.	Asteraceae	30	15.2
				Cassia italica	Fabaceae	18	9.1
Shrubs							
Acacia mellifera	Fabaceae	53	40.5	Acacia mellifera	Fabaceae	72	36.4
Acacia hebeclada	Fabaceae	31	23.7	Grewia spp.	Tiliaceae	65	32.8
Chrysocoma obtusata	Asteraceae	18	13.7	Terminalia sericea	Combretaceae	45	22.7
Rhigozum trichotomum	Bignoniaceae	15	11.5	Commiphora africana	Burseraceae	45	22.7
Grewia spp.	Tiliaceae	12	9.2	Dichrostachys cinerea	Fabaceae	37	18.7
Acacia erioloba	Fabaceae	10	7.6	Bauhinia petersiana	Fabaceae	34	17.2
Ximenia africana	Olacaceae	6	4.6	Catophractes alexandrii	Bignoniaceae	31	15.7
				Acacia reficiens	Fabaceae	30	15.2
				Acacia hebeclada	Fabaceae	20	10.1
				Rhighozum trichotomum	Bignoniaceae	14	7.1

No specific and close link between certain plant species and the occurrence of dense patches of *Harpagophytum* could be detected (Tab. 21). Depending on the country, and probably also on the vegetation type, different species may grow together with *Harpagophytum*. In general, the array of species accompanying *Harpagophytum* was very similar for both countries, but none of the species were recorded for more than 50% of the transects.

On all transects, four to six different grass species typically accompanied patches of *Harpagophytum*. Of these, *Eragrostis* spp. was documented most often. This genus comprises species of low palatability and grazing value such as *E. biflora*, which was restricted to shady places on the transects, as well as valuable grazing grasses such as the perennial species *E. lehmanniana* and other species of medium grazing value (*E. trichophora*, *E. rotifer*). Another frequently accompanying grass species was *Aristida* with *A. adscensiones* and *A. congesta*, both considered as poor grazing grasses. However, *A. congesta* may well be utilised by small livestock in semi-arid regions (MÜLLER 1985, VAN ROOYEN 2001). *Schmidtia* species, especially *S. kalahariensis*, which can indicate overgrazed as well as arid areas, and *S. pappophoroides*, which is considered a valuable grazing grass, were frequently encountered with *Harpagophytum*.

Four to five herb species were observed to accompany *Harpagophytum* per site. Three perennial herb species of the Fabaceae family, *Cassia italica*, *Thylosema esculentum* and *Elephanthorriza elephantina* are also geophytes with below-ground storage tubers from which they re-sprout every year. All of them are widespread on sandy soils in the Kalahari. The encountered Cucurbitaceae as well as *Indigofera* species (Fabaceae) have annual life cycles forming occasionally dense stands on the research sites.

Shrub species encountered along transects were *Acacia* species (Fabaceae), i.e. *Acacia mellifera, A. hebeclada,* and *A. reficiens*. Also very typical for the Kalahari were *Grewia* species (Tiliaceae), which occurred frequently on sites with a patchy distribution of *Harpagophytum*. In the case of strong overgrazing, the small shrubby Asteraceae *Chrysocoma obtusata* was dominant on some sites of South Africa. In Namibia, predominantly in the Tree Savanna and Woodland, species such as *Terminalia sericea* (Combretaceae) and *Bauhinia petersiana* (Fabaceae) grew next to *Harpagophytum*.

Several authors state similar species compositions to be encountered together with *Harpagophytum*. For instance, VEENENDAAL (1984) and WERGER (1978) observed that in Tree Savannas in the northern parts of Namibia, *Harpagophytum* is often accompanies by species of the genus *Acacia, Bauhinia, Colophospermum*, and *Combretum*. In the more central and eastern parts of the country, *Harpagophytum* often occurs in an *Acacia erioloba-Acacia luederitzii* savanna with a grass layer overgrazed by cattle. In southern Namibia, *Harpagophytum* is associated with *Rhigozum trichotomum, Schmidtia kalahariensis,* and *Acanthosicyos naudiniana* (BRUIN et al. 1977). In Botswana, *Harpagophytum* is associated with an open tree savanna dominated by the shrub *Monechma incanum* and the perennial grass *Stipagrostis ciliata* (ERNST et al. 1988).

8.8.5 Summary and conclusions on the impact of the vegetation on *Harpagophytum*

The present findings support the assumption that the surrounding vegetation plays in important role for the occurrence and density of *Harpagophytum*. Different vegetation layers (grasses, annual and perennial herbs, shrubs, trees) were used to test the significance of this relationship. Results indicate that in particular for the grass cover a highly significant negative correlation with the density of *Harpagophytum* is evident. Contrarily, the herb cover experiences a highly significant positive relationship with the *Harpagophytum* resource density. Furthermore, an increase of individuals of *Harpagophytum* proved to be related to a decrease in tree cover. From this, it can be concluded that grasses do have a competitive effect on *Harpagophytum* and that herbs suffer under a competitive impact similar to *Harpagophytum,* meaning a reduction in cover in a dense grass matrix. Due to the predominant importance of the grass layer, further analyses concentrated on the relationship between the grass cover and *Harpagophytum*. It was shown that this relationship is a highly significant negative one (with the exception of the private farmland of Namibia): Whereas under low to medium grazing intensities grasses occurred with various densities, a strong to very strong grazing pressure was reflected by an open grass matrix with low cover values.

Single individuals of *Harpagophytum* may occur in areas with a varying grass cover. Higher resource densities with patches of >10 individuals/transect, however, show a concentration on areas with an open grass matrix. This is in particular true for the communal areas of Namibia, where a high percentage of patches occurred at grass cover values below 10%. From the data, a general relationship is evident between the density of the grass layer and the resource availability. It seems that dense populations of *Harpagophytum* (quantity classes >21 and >50 individuals/transect) can only develop in open areas with a low grass cover. As discussed above, these open areas are typically characterised by a high grazing pressure.

WALTER (1954) offers an explanation with respect to the competitiveness of *Harpagophytum*. He states that the species is not competitive on fine-grained soils and under low rainfall conditions due to its extensive root system in contrast to the intensive root system of perennial grasses. He claims that following a rainfall event, grasses will quickly take up almost the entire water reservoir of the top soil layers leaving only little water to sink into the deeper soil layers where *Harpagophytum* roots are located. In a later publication, WALTER (1964) favours the interpretation that *Harpagophytum* is only able to compete, where grasses are repressed by overgrazing, e.g. at water holes or trampled areas, where the soil often dries out over a long period of time. BLANK (1973) agrees saying that the occurrence of species of *Harpagophytum* on overgrazed pastures and ruderal places links to competition factors. Also STROHBACH (1998) found a concentration of *Harpagophytum* in the near vicinity of water holes and severely degraded areas for various communal resettlement farms in the Omaheke Region of Namibia.

Fig. 28: Photos of the Tree Savanna and Woodland (upper), interdune and dune habitats in the Camelthorn Savanna (middle) and a heavily overgrazed Camelthorn Savanna (Okakarara area) in Namibia (below).

8.9 Spatial distribution of *Harpagophytum*

Plant species are not continuously distributed over a range of habitat and landscape types but occur with a specific pattern in a specific number of habitat types. A habitat range of a plant species is usually smaller than its potential range due to interrelations with other species (STOHLGREN et al. 1998). Not only the amount of habitat available for a species, but also the spatial and spatio-temporal pattern of the habitat can have important implications for the survival of plant populations (HARRISON & FAHRIG 1995). The relationship between habitat amount and population survival is straightforward, meaning that with a decrease of the habitat amount, also a decrease of the population size is evident. Contrarily, an increase of habitat patch size increases the probability of the population survival. At temporally constant habitat availability, these positive effects of a large patch size on the populations are considered to be of greater importance than the negative effects of increasing patch isolation (HARRISON & FAHRIG 1995).

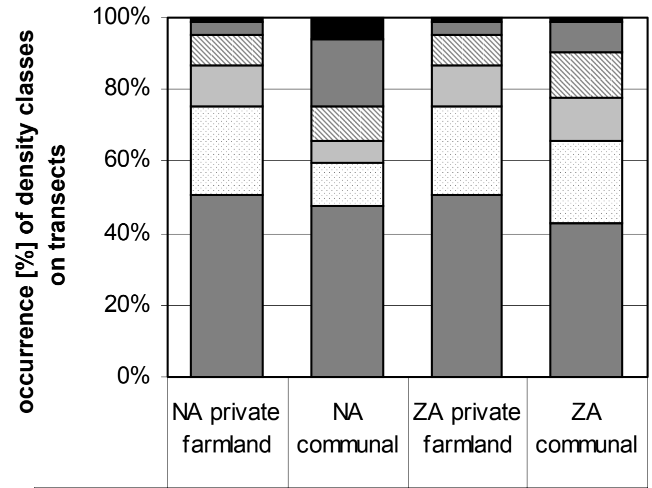
For *Harpagophytum*, several authors described a clumped occurrence of individuals (e.g. NOTT 1986, SCHNEIDER 1997, HACHFELD 1999). It is not known, however, which parameters are responsible for the forming of clumps and how frequent these occur in the landscape. From the theoretical statements above, it is assumed that large clumps of *Harpagophytum* (thereafter referred to as patches) are associated with the availability of a similar habitat amount. In the following, the density and occurrence of patches of *Harpagophytum* in the different research areas is analysed.

Various studies on desert annuals have investigated the driving factors for patch forming, such as the small-scale patchiness of habitat conditions and the influence of shrubs on seedling emergence. It was found that demographic patterns in desert annuals may be species-specific with some species being more abundant beneath shrubs and others being more productive in open areas (e.g. SHMIDA & WITTHAKER 1981, TJELBÖRGER & KADMON 1995, 1997). For geophytic growth forms no such information is available. Only one study has been conducted on the natural growth pattern of *Harpagophytum* (STROHBACH 1999).

8.9.1 Resource distribution on the square kilometre

Based on the transect data, in the following the frequency and density of *Harpagophytum* is analysed using six density classes, i.e. 0, 1-4, 5-9, 10-20, 21-50, >50 individuals/transect (Fig. 29). To interpret the results, following definition is applied (see Chapter 8.2): A patch of *Harpagophytum* is defined as a quantity of >10 individuals/100*2m (quantity classes 10-20, 21-50, >50 individuals/transect). In contrast, a scattered occurrence of single *Harpagophytum* individuals resembles <10 individuals/100*2m (quantity classes 1-4, 5-9 individuals/transect).

Figure 29 indicates that on at least 40% of the transects of all four research areas no individuals of *Harpagophytum* occurred. A lack of individuals was in particular evident for the private farmland of South Africa (58.7%).



	NA private farmland	NA communal	ZA private farmland	ZA communal
>50 ind	1.3	5.9	1.3	1.3
21-50 ind	3.8	18.6	3.8	8.3
10-20 ind	8.1	9.9	8.1	12.2
5-9 ind	11.4	5.9	11.4	12.2
1-4 ind	24.9	12.0	24.9	22.3
0 ind	50.5	47.6	50.5	42.4

land use system & country

Fig. 29: Occurrence [%] of *Harpagophytum* classes on transects of private and communal land in Namibia (NA) and South Africa (ZA).

Private farmland of Namibia (630 transects, 33km²):

- The distribution of density classes is similar to that on private South African farmland.
- On half of the transects (50.5%) *Harpagophytum* was missing.
- On sites with *Harpagophytum*, plants typically grew with a spatially scattered pattern as on 24.9% of the transects only 1-4 individuals occurred.
- Patches were limited to 13.2% of the transects in comparison to almost three times the percentage in the Namibian communal areas. Similar to the communal areas in South Africa only on few transects (1.3%) more than 50 individuals were counted.

Communal areas of Namibia (334 transects, 17km²):

- On almost half of the sites (47.6%) *Harpagophytum* was missing.
- Single individuals (1-9 individuals/transect) of *Harpagophytum* occurred on the remaining transects.
- On more than one third of transects (34.5%) patches with >10 individuals occurred. Yet, patches with higher densities of 21-50 individuals/transect were less frequent (18.6%), and very dense patches with >50 individuals were only counted for few transects.

Private farmland of South Africa (670 transects, 35km²):

- A lack of *Harpagophytum* occurred most frequently (59.9%).
- Additionally on one fifth of the transects (20.4%) only 1-4 individuals occurred indicating a spatial pattern of predominantly none or scattered plants on 80% of the transects.
- Of the remaining transects 11.8% fell into the category of potential patches. The frequency of very high individual densities (>50 individuals) was lower than for the private Namibian farmland (1.1%).

Communal areas of South Africa (229 transects, 11km²):

- On over 60% of the transects none or 1-4 individuals were recorded.
- Significantly less patches with >10 individuals/transect were found in comparison to the communal area of Namibia, i.e. patches occurred on only one fifth (21.7%) of the transects.
- While in Namibian communal land most patches showed large individual numbers, in South Africa patches were less dense with 10-20 individuals per transect. More than 50 individuals were recorded for very few transects only (1.2%).

Concluding, patches of *Harpagophytum* defined as quantities of >10 individuals per 100*2m occur predominantly in the communal areas of Namibia, while for the other research areas these quantities were restricted to a maximum of one fifth of the transects of a square kilometre. On the majority of research sites quantities of >21 individuals occurred only on very few transects. The communal areas of Namibia form an exception as these densities are evident for one quarter of the transects. In most cases, individual densities of 1-4 plants/transect were found. From this it is assumed that *Harpagophytum* typically occurs in a scattered pattern with few individuals growing in near vicinity to each other. A lack of *Harpagophytum* was detected for 47-60% of the transects for all research areas. In particular on private farmland of both countries on more than two thirds of the transects *Harpagophytum* was missing. On South African private farmland, this occurred most frequent. In contrast, patches with >10 individuals were recorded twice to three times that often on transects on communal land.

8.9.2 Resource distribution on the transects

A more detailed understanding of the spatial pattern of *Harpagophytum* brings about the analysis within each square kilometre. Results of this analysis are presented in the following for both countries and land use systems separately. In Figure 30 (a-d) each column represents one square kilometre. The different quantity classes of *Harpagophytum* recorded on the transects of each square kilometre are given in percentage of occurrence:

Private farmland of Namibia (Fig. 30a)

Only on three (out of 33) square kilometres *Harpagophytum* was completely missing. Additionally, for 16 sites on more than half of the transects no individuals occurred. Patches were restricted to half of the research sites, (17 sites). Yet, these were occasional and limited to 1-2 transects per site. Only four sites (12%) showed dense patches with >50 individuals/transect. This sums up to a significantly lower percentage in comparison to the communal area of Namibia. Similarly, the number of sites for which

Harpagophytum was found on every transect was with two (out of 33) square kilometres significantly lower than for the communal areas of Namibia.

Communal areas of Namibia (Fig. 30b)

On one quarter (four out of 17) of sites documented in the communal areas of Namibia, no *Harpagophytum* plants occurred (Figure 29b). For another five sites (29%) a lack of *Harpagophytum* was detected on at least half of the transects. On the other transects single individuals grew scattered with a maximum of 1-4 individuals. Patches of *Harpagophytum* occurred on single transects of eight sites. Of these, six sites inhabited patches on more than half of the transects. Dense patches with >50 individuals were limited to 2-6 transects of these research sites. Only and three square kilometres inhabited individuals of *Harpagophytum* on every transects. These were also the sites with the highest overall number of individuals.

Private farmland of South Africa (Fig. 30c):

On the private farmland of South Africa, seven of a total of 35 square kilometres experienced a complete lack of *Harpagophytum* (Figure 29c). On 17 sites, individuals were restricted to half of the transects. For the majority of sites single individuals occurred with a scattered pattern on at least 70% of the transects. Patches of *Harpagophytum* (>10 individuals/transect) were recorded on single transects for 16 research sites. Only few sites (six sites) showed higher individual numbers with >50 individuals/transect for 1-2 transects. No sites were found on which *Harpagophytum* was recorded for all transects.

Communal areas of South Africa (Fig. 30d)

In the communal areas of South Africa, *Harpagophytum* was at least occasionally missing on all sites. On eight of 11 sites (73%) patches occurred, summing up to a higher percentage than in communal Namibian areas. Of these, only for two sites (in comparison to six sites in the Namibian communal areas) patches of the species were detected on half of the transects. Also, in comparison to the communal areas of Namibia the patches of the South African communal areas were less dense. I.e. only on one site two transects with >50 individuals occurred (in contrast to up to six transects in Namibia). Different to the findings in Namibia is also the fact that no sites showed individuals of *Harpagophytum* on every transect. Instead, at least on two transects of each site the species was missing.

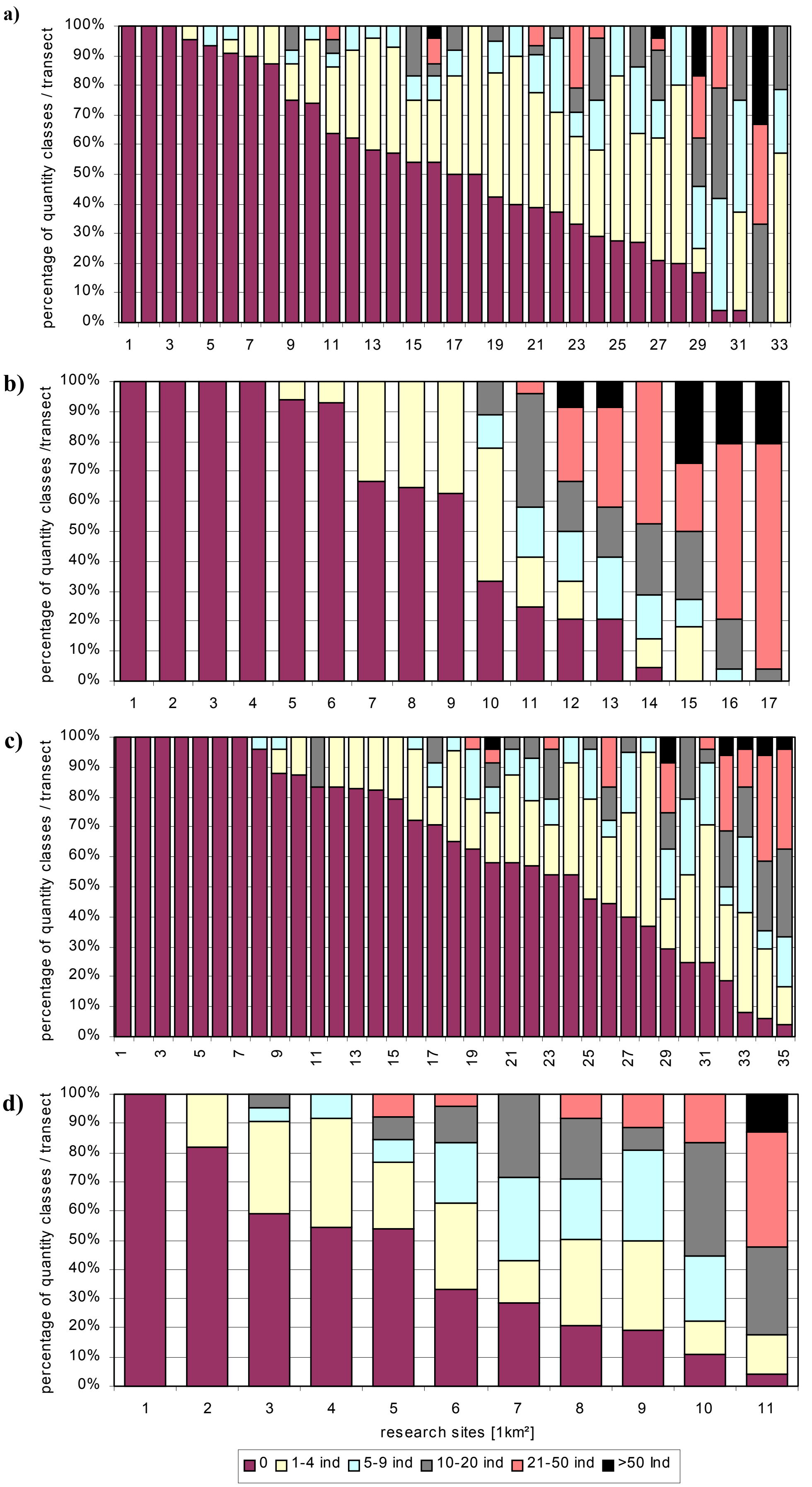


Fig. 30: Occurrence of *Harpagophytum* quantity classes on transects of 1km² sites on a) private farmland (33 sites), b) communal areas (17 sites) of Namibia and c) private farmland (35 sites), d) communal areas of South Africa (11 sites).

Two maps in Figure 31 and Figure 32 show the spatial dispersion of *Harpagophytum* on the square kilometre sites in the different districts and vegetation types of Namibia and South Africa. On the maps it is indicated whether the species on a research sites only occurs with a scattered distribution, whether also patches accompany these single occurrences or whether only a clumped pattern was found.

The maps emphasise that

- In Namibia, an increase in the abundance of patches occurs from south to north parallel to an increase in rainfall, but irrespective of the landownership. Highest abundance of patches was evident for the eastern part of the Otjozondjupa Region, where the Camelthorn Savanna reaches into the Okakarara area. In both, the Camelthorn Savanna and the Tree Savanna and Woodland highest frequency of patches occurs.
- In South Africa, no sites with a singular occurrence of patches were found, but an increase in patch abundance parallel to the rainfall gradient was also evident. In particular in the Kalahari Plains Thorn Bushveld, patches of *Harpagophytum* occurred.

8.9.3 Analysis of variance in the spatial distribution of *Harpagophytum*

It is tested with a Kruskall Wallis Test, if different densities of *Harpagophytum* show a tendency of variation between the research areas, habitat types, vegetation types, grass cover classes, different grazing intensities, and soil substrate types (Tab. 22). For this, the data set was divided into transects with patches (>10 individuals), with a scattered occurrence (1-9 individuals) and with a lack of *Harpagophytum* (0 individuals).

Patches of *Harpagophytum* (>10 individuals/transect):

Patch occurrence varies significantly between the research areas. Patches of *Harpagophytum* are restricted to specific habitat types, which proved to differ significantly with respect to their patch frequency. Patches occur predominantly on plain habitats, but may also develop on the dune base, in interdunes and Omuramba habitats (see Chapter 8.5). The development of patches of *Harpagophytum* is significantly related to the grazing intensity. In particular for the forming of dense patches the Kruskall-Wallis test showed a high significance. Also variations in the grass cover significantly account for differences in patch densities. While for Namibia, the test indicates that patch density and frequency is related to the vegetation type, for South Africa no such relationship was evident. The soil substrate is not a differentiating parameter for the density of patches of *Harpagophytum*.

Scattered occurrence of *Harpagophytum* (1-9 individuals/transect):

Patterns with single individuals occur to the same extent in the research areas. Similar to the patch frequencies, also single occurrences of *Harpagophytum* are significantly correlated to the habitat type. Yet, single individuals of *Harpagophytum* may occur on each of the sampled habitat types. The grazing intensity proved to be related to *Harpagophytum* densities (within 1-9 individuals/transect). While a scattered spatial pattern of *Harpagophytum* varies between the vegetation types, variations in the grass cover do not account for such differences.

Lack of *Harpagophytum* (0 individuals/transect):

None of the analysed variables can provide an explanation for the frequent lack of *Harpagophytum*. No specific habitat type, grazing intensity, vegetation or soil substrate type or grass cover values is related to a lack of *Harpagophytum*. Instead, *Harpagophytum* may or may not be missing in all of these.

Tab. 22: Kruskall-Wallis-Test on *Harpagophytum* densities (patches, single plants, no plants) and research area, habitat type, grazing intensity, vegetation type, soil substrate.

Variables	H (degrees of freedom, sample size)	p
Patches		
Research area	H (3, N= 310) = 22.36473	p =.0001***
Habitat type	H (3, N= 310) = 9.400095	p =.0244**
Grazing intensity	H (4, N= 304) = 16.38242	p =.0026***
Grass cover	H (9, N= 157) = 20.32488	p =.0160**
Vegetation types NA	H (4, N= 187) = 23.04011	p =.0001***
Vegetation types ZA	H (2, N= 115) = 1.632708	p =.4420
Soil substrate	H (1, N= 310) = 2.511783	p =.1130
Single individuals		
Research area	H (3, N= 564) = .3554343	p =.9493
Habitat type	H (6, N= 560) = 19.25204	p =.0038***
Grazing intensity	H (4, N= 529) = 11.30404	p =.0234**
Grass cover	H (8, N= 258) = 9.308989	p =.3169
Vegetation types NA	H (5, N= 284) = 15.27474	p =.0093***
Vegetation types ZA	H (3, N= 255) = 10.78160	p =.0130**
Soil substrate	H (1, N= 562) = 1.156402	p =.2822
Lack of plants		
Research area	H (3, N= 968) = 0.000000	p =1.000
Habitat type	H (6, N= 960) = 0.000000	p =1.000
Grazing intensity	H (4, N= 895) = 0.000000	p =1.000
Grass cover	H (9, N= 417) = 0.000000	p =1.000
Vegetation types NA	H (6, N= 473) = 0.000000	p =1.000
Vegetation types ZA	H (2, N= 371) = 0.000000	p =1.000
Soil substrate	H (2, N= 964) = 0.000000	p =1.000
***= highly significant (p<0.01), **= significant (0.05>p>0.01)		

8.9.4 Summary and conclusions on the spatial distribution of *Harpagophytum*

The understanding of the spatial distribution patterns of *Harpagophytum* is important not only from the pure scientific point of view but also as the distribution pattern indicates the resource available for harvesting activities. While it can be assumed that dense aggregations of individuals give a greater incentive to harvesting (as least time consuming), a scattered distribution may not attract utilisation. Areas with single *Harpagophytum* plants occurring widely spaced may therefore be understood as natural conservation areas of the resource.

For all research areas and the majority of research sites, a spatial distribution pattern of *Harpagophytum* was identified which comprises a combination of

(a) Patches (>10 individuals/transect)

(b) Scattered occurrence of single individuals (1-10 individuals/transect)

(c) Combination of single individuals and patches

(d) Lack of individuals of *Harpagophytum*

Complementary to this spatial mosaic pattern is the finding that a) for some research sites in the communal areas of Namibia individuals of *Harpagophytum* may occur on all transects, and that b) a lack of *Harpagophytum* may be evident for all research sites, in particular for the communal areas of Namibia and the private farmland of South Africa. For all research areas, many square kilometres exhibited a lack of plants on more than half of the transects.

Large resources of *Harpagophytum* occurring as clumps or patches of individuals are available on 50% of the research sites irrespective of the country and land ownership. Yet, on private farmland patches occur only occasionally, i.e. on less than 10% of the sites patches were found on more than half of the transects/km². For Namibian communal areas patch abundance was considerably higher and *Harpagophytum* occurred on more than one third of the sites. In particular in the Otjozondjupa Region of Namibia patches were most frequent.

Not only patch frequency but also patch density showed to vary with respect to land use. Densities of >21 individuals/transect were recorded more frequently on communal sites, where often over 30% of the transects/km² showed such patch densities. This is especially true for the communal area of Namibia. Only the frequency and density of patches, but not of single individuals of *Harpagophytum* varies significantly between the research areas. The abundance of single plant distribution patterns is similar for both countries and types of land ownership.

The habitat type proved to be of importance for both, the development of patches and of a scattered distribution pattern. While plains form the predominant habitat type for patch development, roadsides, dune slopes and dune crest only seem to support the development of a scattered growth of individuals of *Harpagophytum*.

While only in Namibia the abundance of patches is related to the vegetation type, a scattered dispersion pattern of *Harpagophytum* is closely related to the vegetation type in both countries. It could be shown that both broad soil substrate types of the soil substrate is not of importance for the occurrence of either distribution pattern of *Harpagophytum*.

A lack of *Harpagophytum* is not related to any specific environmental condition, but may be evident irrespective of the type of land use, habitat, vegetation, or soil substrate type. For an understanding of the lack of *Harpagophytum* other than the studied parameters have to be analysed. More information is needed on the precipitation and temperature patterns on the research sites, because a missing of *Harpagophytum* in one year does not necessarily account for a general lack of the plant in the area. Instead, this may be due to low rainfall amounts imbibing the resprouting of the geophytic plant. Also, more information is needed on the dispersal (see Chapter 8.10.2), regeneration and competitiveness of *Harpagophytum* as these have a great impact on the development of clumped distributions of plant species.

Harpagophytum quantities recorded in this study are comparable with other authors: LELOUP (1984) reports *Harpagophytum* densities of 263 plants per 200m² on communal land in Botswana. On harvested sites he found lower numbers with 40 and 54 plants. Irrespective of the impact of harvesting, these quantities resemble patches as defined for this study. Yet, as sampling by LELOUP was not random, but placed in high resource harvesting areas, and as sample design was different, no direct comparisons are possible. While the quadrate plots of LELOUP may have covered a patch completely, the linear transects only cut through a patch. In Namibia, NOTT (1986) found a typical scattered pattern of *Harpagophytum* with 5 plants/ha. Locally she recorded patches with much higher quantities with a maximum of 1200 plants/ha. STROHBACH (1999) recorded 1-20 plants/100m² in communal harvesting areas in the Omaheke area, Namibia. No data is available for South Africa.

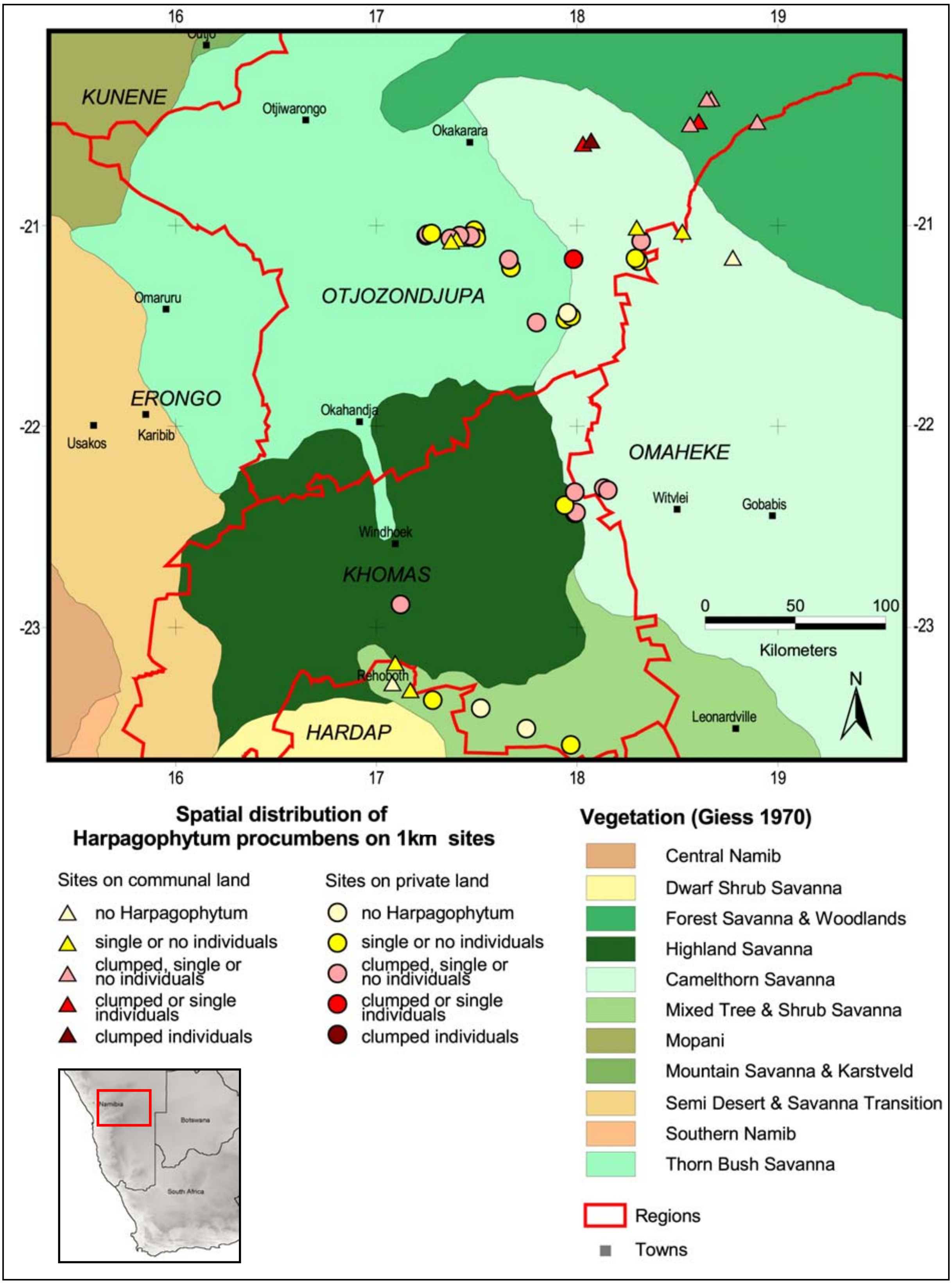


Fig. 31: Spatial distribution of *Harpagophytum* on 1 km² sites on communal and private land of Namibia. Map Source: GIESS (1970), AGRO-ECOLOGICAL ZONING PROGRAMME (2001).

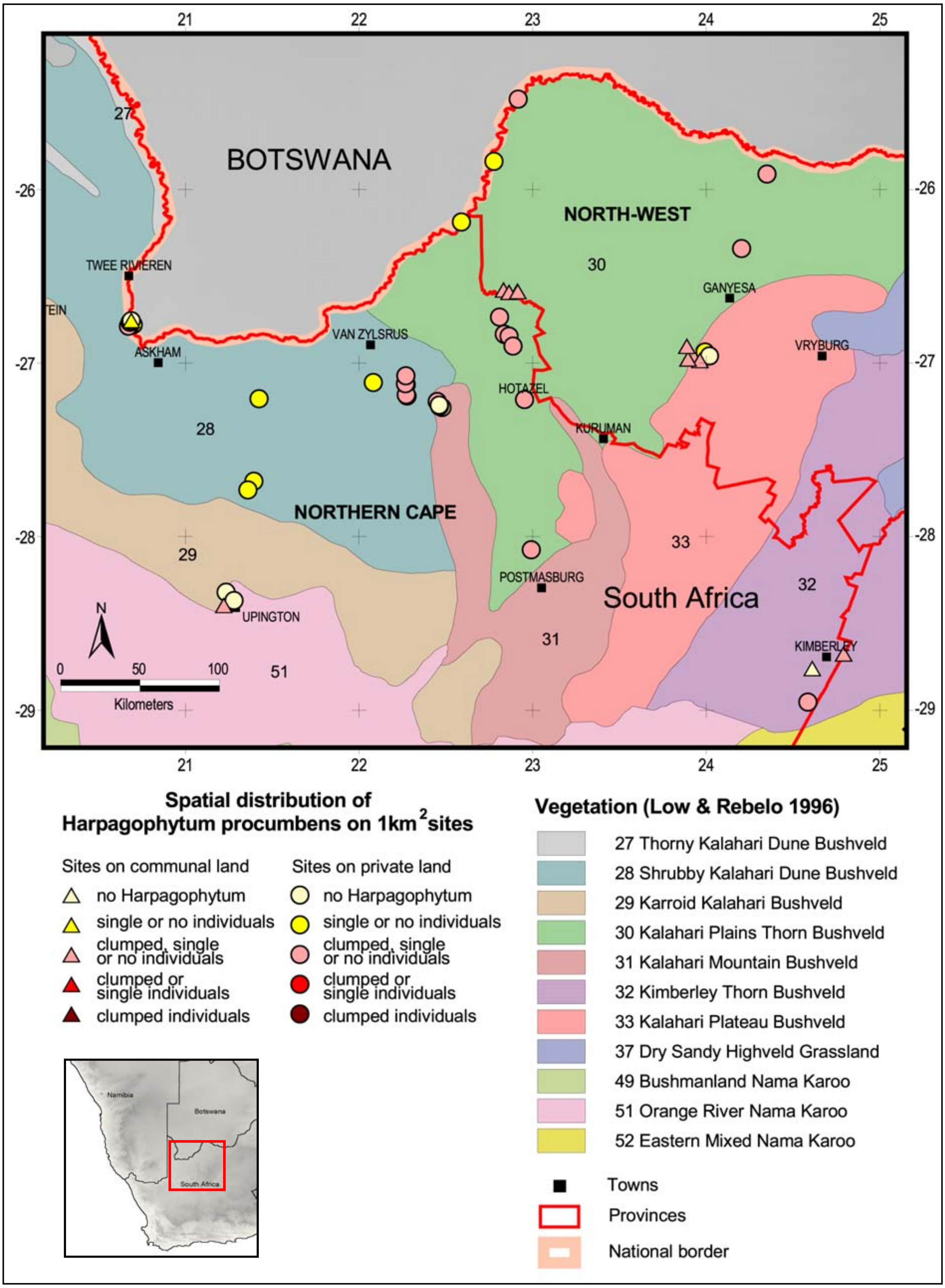


Fig. 32: Spatial distribution of *Harpagophytum* on 1 km² sites on communal and private land of South Africa. Map Source: LOW & REBELO (1996).

8.10 Reproductive effort of *Harpagophytum*

An organism is defined as being the fittest of a given population, if it produces the greatest number of descendants. However, in practise the term fitness is often not restricted to single individuals but to a typical individual or type, respectively (BEGON, HARPER & TOWNSEND 1991). The term fitness is a relative one in such that the number of flowers, fruits or seeds produced by a plant individual cannot be used as an absolute measure for its fitness. Fitness can only be determined in relation to other individuals or populations. Therefore, in this chapter not the term fitness, but the term reproductive effort is used when analysing the quantity of flowers, fruits and seeds of *Harpagophytum*. Here, the term reproductive effort is understood as the effort that results in the production of a specific number of flowers and/or fruits and not in the sense of HARPER & ODGEN (1970) who use the concept of the reproductive effort as relative parameter of the reproductive strategy, meaning the energy and biomass distribution within an individual in favour of reproduction.

The flower quantity as well as the fruit and seed quantity of individuals but also of populations can provide information on the reproductive effort of a species. Whereas the production of flowers only marks the first phase of the reproductive process of an individual, the development of fruits and seeds therein indicates a success of pollination. Yet, a successful reproduction by seeds cannot be defined as a mere result of seed production, but is inseparable also from seed germination and the subsequent establishment of seedlings and juvenile plant individuals (URBANSKA 1992). Irrespective of the fact that fruits may develop, seeds may or may not be vital, i.e. they may have or lack a developed embryo.

In the following, counts of flowers and fruits of *Harpagophytum* on the research sites were used to deduce information on the reproductive effort of the species. Calculations of the potential number of seeds produced by the fruits shall give an estimation of variation in seed bank contribution of *Harpagophytum*.

8.10.1 Flowers

The flowering intensity of an individual can be regarded as a first hint towards its reproductive potential. Geophytes such as *Harpagophytum*, which have a short growth season, are assumed to refrain from flowering until a sufficient large content in utilisable carbon and water content is produced (VON WILLERT et al. 1992). Unfavourable weather conditions may interrupt a plant’s growth cycle and force the plant to abandon the leaves and possibly also the flowers prematurely. In general, flowering time and intensity are influenced by environmental factors as well as by factors inherent to the single individual.

8.10.1.1 Background information on flowers of *Harpagophytum*

The morphology of the flowers of *Harpagophytum* is described in detail in IHLENDFELDT & HARTMANN (1970). Their ecology including flowering time and duration, flowering intensity as well as pollination and possible predation form part of several studies (e.g. BURGHOUTS 1985, HULZEBOS 1987, LELOUP 1984, NOTT 1986).

Flower morphology

Flowers of *Harpagophytum* are solitary, auxiliary on pedicles of 1cm length. The corolla is approximately 6cm long, narrowly cylindrical for about 5mm, then inflated and trumped shaped with a pink to purple colour, which may become yellow inside the tube (STROHBACH-FRICKE 1995). Due to a reduction of a dichasium, typically only one flower occurs per node (IHLENFELDT 1967). Only from the third node onwards a sprout may produce flowering buds.

IHLENFELDT & HARTMANN (1970) state a mean size of the tubulaire of 63mm. They found that the colour of the flowers stays constant within single populations and single individuals. Personal observations (Okakarara region 2001) revealed single white flowering individuals within populations with normal coloured flowers.

Flowering season

Different observations have been made concerning the flowering season of *Harpagophytum*. In Botswana, in the areas of Kgokong and Khakea, flowering time is described to be restricted to December and January (LELOUP 1984), whereas for Namibia NOTT (1986) states a flowering period from December to April. For the North West Province of South Africa, a peak in flowering was recorded during February, which is the highest rainfall month in the rainfall season (VAN DER VYVER 2002).

The production of single flower buds starts 10-15 days after the shooting of the sprouts (BETTI no date) and lasts over the entire vegetation period. However, while the number of plants that developed buds increased considerably during the rainy season, a reduction of flowering plants was found towards the end of the vegetation period in Botswana (HULZEBOS 1987).

Only plants of a certain age are reproductive, which can be determined by the size of the main tuber (LELOUP 1984). HULZEBOS (1987) found a flowering time of 24-36 hours for single flowers of *Harpagophytum* plants in Botswana, with the flowers opening in the evening and closing two days later.

Pollination

No information is currently available on the pollination of *Harpagophytum*. HULZEBOS (1987) states that the species is likely to be pollinated by bees, but self-pollination might also be possible (BURGHOUTS 1985). The author found a remarkable predation of stamen and style of 80% in the Kgokong and Khakea area of Botswana, which hinders pollination.

In general, a union of perianth parts, for instance the calyx-tube in *Harpagophytum*, is characteristic to flowers pollinated by long-tongued insects (PROCTOR, YEO & LACK 1996). These could be a variety of insect guilds such as long-tongued flies, long-tongued butterflies and long-tongued bees. However, in trumpet- and bell-shaped flowers such as those of *Harpagophytum*, insects have typically to crawl inside to feed and to bring about pollination. The emphasis is here on the adaptation to the body form of the pollinator rather than simply to the length of its mouth parts (PROCTOR, YEO & LACK 1996).

Two extrafloral nectaries occur in the axillaries of the prophylls of each flower (IHLENFELDT & HARTMANN 1970). Each of the anthers of the four introrse stamens, which are inserted pair-wise, has 1661 +/- 477 pollen. Fruit-set is not inhibited by an inability of pollen to germinate (HULZEBOS 1987).

8.10.1.2 Flowering intensity

Table 23 below compares total number of sites with the number of sites for which flowering plants of *Harpagophytum* were recorded.. With exception of the private farmland in Namibia, in all other research areas on 70-80% of the sites inhabited by *Harpagophytum* at least some individuals were flowering. The flowering intensity of *Harpagophytum* that is reflected in the data set depends on the time of documentation within the vegetation period. The low flower frequency on private Namibian farmland can be interpreted as a result of the late date of documentation within the rainy season in comparison to the other sites which were recorded in April and May 2001. However, this finding stands in contrast to the findings of HULZEBOS (1987) and BETTI (no date), who claim the production of flowers to last over the entire vegetation period.

Tab. 23: Number and percentage of research sites in the four research areas with plants and flowering plants of *Harpagophytum* in Namibia and South Africa.

Research sites	**Namibia**		**South Africa**	
	Private farmland	Communal areas	Private farmland	Communal areas
Total number of 1km² sites	33	17	35	11
Number of 1km² sites with plants	30	13	28	10
Number of 1km² sites with flowering plants	6	10	20	8
% sites with flowering plants of total site number	18.2%	58.8%	57.1%	72.7%
% sites with flowering plants of sites with plants	20.0%	76.9%	71.4%	80.0%

According to HULZEBOS (1987) and BETTI (no date), once individuals of *Harpagophytum* have produced new shoots at the beginning of the rainy season, the majority of them continuously produce flowers over the entire vegetation period. With regard to this observation, the relationship between total plant and total flower numbers counted on the transects of a research site, represents a first approach towards the reproductive capability of *Harpagophytum*. Limitations to this approach are related to the individuals chosen for the study. Firstly, some may still have been immature, have not yet reached the reproductive phase and hence did not produce any flowers at the stage of observation. Secondly, in some areas the flowering season may have started before the date of documentation and hence the fruit-set had partly started already. To overcome this second limitation, the number of young fruits which were documented parallel to the flowers were added to the flower quantities. The occurrence of young fruits indicates a successful reproduction of *Harpagophytum* with a successful pollination of flowers before the date of documentation.

With exception of the communal areas of Namibia, total flower quantity was between none to approximately 150 flowers/km², while total plant numbers reached up to 600 individuals/km². On sites with larger quantities of *Harpagophytu*m, not necessarily high quantities of flowering buds were found. For the communal areas of Namibia, many individuals were recorded which were flowering intensively but did not show the development of any fruits at the time of observation. For instance, in the Okakarara Region up to 7500 flowers/km² and over 1000 individuals/km² were counted in the communal areas.

Tab. 24: Spearman rank order correlation (r_s) of the number of *Harpagophytum* plants and the flower quantity and the flower plus young fruit quantity on 1km² in Namibia and South Africa.

Spearman rank order correlation	Plant and flower quantity				Plant and flower+ young fruit quantity			
	N	r_s	t(N-2)	p-level	N	r_s	t(N-2)	p-level
Namibia								
Private farmland	30	0.1869	1.0065	0.3228	30	0.0378	0.2003	0.8427
Communal areas	13	0.9392	9.0751	0.0000***	13	0.9614	11.5942	0.0000***
South Africa								
Private farmland	28	0.3891	2.1540	0.0407**	28	0.5069	2.9981	0.0059***
Communal areas	10	0.6173	2.2195	0.0572	10	0.7768	3.4885	0.0082***
***= highly significant (p<0.01%), **= significant (0.01<p<0.05)								

The results of the Spearman rank order correlation between the plant and flower quantity show that for the private farmland of Namibia and the communal areas of South Africa no correlation exists between total plant number and flowering intensity (left part of Tab. 24) indicating that flowering intensity may be low irrespective of the number of *Harpagophytum* plants found. In contrast, a very strong (high r_s value) and highly significant positive correlation is evident for the communal areas of Namibia. Also for the private South African farmland a significant positive correlation was found. This is however not very strong.

The results of the Spearman rank order correlation between the plant and the flower/young fruit quantity (right part of Tab. 24) provides additional information on the total reproductive effort evident on the research sites. Except for the private Namibian farmland, a relationship between flower/young fruit quantities and plant number exists for all research areas. In particular for both communal areas this relationship is strong.

8.10.1.3 Flowering intensity of single individuals

For two research areas, i.e. the communal areas of Namibia (the Okakarara Region) and the private farmland of South Africa, detailed studies were carried out with respect to the flowering intensities of single plant individuals (Tab. 25).

Namibia

On seven research sites (out of eleven) located in the Okakarara Region of Namibia flowering individuals of *Harpagophytum* were documented:

- A maximum of 717 plants and a minimum of 12 plants were found flowering on the transects of one square kilometre.
- Flowering frequency was 3-69%.
- Highest percentage of flowering individuals of *Harpagophytum* occurred on sites no. 58 and no. 59, where plants grew in dense patches with >21 individuals/100*2m.
- The documented populations were mostly composed of large individuals (shoots larger than 10cm in diameter).

Three main factors are considered to be potentially responsible for the explanation of the very high flowering frequency: (a) the exceptional good rainfall has triggered a high reproductive activity of *Harpagophytum* during the observation year. The very high flower quantities may reflect that all sites were documented within two weeks in March 2001 under very good rainfall conditions. (b) the documentation was carried out in the main vegetation period before the start of the fruit-set when plants were still in the main flowering period. (c) the population is characterised by a high reproductive activity which is not necessarily dependent on exceptional rainfall events.

Tab. 25: Number and percentage of flowering plants in Namibian communal areas (Okakarara Region) and South African private farmland.

Site No.	Flowering plants	Total no. plants	Flowering plants [%]
Communal Okakarara area Namibia			
58	317	885	36%
59	717	1035	69%
60	72	672	11%
61	28	369	8%
62	21	376	6%
63	12	159	8%
64	13	493	3%
Total	1180*	3989	30%
Private farmland South Africa			
79	3	6	50%
80	0	6	0%
81	2	33	6%
82	3	63	5%
83	9	133	7%
84	26	132	20%
90	2	257	1%
91	48	323	15%
95	0	122	0%
96	0	9	0%
98	0	52	0%
Total	93	2775	3%
*= flower quantity not counted for all flowering plants			

South Africa

On the private farmland of South Africa on a total of eleven research sites detailed data on the flowering intensity of single individuals of *Harpagophytum* were assessed (Tab. 25):

- On one quarter of the sites no flowering plants were found.
- On sites with *Harpagophytum*, between 1-50%, but predominantly <10% of the plants were flowering.

- Not only total plant numbers but also flowering intensity was lower than in Namibian communal areas. No more than 50 flowering individuals/km² were recorded in contrast to Namibia, where >700 individuals were in flower.
- Similar to the Namibian communal areas mostly large plants with large shoots of >10cm in diameter occurred

From this, it is concluded that on private South African farmland the individuals of *Harpagophytum* were in comparatively worse condition. Possible explanations might be (a) the rainfall conditions. Yet, the sites were documented in March of this year (2002), a year with very good rainfall conditions in southern Africa. (b) the flowering period was already over and the fruit-set had started. (c) the reproductive effort of the documented individuals and populations of *Harpagophytum* was comparatively lower than in the Okakarara Region of Namibia.

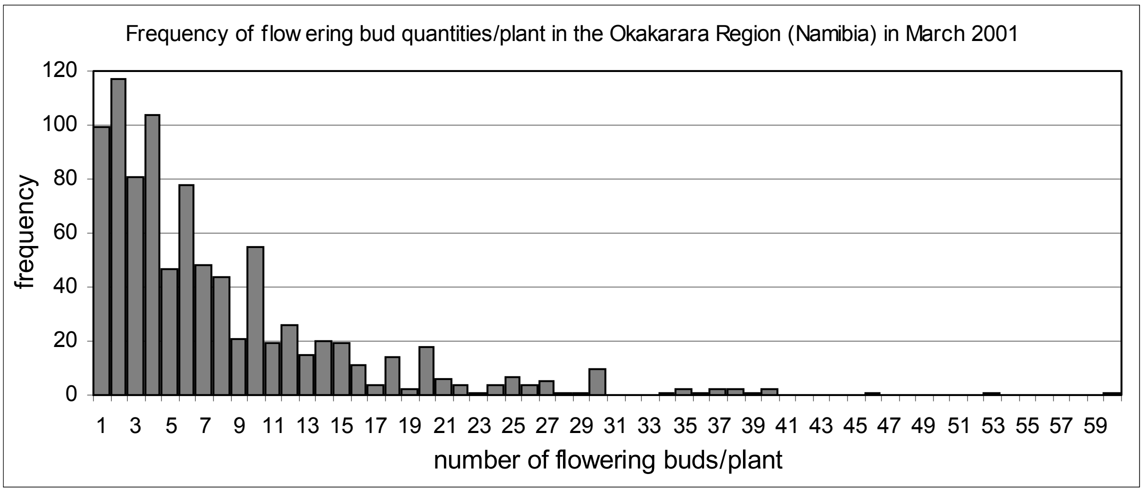


Fig. 33: Frequency of flowering bud quantities per plant. With n=899 flowering plants documented on seven square kilometres in the Okakarara Region (communal area), Namibia.

On the seven research sites documented in the communal Okakarara Region of Namibia (Fig. 33), on 899 plants a total of 6969 flowers were counted. Typically, between 1-10 flowers were produced on a plant with a maximum of 60 flowers. The mean was at 7.8 flowers/plant.

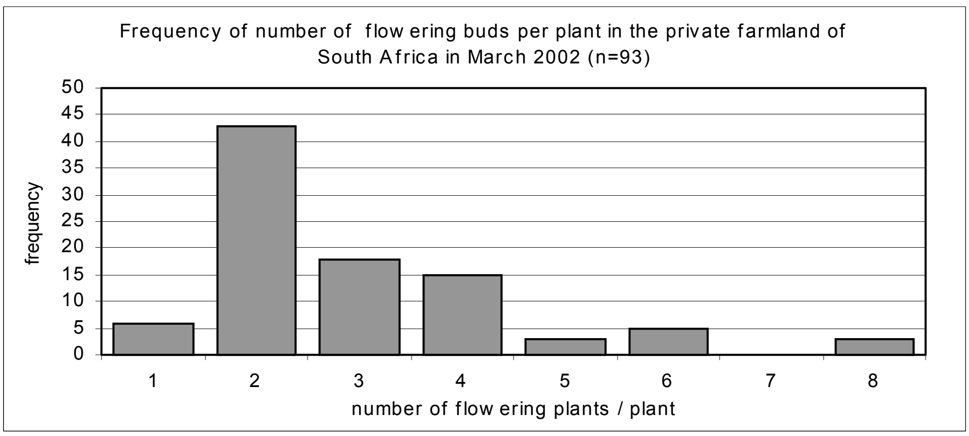


Fig. 34: Frequency of flowering bud quantities per plant. With n=93 flowering plants documented on eleven square kilometres in the private farmland of South Africa.

On private South African farmland, a total of only 275 flowers on 93 plants were recorded (Fig. 34). The distribution and quantity of flower quantities per plant was limited in comparison to the Namibian data set. Only between 1-8 flowers/plant were counted with a maximum of 8 flowers/plant and a mean of 2.9 flowers/plant. Considering that similar to Namibia most individuals had a size of >10cm in diameter, these were not very reproductive.

No data is available from literature concerning the flower quantities of *Harpagophytum.* Therefore, no comparison of my data on flower quantities with other research results is possible. However, comparing both research areas with respect to the flowering intensity of single individuals supports the considerations on the underlying reasons of the different flowering intensities of *Harpagophytum*. The populations of *Harpagophytum* documented in the Okakarara Region of Namibia seem to have a greater reproductive effort and potential than the *Harpagophytum* plants in the private farmland of South Africa.

8.10.1.4 Flowering intensity of *Harpagophytum* in various vegetation types

Flowering intensity of *Harpagophytum* differs between the vegetation types. This is primarily a consequence of variations in individual numbers, but also the condition of the individuals and of the populations may be responsible. Differences may also occur depending on the condition of the individuals and of the populations. In the following, *Harpagophytum* flowering intensity of was analysed for the different vegetation types of both countries (Figure 33, 34).

Namibia

In Namibia, six vegetation types were sampled in the study (Chapter 8.4). On private farmland of Namibia the Thornbush Savanna forms the best represented vegetation type with a sample size of 18 square kilometres. Yet, no flowering individuals occurred on any of the research sites (Fig. 35). Also the Highland Savanna and Camelthorn Savanna were characterised by a lack of flowering plants at the time of observation. Only in the Mixed Tree and Shrub Savanna (southern Kalahari dune areas), characterised by low annual precipitation amounts) occasionally flowering individuals were recorded. Flower numbers, however, only sum up to a maximum density of 1 flower/km².

In the communal areas of Namibia, five vegetation types were sampled of which only on three types more than two square kilometres were documented. Thus, results of flowering intensities/km² in the Mopane Savanna and the Thornbush Savanna can not be interpreted, but only indicate a lack of flowering plants at the time of documentation. Highest flowering intensity was recorded for the Camelthorn Savanna where on half of the sites (25-75% of the data) between 1-2000 flowers/km² were counted. This is a significantly higher quantity than on the private farmland. Significantly fewer individuals of *Harpagophytum* were flowering in the mixed Tree and Shrub Savanna. Yet, total flower numbers were higher than on private farmland of this vegetation type. In the Tree Savanna and Woodland, where very dense patches of *Harpagophytum* occurred, the majority of plants were not in the reproductive stage.

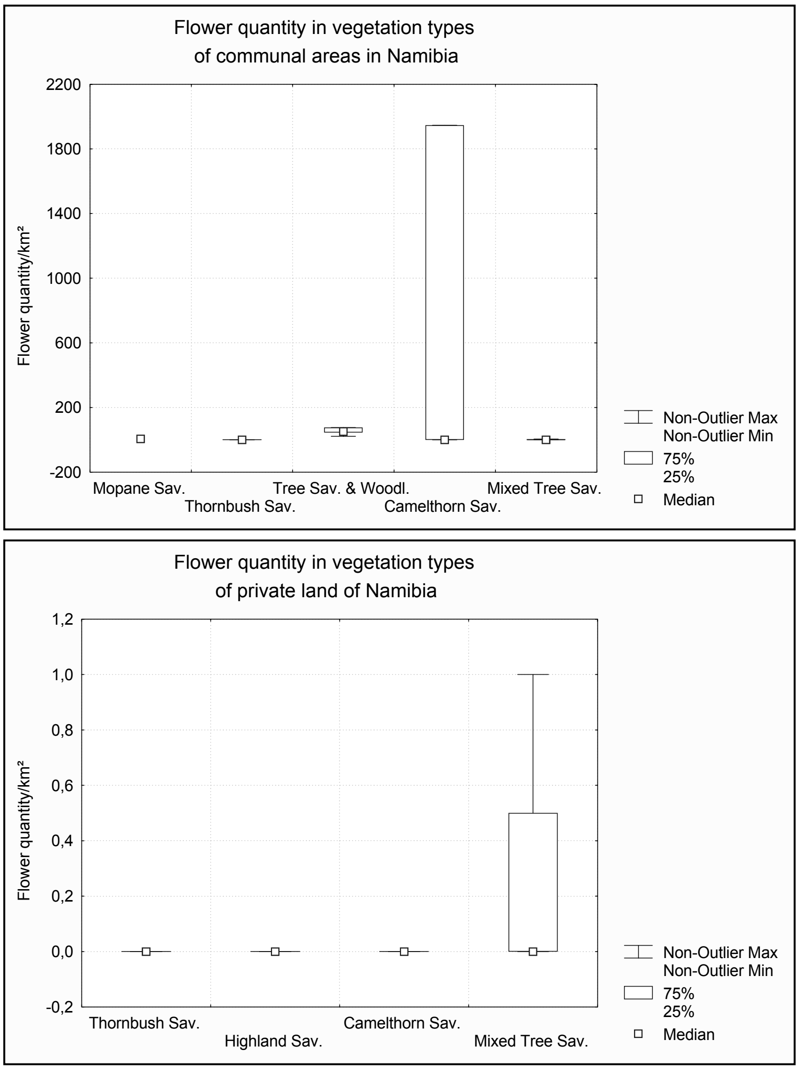


Fig. 35: Box-Whisker plots of the flower quantity/km² in vegetation types in private and communal land of Namibia.

South Africa

Six vegetation types of South Africa were sampled (Chapter 8.4.2). Of these, on private farmland, only in the Shrubby Kalahari Dune Bushveld (14 sites), the Kalahari Plains Thorn Bushveld (12 sites), and the Kalahari Mountain Bushveld (4 sites), more than two sites were assessed. In the latter, only on one site *Harpagophytum* occurred contributing to the analyses shown in Figure 36. For this site, a dense patch with many flowering individuals of *Harpagophytum* and a total of 81 flowers was found. Higher flowering intensity occurred in the Shrubby Kalahari Dune Bushveld, irrespective of the fact that the majority of sites exhibited a low resource of *Harpagophytum*. In the Kalahari Plains Thorn Bushveld higher numbers of *Harpagophytum* individuals were counted, but flowering intensity was limited. Half of the sites showed flower quantities of 0-11 flowers/km². On the research site in the Kimberley Thorn Bushveld only four flowers were counted on a total of 257 plants.

In the communal areas of South Africa, only the Kalahari Plains Thorn Bushveld (5 sites) is covered by more than two research sites. Half of these showed a flowering intensity of 8-34 flowers/km², i.e. higher quantities than on private farmland. Also in contrast, individuals on the communal site in the Shrubby Kalahari Dune Bushveld were not flowering, but in the Kimberley Thorn Bushveld some flowering plants were recorded.

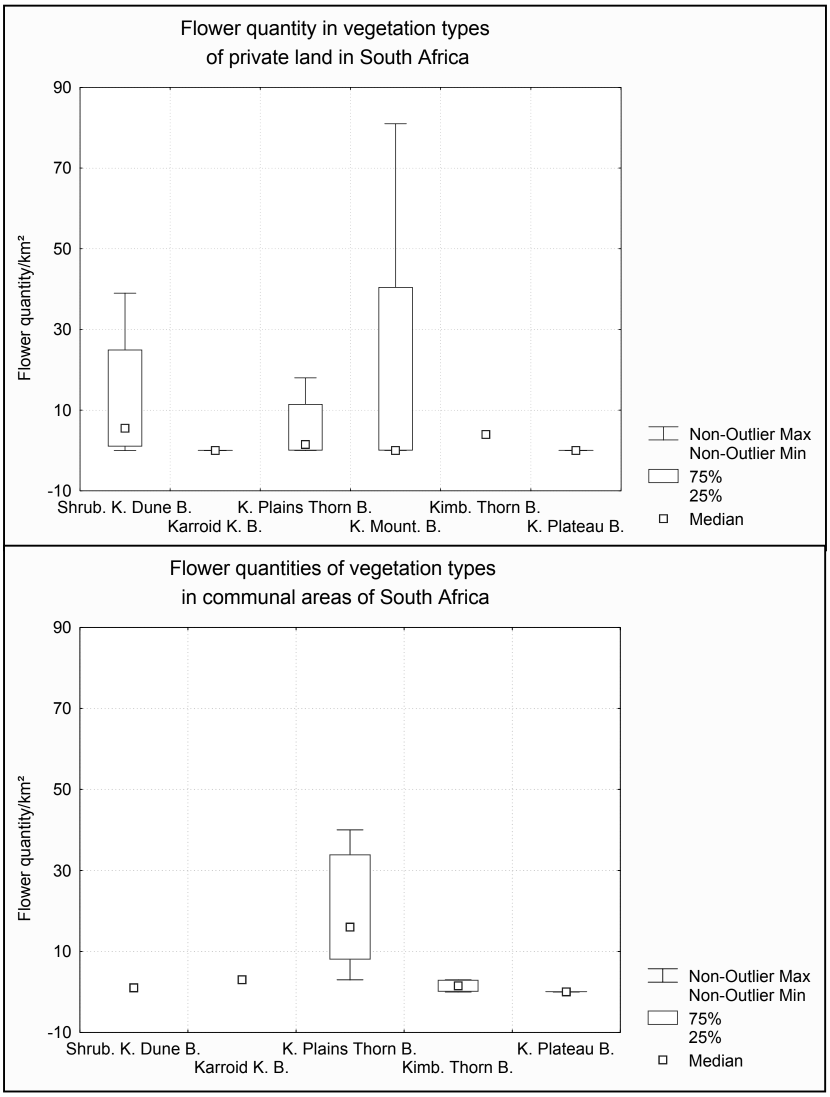


Fig. 36: Box-Whisker plots of the flower quantity/km² in vegetation types in private and communal land of South Africa.

Summarizing, it can be concluded that

- On private farmland of Namibia, a low to missing flower frequency of *Harpagophytum* was evident for all vegetation types.
- In the communal areas of the Camelthorn Savanna a significantly larger number of flowers occurred than in the Mixed Tree and Shrub Savanna or in the Tree Savanna and Woodland. These findings are irrespective of the general occurrence and density of the plant in the different vegetation types.
- Similar high flowering quantities do no occur in South Africa.

- On private farmland of South Africa highest flower quantities of *Harpagophytum* were found in the Shrubby Kalahari Dune Bushveld.
- Highest flower quantities of *Harpagophytum* were found in the communal areas of the Kalahari Plains Thorn Bushveld.

8.10.1.5 Impact of plant size on flowering intensity

The finding of IHLENFELDT & HARTMANN (1970) that solitary flowers start to develop from the third node of a plant's shoot onwards, indicates a correlation between the above ground plant size and the flowering intensity. Based on this observation, plants with above ground organs smaller than 10cm in diameter should have none to very few shoots with more than three nodes. It is expected that these plants only seldom produce reproductive organs. While the flowering of *Harpagophytum* might depend on the size of the shoots, plant diameter cannot be used to determine the age of the plants, and thus, no direct interpretation with respect to the age of the plants is possible by this approach.

The Spearman rank order correlation was used to test the relationship between the plant size and the flowering intensity of *Harpagophytum* (Tab. 26).

Tab 26: Spearman rank order correlation (r_s, 2-sided) of small and large *Harpagophytum* plants with flower number/transect, flower and young fruit number/transect.

Spearman rank order correlation	**Quantity small plants & quantity flowers**				**Quantity large plants & quantity flowers**			
	N	**R**	**t(N-2)**	**p-level**	**N**	**R**	**t(N-2)**	**p-level**
Namibia								
Private farmland	231	0.1209	1.8431	0.0666	231	0.1205	1.8370	0.0675
Communal areas	155	0.1414	1.7664	0.0793	155	0.7010	12.1601	0.0000***
South Africa								
Private farmland	126	0.3962	4.8048	0.0000***	125	0.5576	7.4493	0.0000***
Communal areas	426	0.4148	9.3864	0.0000***	426	0.4551	10.5233	0.0000***
Spearman rank order correlation	**Quantity small plants & flower + young fruits**				**Quantity large plants & flower + young fruits**			
Namibia								
Private farmland	231	0.0124	0.1878	0.8512	231	0.3582	5.8059	0.0000***
Communal areas	155	0.1391	1.7369	0.0844	155	0.7402	13.6160	0.0000***
South Africa								
Private farmland	125	0.3968	4.7948	0.0000***	125	0.7131	11.2811	0.0000***
Communal areas	426	0.4102	9.2622	0.0000***	426	0.6285	16.6368	0.0000***
***= highly significant (p<0.01%)								

Results of the upper part of Table 26 indicate the following:

- A correlation between the quantity of small plants (<10cm in diameter) and the number of flowers counted on the transects only exists for the research sites in South Africa. Yet, the highly significant correlation is not very strong.
- The relationship between large plants of *Harpagophytum* and flower quantities on the transects is highly significant for South African communal and commercial sites.
- Large plants are also significantly related to flower quantity for Namibian communal areas, for which a strong relationship is evident. There, on most sites large plants dominated the populations. This finding supports the observation of IHLENFELDT & HARTMANN (1970) that only plants with a certain shoot length may produce flowers.
- In some areas, individuals may have started to flower earlier and thus fruit-set may have already been initiated at the time of observation. To overcome this time-related weakness, the number of young fruits was added to the number of flowers and a Spearman rank order correlation was calculated (lower part of Tab. 26).

The correlation after an amalgamation of flowers and immature fruits shows that (lower part of Tab. 26):

- The pattern of correlations between small plants and flower frequency is similar to the correlation with only flower quantities.
- The relationship between large plants and the frequency of reproductive organs proves to be highly significant and positive for all research areas. This supports the observation that plants need to reach a minimum size in order to produce flowers.

8.10.1.6 Summary on the flowering of *Harpagophytum*

On the majority of sites in both, communally and privately owned land of South Africa, individuals of *Harpagophytum* were in the reproductive phase. Yet, a relationship between plant numbers and flower quantities is only evident for the communal areas of Namibia. When both, the number of flowers and young fruits are considered, for all research areas but the private Namibian farmland a highly significant positive correlation was evident. Especially for Namibia, this relationship proved to be very strong.

Detailed counts of the flowering intensity of single plant individuals in two research areas (communal Okakarara Region Namibia and private farmland South Africa) indicate a strongly varying flower frequency which is probably due to variations in precipitation amounts, in the age composition of the plant populations and/or in the fitness of the individuals. Striking was the much higher frequency of flowering plants and flowering intensity of single plant individuals in the Okakarara Region in comparison to the private farmland of South Africa. As for both research areas predominantly *Harpagophytum* individuals occurred with a large shoot growth (>10cm in diameter) indicating a principal capacity to produce flowers, the greater flowering frequency and intensity in the Okakarara Region is interpreted to reflect a greater reproductive effort of the populations in comparison to the South African sites.

Flowering intensity of *Harpagophytum* may vary greatly between the vegetation types. Whereas in Namibia, the low flower quantities of the private farmland account for the lack of a flower-rich vegetation type, in the communal areas, the Camelthorn Savanna showed a very high flower abundance of

Harpagophytum. As the Camelthorn Savanna and the Tree Savanna and Woodland, where less flowers were recorded – form the vegetation matrix of the communal parts of the Okakarara Region it can be assumed that here flower intensity is dependent on the composition of the surrounding vegetation. For South Africa, highest flowering intensity was recorded for the privately owned land of the Shrubby Kalahari Dune Bushveld, whereas the Kalahari Plains Thorn Bushveld was the most flower-rich vegetation type of the communal areas.

When combining the quantities of flowers and young fruits, the Spearman rank order correlation proved for the four research areas a highly significant relationship between the above-ground plant size of *Harpagophytum* and the flowering intensity. In particular for the communal areas of Namibia this relationship was very strong. As individuals of *Harpagophytum* only start to develop flowers once they have reached a shoot length of more than three nodes and internodes (IHLENFELDT & HARTMANN 1970), the differentiation into small plants (<10cm in diameter) and large plants (>10cm in diameter) proved to be accurate enough to detect a general correlation between both parameters.

8.10.2 Fruit set

The fruits of *Harpagophytum,* carrying the potential future generations of the species and acting as its dispersal agent, have received attention in various studies (e.g. VOLK 1964, BLANK 1973, HULZEBOS 1987, ERNST et al. 1988, STROHBACH-FRICKE 1995). In several languages the common name of *Harpagophytum* is derived from the impressive fruit architecture that provoked names such as Devil's Claw, "Teufelskralle", "Duiwelsklou", "Kloudoring".

This chapter deals with the fruit-set intensities of *Harpagophytum* recorded for the major research areas and vegetation types. It will be distinguished between young, immature fruits, which are still attached to the mother plant and total fruit quantities, meaning the sum of old (detached fruits from previous years) and young fruits that were found on the research sites.

8.10.2.1 Background information on fruits, fruit-set and dispersal in *Harpagophytum*

Fruit morphology and anatomy

Harpagophytum procumbens produces woody capsules, typically 6-10cm in length with a maximum of 20cm. The fruits are transversally flattened, armed at the sites with long and protruding hooked thorns, 12-16 in number (NOTT 1986, STROHBACH-FRICKE 1995). The thorns are conspicuous, 2-10cm long, elastic and elongated and curved upwards to pointed barbs. They start to grow when the main fruit body has reached two thirds of the final length (HULZEBOS 1987). The anatomy of the fruit is characterised by a membranous exocarp, a parenchymatous mesocarp and a sclerenchymatous endocarp, which is the only layer of the pericarp remaining in old, withering fruits (IHLENFELDT & HARTMANN 1970).

Fruit development

The fruit develops within 3-5 months after the re-sprouting of the plants and approximately two months after pollination (BLANK 1973). Fruits of *Harpagophytum* can be quite heavy, and make up more than half of the total shoot dry weight (HULZEBOS 1987). Fruit weight corresponds to the within-species variability with a mean weight of 3.43 +/-0.93g (ERNST et al. 1988). HULZEBOS (1987) states a dependency of the fruit-set on climatic conditions, i.e. that fruits tend to grow slower under dry conditions with many fruits aborting before ripening. As the fruits do not store any harpagoside or other active ingredients, which might be of pharmaceutical interest, they are not medicinally used (VOLK 1977 in NOTT 1986).

Dispersal

Various means of dispersal have been described for *Harpagophytum* that support the assumptions that dissemination in *Harpagophytum* is complex. Dispersal may range from long-distance transports to the total lack of dispersal. The fruits represent the dispersal unit or diaspore, but also the seeds – once released from the fruit – may be further dispersed. Predominant mode of dispersal in *Harpagophytum* is telechory.

The distance of a successful transport of the diaspore varies with respect to the vector. Depending on the morphological fruit properties the most commonly accepted mode of telechorous dispersal is epi-zoochory. Yet, ELLNER & SHMIDA (1981) raise the objection that morphological traits of the diaspore, which have generally been used to deduce the mode of dispersal, have not always proved to be a reliable indicator of the dispersal distances in natural populations. For *Harpagophytum* it is described that the fruits can function as trample burrs and can cling tenaciously to the foot of cattle, antelopes or small livestock, or that the fruits become entangled in the wool of small livestock (sheep, goats). Fruits can also hook to the mouth and jaws of small and large livestock as well as antelopes (e.g. BLANK 1973, Haumann, pers. comm.). It was observed that the fruits pose a great tenacity also to horses, which not only step into the fruits but the fruits get entangled in the mane and tail hair (Hachfeld, pers. observation). However, it is assumed that the long and protruding curved thorns of the fruit, may not easily cling to the hoofs of large browsing mammals. It seems more probable that in cases of animals stepping into the fruits of *Harpagophytum* they damage them by the trial to remove them. By this, long distance dissemination is avoided and only medium to short distance dissemination takes place. Also anemochory may present an option of a telechorous dispersal mode in *Harpagophytum*. Even though no morphological adaptations exist to anemochory, fruits may be moved by strong winds. Especially in the dry season and under a missing herb and grass cover fruits may start rolling (Hachfeld, pers. observation). Also URBANSKA (1992) claims an impact of the vegetation density, next to the height of the mother plant, on the dispersal pattern of anemochorous plant species. In general, anemochory represents a medium distance dispersal mode. It can also be the second vector of dissemination following a prior dispersal by epi-zoochory.

Fruit release

The fruits of *Harpagophytum* are released from the mother plant at the end of summer, between March and April (ERNST et al. 1988). The capsules are difficult to open, but the pericarp opens with ageing at the distal ends from where the seeds are released. Generally, little is known about the seed release by the fruits, but once the seeds have left the fruit they have to be well trampled into the soil in order to germinate (e.g. BOSS 1934). A good ability of the seeds to swim is given by the aerenchymatous structure of the testa. Therefore, hydrochory (dispersal by water) is regarded as potential dispersal strategy of the *Harpagophytum* seeds by some authors (GANSSEN 1963, ESDORN 1963 in BLANK 1973). These authors interpret the anatomy of the testa as an adaptation to the erratic but typically strong summer rainfall events in southern Africa, which promote hydrochory. Especially in small washes and wadis water can accumulate after erratic rainfall and transport seeds. However, the fact that only few individuals of *Harpagophytum* were found growing next to washes indicates that this mode of dispersal is rather limited.

8.10.2.2 Intensity of fruit set of *Harpagophytum*

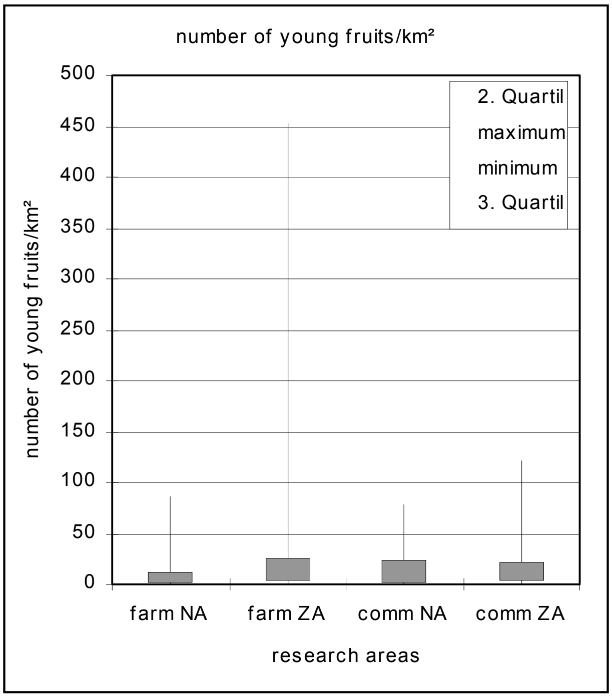
In all four research areas at least on half of the sites fruiting plants of *Harpagophytum* were recorded (Tab. 26). The percentage of sites with fruiting plants is reversed to the percentage of sites with flowering plants, i.e. whereas in the private farmland of Namibia on less than one fifth of all sites flowering plants of *Harpagophytum* occurred, over 60% oft he plants were fruiting in the same area. Whereas the communal areas of South Africa inherit the highest percentage of sites with flowering plants, this is lowest when looking at the number of fruiting plants. This result emphasizes that principally in all four research sites plants of *Harpagophytum* are reproductive. Yet, due to the time of observation in the private farmland of Namibia more plants already reached the stage of fruit-set. In contrast, in the communal areas of South Africa most individuals were still in the phase of flower production.

The detection of old fruits can hint towards a principle occurrence of *Harpagophytum,* irrespective of the missing of sprouting plants at the time of documentation. The lack of *Harpagophytum* in one year can be a result of low precipitation amounts and the subsequent dormancy of the geophytic individuals. Overgrazing or detrimental harvesting activities may present other responsible factors, which, however, would hint towards a decrease in individual numbers. On one to four sites of each research area (Tab. 27) only fruits but no plants of *Harpagophytum* were recorded. As stated above, fruits are dispersed by telechory, i.e. by epi-zoochory and anemochory, and can therefore be removed from the near vicinity of the mother plant. Thus, the number of old fruits recorded on a research site serves only as an indicator for the general occurrence of *Harpagophytum* and of fruit quantities produced in previous rainy season within an area. It cannot account for a correct measurement of fruit production though.

Tab. 27: Number and percentage of research sites in the four research areas with plants, fruiting plants, and released old fruits of *Harpagophytum* in Namibia and South Africa.

Research sites	**Private farmland**		**Communal areas**	
	Namibia	South Africa	Namibia	South Africa
Total number of 1km² sites	33	35	17	11
Number of 1km² sites with plants	30	28	13	10
Number of 1km² sites with fruiting plants /old fruits	19 / 18	24 / 33	8 / 9	5 / 9
Number of sites with only old fruits	3	4	1	3
Number of 1km² sites with both, old fruits and fruiting plants	22	33	10	9
% sites with fruiting plants of sites with plants	63.3%	85.7%	61.5%	50.0%
% sites with fruiting plants and old fruits of sites with plants	73.3%	100.0%	76.9%	90.0%

The left graph of Figure 37 shows that the typical quantity of 2-26 young fruits (25-75% quartile borders) per research site that occurred irrespective of the land ownership and country. Maximum number of fruits may vary and can reach high amounts of several hundred fruits. Single individuals of *Harpagophytum* typically did not have more than 1-5 fruits per plant. In total, no more than 12 fruits were counted on a single plant (Hachfeld, pers. observation).



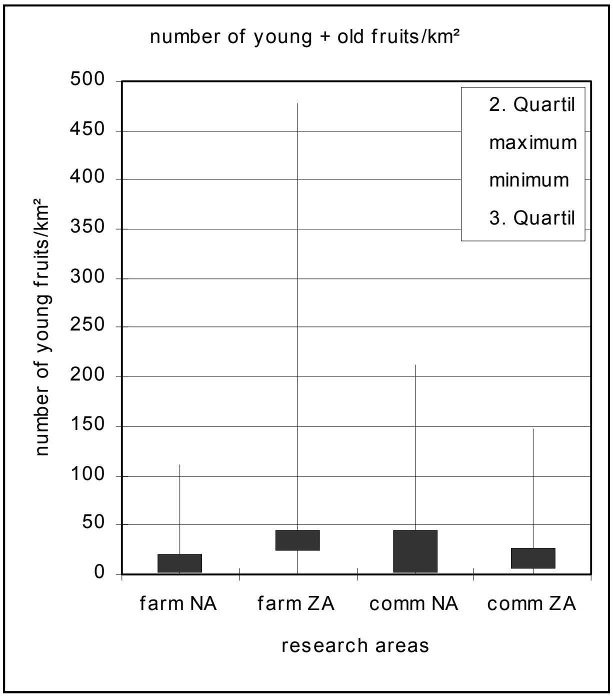


Fig. 37: Quantity ranges of young fruits (left) and young and old fruits (right) of *Harpagophytum* on 1km² sites in communal and private land of Namibia (NA) and South Africa (ZA).

When combining the quantities of young, immature fruits with old and detached fruits, greater differences between the research areas become evident (right part of Fig. 37):

- Whereas in the private farmland of Namibia and the communal areas of South Africa, the quantity of diaspores did not differ (few old fruits were found), in the other two research areas the total number of diaspores increased. On three quarters of the sites in the private farmland of South Africa more than 45 fruits contributed with their seeds to the seed bank of the research sites. Also in the communal areas of Namibia, on half of the sites (values within the 2nd and 3rd quartile in the graph) 2-45 fruits were counted, giving an impression of the reproductive effort of *Harpagophytum* populations.

Tab. 28: Spearman rank order correlation (r_s, 2-sided) of *Harpagophytum* plants with quantity of young fruits.

Research areas	**Spearman rank order correlation of number of plants & young fruits**			
	N	**r_s**	**t(N-2)**	**p-level**
Namibia				
private farmland	138	0.4070	5.1955	0.0000***
communal areas	112	0.0817	0.8596	0.3919
South Africa				
private farmland	166	0.5755	9.0127	0.0000***
communal areas	420	0.5872	14.8319	0.0000***
***= highly significant (p<0.01)				

To test, if the plant density is related to the quantity of young fruits/transects, the Spearman rank order correlation was applied (Tab. 28). It was found that except for the communal areas of Namibia, a highly significant correlation is evident for both data sets.

8.10.2.3 Fruit-set in various vegetation types

Similar to the flowering intensity also the fruit set of *Harpagophytum* differs between the vegetation types. Next to variations in individual numbers and the condition of the individuals or the populations, fruit set intensity is also dependent on pollinator success.

The following was found:

- On private Namibian farmland, fruit-set in *Harpagophytum* occurred in all vegetation types but was highest in the Highland Savanna and the Thornbush Savanna.
- In the communal areas of Namibia, generally higher fruit quantities occurred. Fruit-set was highest in the Tree Savanna and Woodland (only represented by the communal Okakarara Region). Although in the Camelthorn Savanna more flowers of *Harpagophytum* were recorded per research site than in the Tree Savanna and Woodland, with the fruit quantities this relationship was vice versa. Both vegetation types seem to be very reproductive, but were in different stages of reproduction when investigated.
- On private farmland of South Africa the fruit set intensity was highest for the Kalahari Plains Thorn Bushveld while in the Kalahari Mountain Bushveld only on one site plants and fruits of *Harpagophytum* occurred. Fruit quantities in the Shrubby Kalahari Dune Bushveld were comparable to the number of flowers counted for this vegetation type.
- For the communal areas of South Africa only in the Kalahari Plains Thorn Bushveld a significant number of fruits was found.

8.10.2.4 Summary on the fruit-set of *Harpagophytum*

Data analyses indicate that *Harpagophytum* individuals were in the reproductive stage of fruit-set on a minimum of half of the research sites. An even higher percentage of reproductive effort (>73%) was evident when fruit set of several years was considered (young and old fruits). On few sites only old fruits occurred, but *Harpagophytum* was missing. It is assumed that these sites experienced either non-favourable environmental conditions in the observation year preventing the plants from re-sprouting and/or that the previously existing population (indicated by the occurrence of old fruits) is extinct. Typically, between 2-26 immature fruits and 45 immature and old fruits occurred on a square kilometre. Maximum number of fresh fruits/individual was 12.

Quantity of fruit-set in *Harpagophytum* is related to individual numbers. One exception forms the communal area of Namibia, where most plants were still in the flowering phase. In Namibia, the greatest resource of young fruits was documented for the Highland Savanna in the private farmland and in the Tree Savanna and Woodland in the communal areas. In South Africa, for both types of land ownership the Kalahari Plains Thorn Bushveld was the vegetation type with the highest fruit amounts. A similar median of approximately 50 fruits/km² was found for the private farmland of both countries.

8.10.3 Seed bank

Calculations of the seed bank of a species can be used as an indicator for its regeneration potential. Yet, seed production cannot account for the success in reproduction that also comprises a success in germination and establishment. With respect to the potential threat of an over-exploitation in *Harpagophytum* the evaluation of the seed bank contribution may provide useful and indicative measures. In this chapter, the seed bank and germination ability of *Harpagophytum* is discussed. No own field data has been collected on this topic, but fruit counts of the transects together with seed quantities in single fruits stated in literature will be used to extrapolate to the potential seed accumulation of *Harpagophytum* in the soil.

8.10.3.1 Background information on seeds, seed bank and germination of *Harpagophytum*

Seed morphology

The seeds of *Harpagophytum* have a length of 7-8mm and are of oblong shape with a black colour. For the seeds are densely packed in 2-5 rows in the placenta, the shape of the seeds is irregularly edged. The testa is black or grey, with a structure of small warts or honeycombed. As typical for Pedalicaceae the endosperm is very thin (IHLENFELDT & HARTMANN 1970). Data on the seed quantities of *Harpagophytum* varies between 13-100 seeds/capsule (e.g. BLANK 1973, TIETEMA 1986, DE JONG 1985, NOTT 1986, ERNST et al. 1988).

Germination

Seeds of *Harpagophytum* show a high innate dormancy that is generally regarded to be characteristic for environments with high summer temperatures and a low moisture availability (ERNST et al. 1988). The authors expect that similar to other desert ephemerals, *Harpagophytum* lacks a predictive germination strategy due to a high variability in the timing and intensity of precipitation. In general, germination is reported to be very difficult in *Harpagophytum*. The germination rate of natural and non-treated seeds is very low and differs between 1.7% (DE JONG 1985) and 1.4-5.7% (ERNST et al. 1988). Out of 1.000 seed sown out in a test series in Botswana, only 47 seeds germinated (DE JONG 1985, TIETEMA 1986). Similar to the strategy of the seed release in *Harpagophytum*, also germination is adapted to insecure environmental conditions for not all seeds germinate at the same time.

Germination trials

Several studies have been carried out to understand the complex germination process of *Harpagophytum*, but so far no satisfactory results were achieved (e.g. BLANK 1973, VEENENDAAL 1984, DE JONG 1985, ERNST et al. 1988). Some results shall be presented in this context: Firstly, the presence of water is not a trigger for dormancy breaking in seeds of *Harpagophytum* (ERNST et al. 1988). Both, the testa and the endosperm are a barrier for full imbibition of the seeds including the embryo. Germination experiments were carried out with (a) sulphuric acid, which had a lethal effect on seeds; with (b) giberrellic acid which induced a quick and good germination, but with an extremely high mortality rate of seedlings; with (c) alcohol, (d) temperature treatments, (e) in a variety of germination substrates, and (f) in darkness. However, neither of the various experimental approaches showed satisfactory results. Some authors reported a higher germination rate (30%) when peeling off the testa, others did not find any increase in the germination rate by this method (BLANK 1973, DE JONG 1985, ERNST et al. 1988). Also, this method may not be applicable on a large scale for cultivation, as it is rather time consuming and manual skills are required. A natural decay period for the testa of 70 days was not sufficient to induce germination. The germination rate of seeds without an endosperm also varied strongly with respect to the experiment, i.e. either germination rates of over 90% were found within a period of only five days (BLANK 1973) or seed germination was limited to 21.5 +/- 2.1% with only a portion of isolated embryos being able to synthesise chlorophyll (ERNST et al. 1988). The authors concluded that in *Harpagophytum* seed dormancy is regulated by many genetic factors. GUTTERMANN (1994) proved that differences in germination rates might be a result of variations in seed dormancy in relation to the position of seed in the fruit. ERNST et al. (1988) found a composition of seed sizes and seed fitness in fresh fruits where the small seeds (<10mg) lacked developed embryos. In contrast, mean seed weight of intact seeds was 13.9 +/- 5.98mg.

Success in germination of *Harpagophytum* is best when seeds are trampled into the soils by animals. This observation supports the common assumption that *Harpagophytum* is a plant increasing in number with an increase of the grazing pressure. In an experiment in Botswana, seeds germinated neither on the soil surface nor in a soil depth of 7.5-10cm, but a soil depth of 2.5-5cm was required to stimulate germination (DE JONG 1985). Due to root competition establishment is normally suppressed, but seedlings can emerge after the death of other adult plants in the surroundings (SCHNEIDER 1997 and personal observations).

Seed viability

Another adaptation to arid environments is the viability of the seeds: 95% of the seeds are still able to germinate after a long period of time under non-suitable conditions (BLANK 1973). According to ERNST et al. (1988) this is maintained by a restricted respiration rate of the seeds. Experimental results by the authors indicate a low respiration rate in dormant seeds, which accounts for a survival capacity of seeds of more than 20 years under dry conditions in the Kalahari.

Seedlings

In order to be able to survive in the unpredictable environment of the arid parts of southern Africa, seedlings of *Harpagophytum* have to be able to quickly establish themselves. Already 2-3 weeks after a sufficient rainfall event, seedlings of *Harpagophytum* emerge above the soil surface. The root of the seedling penetrates straight into the soils with hardly any side roots. By this, the more humid deep soil layers are reached before the upper soil layer dries up again. The roots of seedlings of *Harpagophytum* can grow up to 90cm soil depth within eight weeks after seedling emergence (ERNST et al. 1988). Within the first five months a parent tuber of 0.5cm is produced, which will grow up to a size of 1-2 cm within the first growing season (VEENENDAAL 1984, DE JONG 1985). Seedlings show a high mortality rate during the dry season. Only seedlings that were able to produce enough dry matter in form of a large enough parent tuber have sufficient reserves to survive the rainless period. Therefore, most effort of the seedling is invested into the development of the reserve organ after germination, whereas the gain of dry matter is initially small in the photosynthesising organs of the above ground sprouts (BURGHOUTS 1985, DE JONG 1985, TIETEMA 1986). The growth rate of a seedling decreases with an increase of its age. ERNST et al. (1988) found a mean relative growth rate of 0.143mg/week for 1-3 months old seedlings. They state that this gain in biomass is comparable with that of plants from dry ecosystems in cold-temperate regions. HULZEBOS (1987) found an increasing chance of survival the earlier germination occurred in the season, i.e. the more time for establishment and root growth was available. In general, mortality among seedlings of *Harpagophytum* is in particular high in the first weeks with a death rate of >50% found in Botswana by TIETEMA (1986) as well as by VENENDAAL (1984).

8.10.3.2 Calculation of the potential seed bank of *Harpagophytum*

Information regarding the number of seeds per capsule vary strongly between different authors (e.g. BROUWER & STÄHLIN 1955, IHLENFELDT & HARTMANN 1970, BLANK 1973, TIETEMA 1986, DE JONG 1985, NOTT 1986, ERNST et al. 1988). For the calculation of the potential seed bank of *Harpagophytum* selected data from literature was used (Tab. 29).

Tab. 29: Seed number/capsule stated by different authors and calculation of potential number of viable seeds/capsule (based on ERNST et al. (1988)).

Author	Number of seeds/capsule	Research area	Potentially viable seeds/capsule (= 63% of total seed number)
Blank (1973)	80 (mean)	Namibia	50.4
de Jong (1985)	52 (mean)	Botswana	32.8
Tietema (1986)	47 +/- 17	Botswana	29.6 +/-10.7
Betti (no date)	13-45	Namibia	8.2-28.4
Ernst et al. (1988)	19-70	Botswana	12-44.1

ERNST et al. (1988) describe a varying composition of seed sizes and fitness of seeds in fresh fruits of *Harpagophytum*: 13.6% of the seeds of the total seed mass determined for a capsule were completely empty and 23.4% had a very small and underdeveloped embryo. For the calculation of potential seed bank of *Harpagophytum,* both percentages were combined to a percentage of 37% of seeds for each capsule that are not able to germinate. From this, it was concluded that the remaining 63% of the seeds of each capsule do have an embryo that is able to germinate. The resulting amount of seeds/capsule that can be used for the estimation of a *Harpagophytum* seed bank is listed in the right column of Tab. 31 differentiated according to the different authors.

Calculations of the contribution of *Harpagophytum* seeds to the seed bank of the research sites are restricted to the occurrence and quantity of fruits at the time of observation. Even though it can be expected that a great percentage of the flowers counted at the sites will also develop into fruits, no information is available on the rate of success in pollination and in percentage of fruit-set in *Harpagophytum*. This however would be needed in order to extrapolate from flowers to seed numbers. The fact that fruits of *Harpagophytum* may be dispersed by animals or other vectors was not considered to be a limitation to the seed bank calculations. It was assumed that fruits are not dispersed over a larger distance than the size of the research areas of one square kilometre (see Chapter 8.10.2.1). The size of the cattle camps poses an additional limitation to long-distance transport of the diaspores by large mammals.

For the calculation of the seasonal contribution to the potential seed bank of *Harpagophytum*, the findings of three authors, i.e. BLANK (1973), DE JONG (1985), and TIETEMA (1986), were chosen to represent a useful cross-section of seed numbers stated in literature. In the following, the calculation will therefore always be related to a viable seed number/capsule of 50.4 (BLANK 1973), of 32.8 (DE JONG 1985), and of 29.6 seeds/capsule (TIETEMA 1986).

In Figure 38a, the number of young fruits counted on the communal and private land of Namibia and South Africa was used to calculate the median of potential seed bank contributions of *Harpagophytum* seeds to the soil seed bank. Irrespective of the different seed quantities stated by the three authors a clear trend is obvious when comparing the four research areas:

- On the private Namibian farmland, comparatively low seed numbers were found, while in the Namibian communal areas at least a median of 600 seeds/1km² site was produced.
- For South Africa, a similar contribution was found for both, communal and private farmland.

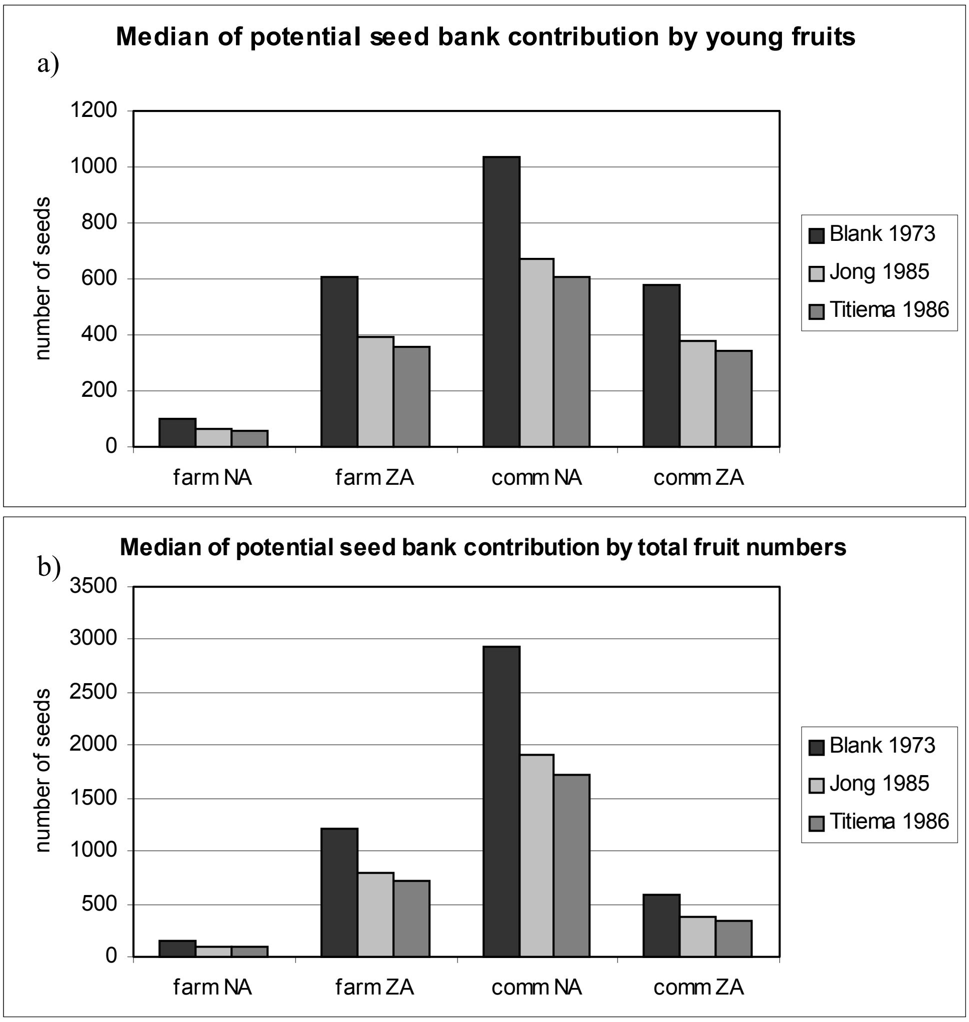


Fig. 38: Mean of potential seed bank contribution of *Harpagophytum* calculated from a) young fruits, b) the total number of fruits (young and old fruits), number of seeds/capsule. Source: BLANK (1973), DE JONG (1985), TIETEMA (1986).

Total number of fruits counted on the research sites at the time of documentation and used for calculations of the seed bank, contributes information on the availability of seeds from the past as well as the current vegetation period (Fig. 38b). Results show that

- Only for some research areas seed bank contribution increases, i.e. on private South African farmland and especially in Namibian communal areas. Only in these research areas many old fruits from the previous rainy season(s) were found.

- For the communal areas of Namibia, for example, more than twice the amount of seeds is potentially added to the soil seed bank when including old fruits.
- In contrast, on private farmland of Namibia and communal areas of South Africa, old fruits produced only a negligible contribution to the soil seed bank.

The calculation of the seed bank contribution of young *Harpagophytum* fruits to the research sites proposes a seed amount that will eventually reach the soil seed bank. Similarly, old fruits found on the research sites have already released or will release their seeds to the soil. For an interpretation of the regeneration potential of *Harpagophytum* the time needed for the release of the seeds from the fruits is not important especially as dormancy mechanisms hinder an immediate germination in any case.

8.10.3.3 Seed bank contribution in various vegetation types

Calculations of seed contributions of young *Harpagophytum* fruits to the soil seed bank show that these vary with respect to the composition of the surrounding vegetation are carried out for all sampled vegetation types. Only sites with plants of *Harpagophytum*, were included.

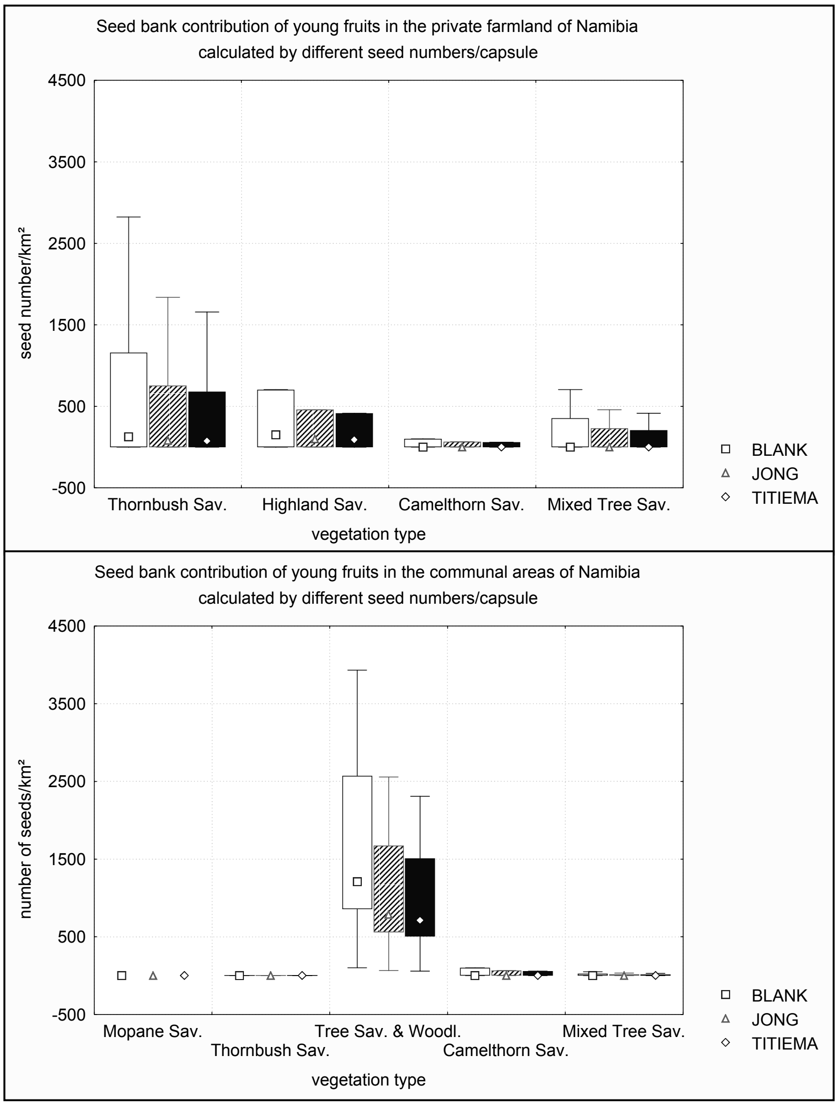


Fig. 39: Non-outlier Box-Whisker plots of seed bank contribution of *Harpagophytum* by young fruits to vegetation units of Namibia.

Private farmland of Namibia (Fig. 39):

In the year of observation *Harpagophytum* contributed seeds to the soil seed bank in all vegetation types. Highest seed numbers occurred in the Thornbush Savanna and lowest in the Camelthorn Savanna. In the Highland Savanna only few seeds were produced in young fruits, but total fruit numbers (old and young fruits) indicate that seed bank contribution may be much higher when including also the old fruits.

Communal areas of Namibia (Fig. 39):

Greatest resource of seeds was produced in the Tree Savanna & Woodland, for which considerably higher seed amounts were extrapolated in comparison to the private farmland of the country. In the other vegetation types seed production was limited.

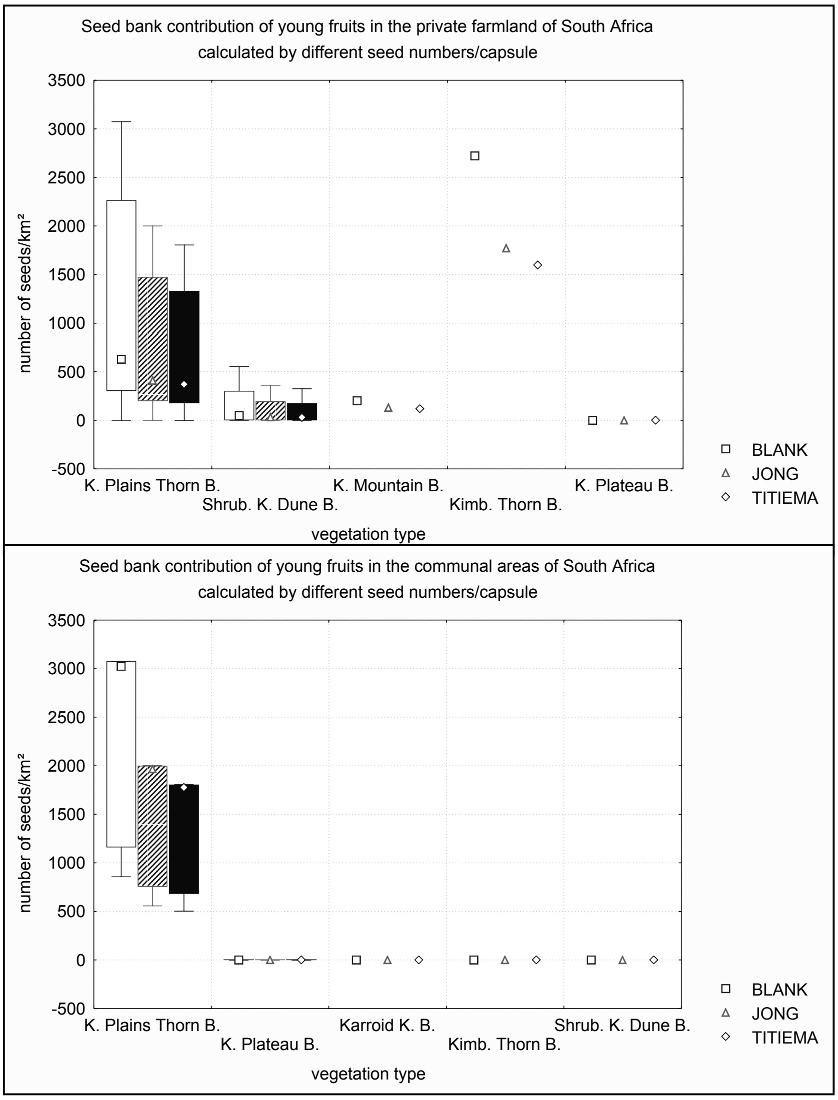


Fig. 40: Non-outlier Box-Whisker plots of seed bank contribution of *Harpagophytum* by young fruits to vegetation units of South Africa.

Private farmland of South Africa (Fig. 40):

Highest contribution to the seed bank by young fruits was found for the Kalahari Plains Thorn Bushveld. A significant seed bank contribution was found for the Kalahari Mountain Bushveld, where only on one site plants of *Harpagophytum* occurred.

Communal areas of South Africa (Fig. 40):

Similar to the private farmland, also for the Kalahari Plains Thorn Bushveld highest potential seed numbers were calculated for the observation year. In the other vegetation types no seeds were contributed.

8.10.3.4 Summary on the seed bank of *Harpagophytum*

Seed counts of *Harpagophytum* carried out by three different authors were used for an estimation of seed numbers/capsule in *Harpagophytum*. By the multiplication of seed and fruit numbers, a calculation of the contributions of seed to the seed bank of the species was carried out for the different research areas. Extrapolations were restricted to fresh fruits and old fruits counted at the time of observation. The calculation of potential percentages of fruit-set from flower quantities was not possible.

The data shows that the greatest input to the seed bank of *Harpagophytum* occurred in the communal areas of Namibia, namely the Okakarara area. It was the Tree Savanna and Woodland in the communal areas that experienced the largest contribution to the seed bank, whereas in the private farmland of Namibia, *Harpagophytum* plants contributed most seeds in the Thornbush Savanna. In South Africa, with respect to young fruits, a similar seed production existed for both types of land ownership, however, a significantly higher production was found for the private farmland when including also old fruits in the calculations. Irrespective of the land ownership the greatest regenerative input of *Harpagophytum* was found for the Kalahari Plains Thorn Bushveld.

One objective towards calculations of seed bank contributions sites may be that seeds of *Harpagophytum* are released gradually from the capsules. Therefore, the seed bank of *Harpagophytum* is not necessarily restricted to an accumulation of seeds in the soil, but fruits lying on the soil surface can also serve as an interim seed bank. This above-ground seed bank may be further disseminated by trampling animals or wind. Within successive years after fruit production, old fruits may have released a varying number of seeds from their capsules. ERNST et al. (1988) counted a remaining number of 22 seeds in three-year old fruits. Annually a mean of 20-25% of the seeds per fruit are released and may establish soil contact. Based on this, fruits of *Harpagophytum* should have released all their seeds within 3-4 years. However, several factors will take influence on this. Not only the intensity of grazing and trampling may promote the fruit deterioration and thus the seed release. Precipitation pattern, by enhancing fruit withering, may contribute to this next to different soil textures that may or not pose an opposition to animals trying to remove the epi-zoochorous fruit. Ecologically, a slow seed release can be interpreted as a good adaptation to unpredictable arid environment because seed germination is spread in space and time (e.g. GUTTERMANN 1994).

8.10.4 Reproductive effort of different *Harpagophytum* densities

To test the reproductive effort of *Harpagophytum* for different spatial density patterns, a Spearman rank order correlation was calculated between transects with a) patches of *Harpagophytum* (>10 individuals/transect) and with b) a scattered growth pattern (<10 individuals/transect) and the amalgamation of immature fruits and flowers. For the analysis both indicators of the reproductive effort were combined, i.e. the counts of flowers and immature fruits/transect (Tab. 30).

Irrespective of the density of *Harpagophytum* on the transects, a significant correlation between the density of individuals and the reproductive effort was evident for most research areas. The only exception experiences the communal area of Namibia, where for a scattered growth of *Harpagophytum* no correlation was found. Yet, for the occurrence of *Harpagophytum* in patches of >10 individuals/transect, this relationship proved to be stronger with larger r_s-values than for the occurrence of the species with a scattered growth pattern. Only for the private Namibian farmland a weak correlation was evident for both, a scattered and a dense growth pattern of *Harpagophytum*.

Summarizing, a reproductive effort in *Harpagophytum* is evident irrespective of its spatial growth pattern. For both, transects with low and with high individual numbers, individual numbers were related to number of reproductive units (flowers and immature fruits). Yet, for dense patches of *Harpagophytum* this correlation is stronger.

Tab. 30: Spearman rank order correlation (2-sided) of number of flowers, immature fruits for patches and single individuals of *Harpagophytum*.

Density of Harpagophytum		**N**	**r_s**	**t(N-2)**	**p-level**
Patches of Harpagophytum					
Namibia	private farmland	76	0.2404	2.1309	0.0364**
	communal area	111	0.4608	5.4200	0.0000***
South Africa	private farmland	51	0.4355	3.3866	0.0014***
	communal area	71	0.4378	4.0454	0.0001***
Scattered growth of Harpagophytum					
Namibia	private farmland	229	0.2520	3.9236	0.0001***
	communal area	60	0.2309	1.8071	0.0759
South Africa	private farmland	124	0.3477	4.0963	0.0001***
	communal area	148	0.2404	2.9927	0.0032***
*** = highly significant (p<0.01), **=significant (0.01<p<0.05)					

8.10.5 Summary and conclusions on the reproductive effort of *Harpagophytum*

Reproductive units

- Flower and fruit frequencies of *Harpagophytum* indicate a reproductive effort for both countries and types of land ownership for at least 70% of the sites (with exception of the private farmland of Namibia).
- Flowering intensity of single individuals of *Harpagophytum* may vary within single populations as well as in relation to the country and land ownership.
- Detailed flower counts suggest that individuals in the communal Okakarara Region of Namibia show a greater reproductive success and ability than individuals in the private farmland of South Africa.

- The production of reproductive units is dependent on the number of individuals available at a specific site. Yet, a significant relationship between plant and flower quantity was restricted to the communal areas of Namibia. In contrast, for young fruits this relationship was evident for all research areas, but the communal Namibian land. The amalgamation of both reproductive units, flowers and young fruits, suggests that reproductive effort is related to individual numbers available at the research sites.

Dissemination

- Dispersers of diaspores of *Harpagophytum* are predominantly small and large livestock as well as antelopes.

In general, for epizoochoric disseminated fruits such as *Harpagophytum*, the specific habits of the disperser in feeding, movement, and rest, amongst other activities, play a substantial role for the future distribution pattern. Zoochory in general leads to an accidental genetic composition of populations, which is related to the construction of the diaspore, the frequency of dissemination and the specific habits of its dispersers. Depending on the management regime, ranges of livestock may vary from very small (when in small camps) to large (when no management system is applied and animal graze and browse with a free range). Antelopes are more frequent on game farms and on commercial farmland than in communal areas. With respect to the evolution of epi-zoochory, MILTON et al. (1990) demonstrated that the occurrence of epi-zoochory has evolved in productive habitats where a large diversity of herbivorous mammals is present. For the Kalahari Desert the authors found a percentage of 8,30% of epi-zoochorous species. Generally, the percentage of epizoochorously dispersed species is low for arid areas of South Africa (VAN ROOYEN et al. 1990, HOFFMAN & COWLING 1990). For the Pedalicaceae family, however, zoochory represents the typical mode of dispersal (HENDERSON & ANDERSEN 1996).

Dissemination and population patterns

- The forming of patch aggregations of *Harpagophytum* individuals as well as a scattered growth of single individuals is to a great extent influenced by the mode and success of dispersal. The tested significant positive relationship between the quantity of flowers and immature fruits with the individual density of *Harpagophytum*, was considerable stronger for aggregated populations than for scattered growth patterns.

VAN OUDTSHOORN & VAN ROOYEN (1999) found that the dispersing animals determine the distance between the mother plant and the diaspore. SHMIDA & ELLNER (1983) claim that epi-zoochory is unreliable inasmuch as although diaspores may be equipped and presented for epi-zoochory, the arrival of the vector is not guaranteed. For open Mediterranean chaparral in Israel they found a highly distorted distribution pattern of dispersal distances with most diaspores moving little (if any) distance from the mother plant while only few diaspores travelled for kilometres.

- Personal observations support the unreliability of long distance dispersal for *Harpagophytum* and indicate that very often fruits remain situated next to the mother plant. In the direct vicinity of plants of *Harpagophytum* several fruits of the previous year were often located in 30cm around the mother plant (which resembles the shoot length of the plant in the previous rainy season). This observation indicates a failure in telechory in addition to the above described commonly accepted telechory.

This so-called anti-telechory, which is characterised by characters of the diaspore or the mother plant that prevents long distance transports of the diaspore, may also be regarded as an adaptation to extreme environments (e.g. GUTTERMANN 1994, JENNY 1995). Although the fruits of *Harpagophytu*m do not show any morphological adaptations to prevent dispersal, epi-zoochory in this species is dependent on large mammals, and in areas with low stocking rates and a good veld-condition anti-telechorous effects do occur.

- Very often small cohorts of 3-6 individuals of *Harpagophytum* were observed growing in dense assemblages in areas where a dense grass cover prevented fruits from rolling (Hachfeld, pers. observation). In contrast, in strongly overgrazed areas, fruits very often assembled under shrubs or in other parts of the vegetation that formed a hindrance for further fruit movement. Seeds do seem to be able to germinate and establish themselves in such safe sites as especially in overgrazed areas, mature plants were found growing beneath thorn shrubs.

WILLSON et al. (1990) also report that epi-zoochorously dispersed diasporas are common in disturbed areas and grazed vegetation types. TODD & HOFFMAN (1999) found for five palatable species in Namaqualand, South Africa, that heavy grazing on communal rangeland resulted in a reduction of flower production and seedlings recruitment. Also *Harpagophytum* may be heavily grazed in dry years or in heavy degraded areas when only little other herb and grass species are available (Hachfeld, pers. observation).

Impact of plant size

Precipitation and to a lesser extent also grazing may determine the above ground shoot-size of *Harpagophytum*. It was assumed that the size of the above-ground organs influences the flowering intensity of *Harpagophytum*.

The division of individuals into small (<10cm in diameter) and large (>10cm in diameter) and their correlation with the flowering intensity and an amalgamation of flower/young fruit quantity proved a significant to highly significant positive correlation of large individuals with the quantity of flowers/young fruits for all research areas.

Impact of the surrounding vegetation

The composition and density of the vegetation may not only be highly influenced by precipitation and land use, but may itself influence the reproductive ability and effort of its components. For the reproductive effort of *Harpagophytum* in the different sampled vegetation types the following was found:

- The reproductive effort of *Harpagophytum* varies in relation to the vegetation types in Namibia and South Africa.
- A correspondence of vegetation types with total fruit quantities and seed quantities (calculated from young fruits) is only evident for sites with high plant quantities.
- Whereas on private farmland of Namibia, greatest density of *Harpagophytum* occurs in three vegetation types (Highland Savanna, Thornbush Savanna, Camelthorn Savanna), flowering intensity was highest in the Mixed Tree and Shrub Savanna.
- In Namibian communal areas, only two vegetation types proved to be reproductive. Whereas *Harpagophytum* plants in the Camelthorn Savanna were predominantly flowering, in the Tree Savanna

and Woodland these were already fruiting. In particular in the communal Okakarara Region of Namibia individuals of *Harpagophytum* were very reproductive.

- For the private farmland of South Africa, both, highest density of individuals and fruit set was recorded for the Kalahari Plains Thorn Bushveld, but flowering intensity was highest in the Shrubby Kalahari Dune Bushveld.
- In the South African communal areas, only in the Kalahari Plains Thorn Bushveld significant numbers of plants, flowers, fruits, and seeds of *Harpagophytum* occurred.

Parallel to the composition of the vegetation, also the variation of flower production and fruit set has often been viewed as a result of limitations by nutrient resources rather than as a result of a lack in pollen availability (e.g. WILLSON 1991, JOHNSON & BOND 1997). Recent studies indicate that pollen limitation may be a widespread cause of fruiting failure (WILLSON et al. 1990). Yet, so far it has only been reported that *Harpagophytum* may be pollinated by bees, but nothing is known about rates of pollination (BURGHOUTS 1985).

Seed bank

The establishment of a viable seed bank that is long-lasting enough to survive also long and dry periods is in particular of importance in arid and semi-arid areas.

- In *Harpagophytum*, fruits are built to retain the seed enclosed in the woody pericarp. Only gradually seeds are released.

This forms a typical characteristic of arid adapted plant species, and seed-holder capsules or other structures of the plant have developed in several species to protect the post-matured seed from predation (e.g. GÜNSTER 1994, VAN OUDTSHOORN & VAN ROOYEN 1999).

- In *Harpagophytum*, the first seeds to be released are those located at the distal ends of the fruit where the two carpels open.

In order for this to happen, fruits need to be moved by either wind or trampling. This may be encouraged by animals trying to remove the epizoochoric fruits clinging onto their hoofs. Seeds located at the proximate end of the fruit remain enclosed until the fruit is either strongly withered or damaged by trampling. By this, seed dispersal is spread in space and time, over a period of typically few to several years, respectively. The fruits do then serve as an above-ground seed bank for a great portion of seeds located in the proximate parts of the fruits.

Seed bank calculations

Results of the seed bank calculations show that

- Similar to the flowering intensity, seed bank contribution was highest for the communal Okakarara Region of Namibia with a potential median of seed production of 600-1000 seeds/km² from young fruits.

- Lowest seed production occurred in the private farmland of Namibia, whereas for South Africa medium quantities were extrapolated. This relationship became even more extreme when also seeds from old fruits of *Harpagophytum* were included in the calculation.

However, for an interpretation of the regeneration potential of *Harpagophytum* the analyses can only serve as a first approach since only the fruit quantities at the time of observation were included in the study.

It can be concluded that further research is needed on the following:

(a) The fruit-set and seed production of an entire vegetation period. This is especially important as the intensity of the fruit-set of a species or individual indicates how successful the production of reproductive organs and the pollination of a species has been.

(b) Seed counts not only of the fruits but also in the soil should be carried out for the different research areas.

(c) The role of harvesting on the regeneration potential of *Harpagophytum* requires further scientific attention.

8.11 Utilisation of *Harpagophytum*

The "ecologically sustainable extraction of a product depends on the plant part used, the composition of the ecosystem, the nature and intensity of harvesting, and the particular species or type of resource under exploitation" (SHELDON, BALICK & LAIRD 1997). Similar to many other medicinal plants, also with *Harpagophytum* the issue of sustainable utilisation is very complex. As only the secondary root tubers and not the fruits, leaves, flowers or shoots contain the active and therapeutically valuable ingredients, the extraction of these has become the matter of many concerns and scientific studies (e.g. VEENENDAL 1984, HACHFELD 1999, STROHBACH 2001, 2002). Next to the loss of habitat, one of the two primary causes of species loss is overharvesting of species that people consider valuable (GROOMBRIDGE 1992).

Harpagophytum being a geophyte, has to build up large reserves of water and biomass within the first year after germination. Reserves need to suffice the ability to bear the unavoidable carbon and water losses during the subsequent period of dormancy as well as to guarantee a renewed flush of green in the following year (VON WILLERT et al. 1992). With the unpredictability of arid and semi-arid environments, adult individuals of *Harpagophytum* have to be capable to survive also a series of dry or unsuitable years in dormancy. An extraction of the entire reserve of the secondary root tubers of *Harpagophytum* may therefore have a severe detrimental impact on the survival rate of individuals, in particular in a series of subsequent bad rainy seasons. So far, nothing is known on the period of years *Harpagophytum* is able to stay dormant without a renewed flush of the plant to refill its carbon and water reserves. Consequently, no studies have been carried out on this issue considering also the additional impact of harvesting on the survival rate and fitness of the species. Long-term observations are required to monitor *Harpagophytum* individuals with respect to its potential susceptibility or its adaptations to drought, respectively. Furthermore, only single case study information is currently available on the time required by a previously harvested plant to recover and to produce new secondary tubers to be harvested. It is expected that no general guideline for a regeneration period can be derived from such single case studies due to great variations in a number of factors, such as precipitation, soil, land use, temperature etc.

This chapter deals with the current harvesting pressure on *Harpagophytum* that is related to the resource availability. To harvest the secondary tubers of *Harpagophytum*, a hole is dug around the plant and the soil material is removed in an area of 1-1.5m around the plant. As secondary tubers reach as far as 1-2m into soil, holes reach a similar depth. To reduce the effort of digging, the vegetation cover in the near vicinity of the *Harpagophytum* plant is typically removed. Often, the surrounding vegetation is damaged as it is covered by the accumulation of dug-out soil. Various harvesting techniques are presented in Chapter 12.2.

In the field, harvesting activities were determined by the following indications:

- The cleared area around a plant is visible for at least a year after harvesting.
- The refilled hole is well visible by its small depression in the following years.
- Harvesting holes of the previous years are especially easy to detect when they are not properly closed after harvesting.
- Young recovering shoots may emerge from the previously harvested plants.

These signs, however, do not allow the detection former harvesting, which dates back to more than a certain number of years. This is for example the case for the area around Rehoboth in Namibia where in the 1970s and 1980s strong harvesting activities took place that is not visible anymore today. Other methods are needed to follow up former harvesting impacts on the resource availability (see Chapter 9 on the results of the re-documentation).

8.11.2 Density of harvested sites

Harvesting of *Harpagophytum* does not take place in the entire distribution area of the species, but concentrates on certain areas (Tab. 31). An utilisation of the resource *Harpagophytum* was evident for the majority of research sites of both countries.

In Namibia, highest harvesting activities were recorded for the Otjozondjupa Region on both, private and communal land. Also for the Windhoek Region, on the majority of the investigated sites harvesting impact was found.

In South Africa, harvesting activities on private farmland were detected for single sites only. This was true for both provinces investigated (Northern Cape-Province 29% and North West Province 14% of all sites). In the communal areas, especially of the North West Province (85% of all sites) signs of harvesting were detected on most of the research sites.

Tab. 31: Number of research sites in Namibia and South Africa with records of harvesting.

Region / Province	No. research sites		No. harvested sites	
Namibia	Private farmland		Communal areas	
Hardap	1	1	4	0
Omaheke	2	2	3	2
Otjozondjupa	22	21	9	8
Windhoek	8	6	-	-
Kunene	-	-	1	0
Total	33	29	17	10
South Africa	Private farmland		Communal areas	
Northern Cape Province	28	8	4	1
North West Province	7	1	7	6
Total	35	9	11	7

8.11.3 Intensity of utilisation

8.11.2.1 Frequency of harvesting holes and *Harpagophytum* plants

The utilisation intensity of the *Harpagophytum* resource is analysed for both countries and both types of landownership using the number of digging holes/km² and the number of individuals of *Harpagophytum*. For this comparison, the range of quantities rather than their median or mean was applied. This was necessary as data is not normal distributed and sampling size is limited.

In Figure 41, the first and third quartile represent 50% of the data set, meaning the quantities of plants and holes that lie inside the 25-75% range. The fourth quartile resembles the maximum while the minimum of plants and holes found was in most cases zero.

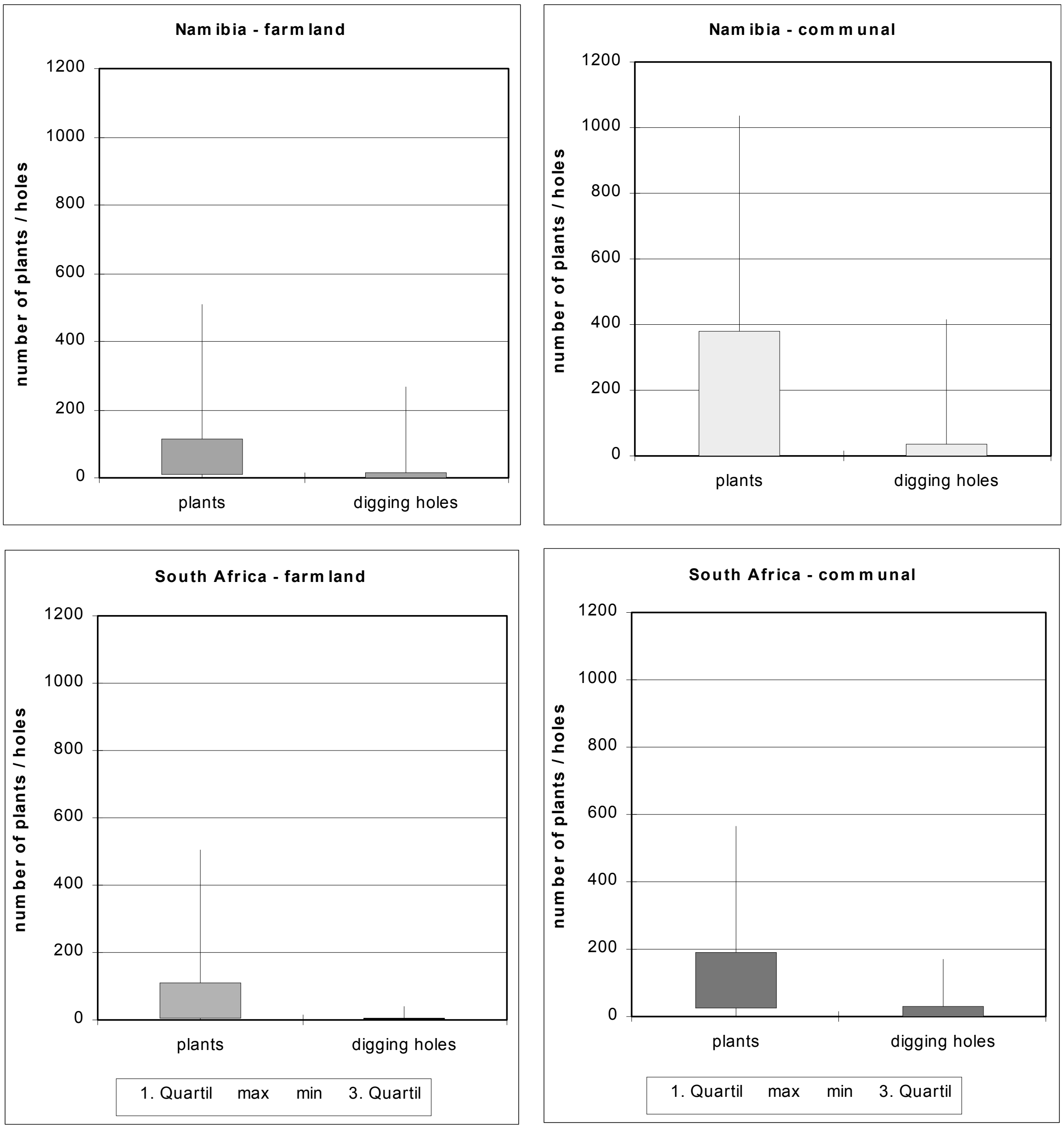


Fig. 41: 1st and 3rd quartile, maximum, minimum of number of *Harpagophytum* plants and digging holes in communally and privately owned land of Namibia and South Africa.

Figure 41 indicates a low resource utilisation (number digging holes) in comparison to a considerably higher resource availability (number of plants). For most research areas the 1st quartile (25% border) of the minimum number of plants as well as digging holes is zero. This indicates that for 25% of all data neither a resource was available nor an utilisation of *Harpagophytum* was evident. The highest intensity of utilisation was found for the communal areas of Namibia.

Private farmland of Namibia

Although an utilisation of the resource occurred on for 24 (of 33) research sites, harvesting activity was in most cases low. On 75% of the sites between 0-16 holes were recorded. Only on one quarter of all sites (near the refugee camp of Osire in the Otjozondjupa Region) more digging holes were found with a maximum of 226 digging holes/km².

Communal areas of Namibia

Here, most signs of an utilisation of *Harpagophytum* were found. Strong variations in both, the utilisation and availability of the resource were evident with 75% of the research sites showing a resource of 1-400 individuals/km² and an utilisation intensity of 0-36 digging holes/km². The fact that for one quarter of all sites a higher intensity of utilisation (maximum of 416 digging holes/km²) was found indicates that in some communal areas intensive harvesting takes place.

Private farmland of South Africa

On private farmland of South Africa the lowest resource availability and utilisation of *Harpagophytum* occurred. On 75% of the sites under investigation between 7-109 individuals but up to 1 digging hole was counted. On all studied private farms a maximum 507 individuals/km² while the maximum of digging holes stayed low with 40 holes/km^2.

Communal areas of South Africa

In the communal areas of South Africa not only the second highest resource availability but also the second highest intensity level of utilisation occurred. Half of the sites inhabited between 24-191 plants/km² and 0-29 digging holes/km². Irrespective of these low values for 50% of the research sites, one quarter of all sites experienced more intensive harvesting activities with a maximum of 168 digging holes/km².

A non-parametric rank correlation test (two-sided Spearman rank order correlation) was applied to test the relationship between individual numbers/transect and the number of digging holes (Tab. 32). For all research areas a positive and highly significant relationship between both variables was evident. Yet, a stronger relationship existed only for the communal areas of Namibia (r_s-value). This indicates that harvesting typically concentrates on areas, where a great resource of *Harpagophytum* is available. Harvesting seems not to be worthwhile when the resource is limited.

Tab. 32: Spearman rank order correlation (2-sided) of the number of individuals of *Harpagophytum* and the number of holes/transect.

Research areas		No. transects	r_s	t(N-2)	p
Namibia	Private farmland	630	0.2257	5.8045	0.0000***
	Communal areas	334	0.4052	8.0752	0.0000***
South Africa	Private farmland	670	0.1732	4.5446	0.0000***
	Communal areas	227	0.1916	2.9283	0.0038***
***= highly significant (p<0.001)					

8.11.2.2 Utilisation intensity in comparison to potential resource availability

The impact of harvesting on wild populations of *Harpagophytum* can be estimated by the number of holes calculated as percentage of the potential resource in a research area (Fig. 42). The total potential resource is defined as the sum of the number of plants/km² and the number of digging holes/km². Maps with the harvesting intensities in Namibia and South Africa are presented at the end of this chapter (Fig. 46, 47).

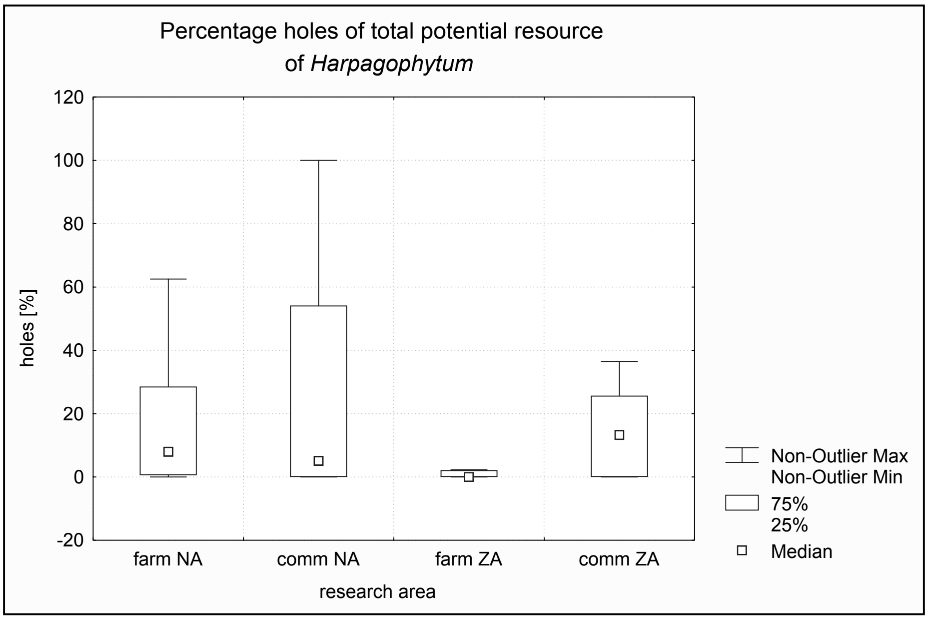


Fig. 42: Box-Whisker Plots of the percentage of digging holes of potential total resource of *Harpagophytum* on research sites of communally and privately owned farmland in Namibia and South Africa.

Private farmland of Namibia

Digging holes may make up as much as 62% of the potential resource. However, for 75% of all sites this relationship was limited to less than 30% (28.6%). The median is also low with 7.9%. Only on <25% of the sites the intensity of utilisation reaches values between 7.9-28%.

Communal areas of Namibia

Highest intensity of utilisation was found for these research areas with the entire potential resource of *Harpagophytum* being partly harvested (the maximum). Also the 75% border of the data is high with 55%. However, the low value for the median (5.1%) indicates that half of all sites experience a lower harvesting intensity. This reveals that next to intensively exploited sites several sites do not suffer of any harvesting pressures.

Private farmland of South Africa

Harvesting intensity on private South African farmland was lowest in comparison to the other research areas. On 75% of all sites the percentage of digging holes on the potential resource is lower than 3% (2.3%). The median is zero indicating that on half of the sites no recent harvesting takes place.

Communal areas of South Africa

Utilisation intensity of *Harpagophytum* remains below 23% of the potential resource on three quarters of the research sites (3rd quartile). The median is the highest of all four research areas (13.3%) and indicates that on half of the sites a resource utilisation of 0-13.3% is evident. The maximum percentage of digging holes reaches almost 90% of the potential resource.

8.11.2.3 Utilisation intensity in regions and provinces

The investigation of the extent of harvesting in the different regions and provinces can provide useful information for conservation and management planning of *Harpagophytum* (Fig. 43). The first and third quartile as well as the maximum and minimum of the percentage of digging holes on the potential resource were used for the analyses. Figure 43 indicates a clear difference in the utilisation intensity of wild populations of *Harpagophytum* among and between private farmland and communal land in Namibia.

Private farmland of Namibia

- In two of four regions sampled in the private farmland of Namibia an utilisation of the resource *Harpagophytum* was detected.
- Hardap Region (n= 1 site): No signs of harvesting were found in this region.
- Omaheke Region (n= 2 sites): Harvesting intensity recorded was low. On both sites only 1-2% of the potential resource was utilised.
- Otjozondjupa Region (n= 22 sites): Here, the highest number of utilised sites and the highest percentage of digging holes on the potential resource was found. On half of all sites between 2.1-39.1% of the potential resource had been removed by harvesting with a maximum of 88%. The median was comparatively high with 10.8%.
- Khomas Region (n= 8 sites): Four research sites located in the eastern part of the Khomas Region at the border to the Omaheke Region showed signs of harvesting. Harvesting intensities on theses sites ranged between 1-22% of the potential resource with a maximum of 26% digging holes of the potential resource. The median was also low with 1%.

Communal areas of Namibia

- In three of four research areas of the Namibian communal land an utilisation of the resource *Harpagophytum* was found.
- Hardap Region (n= 4 sites): Signs of an utilisation of *Harpagophytum* were only visible for one site. A formerly severe impact of harvesting has been reported from the 1970s and 1980s, which is, however, not detectable by the number of digging holes anymore (HACHFELD 1999). For an interpretation of the harvesting intensity in the Rehoboth area see Chapter 9.
- Omaheke Region (n= 3 sites): An utilisation of *Harpagophytum* was found for one site at the border to the Otjozondjupa Region. Harvesting reached little over 50% of the resource.
- Otjozondjupa Region (n=9 sites): Here, the percentage of utilisation is higher than in the private farmland of the region (the research sites on the refugee camp of Osire is included in the communal area). On half of all sites (25-75% border) between 5.1-94.4% of the potential resource had been

removed through harvesting. Digging holes make partly up the entire potential resource indicating that very few or no individuals of *Harpagophytum* were left (or re-sprouting) in the area.

- Kunene Region (n=1 site): Only one site was documented in the, in Kaokoland, where only few plants and no signs of harvesting were found.

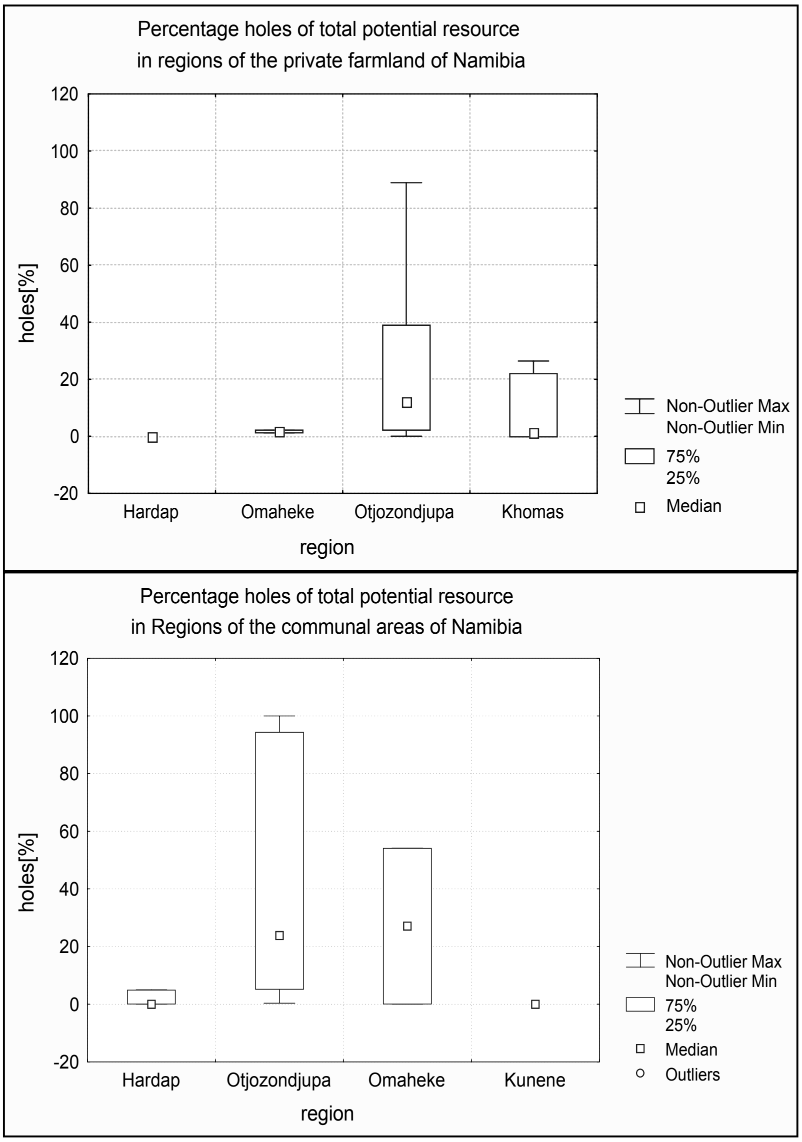


Fig. 43: Box-Whisker Plots of the percentage of number of harvesting holes on the potential resource of *Harpagophytum*. Shown for different regions and districts in communal areas and private farmland of Namibia.

Differences in the utilisation intensity of *Harpagophytum* between privately and communally owned land are more evident for South Africa than for Namibia (Fig. 44). Whereas in the South African private farmland harvesting activities do not seem to influence the resource availability of the species, in the communal areas a clear impact of harvesting was obvious. Figure 44 indicates the following for the four research areas:

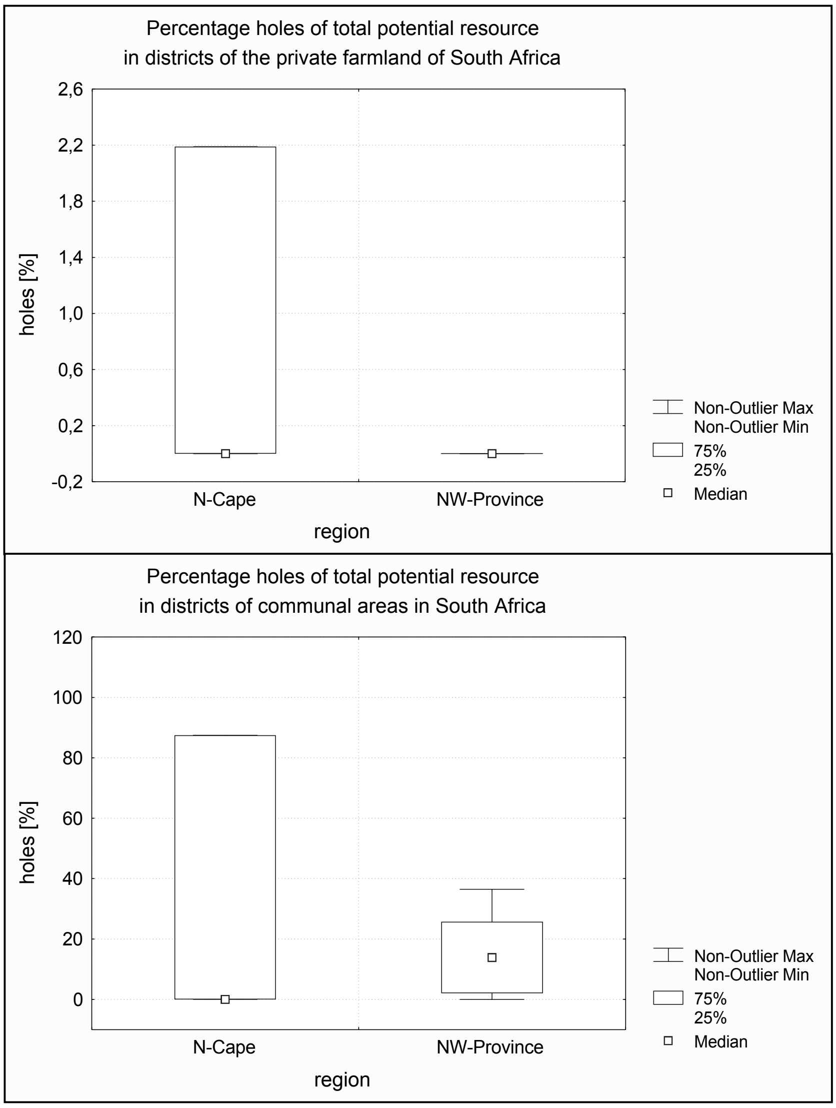


Fig. 44: Box-Whisker Plots of the percentage of number of harvesting holes on the potential resource of *Harpagophytum*. Shown for different regions and districts in communal areas and private farmland of South Africa.

Private farmland of South Africa

- Both provinces show a very low utilisation of the potential resource of the species on private farmland.
- Northern Cape Province (n=28 sites): In this Province an utilisation of *Harpagophytum* was only detected for eight sites where harvesting intensity was restricted to 0-2.2% of the potential resource.
- North West Province (n= 2 sites): Harvesting activities occurred only on one site with single digging, which did not make up a significant portion of the potential resource of *Harpagophytum*.

Communal areas of South Africa

- A considerably higher intensity of utilisation was recorded for the communal areas of both provinces in comparison to the private farmland of South Africa.
- Northern Cape Province (n=4 sites): Due to the low sample size, results of this Box-Whisker plot are misleading. The box (1st – 3rd quartile) does not reflect an utilisation of three quarters of the sites (see

also very low mean value) as only for one site signs of harvesting were recorded. There, the number of digging holes made up 88% of the potential resource. This site is located on the neighbouring farm of one exporter of *Harpagophytum,* in an area where intensive harvesting took place and a very dense patch of *Harpagophytum* has been recorded (Olivier, pers. comm.).

- North West Province (n=7 sites): For six sites an utilisation of *Harpagophytum* was detected. On half of the data set (25-75% borders) between 2-26% of the potential resource had been removed by harvesting. On an additional quarter of the sites either a very low level harvesting occurred or a more intensive exploitation of the resource was evident. The median (13.9%) is similar to the communal areas of the Otjozondjupa Region.

8.11.4 Impact of harvesting on the density of *Harpagophytum*

The results of the previous subchapter indicate a correlation of the abundance in *Harpagophytum* with the utilisation intensity. Greatest harvesting intensity is evident where patches of *Harpagophytum* occur. The frequency of patches is in this chapter used to analyse changes in the *Harpagophytum* resource in the different vegetation types and types of land ownership that are a result of harvesting activities. These are calculated on the basis of potential individual numbers (plants and holes) and are compared with the patch densities (plant numbers, Fig. 45, 46).

Private farmland of Namibia (Fig. 45):

Patches of *Harpagophytum* may occur in the Thornbush Savanna, the Highland Savanna and the Camelthorn Savanna with the highest density of non-utilised patches being in the Thornbush Savanna and the Camelthorn Savanna.

In the Thornbush Savanna harvesting resulted in a conversion of 22% of the patches into a scattered occurrence of the species. Dense patches with 21-50 individuals/transect were converted through harvesting by more than 20%, while very dense patches (>50 individuals/transect) did not show any impact of exploitation.

In the Highland Savanna the frequency of patches was reduced through harvesting by 10%.

In the Camelthorn Savanna some very dense patches (>50 individuals/transect) were converted into dense patches (21-50 individuals/transect).

Communal areas of Namibia (Fig. 45):

As a result of harvesting changes in patch density were evident for two out of three vegetation types.

For the Tree Savanna and Woodland a small percentage of patches was reduced to a scattered occurrence of *Harpagophytum* by harvesting.

For the Camelthorn Savanna only a decrease of dense patches was detectable which were transferred to more open patches with 10-20 individuals per transect.

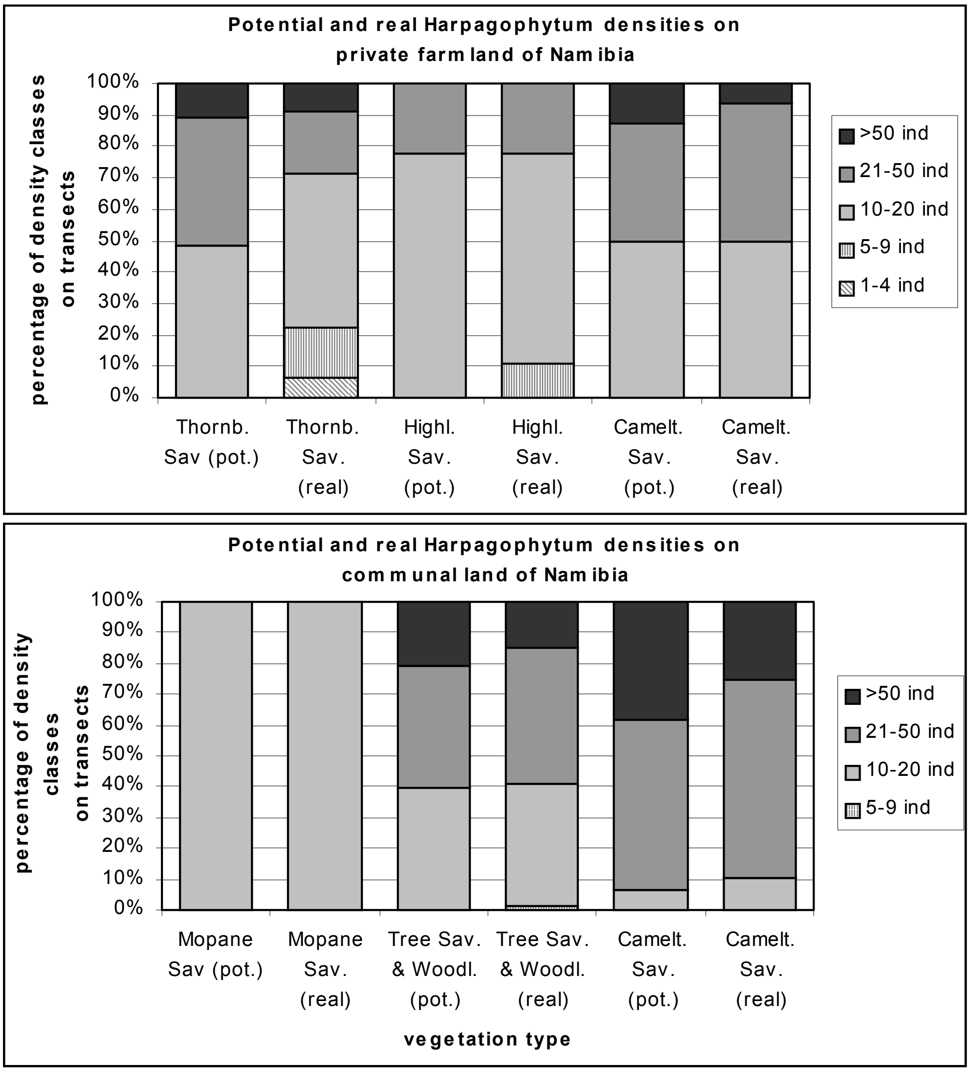


Fig. 45: Potential and real occurrence of patches of *Harpagophytum* in vegetation types of communal and private land in Namibia.

Private farmland of South Africa (Fig. 46):

Generally very few changes of patch structures due to an utilisation of *Harpagophytum* were visible. Patches occurred in four vegetation types, of which only the Shrubby Kalahari Dune Bushveld and the Kalahari Plains Thorn Bushveld experienced a reduction in patch density due to harvesting. There, harvesting led to a transformation of less than ten percent of the patches to a scattered occurrence of *Harpagophytum*.

Communal areas of South Africa (Fig. 46):

The impact of harvesting was most prominent for the Karoid Kalahari Bushveld, the Kalahari Plains Thorn Bushveld and the Kalahari Plateau Bushveld.

On one harvested site in the Karoid Kalahari Bushveld, all patches with formerly 10-50 individuals/transects were either completely destroyed and no plant individuals were left at the time of observation (21%) or patches were reduced to a remaining number of only 1-9 individuals/transect.

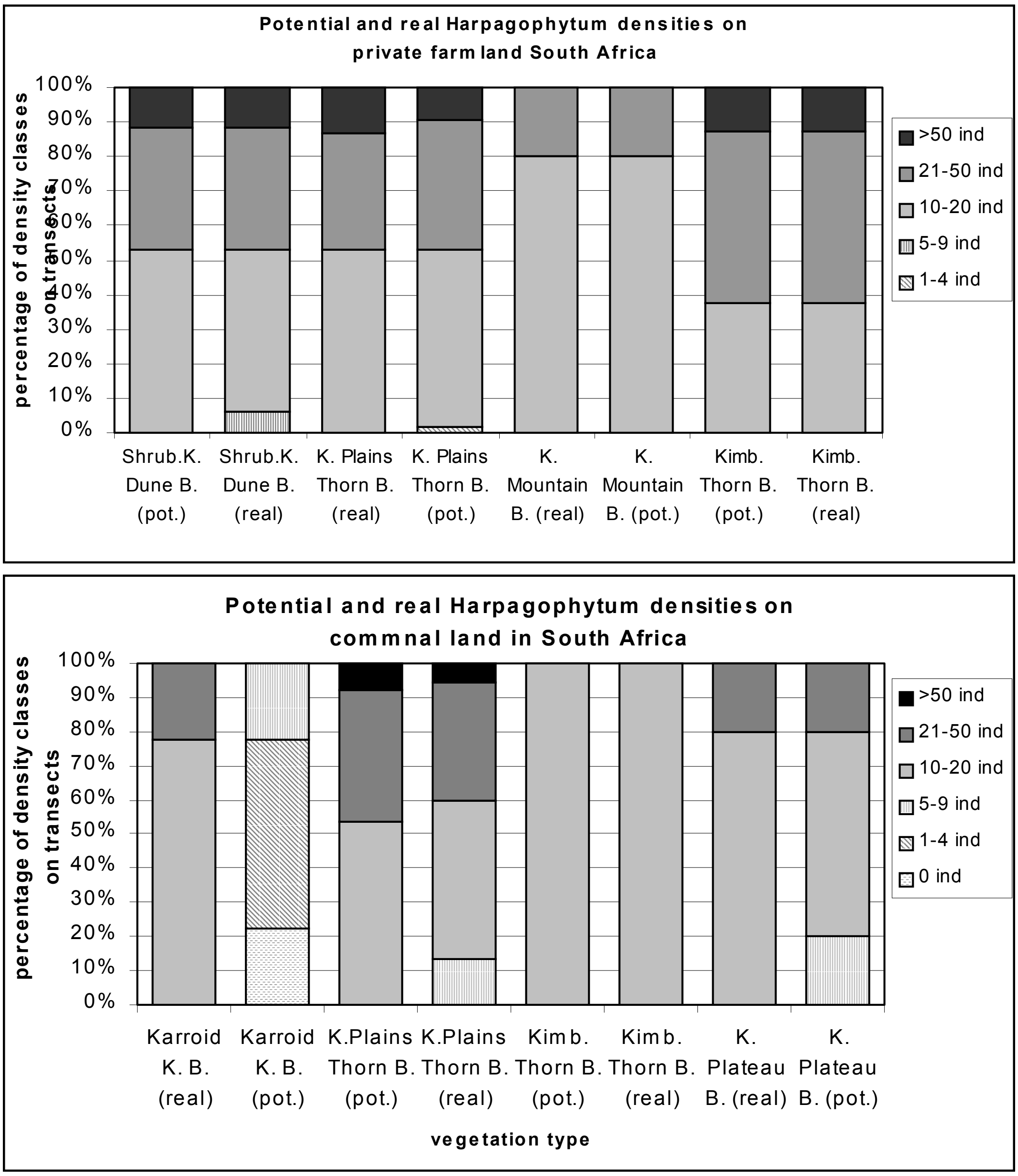


Fig. 46: Potential and real occurrence of patches of *Harpagophytum* in vegetation types of communal and private land in South Africa.

In the Kalahari Plains Thorn Bushveld where several very dense patches were found, harvesting was responsible for the change of 10% of the patches to a scattered occurrence of single individuals.

Only one site in the Kalahari Plateau Bushveld housed patches with more than 10 individuals. On these, harvesting reduced individual numbers on the transects to 20%.

Summarizing it can be concluded that harvesting may destroy patchy patterns of *Harpagophytum*. This was in particular evident in the Thornbush Savanna of private farmland in Namibia, and to a lower extent also for the sites in the Tree Savanna and Woodland and the Camelthorn Savanna. For South Africa, only in the communal areas harvesting reduced spatial aggregations of *Harpagophytum*.

8.11.5 Analysis of variance in the utilisation of *Harpagophytum*

A non-parametric analysis of variance was carried out to test the significance of differences in the utilisation intensity of *Harpagophytum* for the research areas, habitat types, vegetation types of Namibia and South Africa, and the grazing intensity classes. For this, the Kruskal-Wallis-Anova Test was applied (Tab. 33).

Tab. 33: Kruskall-Wallis-ANOVA Test on the significance of difference in the utilisation intensity of *Harpagophytum* in research areas, habitat types, vegetation types and grazing intensity classes.

Difference of utilisation intensity in:	**H (degrees of freedom, sample size)**	**p**
Research areas	H (3, N= 972) = 81.9636	p =.0000
Habitat types	H (6, N= 967) = 26.5649	p =.0002
Namibian vegetation types	H (6, N= 555) = 44.1056	p =.0000
South African vegetation types	H (6, N= 417) = 120.3768	p =.0000
Grazing intensity classes	H (6, N= 966) = 61.9404	p =.0000
p<0.01= highly significant		

The Kruskal-Wallis-Anova Test (Tab. 32) supports the existence of a significant difference between the research areas with respect to the utilisation intensity of *Harpagophytum*. Already in Chapter 8.11.2.2 strong variations in the data ranges, but not in the medians were discussed for the communal and private land of both countries.

The result of the test stresses the highly significant difference in the utilisation intensity of different habitat types. The analysis of the role of the habitat types (dune base, dune crest, dune slope, interdune, plain, roadside, Omuramba) for the occurrence and density of *Harpagophytum*, showed that exploitation of the species is predominantly restricted to plain habitats. Only occasionally the species also grows at the dune base and lower slope areas. In the field, signs of harvesting activities were only detected for plain habitats.

Also for the various vegetation types in Namibia the intensity of harvesting in relation to the potential resource availability of *Harpagophytu*m indicates a strong and highly significant difference. Similar results were found for the vegetation types of South Africa, respectively.

A significant correlation was not only evident for the grazing intensity classes with the resource density, but also with the harvesting intensity of the resource. The role of land use for the occurrence and density of *Harpagophytum* is focus of Chapter 8.7.

8.11.6 Summary and conclusions on the utilisation of *Harpagophytum*

A strongly varying but typically limited resource exploitation in comparison to a much higher resource availability is evident for *Harpagophytum*. The majority of research sites (75% of all data) showed that between 0-16 (private farmland Namibia), 0-36 (communal areas Namibia), 0-1 (private farmland South Africa) and 0-29 (communal areas South Africa) digging holes occur on a square kilometre. Nevertheless, maximum numbers of digging holes partly reached impressive quantities such as 226 holes/km² on private farmland and 416 holes/km² on communal areas of Namibia. In South Africa, a maximum of 168 holes/km² was recorded.

The exploitation level of *Harpagophytum* was determined as portion of harvesting holes on the total potential resource. The potential resource quantity itself was calculated as sum of the number of plants and the number of digging holes for each research site. Results make clear that at least for the year of documentation on one quarter of all sites between 25-50% of the potential resource had been removed by harvesting. One exception is the private farmland in South Africa where no such harvesting intensity was evident. The greatest impact of harvesting was recorded for the communal areas of Namibia, where a large percentage of sites was characterised by a high level of exploitation. Even though for all research areas the intensity of the resource exploitation may partly cover 88-100% of the potential resource, the utilisation intensity is highly variable. On many sites up to date no utilisation of *Harpagophytum* takes place.

The intensity of the exploitation of wild populations of *Harpagophytum* in different regions and provinces emphasises that harvesting concentrates on certain areas only. In Namibia, the Otjozondjupa Region experienced the highest harvesting pressure of both, private and communal farmland. In particular in the Namibian communal areas (mainly the Okakarara area) partly 100% of the potential resource was harvested. In South Africa so far no serious impact of harvesting is evident on the private farmland. Yet, some harvesting does take place in the Kuruman area of the Northern Cape Province, which may increase in future: Several farmers uttered their interest to gain additional income by the harvest of *Harpagophytum* on their farm, whereas others were concerned about the resource and restrict any harvesting activities on their land. In the South African communal areas, harvesting takes place to a considerable extent. Especially in the North West Province, exploitation of the secondary tubers has taken up recently. These attempts are supervised and accompanied by official authorities from Nature Conservation who aim at both, a sustainable extraction of the tubers and an income generation by the communities.

In general, harvesting of the secondary tubers of *Harpagophytum* differs with respect to occurrence and density of the species. Harvesting focuses on areas with a great resource density. This is not only supported by the finding that the highest resource utilisation is evident in the Omaheke Region, but is also proved by the positive and highly significant relationship between the number of individuals of *Harpagophytum* and the number of harvesting holes on the transects. It seems that commercial harvesting is only applied where a large resource of *Harpagophytum* is available and distances between the patches to be exploited are limited.

Harvesting may result in changes of population patterns with a destruction of patchy aggregations of *Harpagophytum* that leads to a subsequent scattered pattern of single individuals. This was particularly evident for the sites in the Thornbush Savanna of Namibia (on private farmland) and sites in the Tree Savanna and Woodland and the Camelthorn Savanna (on communal land). In South Africa, only in the communal areas harvesting was responsible for a change of the patchy pattern of *Harpagophytum*, i.e. in the Karoid Kalahari Bushveld, the Kalahari Plains Thorn Bushveld and the Kalahari Plateau Bushveld.

The significant differences in the utilisation intensity of *Harpagophytum* with respect to the habitat and vegetation type as well as the land use intensity accounts for this finding as also the resource varies with respect to these. It can be concluded that no uniform level of utilisation in *Harpagophytum* exists for southern Africa. Instead, the resource density as well as the utilisation intensity of the resource concentrates on a selected range of vegetation types and certain land use tenures.

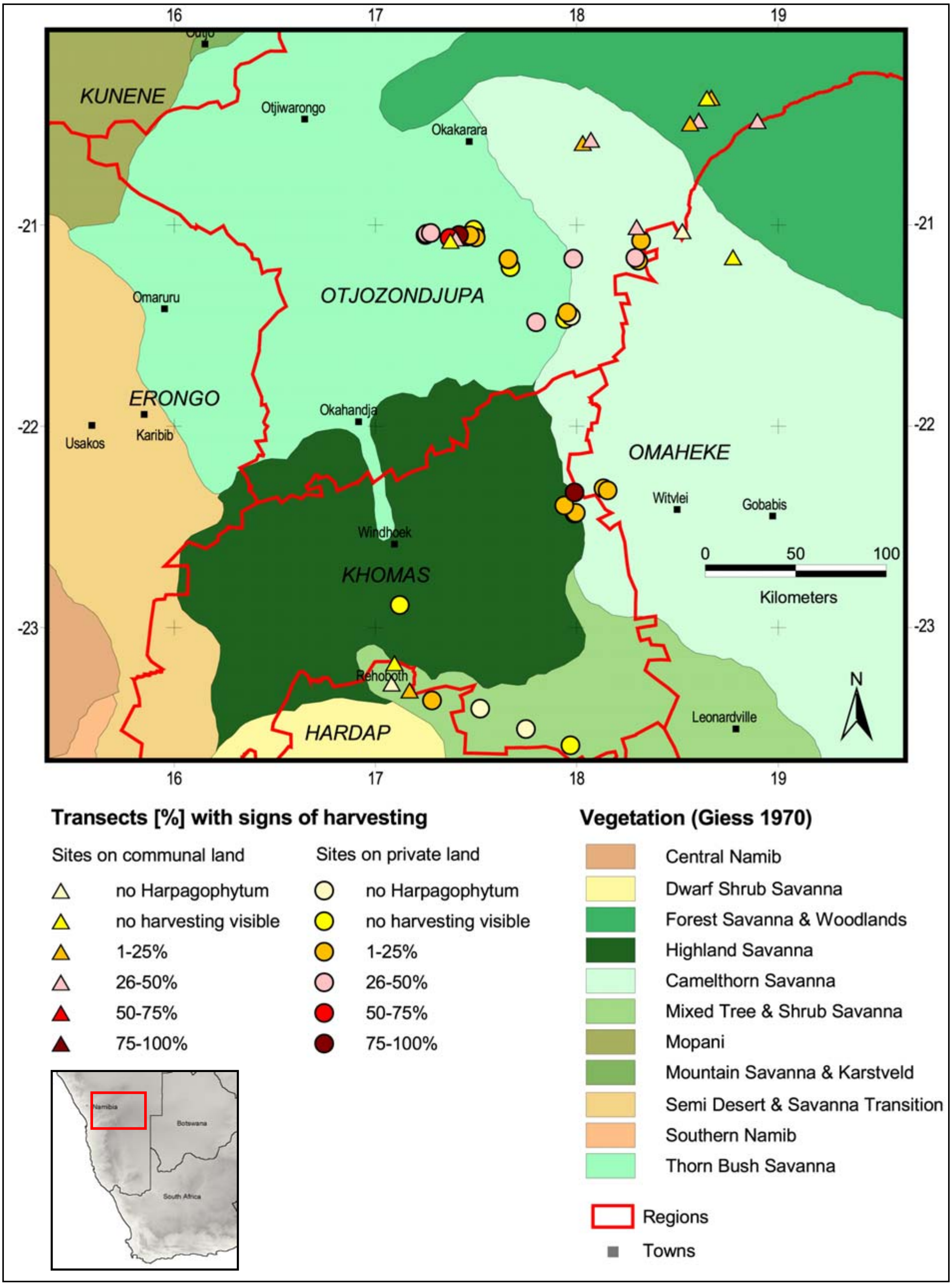


Fig. 47: Harvesting intensities on 1km²-sites on communal & private land of Namibia.
Map Source: GIESS (1970), AGRO-ECOLOGICAL ZONING PROGRAMME (2001).

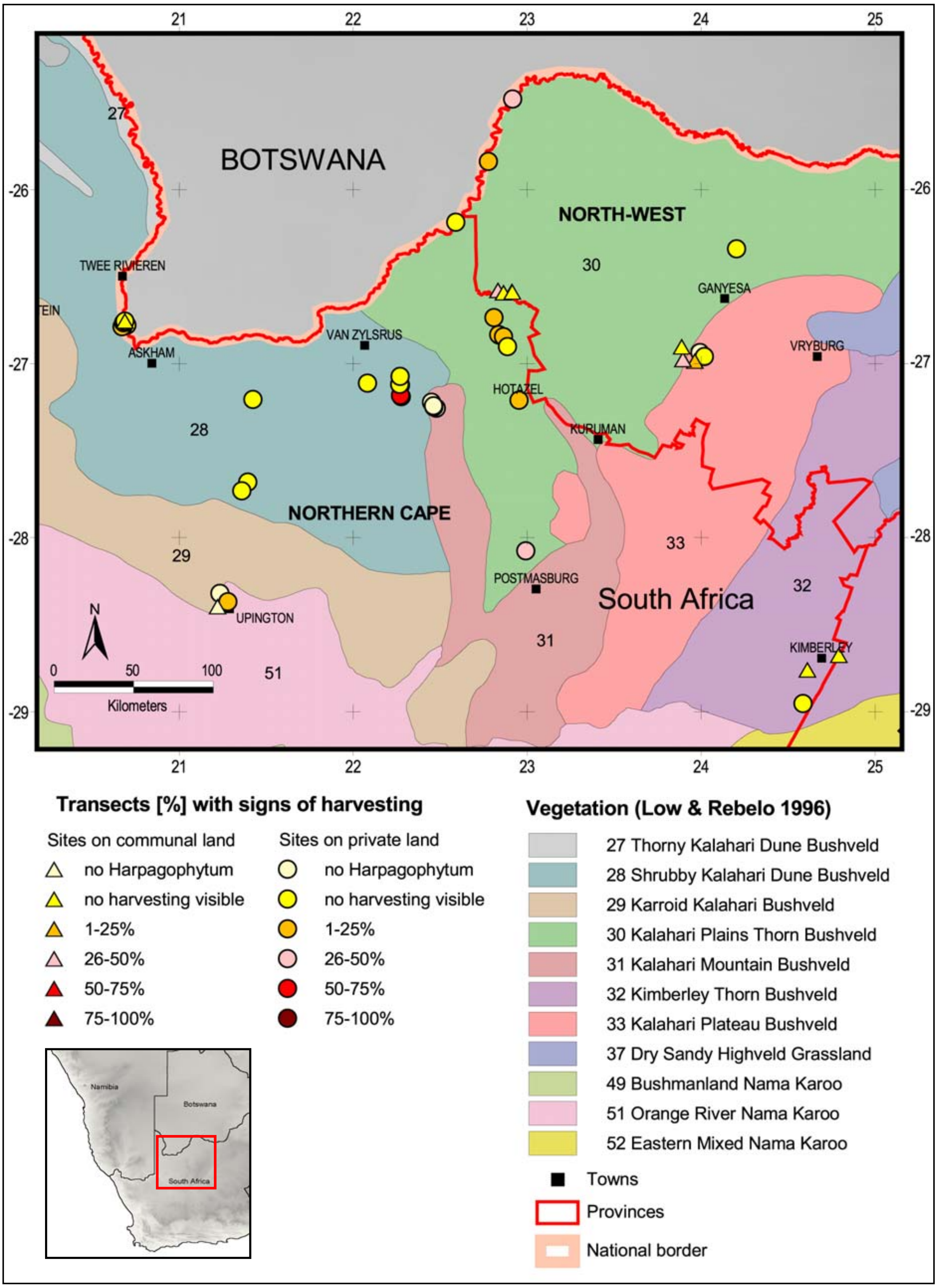


Fig. 48: Harvesting intensities on 1km²-sites on communal & private land of South Africa.
Map Source: LOW & REBELO (1996).

8.12 Discussion and conclusions on the ecology of *Harpagophytum*

This chapter summarises and discusses the results of the assessment of *Harpagophytum* on the one square kilometre sites in communally and privately owned land of Namibia and South Africa. Special focus is put on the discussion of factors influencing the spatial distribution of *Harpagophytum*. Important results are inserted followed by an interpretation and discussion of the findings.

8.12.1 Resource availability of *Harpagophytum*

In general, *Harpagophytum* occurs more frequently and with a greater abundance in communal in comparison to private farmland. The greatest resource density is evident for communal areas of Namibia.

It has to be distinguished between distribution patterns on the small scale within a few hundred metres and patterns on the landscape level (Fig. 49).

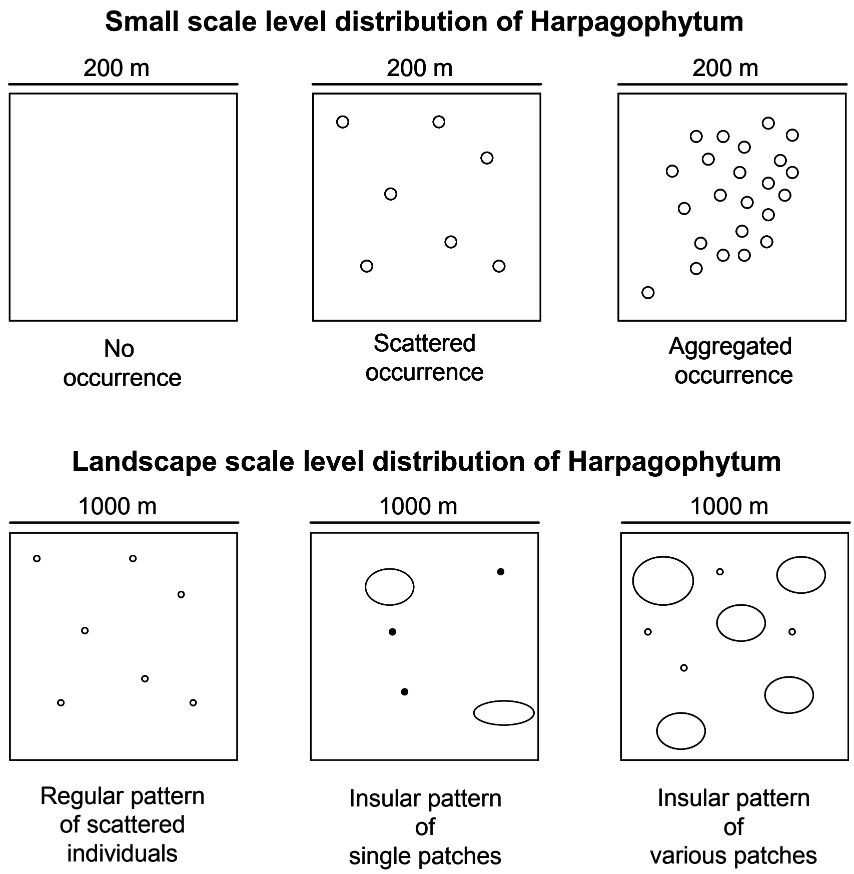


Fig. 49: Scheme of distribution patterns of *Harpagophytum* on the small-scale-level with a lack, a scattered occurrence and an aggregated occurrence, and on the landscape level with regular and insular patterns. Dots represent single plants, circles represent patches of *Harpagophytum*.

Spatial patterns of *Harpagophytum* on the small-scale comprise

(a) patches or aggregations of *Harpagophytum* (>10 individuals/transect),

(b) a scattered occurrence of single individuals (1-9 individuals/transect), and

(c) a lack of *Harpagophytum.*

The spatial distribution patterns show different priorities in occurrence. In particular insular growth pattern (patches) seem to have a limited distribution and higher requirements to environmental conditions.

(a) Patches:

- Patches of *Harpagophytum* occur on approximately 50% of all research sites irrespective of the country and land ownership.
- On private farmland patches occur only occasionally and are restricted to few transects per square kilometre (a maximum of 10% of the transects).
- In communal areas *Harpagophytum* patches are evident twice to three times as often as on private farmland (often on more than 30% of the transects). In the communal areas of Namibia dense patches are most frequent.
- Patches may vary in their densities. The photo in Figure 42 shows a very large and dense patch in the communal Okakarara area in the Otjozondjupa Region of Namibia.

(b) Scattered occurrence:

- A scattered occurrence occurs irrespective of the country and land ownership.
- On private farmland *Harpagophytum* is more often restricted to a scattered growth pattern in the landscape.

(c) Lack of *Harpagophytum*

- *Harpagophytum* may be missing in all vegetation types and types of land ownership.

On the landscape level, a scattered occurrence of single individuals will result in a regular pattern of *Harpagophytum* in the landscape, respectively on the one-square kilometre research sites (Fig. 50). Patches will not cover the entire landscape but will occur additional to single individuals. This insular pattern may either be composed of few patches in a matrix of single individuals, or may be - in a high resource area - characterised by various patches parallel to single individuals on the landscape level.

Fig. 50: Patch of *Harpagophytum* (highlighted by red circles) on a communal farm in the Okakarara area (Otjozondjupa Region) of Namibia.

Abiotic conditions

(a) Impact of the habitat

Seven habitat types were sampled in the course of the study. For the abundance of *Harpagophytum* the following was found:

- Plain habitats form the major habitat type for *Harpagophytum*. Next to simple plains, these include Omurambas (periodically flooded plains) and disturbed areas such as roadsides.
- The potential of *Harpagophytum* to develop dense patches is restricted to few habitat types. These are plains and in dune areas, the dune base and interdunes.
- A scattered distribution of *Harpagophytum* is evident in all sampled habitat types but is clearly also concentrated on plains.

Interpretation: A habitat type has no homogenous structure but in reality resembles landscape mosaics of several small habitat patches (HANSKI 1995). This implicates that the occurrence of *Harpagophytum* within plain habitats can be seen as consequence of several additional abiotic and biotic parameters such as interspecific competition by other plant species and soil water availability (e.g. EVENARI et al. 1971). For certain habitat types such as dune crests and steep dune slopes, which are characterised by their susceptibility to wind erosion and a more rapid evaporation of soil water (due to more intensive exposure to wind), it is assumed that they are too unstable to build up a long-lived seed bank of *Harpagophytum.* By this, seed germination as well as seedling establishment is limited. The finding that *Harpagophytum* may principally occur (as scattered single individuals) in all habitat types indicates that an occasional successful establishment may be possible also in habitats that are not generally suitable for *Harpagophytum*. Small-scale variation in habitat conditions and the availability of safe sites (e.g. under shrubs) may account for this. From these considerations it is concluded that a scattered growth of *Harpagophytum* is determined by interspecific, but not innerspecific competition.

(b) Impact of soil conditions

- *Harpagophytum* favours sand substrates with a varying loamy component.
- Predominantly white, yellow to brown and red soil colour hues occur on sites with *Harpagophytum.* While lowest resource density is evident on white soil substrates, highest occur on yellow-red and brown-red soils.
- pH values of *Harpagophytum* habitats range from slightly acid to neutral or slightly alkaline.

Interpretation: Several authors found similar results and report that red and yellow-red, sandy soils are preferred soil substrate for *Harpagophytum* (e.g. IHLENFELDT & HARTMANN 1970, VOLK & LEIPPERT 1971, TAYLOR & MOSS 1982, VEENENDAAL 1984). Yet, as this still covers a relatively broad range of soil conditions, further research is needed on small-scale variations of chemical and physical soil properties inside and between patches of *Harpagophytum*. In particular with respect to the duration of water availability in soil subsequent to rainfall further research could provide valuable information also on germination processes.

(c) Impact of precipitation

- The frequency and abundance of *Harpagophytum* increases with an increase in rainfall amount and predictability.
- In Namibia, *Harpagophytum* densities increase parallel to the rainfall gradient from south-west to north-east.
- In South Africa, *Harpagophytum* densities increase parallel to the rainfall gradient from west to east.

Interpretation: Due to its geophytic growth form *Harpagophytum* is able to immediately respond to single rainfall events. Therefore, only during the vegetative periods when all plant species have produced shoots, competition may have a negative impact on the occurrence of *Harpagophytum*.

In particular in areas towards the more arid fringes of the distribution area of *Harpagophytum*, where precipitation has a strongly limiting effect, this poses an advantage for geophytes in comparison to annual species. Contrarily, in areas with higher annual precipitation and lower evaporation rates, various perennial grasses and herbs will dominate the vegetation. Due to their perennial growth form, they continuously compete with the perennial geophytic *Harpagophytum* plants for soil water and nutrients. Results show that an increase in the frequency of *Harpagophytum* is positively related to precipitation only in the semi-arid areas where rainfall is highly erratic and unpredictable. Contrarily, in semi-humid areas competition will outweigh the advantage of the geophytic life form.

Biotic conditions

(a) Impact of the vegetation type

Harpagophytum occurs in various vegetation types. Results of the study indicate that a medium abundance of *Harpagophytum* is evident for all vegetation types. Among these, a comparatively higher resource occurs in Namibia in comparison to South Africa.

Namibia

Highest resource density exists in the communal areas of the northern-most research area with the highest annual rainfall (Tree Savanna and Woodland), whereas for the more arid areas the resource is significantly smaller (Mixed Tree and Shrub Savanna). On private farmland of Namibia, the highest abundance of *Harpagophytum* occurs in the Thorn Shrub Savanna.

South Africa

Greatest resource abundance of *Harpagophytum* is evident for the Kalahari Plains Thorn Bushveld for both, communal and private farmland. This area receives medium rainfall amounts (300mm/yr^{-1}) in contrast to the Kimberley Thorn Bushveld, where irrespective of the high annual rainfall (>450mm/yr^{-1}) only on one single site a dense patch of *Harpagophytum* has been recorded.

(b) Impact of surrounding vegetation layers

The following correlation were found between *Harpagophytum* densities and the vegetation layer:

- The density of the grass layer has a strongly limiting impact on the abundance and spatial dispersion of *Harpagophytum*.
- Contrarily, the herb layer increases parallel to an increase of *Harpagophytum*.
- The density of the shrub and tree layer is not correlated with the density of *Harpagophytum*.

Interpretation: This result indicates that grasses play a competitive role not only for the occurrence of *Harpagophytum* but also for the occurrence of herbs. This finding supports the conclusion made above that due to its geophytic growth form *Harpagophytum* is able to compete with herbs, but not with grasses. Low to medium grazing intensities favour the development of a variable density of the grass layer, while a strong to very strong grazing intensity results in a predominantly open grass layer. This was in particular evident for the communal areas of Namibia and to a lesser extent also for South African communal sites.

The population pattern of *Harpagophytum* is influenced in that

(a) Patches of *Harpagophytum* seem to be limited to areas with an open grass layer, which are typically due to a high grazing intensity. This was especially obvious for the communal areas of Namibia, the Tree Savanna and Woodland and the Camelthorn Savanna.

(b) Scattered *Harpagophytum* individuals may occur independently of the density of the grass matrix.

Interpretation: The significant correlation between the patch occurrence of *Harpagophytum* and the vegetation type in Namibia, suggests that interspecific competition plays an important role for the development of patches in *Harpagophytum*. The aggregation model by HANSKI (1995) describes a general mechanism of coexistence for competing species in mosaic landscapes. From this, it can be assumed that also the patchy occurrence of suitable habitats may be responsible for patch forming in *Harpagophytum*. HANSKI (1995) describes that spatial aggregations of habitat fragments facilitate the co-existence of species only, if the competing species do not have completely correlated spatial distributions.

(c) Impact of the vegetation density

It was observed that

- In extremely dense stands of *Harpagophytum* merely no other species occurred next to *Harpagophytum*.
- In medium dense patches other species may be associated with *Harpagophytum*.

Interpretation: Several authors describe interspecific competition to control the spatial pattern of *Harpagophytum* (e.g. WALTER & VOLK 1954, BLANK 1973, LELOUP 1984, ERNST et al. 1988). Next to interspecific competition, the minimum space required for each individual of *Harpagophytum* will determine the possibility of coexistence. Minimum distance between *Harpagophytum* individuals to avoid innerspecific competition is supposed to be 1.5m (BLANK 1973) or 1m² (FECHTER in BLANK 1973). SCHNEIDER (1997) states that innerspecific root competition normally suppresses the germination of seeds next to adult individuals of *Harpagophytum*. He found that seedlings are only able to emerge after the death of adult plants in the vicinity due to lower less innerspecific competition. For the same reason a South African farmer and exporter of *Harpagophytum* observed that shoots from new seedlings or dormant adult individuals of *Harpagophytum* emerged from the soil in the following year after the parent tubers have been removed while harvesting *Harpagophytum* (Olivier, pers. communication).

(d) Impact of land use

Land use intensity, determined by the grazing intensity in this study, plays an important role for the occurrence and resource status of *Harpagophytum*. The impact of land use is typically reflected by the changes in density and composition of the surrounding vegetation (e.g. HOFFMAN & ASHWELL 2001).

A comparatively higher grazing impact on the vegetation was recorded for communal areas in comparison to private farmland.

Land use impacts the spatial patterns of *Harpagophytum* in that

(a) *Harpagophytum* may grow at all grazing intensities and in all research areas, but its density is related to the grazing pressure of the vegetation.

(b) Patches of *Harpagophytum* tend to be limited to areas with a high grazing pressure on the vegetation. This is in particular evident for the communal areas of both countries.

(c) A scattered occurrence of *Harpagophytum* with single individuals growing widely spaced from each other may develop at all sampled land use intensities.

Interpretation: Also HARRISON & FAHRIG (1995) see a close relation between the disturbance rate and the patch lifespan of species. Patch lifespan itself is determined by the life span of the organisms inhabiting the patch (i.e., habitat). The authors see the importance of dispersal modes for patch forming and claim that patch sizes as well as inter-patch distances also have to be considered relative to dispersal distance (HARRISON & FAHRIG 1995).

For *Harpagophytum*, a direct relationship can be assumed between the grazing intensity and the mode of dispersal. The more dispersing vectors are available, the higher is the probability of a successful dissemination in *Harpagophytum*. Open areas induced by overgrazing will promote medium to long distance transport of the diaspore, not only by epi-zoochory but also by anemochory. A medium or long distance transport of the diaspore and a delay in seed release by the serotinuous fruits while these are still further distributed, may result in the germination of single seeds and thus lead to a scattered distribution of single *Harpagophytum* individuals. Trampling on the other hand, will encourage the breaking-up of the capsules and thus the sudden seed release of a great portion of seeds and their transport into deeper soil layers. By this, dissemination over a longer distance may be avoided, and as a consequence successful patch forming may occur. Thus, a lack of long distance dispersal may be crucial to the development of patches in *Harpagophytum*. Dense aggregations of *Harpagophytum* indicate a successful germination and establishment of seedlings in the near vicinity of each other.

Personal observations indicate that

(a) Patches of *Harpagophytum* can have an extension of few metres (3-5 plant individuals) to 200x200m (several hundred plant individuals). Patch frequency is restricted: On a farm of thousands of hectare in size usually only few clumped populations occur.

(b) The spatial distribution of single individuals of *Harpagophytum* is related to the habitat type, grazing intensity and vegetation types.

(c) A lack of *Harpagophytum* may occur at all types of land use, habitat, vegetation, and soil substrate.

The findings in this study for Namibia are well in line with other studies. For Namibia, NOTT (1986) found a typical scattered pattern of *Harpagophytum* with quantities of 5 plants/ha. Locally she also recorded patches with much higher numbers of a maximum of 1200 plants/ha. STROHBACH (1999) recorded quantities of 1-20 plants/100m² in harvesting areas on communal farmland in the Omaheke area of Namibia, which corresponds to a scattered as well as a clumped pattern of *Harpagophytum* similar to the finding of this study. BRUINE et al. (1977) assumed plant numbers of 5.5-7 plants/ha for the Keetmanshoop and Mariental area, which is equivalent to 0.6-0.8 plants per 100m². These quantities are comparable with the scattered occurrence found in this study. No data is available for South Africa.

A lack of *Harpagophytum* is not necessarily an indicator for unsuitable habitat conditions in general, but may have various other reasons: A complete absence of *Harpagophytum* in an area may be due to unfavourable climatic conditions and a lack of rainfall during the months previous to the documentation. However, a lack of individuals on only some transects at research site where *Harpagophytum* generally occurs, is most probably due to other than climatic factors. It is assumed that the patchiness of habitats properties such as soil water availability plays a major role (HANSKI 1995, HARRISON & FAHRIG 1995).

Summarizing, variations in the spatial distribution of *Harpagophytum* even on favourable soils and on suitable habitats indicate that extrapolations of individual numbers for a quantitative assessment of the total resource amount for a larger area difficult.

8.12.2 Reproductive effort of *Harpagophytum*

The production of flowers, fruits and viable seeds forms an important prerequisite for the persistence of populations of *Harpagophytum*.

(a) Reproduction

Results on the reproduction of *Harpagophytum* show the following:

- Reproduction of *Harpagophytum* occurs in all research areas.
- Only for the communal areas flower quantity is correlated to individual number of *Harpagophytum*.
- Total of reproductive organs at the time of documentation (of flowers and immature fruit) is positively correlated with plant numbers for all research areas but the South African communal land.
- Reproductive effort of *Harpagophytum* varies between the vegetation types, districts and regions.

Interpretation: Areas such as the Okakarara area (Otjozondjupa Region) of Namibia where dense populations of *Harpagophytum* can develop show a greater reproductive effort than areas where the occurrence of the species is limited. Consequently, the greater reproduction rate as well as the larger resource may lead to a more successful regeneration of *Harpagophytum* in comparison to low resource areas. The fact that harvesting may have a negative impact on this is discussed below. The mode and distance of dispersal may influence the development of patches, patch sizes and inter-patch distances.

(b) Impact of plant size

- The plant size has an impact on the flowering intensity of *Harpagophytum* since only individuals with large shoot growth produce flowers.

Interpretation: Generally, shoot diameter cannot be used as an indicator for the age of the individuals. Yet, different classes of above-ground shoot sizes within a patch and under similar habitat conditions can be interpreted as composition of different age classes (LELOUP 1984). Only when patches comprise individuals of various ages, a constant regeneration potential and thus a stable population structure can be assumed (e.g. HARPER 1977).

(c) Seed bank

Fruit development and seed production are important phases of the reproductive cycle. The calculation of contributions to the seed bank, which was based on seed counts of various authors (BLANK 1973, DE JONG 1985, Titiema 1986, Ernst et al. 1988) revealed that

- Highest seed production per area occurs in areas where the greatest resource is available.
- Highest seed production (a mean of 600-1000 seeds/km²) is evident for communal farmland of the Okakarara area in Namibia (Tree Savanna and Woodland) in contrast to a mean of only 100 seeds/km² on Namibian private farmland and a mean of 380-600 seeds/km² on South African sites.
- When combining seed numbers of old and young fruits, up to a mean of 1700-3900 seeds/km² contribute to the seed bank of *Harpagophytum* in the Namibian communal areas. Contrarily, for the

Namibian private farmland no increase is evident and for South African research sites this was very limited (mean of <1500 seeds/km²).

Interpretation: Results indicate that in some areas very high seed amounts per year may contribute to the seed bank of *Harpagophytum*. Yet, germination rates in the species are very low with 1.4% (DE JONG 1985) or 1.4-5.7% (ERNST et al. 1988). Even at optimal experimental conditions with a germination rate of 1.4% less than 10 seedlings would germinate on 24 transects/km². Under natural conditions, additional factors to the low germination rate will have an impact on seed germination. These are success in seed release, placement of seeds at a suitable habitat site, transport to deeper soil layers, favourable rainfall conditions for germination, and a lack of seed predation. It can be expected that under natural conditions seed germination is much lower than 1.4%. Additionally, seed production may vary greatly between the years depending on the annual precipitation. This is supported by HULZEBOS (1987) who found that fruits tend to mature slower under dry conditions with many fruits aborting before ripening. In areas with many reproductive individuals, the long viability of seeds of *Harpagophytum* may eventually sum up to considerable amounts of seeds in the soil seed bank, which may theoretically allow a regeneration even decades after their production. Sampling of the seed bank of various areas and the determination of the total fruit-set throughout a vegetation period could bring more information on soil seed densities in patches and between patches of the plant.

8.12.3 Utilisation of *Harpagophytum*

Next to the destruction of suitable habitats (e.g. by conversion into cropping fields), climatic constraints and the increasing exploitation of *Harpagophytum* by harvesting may pose a threat to the plant.

(a) Harvesting

Results indicate the following:

- Harvesting of *Harpagophytum* is evident for the majority of research sites of both countries.
- In general, a strongly varying but typically limited resource exploitation in comparison to a much higher resource availability is evident.
- Currently, between 24-42% of the potential resource (number of plants and holes per site) have been removed on one quarter of all sites (with the exception of the South African private farmland).
- Although harvesting intensity is restricted on many sites, destructive removal of plants may partly reach impressive quantities of several hundred holes/km².
- At some sites resource exploitation in *Harpagophytum* reaches 88-100% of the potential resource available.
- For Namibia, highest level of utilisation is evident for the eastern part of the Otjozondjupa Region. Harvesting pressure is greater in the communal areas, in particular the Okakarara area, than on private farmland.
- For South Africa, harvesting activities on private farmland can currently be neglected, but may take up in the coming years. For the communal areas an impact of harvesting is detected to a considerable extent for the North West Province.

Also POWELL (2002), Nature Conservation Northern Cape Province, and VAN DER VYVER (2002), Nature Conservation North-West Province, report an increasing demand of secondary tubers from the South African communal areas.

(b) Future resource availability

With respect to the future resource availability the following can be stated:

- Irrespective of the partly high harvesting pressure, in many of the sampled areas no utilisation of *Harpagophytum* takes place so far.
- The level of exploitation is related to the density of *Harpagophytum.* Harvesting is highest in areas with the greatest resource. For Namibia, these are the communal areas of the Otjozondjupa Region. For South Africa, these were the communal areas of the North West Province.
- Harvesting intensities vary depending on the habitat type, vegetation type and land use intensity.
- As higher grazing pressures on the matrix vegetation resulted in a decrease of the grass cover and this, again, favoured the occurrence of *Harpagophytum*, land use intensity is positively related to the density and utilisation of *Harpagophytum*.

8.12.4 Regeneration potential

Based on the observation that the exploitation intensity of *Harpagophytum* depends on the availability of the resource, it is concluded that dense patches of *Harpagophytum* are in particular susceptible to exploitation. This is supported by the finding that

- A disintegration of the patch structure of *Harpagophytum* induced by harvesting can be identified for several areas.
- In various vegetation types, detrimental harvesting activities resulted in the conversion of patches to a scattered occurrence of *Harpagophytum*.

Typically plants with a large parent (main) tuber are harvested (for a higher yield of secondary tubers). As the parent tuber diameter is an indicator for the age of the plant, harvesting will result in a change of the population composition with respect to age classes in *Harpagophytum*.

Interpretation: LELOUP (1984) found that patches of *Harpagophytum* comprise individuals with large and small caudexes, indicating the occurrence of different age classes within a population. Individuals with similar tuber diameters are likely to have originated from seed, which germinated during the same rain event. He demonstrated that plants of *Harpagophytum* are more vigorous with increasing age and that flowering and forming of fruits only start when the parent tuber has reached a certain diameter. As populations are more robust the more heterogeneous they are, it is expected that harvesting will influence the vigour of *Harpagophytum* populations. It is not known so far, which time periods are needed for the regeneration of a patch previously segregated by harvesting. Furthermore, the minimum resource density of reproductive individuals needed for re-colonisation of previously harvested habitats is not known. Both will depend on several abiotic factors, in particular on precipitation amount and frequency but also on biotic factors such as dispersal patterns and competition.

For a potential regeneration of over-exploited areas the following should be considered: Theoretical models such as the meta-population (DANIELSON 1992) show that whenever there are at least one to few large patches (habitat patches) for which population survival is ensured, these patch populations can act as a permanent source of diasporas for populations at other, less suitable (habitat) patches (sink population) and may ensure the survival of the population on the landscape level (meta-population) (HARRISON 1991). If the areas between suitable habitats for a species are inhospitable to the transfer of diaspores, rates of diaspore input into the sink population are limited (HARRISON & FAHRIG 1995). For plants, dissemination strategies and dispersal distance would account for this. This would mean that after the devastation of a patch of *Harpagophytum*, a regeneration of the patch is only possible, if medium to long distance dispersal is successful and seeds from other patches are transported to the former patch site. However, distances between the patches should not be further apart than the potential dispersal distance. Also, the existent and long-lived seed bank of *Harpagophytum* may be able to induce regeneration at a overexploited site.

Yet, personal observations indicate that

- Regeneration of destroyed patches may take very long time and is often impossible.
- In areas (few hectares in size) for which a dense occurrence of *Harpagophytum* had been recorded previously to its clearing for crop-farming, even within a period of six years after the end of crop-growing, no individuals of *Harpagophytum* had re-entered the area (pers. observation, Namibia)
- On one farm in the North West Province, South Africa, irrespective of dense patches of *Harpagophytum* in the surrounding area of the farm, i.e. in the adjacent communal areas, which may have served as a source of diaspores, no regeneration of former populations were visible (pers. observation, South Africa).

Interpretation: These findings contradict HARRISON & FAHRIG (1995) who claim that positive effects of large (habitat) patches inhabited by individuals (here in the neighbouring communal areas) may outweigh the effects of increasing (habitat) patch isolation. For plants like *Harpagophytum* with a predominantly limited dissemination range, a low germination rate and a high risk in the seedling establishment due to low rainfall amounts, this hypothesis seems not to apply. LELOUP (1984) found that differences in population dynamics and in the reaction of *Harpagophytum* to the harvest appear to be mainly confined to difference in soil textures and not in patch sizes. He found the soil texture to be more important for population dynamics than the amount of rainfall, but he did not consider dissemination in the species.

Concluding, it can be expected that in addition to persistent or only very slowly (if at all) recovering human induced changes in the population size of *Harpagophytum*, natural fluctuations in the population density have to be taken into account. These typically depend on the amount of rainfall. The fluctuations may follow cycles, i.e., series of years with high or low rainfall. A series of years with low rainfall requires a certain time period for the recovery. Nothing is known so far about how long dormant individuals of *Harpagophytum* may be able to survive without resprouting. Only extensive long-term monitoring could give more insight into this. Annual fluctuation in the appearance of *Harpagophytum* will also affect the human impact on *Harpagophytum*. With respect to harvesting techniques as well as to the quantities harvested in dry years it is more probable that also the young plants with only a small main tuber are likely to be dug out. This is assumed to reduce the reproductive and regenerative capability of the population that is again needed to survive during and recover after the drought period.

9 Re-documentation of *Harpagophytum*

9.1 Approach

Long term monitoring of plant communities forms an essential prerequisite for the understanding of vegetation responses to both, long-term climatic changes and short-term anthropogenic or natural disturbances (GOLDBERG & TURNER 1986). In particular in arid, but also in semi arid regions, where unpredictable and episodic events such as precipitation are of crucial importance for the understanding of single species of plant communities, a continuous and long term monitoring can offer a useful and predictive tool (e.g. HENSCHEL & SEELY 2000). For the interpretation of today's vegetation patterns, the situation prior to the first scientific documentation needs to be known. Often this knowledge on the past resource utilisation of an area, a habitat type or a species, is only conserved at the scale of local individual memory. Occasionally, old photographs are used to overcome the lack of quantitative field data such as long-term permanent sites. The re-documentation of old photographs offers the chance to analyse changes between the past and today (e.g. HOFFMAN & COWLING 1990, HOFFMAN 1991, ROHDE 1997). Such comparisons proved to be able to contribute interesting results even on debates such as the spreading of biomes (HOFFMAN 1991).

In this study, old collecting sites of herbarium specimen of *Harpagophytum* were used to initiate a monitoring of the plant in Namibia. The re-documentation was done once for several sites while a number of selected sites were monitored over a period of three years. This re-documentation was considered a proper tool to investigate and evaluate potential changes in the occurrence and density of the species that have taken place in comparison to its former occurrence. The previous collecting sites chosen for re-documentation originate 17-37 years ago, dating back to a time period between 1962-1985. Baseline information on the densities of *Harpagophytum* at these first collections is based on personal communications. In particular, H.-D. Ihlenfeldt (Institute of Botany, University of Hamburg) conducted extensive collections of *Harpagophytum* in the 1960s and 1970s for a revision of the genus (IHLENFEDLT 1964, IHLENFELDT & HARTMANN 1970). Ihlenfeldt kindly contributed most information on the original resource density and utilisation of *Harpagophytum.*

Using the approach of a direct comparison of the status of single populations at the time of original specimen collection and today, it was aimed at a better understanding of the year to year changes in the occurrence of *Harpagophytum,* their extents and causes. The regeneration capacity of the geophytic plant after drought and harvesting was investigated. The comparison of densities of *Harpagophytum* in the past and today enables to understand how persistent the effects of harvesting are on the species.

As several previous collecting sites are located in areas for which harvesting had been reported for the past, the re-documentation was able to test, whether the exploitation of *Harpagophytum* resulted in changes of the populations. Comparison of data of the different periods of observation was used a) for the estimation of a possible decrease of *Harpagophytum* over the past decades and b) for the estimation of the regeneration potential of *Harpagophytum* after harvesting.

Here, results are presented on a) the single re-documentation of several old collecting sites in Namibia in the year 1999, and on b) a three year monitoring of a selection old collecting sites in Namibia.

9.2 Methods

9.2.1 Field campaigns

Fieldwork was conducted in three vegetation periods, i.e. from February to April in 1999-2001. While in 1999 a number of 29 sites was re-visited in Namibia, in the following years monitoring concentrated on nine of these sites.

Rainfall previous to the documentation in 1999 was very low, resulting in a generally sparse vegetation cover at the research sites. In the years 2000 and 2001, rainfall varied strongly between the research sites. Depending on the date of documentation, precipitation ranged from low to high amounts.

9.2.2 Methods of re-documentation

As the source data had been collected as single plant collections and not as comprehensive vegetation relevée, site descriptions varied greatly in detail with exact co-ordinates missing for all sites. Only collecting sites with detailed information available (either oral or written) on the locality and the former quantity of *Harpagophytum* could be included in the study. In the case of an unclear collecting location, more than one site was documented in the former collecting area. Where possible, old collecting sites with quantitative details available were preferably re-documented. H.-D. Ihlenfeldt kindly supplied data of his extensive data base on former *Harpagophytum* collecting sites. Other data on collections was contributed by the NBRI (National Botanical Research Institute) in Windhoek, Namibia. Due to the variable collecting methods and inaccuracies in the location information (no detailed GPS references available), the re-documentation could not be based on a homogenous plot design. Instead, the linear transect method was applied.

The following methods were applied:

- First impression: general walk through the collecting area to determine occurrence and spatial patterns of *Harpagophytum*.
- Linear transect walks: counts of individuals of *Harpagophytum* on 100*2m transects. In the case of a lack of individuals on the general walk through the area, only few transects were done. In the case of the occurrence of *Harpagophytum*, several walks were recorded. Each year the same number of transects was walked for each site, but variations occurred between the sites.
- Additional information collected on transects: details on the size of populations and individuals of *Harpagophytum*, including plant size, flower and young fruit quantities as well as the occurrence of old detached fruits.
- Habitat description: documentation of surrounding vegetation including major growth forms and species composition.
- Location: GPS co-ordinates (start and end) parallel to a detailed site description of each transect walk.
- Impact of harvesting: Identification of manmade digging holes in the field. Typically, these are visible for at least two years after the harvest (Chapter 8.11).

For the comparison of the old and current data sets, no exact counts of individuals could be used as the source data does not contain information on exact individual numbers. Therefore, source data information was divided into broad quantity categories:

(a) Lack of individuals

(b) Sporadic or common occurrence

(c) Patches

(d) Very dense patches

9.3 Research areas

The re-documentation of the 29 former collecting sites was done in four regions in communal, private farmland and state land of Namibia (Tab. 34). Nine sites for which monitoring continued also for the years 2000 and 2001 are located in four regions.

Tab. 34: Research areas of the re-documentation sites documented in 1999 and in 1999-2001 in Namibia.

Region	**Number of re-documentation sites**					
	Private farmland		Communal area		State land	
	1999	2000+2001	1999	2000+2001	1999	2000+2001
Erongo Region	5	2	–	–	–	–
Hardap Region	3	–	2	2	–	–
Khomas Region	11	4	–	–	2	1
Omaheke Region	8	–	–	–	–	–
Total	27	6	2	2	2	1

The map in Figure 51 shows the location of the re-documentation sites in the different regions and various vegetation types following the classification of GIESS (1970). Sites that were documented once and sites, which were documented over a period of three years, are highlighted by a different colour.

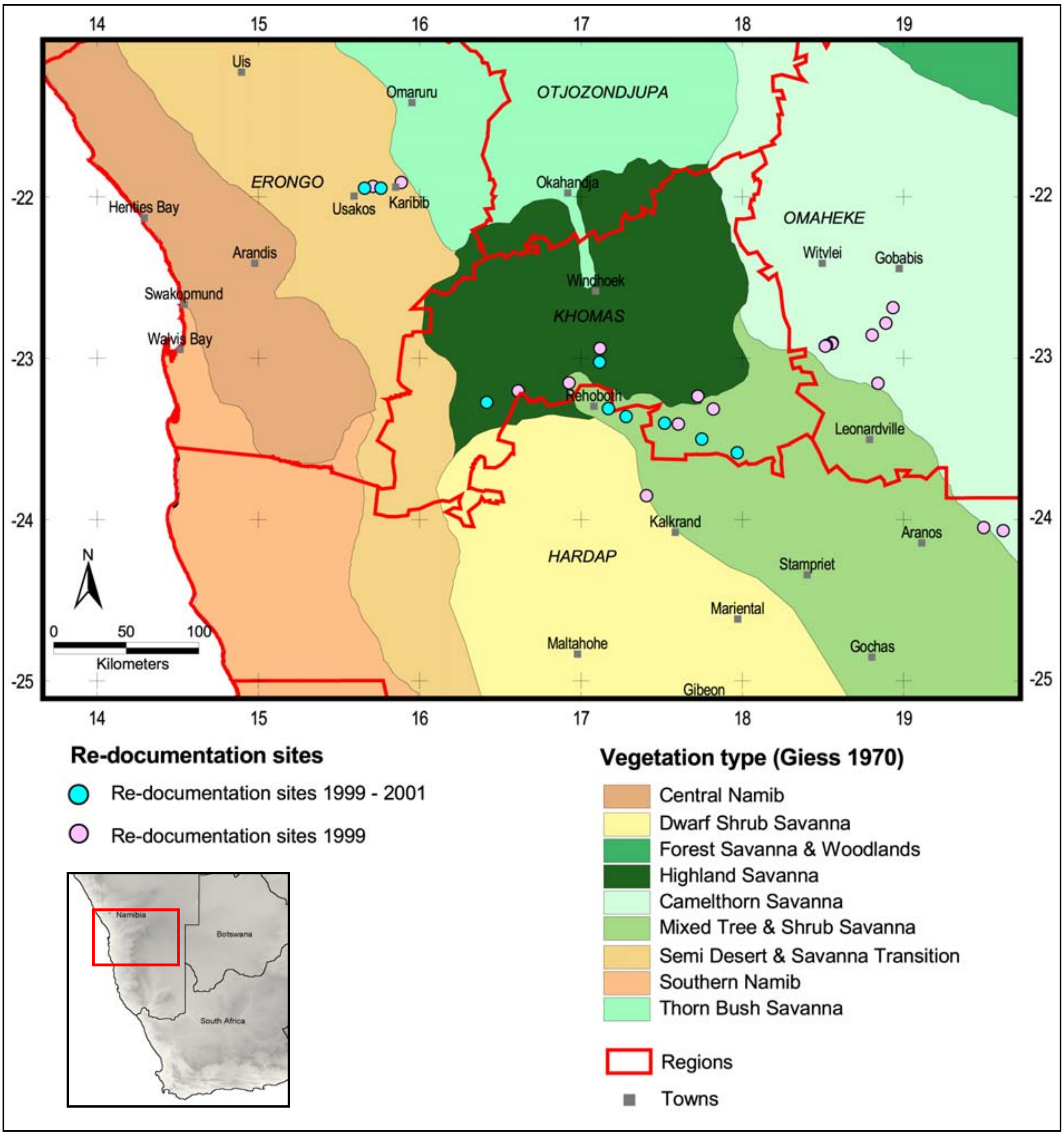


Fig. 51: Location of the re-documentation sites in Namibia. Map Source: GIESS (1970), AGRO-ECOLOGICAL ZONING PROGRAMME (2001).

9.4 One-year re-documentation of *Harpagophytum*

9.4.1 Results

9.4.1.1 Changes in *Harpagophytum* quantities

Comparing the population densities found in 1999 with those at the time of the first documentation (documented by other authors) changes in the density of *Harpagophytum* are evident for a considerable number of sites (Tab. 35). On 62% of the sites with a former occurrence of *Harpagophytum* some decades ago, no plants were found in 1999. On other sites a sporadic occurrence or occasionally also patches of *Harpagophytum* were still found today.

Tab. 35: Number of sites with *Harpagophytum* recorded on old collecting sites by number of sites with *Harpagophytum* in 1999.

Plants in old collection	**Plant quantities in 1999**			**Total**
	None	**Sporadic**	**Patches**	
No of sites	18	8	3	29
[%]	62.1	27.6	10.3	100.0

Tab. 36: Quantities of and changes in the occurrence of *Harpagophytum* found in the different Regions of Namibia in old collections and at the re-documentation in 1999.

Region	**Quantity in old data**	**Quantities in 1999 (on 1km^2)**			**No. of sites**		
		0 ind.	1-5 ind.	>30 ind.	No changes	Changes	No Info
Erongo	Sporadic	1	1	–	1	–	4
	Patches	2	–	–			
	No data	1	–	–			
Hardap	Very dense patches	–	2	–	–	2	3
	No data	3	–	–			
Khomas	Common	1	1	1	3	4	4
	Patches	–	1	–			
	Very dense patches	3	–	–			
	No data	1	3	–			
Omaheke	Patch	–	–	2	2	–	6
	No data	4	2	–			
Total		16	10	3	6	6	17

Changes in the density of *Harpagophytum* over the past decades varied between the four regions sampled (Tab. 36). Table 36 lists the quantities of *Harpagophytum* on old collecting sites, compares these with the quantities/1000m^2 found in 1999 and interprets whether meanwhile changes in the individual density occurred. Individual numbers/transect were added and a mean of individual numbers/1000m^2 was calculated.

Table 36 indicates the following:

- Erongo Region: For collecting sites in this region, the source data only states a sporadic occurrence or single patches of *Harpagophytum*. No changes in the resource status were found with the re-documentation in 1999.
- Hardap Region: Contrarily, on two sites near the town of Rehoboth, a decrease of the resource from very dense patches to a scattered growth of 1-5 individuals/1km² was detected.
- Khomas Region: Great variations in the density of *Harpagophytum* were reported for eleven sites, ranging from a common growth pattern to very dense patches. In 1999, on most of these sites not more than 1-5 individuals/1000m² were found. From this a reduction of *Harpagophytum* populations was concluded for four sites, whereas for three sites no change in the resource status was evident.
- Omaheke Region: Only for two sites density data was available from old collecting sites. For these, no changes in the densities of *Harpagophytum* were found.

9.4.1.2 Utilisation of *Harpagophytum* on re-documentation sites

An utilisation of *Harpagophytum* at the time of the first visitation of the sites was reported for five sites in the vicinity of the town Rehoboth (Tab. 37). Of these, plants were only visible on two sites in 1999. Current signs of harvesting were only evident for one re-documentation site.

Tab. 37 : Occurrence and utilisation of *Harpagophytum* on re-documentation sites in 1999 and in old data.

Occurrence and utilisation of Harpagophytum	No plants found	Plants found	Total
No utilisation visible in 1999	12	11	23
Utilisation visible in 1999	1	–	1
Utilisation reported for old data	3	2	5
Total	16	13	29

The harvested site is located in the Semi Desert and Savanna Transition in the Erongo Region, between the towns of Karibib and Omaruru. Vegetation cover at the site was sparse due to low rainfall quantities and possibly also a high grazing pressure. Only few herbs and grass individuals were encountered next to digging holes of *Harpagophytum*. Remnants of harvesting indicated the application of non-sustainable harvesting techniques. Large, and not closed-up holes were found together with dead plant material of *Harpagophytum*. The spatial distribution of digging holes was patchy with a maximum density of digging holes of 12 holes/1000m². No living plants were found. From this, it is concluded that harvesting activities had a detrimental effect on the *Harpagophytum* population in this area, which led to the disappearance of the species. Yet, from this single re-documentation a complete destruction of the population cannot be deduced. It is not known whether a regeneration of the species may occur in the area in high rainfall years, either by a re-sprouting of dormant adult individuals or by germination out of the dormant soil seed bank.

9.4.1.3 Environmental conditions at re-documentation-sites

In the previous chapter (Chapter 8) it was shown that the occurrence of *Harpagophytum* is closely correlated to the time and quantity of precipitation, to specific habitat and soil substrate types. Due to a lack of data on detailed rainfall amounts on the re-documentation sites, rainfall quantities for both, the former collecting and recent documentation data, can only be divided into three broad categories: low, medium and high rainfall amounts (Tab. 38).

Tab. 38: *Harpagophytum* quantities/km² recorded in 1999 at different rainfall quantities.

Rainfall in 1999	Individuals/1000m²			
	0 ind.	1-5 ind.	>30 ind.	Total
Low	10	7	2	19
Medium	5	2	1	8
High	1	-	-	1

In 1999, high rainfall was only evident for one site while most sites experienced low precipitation amounts. It is assumed that subsequent to the low rainfall, no or only few *Harpagophytum* individuals were found. High densities with >30 individuals/km² grew at three sites with low or medium rainfall quantities. Of these, two sites are located on plain habitats of a farm in the Camelthorn Savanna (Omaheke Region), which were characterised by few dense patches of *Harpagophytum*. The other site is located next to the main tar road (habitat type roadside) between Windhoek and Rehoboth, where one dense patch of *Harpagophytum* occurs. This site has been monitored over a period of three years (see Chapter 9.5).

In arid to semi-arid regions, precipitation represents the most prominent factor to influence the composition and density of the vegetation. In particular with respect to ephemeral species, precipitation accounts for great changes in abundance and dominance. At the re-documentation sites, in 1999, total vegetation cover on sites with an occurrence of *Harpagophytum* varied between 7,5% and a maximum of 60% with predominantly 35-45%. Grass and herb cover was in general low making up less than 10% of the vegetation cover. In contrast, on sites for which a lack of *Harpagophytum* was obvious in 1999, vegetation cover often reached up to 85%. In areas with sparse rainfall cover stayed below 30%.

Predominant documented habitat types were plains while dune habitats, pans, river edges and disturbed areas such as roadside were only samples with less than 20 transects each. Individuals of *Harpagophytum* were limited to four habitat types,

(a) Dune base

(b) River edge

(c) Roadside

(d) Plain

In comparison to the frequency of documentation, on plain habitats a comparably lower number of transects inhabited individuals of *Harpagophytum*.

9.4.1.4 Re-productive effort of *Harpagophytum* on re-documentation sites

The importance of the reproductive activity for the sustainability of a species population was focus of Chapter 8.10. It was shown that the reproductive effort and success of *Harpagophytum* has a significant influence not only on regeneration processes but also on spatial patterns, i.e. on patch forming, patch density or a scattered pattern of occurrence.

Also on the re-documentation sites, data on the reproductive effort of *Harpagophytum* (number of flowers, young fruit, old fruit) was recorded (Fig. 52). On only half of the thirteen sites with an occurrence of *Harpagophytum,* individuals were in the reproduction phase and produced flowers and young immature fruit. Flowering was restricted to few plant individuals at each site. Quantities of old fruits varied between single fruits every 100-200m and large quantities.

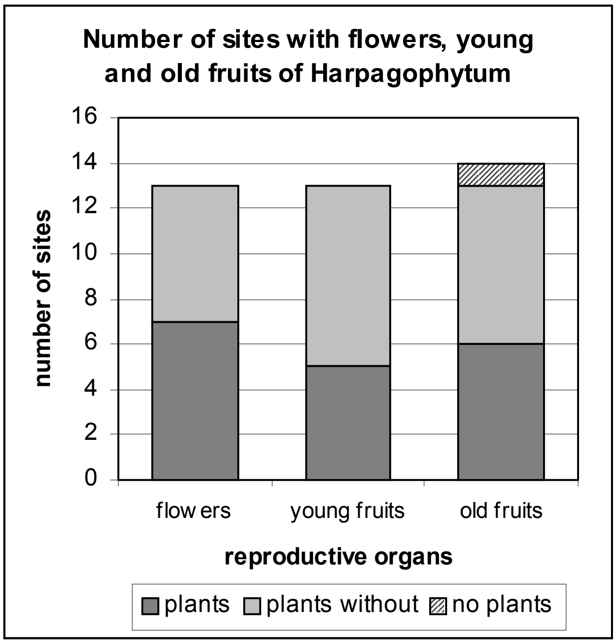


Fig. 52: Number of re-documentation sites with flowering and fruiting *Harpagophytum* plants and old detached fruits recorded in 1999.

At the time of documentation plant sizes on the research sites were usually small and with diameters of 5-15cm. It is assumed that the small plant size is responsible of the low flowering frequency. Already in Chapter 8 it was discussed that the above-ground plant size of *Harpagophytum* that is related to the age and vitality of the individuals as well as to the rainfall, is also a direct indicator for low water availability and thus low precipitation rates previous to the time of observation.

9.4.2 Summary and conclusions on one-year re-documentation of *Harpagophytum*

For the investigation of a possible decrease of *Harpagophytum* over the past decades, old herbarium specimen collecting sites were re-visited in Namibia. Of 29 re-documented sites, individuals of *Harpagophytum* were found on only 13 sites in 1999. For six sites a decrease in individual densities was evident, i.e. in the Khomas Region and the Hardap Region. The additional analysis of the reproductive effort of *Harpagophytum* indicates a low production rate of flowers and fruits for the year of documentation.

Results of the re-documentation indicate an apparent decrease in the occurrence of *Harpagophytum* from very dense and dense patches to few or missing individual in 1999. This, however, cannot necessarily be interpreted as a collapse of the populations in the research areas over the past decades.

Several aspects have to be taken into consideration:

- The occurrence and production of green above-ground shoots of *Harpagophytum* is closely linked to environmental factors such as precipitation.
- Rainfall previous to the documentation has a major impact on the dormance-breaking of the geophytic plant.
- During the time of the first collections of *Harpagophytum*, Namibia experienced extremely good rainfall. (Ihlenfeldt, pers. comm.).
- Contrarily, precipitation at the time of re-documentation (1999) stayed below average and rainfall started comparatively late in the season.

This may have resulted in a low number of resprouting *Harpagophytum* plants at the time of observation. It may well be that a greater resource of plant individuals is present in the dormant phase and just did not produce new shoots due to unfavourable environmental conditions. To overcome this weakness in the methodology, for a selected number of sites monitoring was continued for another two years (Chapter 9.5). The apparent decrease in occurrence of *Harpagophytum* during the rainy season of 1999 cannot be related to unsuitable habitat or soil conditions for these have not principally changed over the past decades. Also, these represent typical *Harpagophytum* habitats (sandy plains and sandy roadsides). It may, however, well be that changes or increase in land use have resulted in changes in the grazing pressure of some areas. Re-documentation sites along roadsides are also susceptible to human induced changes and destruction.

The impact of harvesting of *Harpagophytum* was only visible for one site in the Erongo Region, where detrimental harvesting methods led to a complete lack of the species in 1999. Former harvesting activities have been reported from the Hardap Region in the area of Rehoboth. In personal communications, also with a former harvester of this area, it was claimed state that intensive harvesting occurred in the area a decade ago leading to a dramatic decrease of the resource (Boll, pers. comm.). At the beginning of international trade in *Harpagophytum* a major percentage of secondary tubers was extracted from the Rehoboth area (harvester, pers. comm..). Extremely good rainfall in the mid 1970s in the area of Rehoboth, with rainfall quantities of 2-3 times the average may account for the dense patch forming of *Harpagophytum* at that time. Ihlenfeldt reports great quantities of plants in the area east of Rehoboth for this time period. He also found large numbers of fruits clinging to the fences along the roads. Yet, at the time of re-documentation in the year 1999, a lack of *Harpagophytum* or very low individual numbers were recorded. No signs of harvesting activities were found anymore which is due to the fact that firstly no current harvesting takes place and secondly that the old digging holes are not persistent, and can only be detected for few subsequent years. Thus, the interpretation towards a sever reduction of *Harpagophytum* for the area of Rehoboth is not based on so-called “hard” field data, but based on observations of various people having been active in the area in the 1970s. Even for today, inhabitants of the area reported of occasional harvesting for one site. Yet, due to the very low resource density, no commercial exploitation is possible anymore (harvester, pers. comm.).

Summarizing, it can be concluded that considerably lower individual numbers occurred for a number of re-documentation sites. However, due to low rainfall quantities previous to the time of documentation, a persistent decrease of *Harpagophytum* can only be stated for few sites. For these, the decrease was a result of unsustainable harvesting activities three decades ago, which led in the Rehoboth area to an almost depletion of the resource. Current harvesting activities in the Erongo Region resulted in a destruction of the patchy growth pattern of *Harpagophytum* for one site.

9.5 Three-year re-documentation of *Harpagophytum*

For a selection of nine old collecting sites, monitoring was continued for additional two years, summing up to a total of three years of re-documentation (Tab. 38).

9.5.1 Results

Of the nine monitoring sites, strong harvesting activities were only reported from sites in the area between Rehoboth and Uhlenhorst (sites no. 5-7, Tab. 39). In this area, intensive harvesting of *Harpagophytum* took place in the 1970s and 1980s. This was the first area in Namibia, where large scale harvesting of *Harpagophytum* was implemented (Chapter 12). However, after a strong decrease and a nearly depletion of the resource, harvesting stopped (Chapter 9.4). No harvesting activities have been reported from the other previous collecting sites. These sites thus represent areas not influenced by human harvesting impacts within the distribution area of *Harpagophytum*.

Tab. 39: Re-documentation sites with district, region, collector, date of first collection, and density of *Harpagophytum* at the time of collection.

No.	Re-documentation site	District (Region)	Old collecting site	Harpagophytum in old data
1	Farm Waldau	Okahandja (Otjozondjupa)	Ihlenfeldt 1962, 1976	Sporadic on sand
2	Btw. Karibib & Usakos	Karibib (Erongo)	Ihlenfeldt 1961	Dense population
3	Farm Hohenheim	Karibib (Erongo)	Straub in 1980`s	Small population
4	Communal area – Rehoboth	Rehoboth (Hardap)	Ihlenfeldt 1962	Very dense population
5	Btw. Rehoboth & Uhlenhorst	Rehoboth (Hardap)	Ihlenfeldt 1962	Very dense population
6	Btw. Rehoboth & Uhlenhorst	Rehoboth (Hardap)	Ihlenfeldt 1962	Very dense population
7	Btw. Rehoboth & Uhlenhorst	Rehoboth (Hardap)	Ihlenfeldt 1962	Very dense population
8	Btw. Uhlenhorst & Dordabis	Windhoek (Khomas)	No old data	–
9	Road Rehoboth-Windhoek	Windhoek (Khomas)	Giess 1959, Ihlenfeldt 1962	Common on sandy plains

As no quantitative data on the rainfall quantities during the years of observation is available for the first documentation, densities of *Harpagophytum* found today were assigned to estimated quantities, which were then compared with our quantitative field data.

Environmental conditions for the period of monitoring include the following:

- In the 1960s, when most of the monitoring sites were visited the first time and herbarium specimens were collected, rainfall in Namibia was very high. These favourable rainfall conditions lasted over a period of several years when rainfall quantities exceeded the average rainfall amounts by more than 100mm/a.
- Over the period of the past three years of monitoring (1999-2001), rainfall quantities in Namibia varied strongly.
- In 1999, when the re-documentation of the previous collecting sites started, rainfall was below average in the entire country.
- In 2000 and 2001, Namibia experienced exceptionally good rainfalls, which were almost similar to those in the 1960s. The density of *Harpagophytum* found in these exceptional rainfall seasons allows a comparison with the resource status of the plant reported by Ihlenfeldt for the 1960s and 1970s.
- In 2000, rainfall begun late in the rainy season and thus re-documentation of many sites was carried out before the strong rainfall events started in the country.

In the following, rainfall quantities during the years of observation will be discussed parallel to the results of each re-documentation site. As no quantitative data is available for the previous years, analyses were carried out descriptively. Densities of *Harpagophytum* found by the collectors were assigned to estimated quantities, which were then compared with our quantitative field data.

9.5.1.1 Re-documentation site No. 1 – Farm Waldau

GPS: S 21°56`42.9 // E 15°39`26.8	MAP: 2115DB
site description:	Tar road btw. Karibib and Usakos, stop at GPS co-ordinates, north over railway line over fence
soil:	sand, beige

This monitoring site is located in the Okahandja District (Otjozondjupa Region) in an area characterised by an undulated landscape where sandy patches form a mosaic with gravel dominated areas and rocky outcrops. *Acacia mellifera* stands with small shrubs and a varying herb and grass cover dominate the vegetation. GIESS (1970) described a Thornbush Savanna vegetation type for this area. No harvesting activities were found on this site.

The herbarium collection of *Harpagophytum* by Ihlenfeldt dates back to the years 1962 and 1976. For this time, Ihlenfeldt reported the species to occur sporadically on sand in this area. The quantities of *Harpagophytum* documented in the years 1962, 1976 and 1999-2001 are presented in the Figure 53 below.

In the graph of Figure 48, each row represents one transect walk. As in the years 1999-2001 more than one transect was documented, several rows indicate the quantities of the species found each year. In contrast, the density of plants found in 1962 and 1976 is represented by one row only, the two lowest rows in the graph. To make a comparison of the data possible, Ihlenfeldt's estimation of a sporadic occurrence of *Harpagophytum* was assigned to a number of five individuals per transect in the graph.

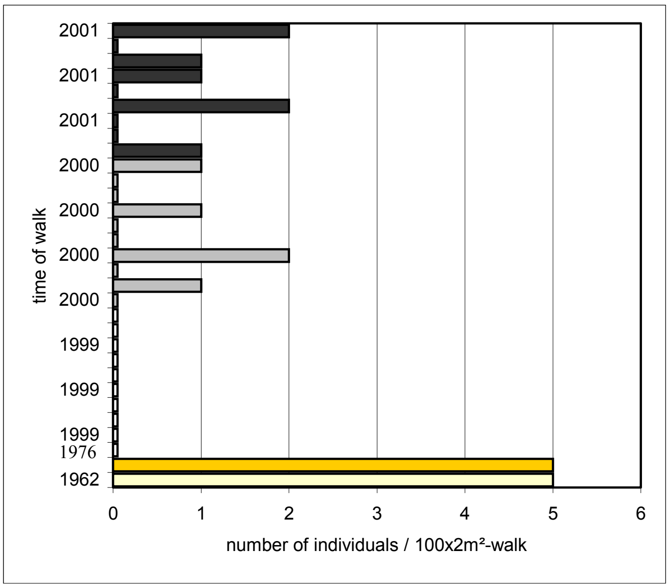


Fig. 53: Re-documentation site No. 1: Number of individuals found on transect walks of 100x2m in the years 1962, 1976, and 1999-2001.

Mean annual precipitation of the area is 200mm. In 1962 and 1976, rainfall in the research area was good and above average with several hundred millimetres. In contrast, in 1999, rainfall was very low and stayed far below the average amount. In that year, no plants were found on a walk through the area and on the ten transect walks. This changed in 2000 and 2001 when at least a few individuals of *Harpagophytum* were counted on some of the 100m transect walks.

The graph shows that no great changes in the occurrence of *Harpagophytum* took place over the past decades except for changes due to the rainfall pattern. No decrease was detectable, i.e. individuals still grow sporadically in the areas of the farm Waldau. Due to the lack of individuals in the year 1999, no flowers and young fruits were found on the collecting site. In the other years of observation at least some plants were found which were flowering and fruiting indicating a potential regeneration of the population.

9.5.1.2 Re-documentation site No. 2

GPS:	S 21°56`42.9 // E 15°39`26.8	MAP: 2115DB
site description:	Tar road btw. Karibib and Usakos, stop at GPS co-ordinates, north over railway line over fence	
soil:	sand, beige	

This monitoring site is situated near the road between the towns of Karibib and Usakos in the Erongo Region. The vegetation forms part of the western part of the Nama Karoo Biome close to its transition to the Desert Biome. The vegetation is characterised by the Semi-Desert and Savanna Transition (GIESS 1970). The area is heavily grazed and dominated by *Acacia* shrubs with a varying grass cover that depends on the rainfall quantity.

Mean annual rainfall is very low with quantities of 150-200mm. Rainfall events are characterised by a strong variation in time and space. In 1962, a year with good rainfall, Ihlenfeldt documented a dense population of *Harpagophytum* in the research area. This is indicated by the amount of ten individuals/transect walk in the lowest row of Figure 54. Neither in the re-documentation in the year 1999 – which was a dry year – nor in the years 2000 or 2001, which were very good rainfall years, any individuals of *Harpagophytum* were found in this research area.

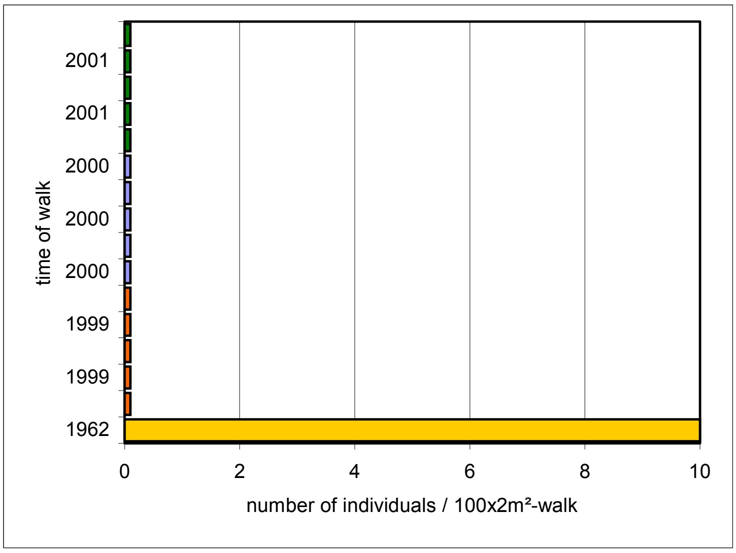


Fig. 54: Re-documentation site No. 2: Number of individuals found on transect walks of 100x2m in the years 1962 and 1999-2001.

In general, the density of the resource is expected to be very limited in the wider range of the research site, as this area is predominantly characterised by a stony and calcareous substrate. Such substrate is not considered to form a suitable habitat for *Harpagophytum* (see also Chapter 8). No hints towards an impact of harvesting were found that might have led to changes in individuals densities from the past to today. The decrease in individual numbers may therefore be interpreted as follows: a) the exact location of the population Ihlenfeldt had described for his collection, was not found when re-visiting the sites, b) the grazing pressure has been very high over the past years and is responsible for the vanishing of the population, c) harvesting does take place in the area which was however not detected by us in the field, or d) the series of low rainfall years over the past decades (approximately from 1980-1999) is responsible for the lack of *Harpagophytum*. Possibly the population described by Ihlenfeldt in 1962 did not manage to survive the long drought period.

9.5.1.3 Re-documentation site No. 3 – Farm Hohenheim

GPS:	S 23°16`28.7 // E 16°24`51.9
site description:	ask owner Mr Straub for details: small path along fence to small rivier
soil:	loamy sand

This monitoring site is situated on the farm Hohenheim at the border of the escarpment near the Gamsberg in the Khomas Region of Namibia. The vegetation belongs to the Nama Karoo Biome, and the vegetation type is characterised by its transition between the Semi-Desert and the Highland Savanna described in GIESS (1970). The substrate of the site is a loamy sand inhabited predominantly by perennial grasses and small shrubs. Data for this monitoring site was not derived from old collecting data, but from an interview with the owner of the farm Hohenheim in 1999. According to him, only on one spot *Harpagophytum* exists on his farm (Straub, pers. comm..). This spot is situated at the edge of a small river bed. Today, the population is not harvested anymore, while in the 1980s one to two plants were harvested each year by his mother for personal use. No commercial harvest takes place on the farm.

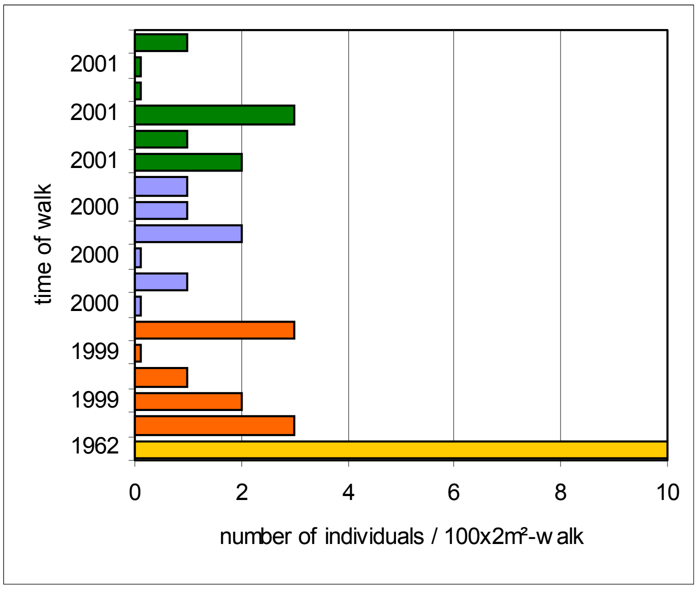


Fig. 55: Re-documentation site No. 3: Number of individuals found on transect walks of 100x2m in the years 1980 and 1999-2001.

In Figure 55, the density of *Harpagophytum* found in the 1980s is indicated by the lowest row with a number of ten individuals per transect. The population found on the site was very small in size and extended only over an area of 40x50m. Therefore only five transect walks were done each year represented by five rows for 1999-2001.

With 150-200mm mean annual rainfall in the area is as low as on the previous site. However, it is assumed that soil water conditions at the monitoring site are more favourable due to the direct vicinity of a small river. No detailed information on the rainfall conditions in the 1980s were available. In the period of the re-documentation rainfall amounts were very similar to the other research areas. I.e. in 1999 rainfall stayed far below average, whereas in the year 2000 and 2001 rainfall amounts were higher and above average.

The graph of Figure 50 illustrates that the number of individuals did not change considerably between the years irrespective of the rainfall amounts. From 1999-2001 between 0-3 individuals/transect were counted in the small population. In all years of observation, the plants fruited and flowered. The size of the population did not change according to the owner of the farm and our observations. No decrease of the population due to the impact of environmental conditions took place.

9.5.1.4 Re-documentation site No. 4 – Rehoboth

GPS: S 23°18`43.4 // E 17°10`10.1		MAP: 2317AB
site description:	stop at GPS co-ordinates, stop 9 km after turn-off of road at dune base	
soil:	sand	

This and the following monitoring sites are situated in the Savanna Biome of the Hardap Region. The vegetation belongs to the Southern Kalahari type, the Mixed Tree and Shrub Savanna, respectively (GIESS 1970). Single *Acacia erioloba* and *Boscia albitrunca* trees grow together with a herb layer and an open annual grass layer. The area is highly overgrazed, especially in years with low rainfall. This site is located in the communal area of the town Rehoboth. The habitat types of this site comprise a red sand dune with dune slopes, a dune crest and dune foot as well as the surrounding plains.

For the 1970s strong harvesting activities have been reported from several people for this and the following three re-documentation sites (sites no. 5-7). This is especially true in the nearer vicinity of the town Rehoboth itself, where this site no. 4 is located.

Mean annual rainfall of this area is 250-300mm. In 1962, when Ihlenfeldt did his collections, rainfall in this area was extremely good. The annual rainfall amounts exceeded by several 100mm the normal quantities. At that time, Ihlenfeldt documented large clusters of fruits clinging to the fences and high densities of individuals growing in the area. This is indicated by the number of ten individuals/transect in the lowest row of the graph (Fig. 56).

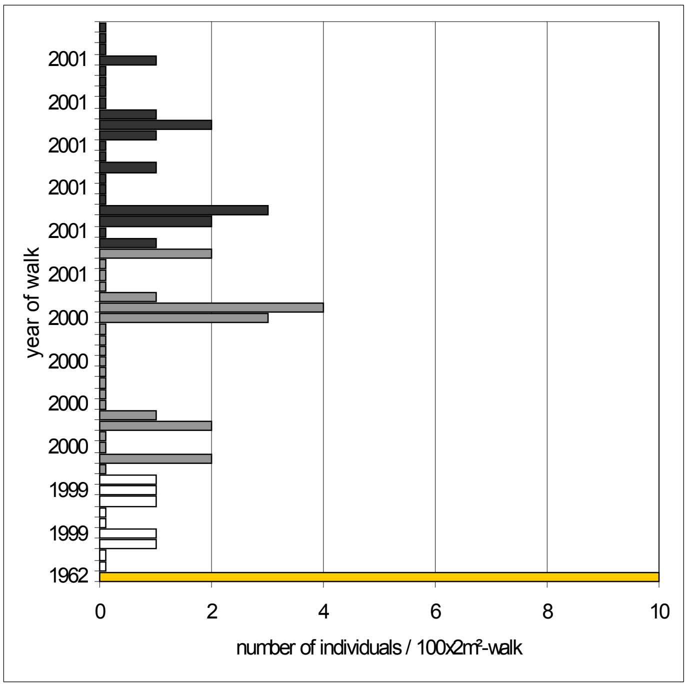


Fig. 56: Re-documentation site No. 4: Number of individuals found on transect walks of 100x2m in the years 1962 and 1999-2001

In 1999, rainfall was low and only few individuals with a maximum of one plant per 100m walk were found. In 2000, rainfall started late but contributed an above average amount to the area. As the re-documentation was carried out before the rain started the number of individuals counted was low with a maximum of 4 plants/100m walk. In 2001, a year with rainfall quantities high above average, the assessment of the site was done after the rainfall. Yet, irrespective of the better water supply in comparison to previous years no higher density of individuals were found. In all years of observation, plants only occurred on dune foot and plain areas, but never on the dune crest.

From this, it is concluded that a strong decrease in the resource is evident since 1962. Harvesting activities in the 1970s did harm the population structure of this area to a great extent. This resulted in a destruction of formerly dense populations of *Harpagophytum* to a very occasional growth of the species. Irrespective of the high rainfall in both years, no new seedlings of *Harpagophytum* were found, leading to the conclusion that no regeneration took place in the area. An informant in the area also said that they still harvest single plants from the areas, but that not much is left today to make a commercial exploitation worthwhile.

9.5.1.5 Re-documentation site No. 5

GPS:	S 23°21`43.4 // E 17°16`42.6	MAP: 2317AB/AD
site description:	stop at GPS co-ordinates south of pad: red sandy plain	
soil:	red sand	

This monitoring site is located next to the road C25 on private farmland in the Hardap Region. Sandy plains dominate the landscape while sand dunes are missing. The vegetation belongs to the Mixed Tree and Shrub Savanna (Southern Kalahari) (GIESS 1970) and comprises single *Acacia erioloba* tress with a varying grass cover. In 1962, Ihlenfeldt reported large quantities of fruits and plants of *Harpagophytum* on this site. This in indicated by a number of ten individuals per transect in the lowest row of the graph below (Fig. 57).

Rainfall patterns for 1962 and 1999-2001 were similar to the previous sites (see site no. 4). In 1999, due to low precipitation, the scattered grass and herb cover was almost completely grazed. In 2000, a year with good but late rainfall, the site was documented before rainfall started. This resulted in a very sparse annual plant cover. Due to the exceptional rainfall in the year 2001, vegetation cover was dense and comprised a dominance of ephemeral species.

Irrespective of the quantity of rain, no changes in individual numbers of *Harpagophytum* were evident. With a maximum of 3 plants/transects and a total of 5-7 plants on six transect walks, plant numbers stayed far below the observed quantities of Ihlenfeldt in 1962. In the three years of observation, only one single population of *Harpagophytum* was detected in the area which was re-documented each year. Neither a regeneration nor an expansion of the population was found.

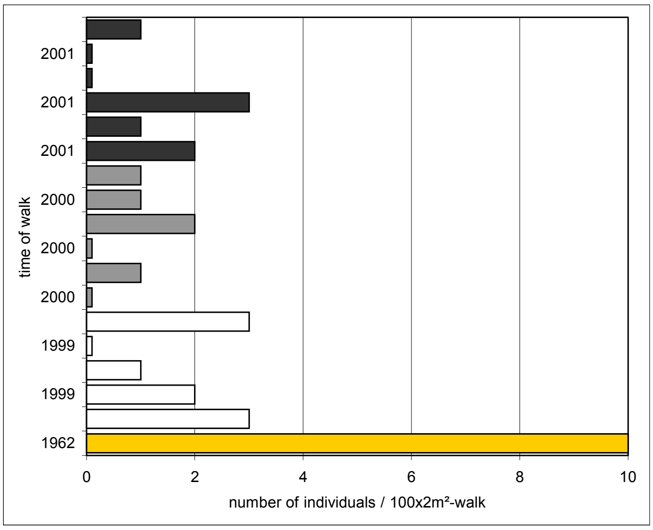


Fig. 57: Re-documentation site No. 5: Number of individuals found on transect walks of 100x2m in the years 1962 and 1999-2001.

From these results similar conclusion to the site no.4 are drawn. Although the site seems in general suitable for the occurrence of *Harpagophytum*, only one scattered population was found. The observation of a large resource availability by Ihlenfeldt almost 40 years ago hints towards a decrease induced by either a former harvesting impact – which is today not detectable in the field anymore – or by high harvesting pressures which may have a continuous impact which may lead to a reduction of the fitness of the population.

9.5.1.6 Re-documentation site No. 6

GPS: S 23°24`12.8 // E 17°31`06.5		MAP: 2317AD
site description:	stop at GPS co-ordinates south of pad	
soil:	red sand	

This monitoring site is also located next to the road C25 in the Hardap Region of Namibia. The site is characterised by a sandy, but hard substrate. The vegetation belongs to the Mixed Tree and Shrub Savanna (Southern Kalahari) (GIESS 1970). Probably due to the harder soil, medium sized shrubs, especially *Acacia mellifera*, and a varying cover of herbs and grasses dominate the composition of the vegetation. A strong grazing impact on the vegetation was observed for the area with an increase in the grazing pressure for low rainfall years.

Also for this site, in 1962 Ihlenfeldt reported a large quantity of individuals of *Harpagophytum*. This is illustrated by the number of ten individuals per transect in the lowest row of the graph (Fig. 58). In each of the three years of monitoring, five transects as well as a general walk through the area were documented.

Mean annual precipitation of this area is lower than on the previous two sites with a mean quantity of 200-250mm/year. Rainfall quantities during the time of documentation varied similarly to the previous research sites.

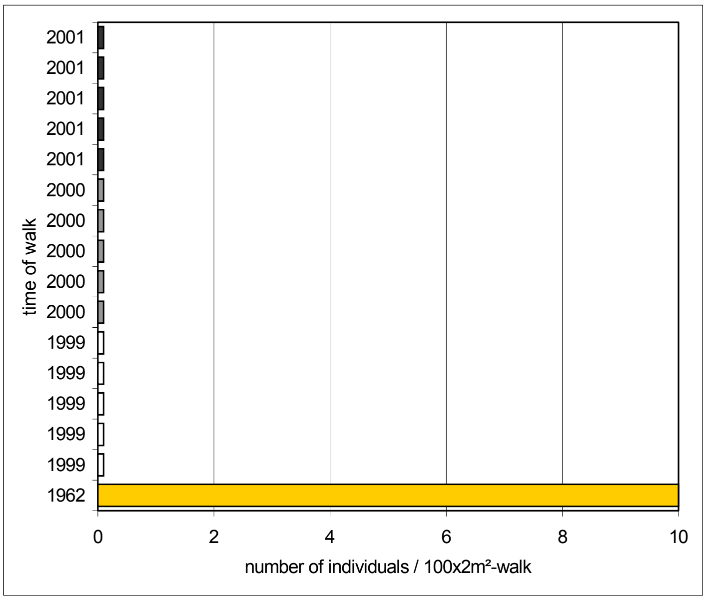


Fig. 58: Re-documentation site No. 6: Number of individuals found on transect walks of 100x2m in the years 1962 and 1999-2001.

Irrespective of some excellent rainfall seasons (e.g. the year 2001) and in contrast to the previous monitoring sites, no individuals of *Harpagophytum* were found in any of the three years of observation.

The reason for the lack of the species may be similar to those of site no.2. It is assumed that we either followed an inaccurate site description and did not re-document the original population, which was described by Ihlenfeldt or that the population of *Harpagophytum* does not exist anymore due to harvesting activities or other impacts such as a strong over-grazing.

9.5.1.7 Re-documentation site No. 7

GPS:	S 23°30`12.2 // E 17°44`50.8	MAP: 2317DC
site description:	stop at GPS co-ordinates, old dune runs parallel to pad, stop where it is nearest, site is located to the south	
soil:	red sand	

This monitoring site is situated in the Hardap Region next to a large sand dune that runs parallel to the road. The site stretches over a lower dune slope, its dune base and a wide interdune area. The substrate at the sites is red sand. The vegetation belongs to the Mixed Tree and Shrub Savanna of the Savanna Biome (GIESS 1970). The cover of the vegetation varies with respect to the position in the dune system, i.e. between the dune base, dune slope, dune crest, and interdune, as well as between the years depending on the rainfall. This site was heavily grazed in all three years of observation.

Mean annual rainfall in the area varies between 200-250mm. This amount was exceeded to a major extent in the year 1962, when Ihlenfeldt did his collection of *Harpagophytum*. In the years of observation, from 1999-2001, rainfall quantities changed similar to the rainfall conditions on the previous monitoring sites.

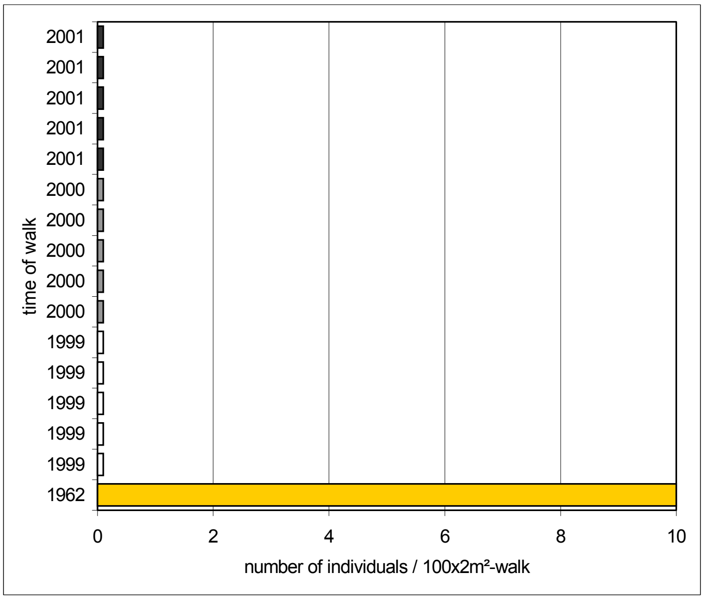


Fig. 59: Re-documentation site No. 7: Number of individuals found on transect walks of 100x2m in the years 1962 and 1999-2001.

Ihlenfeldt recorded a high density of *Harpagophytum* individuals for the area at the first herbarium specimen collection in 1962. This is indicated by the lowest row in the graph. Yet, no individuals were recorded for the years 1999-2001 (Fig. 59). Again, several factors might be responsible for the lack of the species in the area. They range from an detrimental impact of high grazing pressure or of overexploitation by harvesting to a failure in locating the original collecting site.

For future monitoring purposes, it can be concluded that a continuation of the monitoring of this and the previous site does not seem to be worthwhile. The varying quantities of rainfall were only reflected by differences in the matrix vegetation, but did not show any impact on the occurrence of *Harpagophytum*.

9.5.1.8 Re-documentation site No. 8

GPS:	S 23°35`11.4 // E 17°58`02.5	MAP: 2317DC
site description:	Path from Uhlenhorst to C15 (Dordabis), after 10km, where dunes on both sides of pad, site is located to the east	
soil:	red sand	

No old collecting data exists for this monitoring site. However, as this site represents another Kalahari dune habitat, it was included in the study. Transect walks of this sites were carried out on the dune base, dune slope, dune crest, and in the interdune. The vegetation belongs to the Mixed Tree and Shrub Savanna (GIESS 1970). The composition of the vegetation comprises few medium sized shrubs in the interdune, single stands of *Acacia erioloba* trees and a varying density of herbs and grasses. No signs of harvesting activities were found, but the impact of cattle grazing was well visible. Mean annual rainfall is 250-300mm.

In 1999, the Cucurbitaceae *Acanthosycios naudinianus* formed dense stands on the site resulting in a herb cover of 60%. It is assumed that due to competition, only few other herbs were encountered next to *Acanthosycios*. In 1999, only few individuals of *Harpagophytum* occurred at the dune base and in the interdune. A maximum of 2 plants/transect and a total of five plants were counted (Fig. 60).

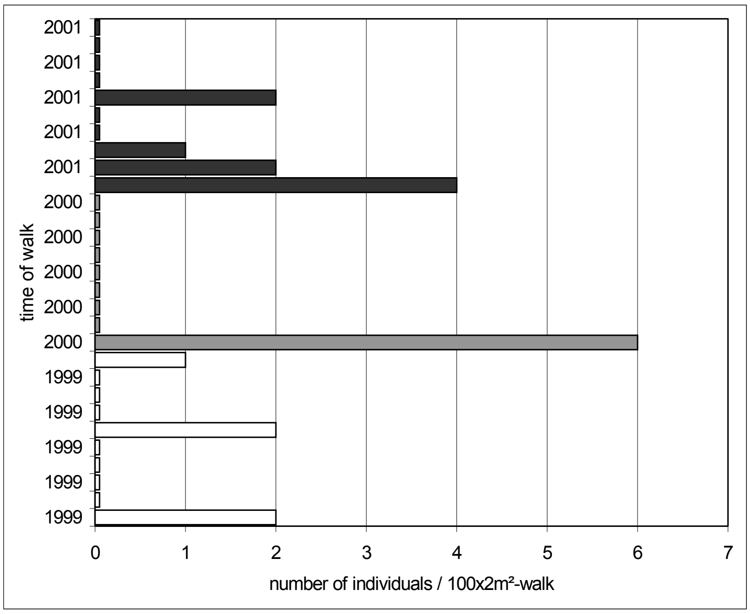


Fig. 60: Re-documentation site No. 8: Number of individuals found on transect walks of 100x2m in the years 1999-2001.

In 2000, previous to the good rainfall, individual numbers were low with six plants growing along an old car track in the interdune. Plants were flowering and fruiting. Vegetation cover was high with a herb and grass cover of each 50%. Dominant annual grass species was *Schmidtia kalahariensis*. In contrast to 1999, *Acanthosycios naudinianus* occurred only sporadically on the transects.

In 2001, an exceptional rainy season also in this area, the cover of the matrix vegetation was very dense. For this year, also a higher individual number of *Harpagophytum* was found. However, the total number of individuals stayed low with a total of nine individuals found on ten transects in the area. Similar to the previous years, plants were flowering and fruiting. Some detached fruits from the previous years were also found. Summarizing, species numbers did not change irrespective of changes in rainfall amounts. No new seedlings of *Harpagophytum* were found. This may be due to the high grazing pressure (by cattle) or due to competition by other Kalahari species such as the above mentioned Cucurbitaceae *Acanthosycios naudinianus.*

9.5.1.9 Re-documentation site No. 9

GPS: S 23°00` // E 17°10`		MAP: 2317AC
site description:	26 miles south of Windhoek, stop on tar road at "km 40" sign, where fence starts some meters from road away	
soil:	white sand	

This monitoring site represents another typical habitat for the occurrence of *Harpagophytum*, i.e. disturbed areas such as roadsides. This site is located between the capitol Windhoek and the town Rehoboth in an approximately 200m wide strip between the tar road and the railway line.

Data for this site dates back to W. Giess, who collected herbarium specimen at this site as early as 1959. He stated the species to be common there. Ihlenfeldt re-visited this collecting site in 1962 and 1976 and found similar plant densities. These findings are represented in the lowest row of the graph below dated with 1959 (Fig. 61). The number of 23 individuals/transect was assigned to the estimate of a common occurrence.

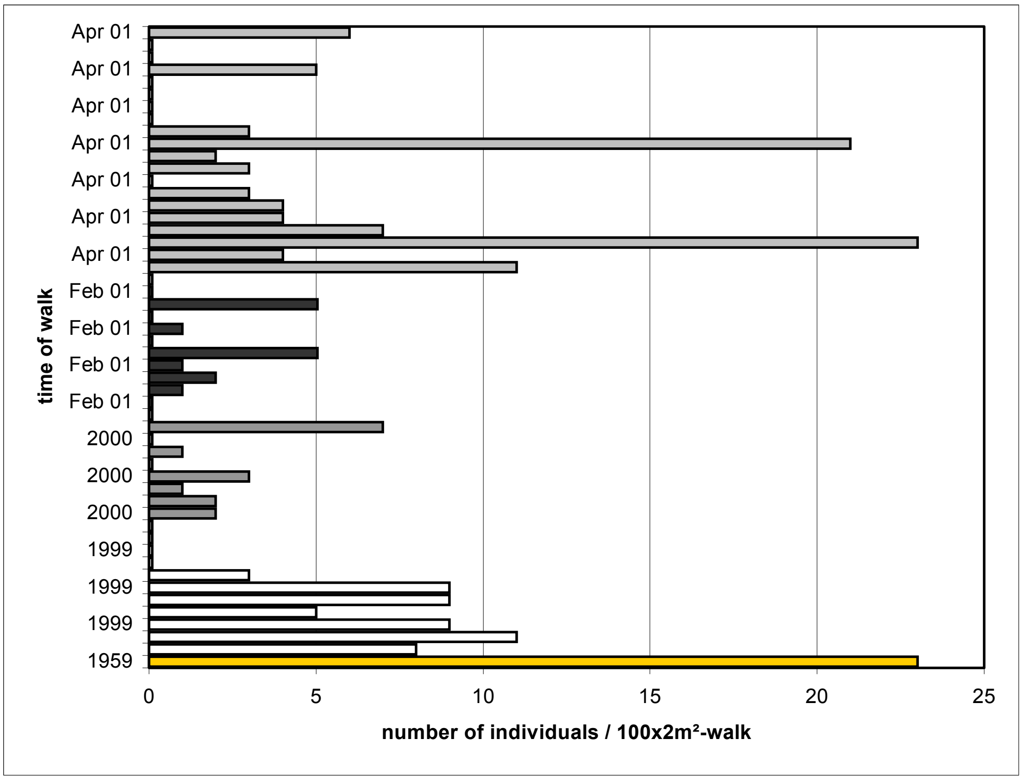


Fig. 61: Re-documentation site No. 9: Number of individuals found on transect walks of 100x2m in the years 1959 (and 1962, 1976) and 1999-2001. In 2001, two series of documentations were done, i.e. in February and in April.

The vegetation of the area belongs to the Highland Savanna of Namibia (GIESS 1970). Yet, a strong influence of disturbance in the vegetation composition is evident due to the direct vicinity to the tar road. The vegetation of the site is characterised by a sparse shrub and tree layer. Depending on the rainfall, the herb and grass cover varied between 3% in 1999 (low rainfall) and 85% in April 2001, when extremely good rainfall occurred. Rainfall in the years of observation was similar to the previous sites. Mean annual rainfall quantities in the area are 250-350mm.

In the year 2000, this site was documented before the good rainfall started. In the year 2001, the site was documented twice, before the exceptionally good rainfall started (February 2001) and after the rainfall events (April 2001). At all times of observation ten transect walks as well as a general walk through the area were carried out.

The data in the graph of Figure 56 indicates a good correlation of the occurrence of *Harpagophytum* with the rainfall quantities of the different years. In 1999, when rainfall was below average, a maximum of 11 individuals/transect were counted. In total, 54 plants were found on ten transect walks. In 2000, the site was documented before the rainfall occurred and therefore very few individuals occurred with a maximum of 7 individuals/transect and a total of 16 plants. Similar quantities were observed in February 2001, when a total of 15 individuals/transect was found. In April 2001, high rainfall favoured probably good growing conditions also for *Harpagophytum*, leading to large individual numbers of up to 23 individuals per 100m walk. In total, 96 individuals were counted. At this time, also some manmade digging holes were detected, which hind to some harvesting activities. From the results it is concluded that no decrease in the population density of *Harpagophytum* occurred over the past decades. The common occurrence of *Harpagophytum* reported for three years (1959, 1962, 1976) and the quantities of the three-year monitoring (1999, 2000, 2001) did not bring about any changes in individual densities. No harvest of the secondary tubers occurs at the site and the evident and continuous disturbance of the site does not seem to restrict growing conditions of *Harpagophytum*.

9.5.2 Summary and Conclusions on three-year monitoring of *Harpagophytum*

Of nine monitoring sites documented in Namibia over the period of three years (1999-2001), a decrease in the resource density of *Harpagophytum* was detected for five sites (Tab. 40). These sites are located in the Rehoboth District (Hardap Region) and in the Karibib District (Erongo Region).

On three of the sites for which Ihlenfeldt described a dense to very dense population of the species in the 1960s, no individuals could be recorded anymore in none of the three years of observation. Resource availability was reduced on two sites from a very dense population to the occurrence of single individuals.

Tab. 40: Summarizing table on the potential changes in the density of *Harpagophytum* between old collecting data and re-documentation data of 1999-2001.

No.	District (Region)	Harpagophytum resource in old data	Harpagophytum resource in 1999-2001	Changes in resource (=) no change (r) reduction	Harvesting activities
1	Okahandja (Otjozondjupa)	Sporadic	Sporadic	=	No
2	Karibib (Erongo)	Dense population	None	r	?
3	Karibib (Erongo)	Small population	Small population	=	No
4	Rehoboth (Hardap)	Very dense population	Single individuals	r	Previously v. strong
5	Rehoboth (Hardap)	Very dense population	Single individuals	r	Previously v. strong
6	Rehoboth (Hardap)	Very dense population	None	r	Previously v. strong
7	Rehoboth (Hardap)	Very dense population	None	r	?
8	Windhoek (Khomas)	No info	Single individuals	=	No
9	Windhoek (Khomas)	Common	Common	=	Yes, but small

Irrespective of strongly varying rainfall quantities within the three years of monitoring no variations in individual numbers of *Harpagophytum* were evident. Furthermore, no signs of regeneration or the establishment of seedlings of *Harpagophytum* were found in years with very high rainfall quantities.

The scheme in Figure 62 highlights the lack of regeneration in *Harpagophytum* for the four research sites: From the findings of the three-year monitoring the changes that occurred on the research sites can be recapitulated. As today either a lack of *Harpagophytum* or only single individuals were found on the research sites, it was interpreted that in an originally dense patch indicated by the large circles several (middle scheme) to all plants (lower scheme) were removed by harvesting. Harvesting activities may either be evident today or may date back to a time period after the first data collection and may have finished by today.

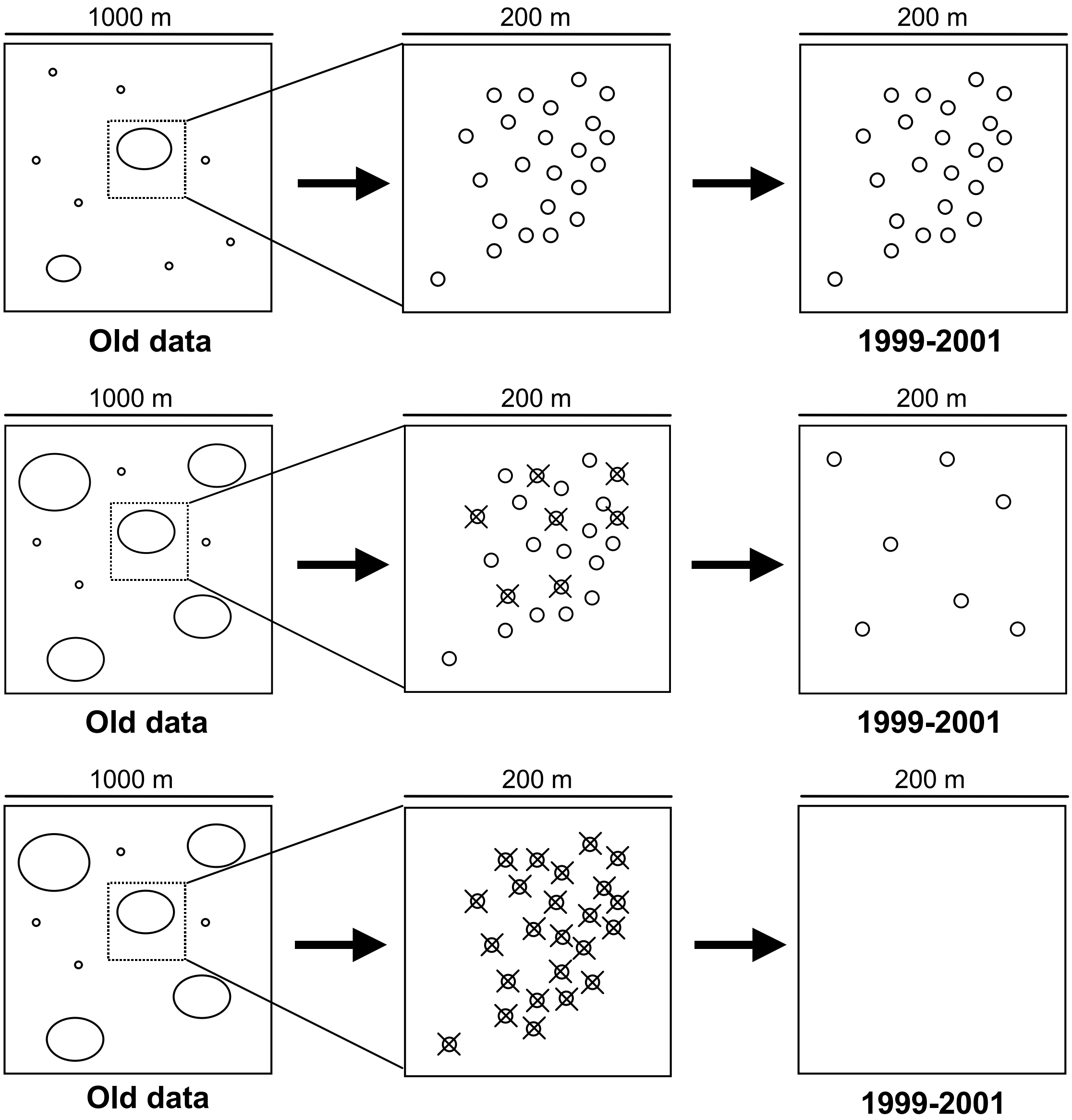


Fig. 62: Schemes of possible changes in *Harpagophytum* densities between first documentation (old data) and re-documentation (1999-2001). Upper scheme: no changes occur in a sporadic occurrence of *Harpagophytum*, middle: a dense population of *Harpagophytum* is reduced to scattered individuals, lower: a dense population of *Harpagophytum* is permanently destroyed by harvesting.

The fact that irrespective of some high rainfall years within the period of re-documentation, no significant changes in the density of *Harpagophytum* were evident for neither of the research sites leads the conclusion that variation in rainfall quantities are not responsible for the long-term reduction of the resource on the research sites. Instead, harvesting activities seem to play an important role. Information on the impact of harvesting was available for three sites in the Rehoboth area, for which a previously strong harvesting activity was reported from the 1970s and 1980s, a time period after the first collection was done by Ihlenfeldt. Even though, harvesting had stopped several years ago and no signs of harvesting are evident anymore today, the results indicate that no regeneration of the population took place since then. Even after the exceptional good rainfall of the years 2000 and 2001 no additional seedlings or adult individuals re-sprouting after dormancy could be documented in the research areas.

Different explanations are possible:

- Due to a long-term over-utilisation of *Harpagophytum* two to three decades ago, using detrimental harvesting techniques, the seed bank of the harvested areas has been permanently destroyed. The time period of extraction of the secondary tubers within the vegetation period was such that no fruits were produced over a longer period of time, which resulted in a decrease of the soil seed bank of the species. No regeneration out of the seed bank has therefore been possible.
- The seed bank of *Harpagophytum* is still existent and viable, but the high grazing pressure does prohibit the permanent establishment of new seedlings of *Harpagophytum*. Yet, personal observations show that no remnants of seedlings were found also in high rainfall years, when grazing pressure on *Harpagophytum* was very limited due to other more palatable plant species.

For four of the nine monitoring sites no change in the resource status of *Harpagophytum* was found between the first documentation and today (Tab. 39). The four sites are located in the Windhoek District (Khomas Region), the Karibib District (Erongo Region) and the Okahandja District (Otjozondjupa Region). The resource density of *Harpagophytu*m on these sites is limited. Next to a sporadic occurrence, one small population of 40x50m or a common occurrence on disturbed areas next to the road was reported. This is indicated in the upper scheme of Figure 57, showing that the *Harpagophytum* population in the old data is characterised by only few patches and a higher number of single scattered growing individuals. From the monitoring data assessed in 1999-2001 that indicates similar quantities of *Harpagophytum*, a successful regeneration of *Harpagophytum* in these low resource areas is interpreted.

Also for these sites, variations in rainfall quantities over the period of the study did not seem to influence the quantity of individuals counted. In contrast to the sites, which showed a strong reduction in the resource status, on these four sites none or only a very small impact of harvesting activities was found.

The findings are interpreted as follows:

(a) Harvesting impacts are not responsible for the low species numbers found. The resource status had been low also in the previous decades.

(b) Instead, it seems that sites with a generally low resource density are not attractive for harvesting activities in the first place (see also Chapter 8.11).

(c) The low resource availability is a natural phenomenon resulting from the environmental conditions at these sites.

The continuation of the monitoring from 1999 also over two subsequent years provided interesting insights into changes of different types of *Harpagophytum* populations. Marked differences became obvious between areas influenced by harvesting and those where harvesting does not occur. It could also be shown that precipitation though a very important factor for the annual regeneration of a population (by resprouting of the geophytic plant) seems to fail when it comes to a long-term regeneration of whole populations of *Harpagophytum* after harvesting.

Monitoring results are summarised as follows:

- An over-exploitation of the resource by harvesting did harm or even deplete the populations of *Harpagophytum* in at least some areas of the country. This is especially true for the area near the town of Rehoboth in the Hardap Region.
- The fact that the high harvesting intensity dates some decades back, stresses the long term and possibly non-returnable impact, which an over-exploitation of the resource may have.
- In other areas where the resource abundance is no as high and population sizes are naturally limited, harvesting of the secondary tubers of *Harpagophytum* did rarely take place. As a consequence, no reduction of the resource was found in these areas.
- Variation in rainfall amounts does not seem to influence the population status of *Harpagophytum* as in all three years of observation no significant change in or regeneration of the resource status was found.
- The results of the additional two years of monitoring confirm the findings of the first re-documentation in 1999 (HACHFELD 1999), in which a permanent reduction of the resource was stated for some areas of the country.

Further research is needed on the long-term impact of harvesting on the population status of *Harpagophytum.* The old herbarium collecting sites should be revisited in a few years time. This can be done with the help of the GPS coordinates that were documented on the monitoring sites. Also with a continuation of the monitoring it will be possible to further evaluate the impact of precipitation events on the regeneration of *Harpagophytum* populations.

10 Interviews

10.1 Approach

Survey questionnaires provide a powerful tool by which information can be transported from the world of everyday behaviour and opinion into the world of research and analysis (CZAJA & BLAIR 1996). In general, survey research is inherently interdisciplinary in such that data collection involves the persuasion of respondents and social interaction between them and the interviewer. For this study, a questionnaire was designed and distributed to gather information on the present distribution and occurrence of *Harpagophytum* in Namibia. This was considered a useful tool supplementary to the ecological field sampling with mapping of *Harpagophytum* and re-documentation of old collecting sites (Chapters 8, 9). The questionnaire represents a standardised and quantitative method with which the knowledge and perception of a wide range of people on a specific topic can be assessed (e.g. MAYER 2002). The inclusion of a greater range of people and hence also of area covered by the study may surmount natural spatial and temporal limitations of single field sampling sites. This is because the knowledge of the farmer is used which represents a reflection of his experience and knowledge of his land over a longer period of time. PERKINS (1999) remarked on this difference between experience-based data and one-time snapshot data that “What may be termed as ‘common sense’ to the communities (here, the farmers) appears to the scientist as a wealth of data, that is nonetheless agonisingly locked up in a format that no spreadsheet can accommodate”.

It can be expected that even modest-size surveys typically require considerable time, material, money and assistance (CZAJA & BLAIR 1996). Unlike the typical survey, which is designed and implemented by a team effort of many people with diverse skills, in scientific or scholarly enterprises surveys such as this one, this is often done by the lone researcher. Also, interviews depend to a great extent on language comprehension and discourse. Based on limitations with regard to access and language, the initial idea to include both, commercial and communal areas of Namibia in the interviewing process had to be given up. Next to a much greater effort in organisation and kilometres to be overcome, this would have required the involvement an additional persons for translations. Thus, the results of this chapter reflect the perception of the Namibian farmers on the resource and utilisation situation of *Harpagophytum* on commercial land. As only *Harpagophytum procumbens* is registered as medicinal valuable and official drug, the questioning was restricted to the distribution area of this species.

10.2 Methods

The interviews were distributed in written form due to the extremely large sample area Sampling criterion was the location of the farm. Sampling approach was not random in such that no random selection of farmers to be interviewed took place prior to the distribution of the questionnaire. This was not possible as all Namibian commercial farming areas within the distribution area of *Harpagophytum* were not known in advance.

The distribution of the questionnaires was implemented in the rainy season of 1999 when the main harvesting season of *Harpagophytum* had started and plants were visible with their above ground shoots. This time period was chosen because a greater consciousness was expected when *Harpagophytum* can actually be identified in the field. For an optimal distribution of the questionnaires, approximately 30 farmer associations of Namibia were approached. Various extension officers of the Ministry of Agriculture or Forestry Department kindly supplied names and addresses of the head or secretary of the various farmer associations in Namibia.

The questionnaire was either distributed personally on a farmer association meeting in connection with a short introduction of the topic or the head of the farmer association was visited and the purpose of the study was discussed with him. In some cases it was only possible to have telephone contacts and subsequent to this a number of questionnaires was sent to the farmer association. Once, a farmers "braai competisie" was visited and personal interviews were carried out. On another occasions, a boy and girl scout festival was used to interview the accompanying parents, who were farmers of the areas.

Irrespective of the personal or written interview, the similar questionnaire was used. The questionnaire was translated into three languages (German, English, Afrikaans) in order to meet the needs of the multi-langual country. The complete questionnaire is given in English in the attachment.

Each questionnaire contains 32 questions, which were either open, closed or half-closed. Partly, also multiple answers to the questions were possible. Resulting data is either nominal or ordinal scaled. For the analysis, a coding was carried out and qualitative answers were transferred into quantitative data. Questions to open answers were categorised to main answered categories. A special code was assigned in the case of refused answers. In the case that no answer to a question was possible due to a negative answer to the previous question, a missing value was used. Questions were addressed to reflect the perception of Namibian commercial farmers. It was tried to formulate questions, which follow the criteria for a comprehensive and unequivocal design of a questionnaire as stated by MAYER (2002), meaning short and concrete questions which are not suggestive or hypothetical, which do not expect too much from the interviewee, and do not comprise double denials.

The following topics are covered in the questionnaire:

(a) Occurrence and density of *Harpagophytum* on the farm

(b) Biology and habitat preferences of *Harpagophytum* on the farm

(c) Harvesting of *Harpagophytum* for private or commercial purposes on the farm

(d) Potential problems with parts of *Harpagophytum* for cattle and other livestock on the farm

(e) Perception on the threat of a potential decrease of *Harpagophytum*

Farmers were asked to estimate the density of *Harpagophytum* on their farm, i.e. whether the species is very rare (few individuals only), rare (up to 5 individuals/ha), common (5-50 individuals/ha), frequent (50-200 individuals/ha) or occurs in great densities (>200 individuals/ha).

Shape files of the AGRO-ECOLOGICAL ZONING PROGRAMME (2001) were used to produce maps and to extract the farm sizes. These files also offered information on the potential stocking rates for cattle and sheep/goats. Data on the carrying capacity together with data on the vegetation types classified in the vegetation map of GIESS (1976) was correlated to *Harpagophytum* densities assessed in this study.

10.3 Research areas

The greatest number of questionnaires was answered in the Otjozondjupa and the Omaheke Region (Tab. 41). As some farmers own more than one farm and answered the questions for more than one farm, total number sums up to a number of 101 farms. Total area covered was 142,492ha and 162,441ha, respectively. For the Erongo Region and the Kunene Region (Outjo District) only few farmers sent in answers of the questionnaire. Total area covered by the questionnaire is 563,810ha.

The location of the interviewed farms together with the quantities of *Harpagophytum* that were stated by the farmers is shown in the map of Figure 63. While not all farms were found in the farm map of the AGRO-ECOLOGICAL ZONING PROGRAMME (2001), other farmers own more than one farm, which are which are shown in the map.

Tab. 41: Namibian regions and districts with number of farms and area [ha] covered by the questionnaire.

Region	District	Number of farms	Area [ha] covered
Erongo	Karibib	2	27.781
	Omaruru	4	14.227
	sum	6	42.008
Hardap	Maltahöhe	3	14.904
	Mariental	13	78.863
	sum	16	93.767
Karas	Keetmannshoop	9	40.695
	sum	9	40.695
Khomas	Windhoek	11	74.481
	sum	11	74.481
Kunene	Outjo	1	7.925
	sum	1	7.925
Omaheke	Gobabis	29	162.441
	sum	29	162.441
Otjozondjupa	Okahandja	13	67.648
	Otjiwarongo	16	74.844
	sum	29	142.492
Total		101	563.810

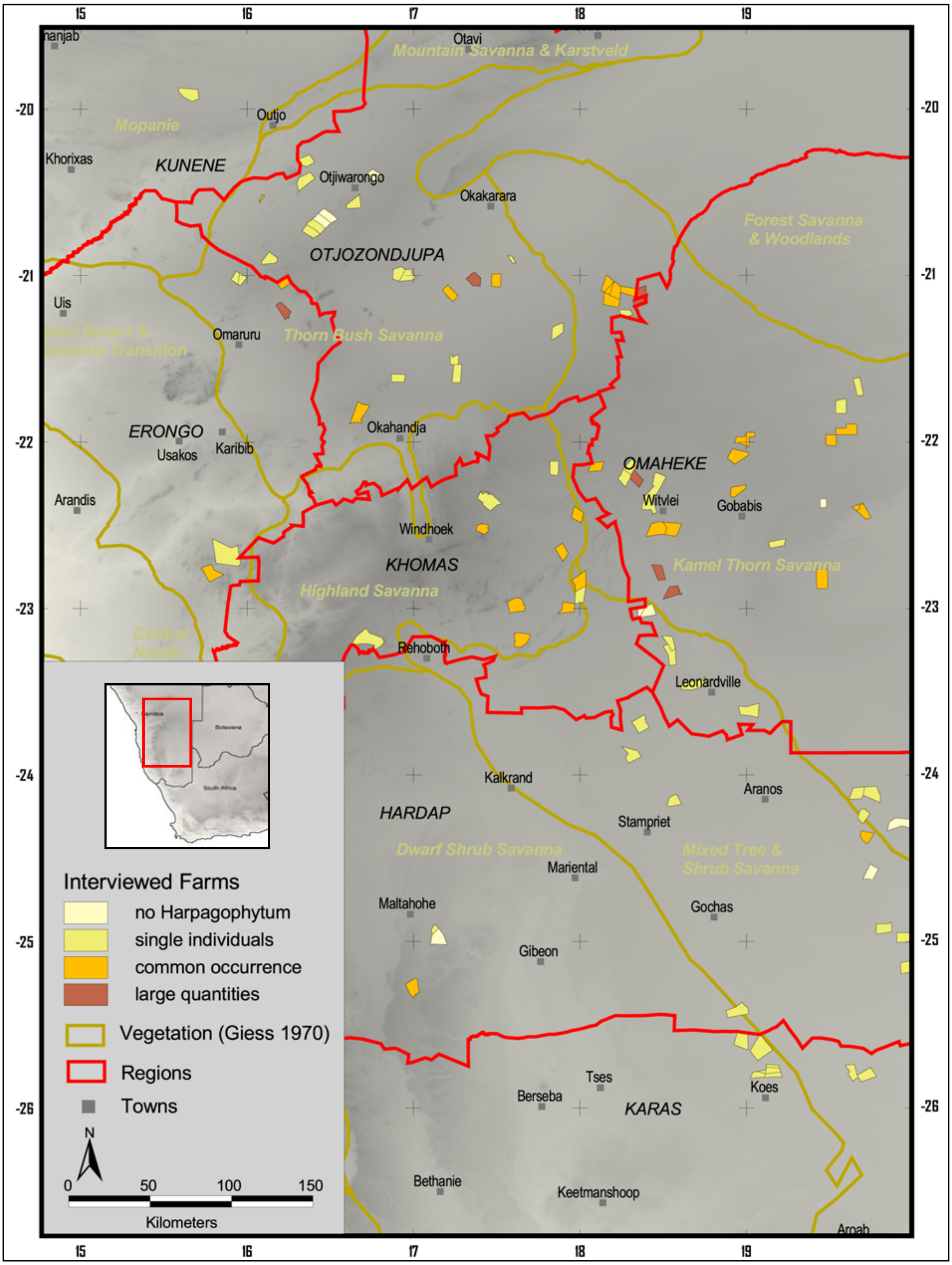


Fig. 63: Map of the farms that participated in the questionnaire with density of occurrence on these farms. Map Source: GIESS (1970), AGRO-ECOLOGICAL ZONING PROGRAMME (2001).

10.4 Results

In total, a number of approximately 500 questionnaires were distributed to Namibian farmers in the year 1999. At the time of January 2002, 90 questionnaires had been handed in. This equals a percentage of answers of 18%. Compared to other questionnaire initiated by the Ministry of Environment and Tourism in Namibia in previous years on various issues, this percentage can be considered as normal to above normal (Lindeque, pers. comm.)

In the following, important results of the questionnaire were selected. Results are grouped into five main foci, i.e. the frequency and density of *Harpagophytum*, the ecology of *Harpagophytum*, the utilisation and harvesting of *Harpagophytum*, the estimation of a potential decrease of *Harpagophytum* in the area, and the conservation of the resource.

10.4.1 Frequency and density of *Harpagophytum*

For the interpretation of the frequency of *Harpagophytum* on Namibian farmland, answers from the questionnaires were differentiated in different density classes (Tab. 42). Almost half of the farmers (47.7%) stated that *Harpagophytum* grows with a rare to very rare occurrence on their farm, meaning that only single individuals were observed in the field, but no dense patches with a large number of aggregated individuals. A common occurrence of *Harpagophytum* was reported by almost 40% of farmers. Yet, the fact that large quantities were restricted to only six farms (6.7%) of the interviewed farmers indicates that only few farmers observed dense patches of *Harpagophytum* on their farm. A lack of *Harpagophytum* was reported for five farms.

Tab. 42: Crosstable of the questions "How frequent is *Harpagophytum* on your farm?" and "What is the density of *Harpagophytum* on your farm?"

Density of Harpagophytum	How frequent is H. on your farm?	
	No. of answers	Answers [%]
Does not occur	5	5.6
Very rare (few plants only)	21	23.3
Rare (up to 5 plants/ha)	22	24.4
Common (5-50 plants/ha)	35	38.9
Frequent (50-200 plants/ha)	6	6.7
Large quantities (>200 plants/ha)	1	1.1
No answer	5	5.5

Tab. 43: Density of *Harpagophytum* stated for farms in different regions of Namibia.

Quantity / Region (No. farms)	Omaheke	Karas	Khomas	Hardap	Erongo	Otjozon-djupa	Kunene
No Harpagophytum	-	-	2	4	-	3	-
Very rare/rare (single plants)	13	9	6	7	3	12	1
Common	16	1	7	2	2	3	-
Frequent (large quantities)	4	-	-	-	1	2	-

Only for Omaheke Region, the Erongo Region and the Otjozondjupa Region large quantities of *Harpagophytum* are reported (Tab. 43, map in Fig. 57). The farms are situated between the 300-400mm isohyete (mean annual rainfall quantity) indicating a fairly good water supply during the rainy season. Also a common occurrence of *Harpagophytum* is predominantly reported from the higher rainfall areas of the interviewed farms. In contrast, in the southern and drier parts of the country mostly single individuals of *Harpagophytum* were reported (see BARNARD 1998).

The question whether the density of *Harpagophytum* varies between different years is of high significance for the initial motivation of the study that is to find out more about the ecology of the species (Tab. 44). The majority of interviewees observed changes of *Harpagophytum.* These were however not specified in greater detail. A number of 19 farmers claimed that no changes occur in the occurrence and density of the species between the years. Only on farms, where *Harpagophytum* is reported to be very rare to rare, it was not observed in every year. Parallel to a common, frequent or very dense occurrence, the density may change between the years, but not the occurrence in general.

Tab. 44: Crosstable of questions on "Does the density of *Harpagophytum* change between the years?" and "What is the density of *Harpagophytum* on your farm?"

Variations and density [no. of farms]	Very rare	Rare	Common	Frequent	Very dense
No change in density between years	6	7	4	2	
Change in density between years	1	7	26	4	1
Does not occur every year	9	6			
Other	2		2		

10.4.2 Ecology of *Harpagophytum*

The importance of environmental conditions for the occurrence and vigour of *Harpagophytum* has been discussed in the previous chapters where findings were based on results of field studies (Chapters 8, 9). Here, the perception of the Namibian farmers on this issue is presented.

10.4.2.1 The role of the abiotic environment for the occurrence of *Harpagophytum*

Next to the habitat type, the soil substrate and climatic parameters may determine the occurrence of *Harpagophytum*.

Most farmers (70%) state that *Harpagophytum* occurs on plain habitats on their farm (Fig. 64). In this context, plain habitats comprise non-undulated areas such as interdunes, open and flat plains. 10% or less of the farmers found the species to also occur on disturbed areas such as roadsides, on dune habitats, or washes.

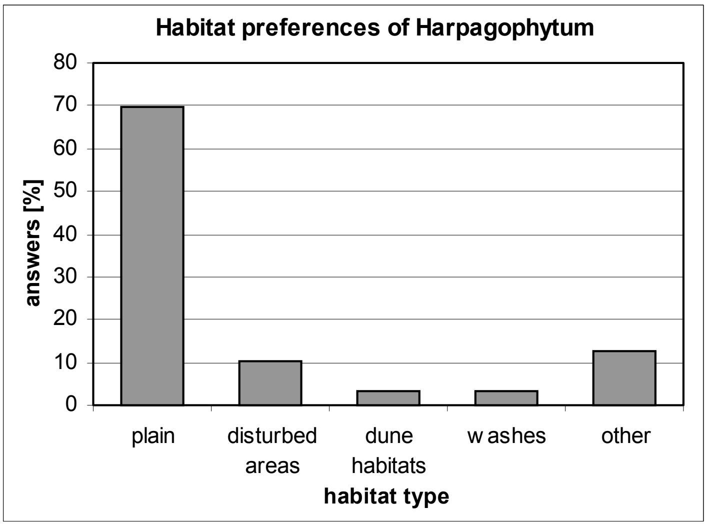


Fig. 64: Percentage of answers from the questionnaire on the different habitat preferences of *Harpagophytum*.

According to the Namibian farmers *Harpagophytum* is predominantly restricted to sandy soils (67.4%, Tab. 45). Sandy substrates are often deep and may have a loamy component (17.4%). Soils with a higher content of loam, identified as loamy soils, may provide a suitable substrate for *Harpagophytum* according to 10.5% of the interviewees. Contrarily, rocky soils with a high percentage of stones and rocks are not considered to promote the occurrence of *Harpagophytum*. Only three farmers stated to have found the species at sites characterised by such substrates.

Tab. 45: On which soils does *Harpagophytum* grow?

Soil substrate preferences	No. of answers	Answers [%]
Sandy soils	58	67.4
Loamy soils	9	10.5
Stony soils	3	3.5
Sandy, loamy soils	15	17.4
Sandy, stony soils	1	1.2

Tab. 46: Which factors determine the occurrence of *Harpagophytum*?

Driving factors	No. of answers	Answers [%]
Amount of rain	28	32.6
Date of rain	10	11.7
Time & amount of rain	24	27.9
Temperature	1	1.2
Rain & temperature	5	5.8
Grazing	1	1.2
Rain & grazing	11	12.8
Other	4	4.7
No answer	2	2.3

Of 86 farms for which an occurrence of *Harpagophytum* was stated, for most (72.1%) precipitation is identified as most important factor determining the growth and shooting of the species (Tab. 46). The amount of rain is considered to have a stronger impact on this than the date of rain. Yet, 24 farmers found a combination of both most important. Next to precipitation, the temperature and a combination of both, temperature and precipitation, is understood to be a trigger for the re-sprouting of *Harpagophytum*. Other parameters such as the grazing intensity may influence the growth of *Harpagophytum* when combined with precipitation (12.8%).

10.4.2.2 The role of biotic environment for the occurrence of *Harpagophytum*

The abiotic habitat conditions are supplemented by biotic components such as the composition and density of the vegetation. Therefore, the questionnaire also contained some questions on the vegetative preferences of *Harpagophytum*.

Namibian farmers identify areas with a sparse vegetation cover as most appropriate for the occurrence of *Harpagophytum* (47.1%, Tab. 47). Open areas such as cleared fields, heavily overgrazed and trampled areas and roadsides may provide suitable habitats according to 20% of the farmers. Yet, *Harpagophytum* was found also under dense vegetation, but composition of the vegetation was not stated.

Tab. 47: How dense is the vegetation surrounding *Harpagophytum*?

Vegetation density	No. of answers	Answers [%]
Grows in open areas	17	20.0
Grows in sparsely vegetated areas	40	47.1
Grows in densely vegetated areas cover	15	17.6
Other	10	11.8
No answer	3	3.5

Tab. 48: Number of interviewed farms (with known locality) in four quantity classes of *Harpagophytum* and different vegetation types (after GIESS 1970).

Vegetation type (Giess 1970) (no. of farms)	Lack of individuals	Single individuals	Common occurrence	Large quantities
Camelthorn Savanna	2	14	11	5
Dwarf Shrub Savanna	2	7	1	-
Highland Savanna	-	4	6	-
Mixed Tree and Shrub Savanna	2	16	2	-
Mopane Savanna	-	1	-	-
Semi-Desert and Savanna Transition	-	1	1	-
Thornbush Savanna	3	16	8	2

Different quantity classes were assigned to the sampled vegetation types (map in Fig. 58, Tab. 48). Large quantities of *Harpagophytum* only occur in the Camelthorn Savanna and the Thornbush Savanna. While a common occurrence with 5-50plants/ha concentrates also on these types, it is reported for most vegetation types. Single individuals were found for all seven vegetation types.

10.4.2.3 The role of land use for the occurrence of *Harpagophytum*

Chapter 8.7 discussed the role of land use for the occurrence of *Harpagophytum* and showed that an increase of the grazing pressure promotes an increase in *Harpagophytum* densities.

To test this proposed relationship from the perception of Namibian farmers, answers on the density of *Harpagophytum* are related to the official carrying capacity stated for the questioned farms. In general, the carrying capacity or stocking rate of an area or farm may vary considerably from year to year and in different parts of the country (TAINTON 1999). The stocking rate is defined as “the number of animals of a particular class which are allocated to an unit area of land for a specified period of time (usually the growing period)” (MORRIS, HARDY & BARTHOLOMEW 1999). It is expressed as animal numbers per unit land (ha) or as land area available for each animal. Here, data on the carrying capacity of the questioned farms was extracted from the AGRO-ECOLOGICAL ZONING PROGRAMME (2001), and carrying capacity is listed according to this with kg/ha (Table 51). The carrying capacity is only an indicator for the utilisation potential of an area, and does not reflect the individual land use practises with stocking rates and grazing regime. Nevertheless, it is assumed that farmers will not understock their farms to a great extent and that thus a high carrying capacity will reflect a potential high grazing pressure.

When comparing the official carrying capacity of the questioned farms with the frequency of *Harpagophytum* individuals found on the farms, it is found that *Harpagophytum* may occur on grazing land with a carrying capacity that ranges from 10kg/ha to 45kg/ha (Tab. 49). A frequent or very dense occurrence of the species (50-200, >200 individuals/ha) was predominantly reported for farms with a registered carrying capacity of 30-45kg/ha. This indicates that *Harpagophytum* is likely to occur in areas with a higher grazing pressure due to higher stocking rates. The two-sided Spearman rank order correlation indicates a highly significant and positive relationship between both variables (n=105, R=0.4549, p=0.0000).

Tab. 49: Carrying capacity based on Agro-Ecological Zoning Programme (2001) in relation to *Harpagophytum* density on the interviewed farms.

Density of Harpagophytum	Carrying capacity (No. answers)						
	10 kg/ha	12 kg/ha	18 kg/ha	24 kg/ha	30 kg/ha	36 kg/ha	45 kg/ha
Very rare (few plants only)	6	3	4	2	5	5	2
Rare (up to 5 plants/ha)		1	1	4	6	5	10
Common (5-50 plants/ha)	1	1	1	1	4	13	7
Frequent (50-200 plants/ha)					2		3
Large quantities (>200 plants/ha)						1	
Total	7	5	6	7	17	24	22

The dissemination of fruits of *Harpagophytum* has been subject of the previous Chapter 8.10, where the efficiency of the telechorous mode of dispersal was discussed. Here, the perception of the interviewees on potential problems of the dispersed fruits for the livestock is discussed.

An efficient epizoochorous transport of the fruits of *Harpagophytum* was observed by most farmers, who state that the fruits may either get entangled in the fur or in the hoof of livestock (Tab. 50). It was reported that in particular for calves the fruits occasionally pose a problem, when they feed on the shoots and immature fruits get caught in their throats. Several farmers stated to have lost at least once a calve by this. Only three farmers did not have any personal experience with the fruits of *Harpagophytum*.

Tab. 50: Crosstable of questions on “Do the fruits of *Harpagophytum* pose problems to your livestock?” and “If so, what are the problems?”

Occurrence of problems	If so, what are the problems? (No. of answers)			
	Caught in fur	Caught in hoof	Caught in throat	No answer
Yes	7	8	11	1
No	1	2	-	-
No answer	-	1	-	1

10.4.3 Utilisation and harvest of *Harpagophytum*

Several questions dealt with the utilisation of *Harpagophytum*, harvesting activities on the farms, plant parts harvested, harvesting techniques, and harvesting season. Only 52 farmers answered the questions on utilisation. On 66% of these the secondary tubers of *Harpagophytum* were not harvested farm while 34% of the farmers stated that the plant is harvested on their land (Fig. 59).

Three groups of people are involved in the harvesting of *Harpagophytum* on private farmland in Namibia (Tab. 51). Of 28 farmers, who stated an utilisation of *Harpagophytum* on their farm, on the greatest percentage of farms harvesting was done by the farm workers (59.3%). One quarter of the farmer harvested the plant themselves. Harvesting activities by people from outside the farm were reported by 14.8% of the farmers. These were predominantly due to illegal harvesting activities by refugees such as in the vicinity of the Osire refugee camp in the Otjozondjupa Region.

Tab. 51: Crosstable of question on “Who is harvesting *Harpagophytum* on your farm?” and “What is the purpose of harvesting?”

Purpose of harvest?	Who is harvesting? (% answers)			
	Farmer	Farmworker	Other people	Total
Commercial use	2 (7.4)	5 (18.5)	4 (14.8)	11 (40.7)
Private use by farmer	5 (18.5)	2 (7.4)	–	7 (25.9)
Private use by farm worker	–	6 (22.2)	–	6 (22.2)
No answer	–	3 (11.1)	–	3 (14.8)
Total	7 (25.9)	16 (59.2)	3 (14.8)	

The purpose of harvesting differs with respect to the person harvesting. The farmer himself predominantly harvests for his private medicinal use, only occasionally he sells the dried secondary tubers. Farm workers harvest *Harpagophytum* either for commercial purposes or for their private use. Seldom they also dig the tubers for the farm owner. Generally, on Namibian farmland the resource is to the same extent exploited for private use (48.1%) as for commercial use (40.7%).

Only few farmer who stated an utilisation of *Harpagophytum* on their farm, answered the question on the quantity of harvested material (Tab. 52). Small amounts of dried secondary tubers are typically harvested for private use. Most of the farmers stated that only few kilograms are harvested each year from their farm. Medium amounts with 50-100kg/yr (dried material) are either harvested for commercial purposes or for private farm use. In contrast, high amounts of >200kg/yr are always correlated with a commercialisation of the resource exploitation. These were only reported from three farmers, in contrast of a total of eleven farmers who said that commercial extraction is carried out on their farm.

Tab. 52: Crosstable of questionnaire on "What is the purpose of harvesting?" and "How much is harvested on your farm each year?"

Harvesting purpose [answers, (%)]	Harvesting amount			
	Small (few kg/yr)	**Medium (50-100kg/yr)**	**High (200-300kg/yr)**	**Very high (>300kg yr)**
Commercial use	1 (6.7%)	2 (13.3)	2 (13.3%)	1 (6.7%)
Private use by farmer	3 (20.0%)	3 (20.0%)	–	–
Private use by farm worker	3 (20.0%)	–	–	–
Total	7 (46.7%)	5 (33.3%)	2 (13.3%)	1 (6.7%)

The farmers answered the question on the harvesting techniques and periods on the bases of personal experience and knowledge or personal observation of other people harvesting on their land (Tab. 53). Although most farmers were aware of the fact that only the underground parts of the *Harpagophytum* plants are of medicinal value (68.8%), only one third stated that harvesting is restricted to the secondary tubers. Three farmers thought that the conspicuous fruits of *Harpagophytum* are utilised.

With respect to the harvesting techniques, most farmers (53.3%) observed or were of the opinion that in the course of extraction the entire plant is removed from the soil. Personal communications reveal both, either the farmer observed this happening or he/she was of the opinion that this is the correct harvesting method. 23.3% of the farmers knew that a sustainable harvesting technique is related to a restriction of the extraction to the secondary root tubers.

According to the interviewee, the best period of the year to harvest the root tubers of *Harpagophytum* is the rainy season (58.5%). This corresponds to the months of February to April when the above-ground shoots of the plants are visible and the plants are easy to identify in the field. Harvesting of *Harpagophytum* after the vegetative period, from May to October, when the above-ground shoots of the plant are dry and may be withered, was considered suitable by 22% of the farmer. Harvesting activities that last throughout the entire year were only stated by two farmers.

Tab. 53: Questions on the plant parts harvested, the harvesting technique and season of harvesting.

Harvesting of Harpagophytum	No. of answers	Answers [%]
Plant parts used		
Fruit	3	9.1
Main root (parent tuber)	3	9.1
Secondary tubers (storage tubers)	11	33.3
All root parts	12	26.4
No answer	4	12.1
Harvesting techniques		
Whole plant dug out	16	53.3
Only dug out till a certain depth	2	6.7
Only side roots dug out	7	23.3
Other	2	6.6
No answer	3	10.0
Harvesting season		
Rainy season (Feb. - April)	24	58.5
After rainy season (May - October)	9	22.0
All year	2	4.9
No answer	6	14.6

10.4.4 Decrease of the resource *Harpagophytum*

The extraction of the secondary root tubers of *Harpagophytum* may be detrimental to the population status of the species. In particular, when non-sustainable harvesting techniques are applied and frequency of harvest is very high. To evaluate the perception of the Namibian commercial farmers several questions on a potential decrease of *Harpagophytum* in their area were included in the questionnaire. These questions are not strictly related to the farm of the interviewee, but the wider area of the farmer association or the region. The farmers answered this question irrespective of an utilisation of the plant on their farm.

Slightly more than half of the interviewees (55.9%) did not see a general decrease of *Harpagophytum* in their region (Tab. 54). 24 farmers of a total of 86 farmers who answered this question were concerned about a decrease of the resource in their area.

No relationship is evident between an utilisation of *Harpagophytum* on a commercial farm and the opinion that the species may be decreasing in the region. Only nine farmers of a total of 28 farmer who stated harvesting activities from their farm, uttered a concern on a possible decrease of the resource in their region. Most farmers were of the opinion that the plant is not endangered even though it was exploited on their land.

Tab. 54: Crosstable of questions on “Is *Harpagophytum* decreasing in your region?” and “Is the plant harvested on your farm?”

Decrease visible [No. of answers (%)]	**Harvesting**	
	Yes	**No**
Yes	9 (11.0%)	15 (18.3%)
No	17 (20.7%)	31(37.8%)
No answer	2 (2.4%)	8 (9.8%)
Total	28 (34.1%)	54 (55.9%)

Most of the farmers (42.9%) assumed that natural factors such as changes in rainfall patterns, in particular a decrease of rainfall amounts, will eventually lead to a decrease of the resource (Tab. 55). As many identified considerably lower precipitation amounts over the past decade, they anticipate that a continuous decrease in rainfall will eventually also effect the survival of the plant. Yet, almost the same percentage (34.4%) assumes a decrease of *Harpagophytum* to be due to over-exploitation and detrimental harvesting techniques. Overgrazing is considered by one farmer to affect the occurrence of *Harpagophytum*.

Concerns that it will not be possible to harvest the plant in future decades was uttered by one quarter of the interviewees who assume that the plant suffer from over-exploitation. Yet, the majority does not see a threat of extinction for *Harpagophytum* within the next decade.

Tab. 55: What may the reason be for a decrease of *Harpagophytum* in your region?

Reasons for a decrease	**No. answers**	**Answers [%]**
Environmental (changes in rainfall etc)	15	42.9
General over-exploitation	5	14.3
Detrimental harvesting techniques	6	17.1
Over exploitation & detrimental techniques	1	2.9
Overgrazing	1	2.9
Other	1	2.9
No answer	6	17.1
Total	35	100.0

Actions to be taken to conserve the resource range from:

(a) A permit system should be established and applied

(b) Harvesting should be controlled

(c) No more harvesting should take place

(d) The price for the secondary tubers should rise dramatically

(e) Harvesters should be trained

(f) The plant should be grown in plantations

(g) Nothing can be done

10.5 Summary and conclusions on the results of the questionnaire

The evaluation of the occurrence and density of *Harpagophytum* needs to consider the year-to-year variations of the species. Looking at one year only, it is very difficult to properly estimate whether a species like *Harpagophytum* is decreasing. Therefore, a minimum length of the study period has to be applied. By the use of a farmer interview, this limitation was overcome as the knowledge of the interviewee is based on a long-term observation of the managed land and is thus reflecting a greater timer period than single field assessments. The questionnaire distributed on Namibian private farmland was able to provide additional and valuable information on the occurrence and density of *Harpagophytum* in Namibia.

Namibian farmers report the plant to occur less frequent than indicated by the results of the square kilometre sites (Chapter 8). When comparing the quantities of both approaches, some differences become obvious (Tab. 56). Low quantities of *Harpagophytum* were recorded less often on the square kilometre sites (15.2%) than on the interviewed farms (47.7%). The percentage of a common occurrence of the resource was approximately similar. The greatest difference exists for large quantities and a frequent occurrence of *Harpagophytum*. Whereas less than 10% of the farmers stated such amounts for their farms, in the field studies on almost half of the farms at least some sites with such a high resource availability were documented. This discrepancy may be interpreted in three possible ways: (a) It may be that the farmers did not detect all patches or dense aggregations of *Harpagophytum* on their farms and that they therefore did not state such quantities in the questionnaires. (b) As the plant grows in an alteration of scattered single individuals and dense patches, it is difficult to state total numbers per hectare. Therefore it might be that the farmers gave an overall estimation of quantities on their farm and levelled out the higher quantities of occasional occurring patches. (c) The quantities recorded on the square kilometre sites are related to plant numbers counted 24 transects within a square kilometre. These might results in higher total numbers as the farmers were not asked to include such a large area into their estimation.

The results of a questionnaire from 1986 (NOTT 1986) match well with the results of this questionnaire. NOTT reports an average density of 5-7 plants/ha with locally much higher quantities. For some areas, she reported much higher numbers of individuals, such as on three camps on the farm Burgdorf (Khomas Region near Windhoek). There, plant numbers between 360-199 plants/ha up to 1997 plants/ha were counted. In general, NOTT gives a possible maximum number of 1200 plants/ha for wild populations (NOTT 1986). SCHNEIDER (1997) states similar population densities for a farm at Swartrand in southern mid Namibia, where plant numbers can vary between 500-2000 plants/ha.

Large quantities as well as a common occurrence of *Harpagophytum* were only reported for the Omaheke Region, the Erongo Region and the Otjozondjupa Region, in areas with mean annual rainfall amounts of 300-400mm. Vegetation types of these areas are the Camelthorn Savanna and the Thornbush Savanna. In the southern and more dry parts of the country *Harpagophytum* is reported to only occur with single individuals. In general, a low density of *Harpagophytum* is stated to occur in all sampled vegetation types of Namibia.

Tab. 56: Density of *Harpagophytum* according to the results of the questionnaire and of the square kilometre sites on private farmland of Namibia.

Questionnaire (n=90)		**Square kilometre sites on Namibian farmland (n=33)**	
Harpagophytum density	**Answers [%]**	**Density classes**	**Density on 1km^2 [%]**
Very rare (few plants only)	23.3	1-9 ind. /km^2	15.2
Rare (up to 5 plants/ha)	24.4		
Common (5-50 plants/ha)	38.9	10-49 ind. /km^2	33.3
Frequent (50-200 plants/ha)	6.7	50-99 ind. /km^2 100-199 ind. /km^2	36.4
Large quantities (>200 plants/ha)	1.1	200-499 ind./km^2 >500 ind. /km^2	9.1
No answer	5.5	–	–

Year-to-year variations in the density and occurrence of *Harpagophytum* were identified by most farmers to be driven by rainfall patterns. Other factors possibly responsible for such variation may be extreme temperatures, slight changes in the grazing regimes of such areas or harvest activities. As only on some of the farms *Harpagophytum* is extracted, it can not be regarded as main driving factor determining annual variations of the occurrence of the species. The perception of the farmer contrasts the results of this field study (Chapter 9.7), in which shows that *Harpagophytum* is positively correlated with the grazing intensity. For various authors the species is an indicator for overgrazed areas (e.g. IHLENDFELDT & HARTMANN 1970). The species is said not to be very competitive in comparison to perennial grasses and partly also to annual grasses. "On good and intact pastures *Harpagophytum* should not be found in great numbers" (Rust, pers. comm.). This opinion is reflected in the answer to the question on the density of the vegetation surrounding *Harpagophytum*. Most farmers found that the plant occurs in areas with a sparse vegetation cover.

Following the perception of Namibian farmers, plain habitats provide the best conditions for the occurrence of *Harpagophytum*. This result matches well with the findings of the field sampling (Chapter 9.5) and with literature. IHLENDFELDT & HARTMANN (1970), for instance, stress the tendency of *Harpagophytum* to become a ruderal plant to grow on disturbed places (WALTER & VOLK 1954, VOLK & LEIPPERT 1971). The observation of the interviewees that *Harpagophytum* is mainly restricted to sandy soils with a varying content of loam, is also reflected in the questionnaire of NOTT (1986), for which 96% of the farmers reported the plant to grow only on red sandy soils, the rest was found in clay pans and on white sandy soils. According to IHLENFELDT & HARTMANN (1970), the colour of the sand of *Harpagophytum* habitats varies between red, white, yellow to brown, but soils with red sand are favoured (see also BLANK 1973, MOSS 1983).

In literature it is often reported that fruits of *Harpagophytum* may cause problems for livestock (BOSS 1934, BREYER-BRANDWIJK 1962, BLANK 1973). This was also observed by Namibian farmers who considered the fruits to be a potential problem. The epizoochorous properties are supported by the perception of the Namibian farmers. Thus, telechory forms at least one option of a successful dispersal in *Harpagophytum*. Only very occasionally the furits are said to pose a threat to livestock when fruits get entangled in the throats. A severe problem stated by BOSS (1934), i.e. the grazing the shoots of *Harpagophytum,* was not observed by any farmer. Due to the fibrous tendrils which accumulates to dense masses of undigested plant material in the intestines of cattle, the grazing and may eventually lead to an obstruction of the intestines and possibly to the death of the animal. According to the observation of Namibian farmers *Harpagophytum* occurs in parts of the farms, which are frequently grazed by livestock. Comparisons with the data on the potential carrying capacity of the farms extracted from the AGRO-ECOLOGICAL ZONING PROGRAMME (2001), indicate that great densities of *Harpagophytum* occur in particular in areas with a high carrying capacity. Based on the assumption that generally farms are not likely to be understocked, it is concluded that these areas also in reality experience a certain grazing pressure. Grazing and trampling is mentioned also in literature as an important threat to the plants especially in dry years (FECHTER 1973).

The utilisation of *Harpagophytum* is restricted to one third of all interviewed farmers. Harvesting activities are to the same extent initiated for private as for commercial purposes. Yet, when very larger quantities of >200kg are harvested annually, harvesting is done commercially. At the time of NOTT's interviews only 15% of the Namibian farmers – half the percentage of farmers interviewed now – said that harvesting still occurred on their farm. NOTT (1986) found out that between the 1960s and 1980s approximately 75% of the interviewed farmers stated that the plant had been used on their land. The decrease of commercial extraction on private farmland from that time till 1986 was probably not only due to a decrease in harvesting amounts and a lower request of material in general, but also to a change in large scale rainfall patterns. In the mid 1980s after some years of very good rainfall plant numbers decreased again as rainfall stayed more and more below average. Consequently, many harvesters lost interest in digging up the roots. Also up to a few years ago many farmers were not aware that *Harpagophytum* is still exported. Only recently an increased interest of the farmers in an additional cash income for themselves or their labourers can be noticed. This has been supported by the discussions on a potential CITES appendix 2 listing of *Harpagophytum*, which has been discussed in Namibian newspapers and journals (e.g. MC VEIGH 2000, ALLGEMEINE ZEITUNG 2000, HALLBAUER 2000, HEINRICH 2000, INAMBAO 2001). Another reason for a sudden decrease in harvesting amounts could be a decrease in the consumers` interest in tea products of *Harpagophytum* in the 1980s, which were the only drug products derived of the roots at that time. Only since 1990 also tablets and capsules besides tea are produced and supplement the list of retail products. These products might have better a marketing potential than the bitter *Harpagophytum* tea, leading to a renewed increase of demand today (see Chapter 14). Furthermore, a shift in harvesting regions can be observed throughout the years. Whereas at the beginning of the commercial trade in *Harpagophytum*, only the Namibian farmers were involved in the harvesting and thus harvest took place on commercial farmland only, currently the opposite is true. Most of exported material is extracted from communal areas, whereas commercial farmland is at the moment only randomly involved in harvesting.

Best period of the year to harvest the secondary tubers of *Harpagophytum* was stated to be the rainy season, from February to April, respectively. Yet, NOTT (1986) argues that in the rainy season tubers contain up to 95% of the total weight of water whereas in the dry season it is only 75 – 80%. Most farmers report an unsustainable harvesting method like the complete extraction of the *Harpagophytum* plants when harvesting. The observation, respectively the knowledge, that only the secondary tubers are to be harvested was given only by seven farmers. A sustainable harvesting technique would be the digging up of only the side roots with the valuable secondary storage tubers whereas the main root tuber is left untouched for the purpose of regeneration in the soil (see Chapter 12).

The majority of the Namibian farmers does not think that the resource availability of *Harpagophytum* is decreasing in their region. This opinion is irrespective of a potential utilisation of the plant on the farm. Also, most interviewed farmers are not concerned about a possible decrease of *Harpagophytum* in the following years. The reason for the opposite perception of some farmers may be due to the following: In areas where refugee camps are situated within the private farmland and problems occur due to illegal harvesting activities (Osire near Otjiwarongo), farmers are more likely to find over-exploitation and harmful harvesting techniques responsible.

11 Synthesis of field studies in *Harpagophytum*

Field research on *Harpagophytum* was conducted in southern Africa over the period of 1999-2002. Research was based on a comprehensive approach comprising three different types of assessment. These were:

- A detailed assessment of 96 research sites of one square kilometre in size
- A re-documentation of old collecting sites over a period of one year (24 sites) and three years (9 sites)
- The implementation of 90 interviews with land owners in Namibia

Each type of assessment contributed differently to the understanding of the ecology and utilisation of *Harpagophytum*. While the mapping of the abundance and frequency of *Harpagophytum* (Chapter 8) concentrated on spot checks with a high level of detail and a comparatively high sample size, with the monitoring (Chapter 9) of old collecting sites, changes in the abundance and frequency of *Harpagophytum* could be traced back over several decades. For some of the sites monitoring continued over a period of three subsequent years (1999-2001) so that also year-to-year changes of the abundance of *Harpagophytum* in relation to precipitation could be analysed. The interviews (Chapter 10) covered both, a large area and a large time period as data collecting was based on the experience of the Namibian farmers who's knowledge of their farm(s) is typically based on a long period of time.

Research areas of the study cover great parts of the distribution area of *Harpagophytum* (*H. procumbens* ssp. *procumbens*) in Namibia and South Africa as indicated by the herbarium specimen data of the PRECIS data bank in Pretoria, South Africa, and of the National Botanical Research Institute in Windhoek, Namibia.

The map in Figure 65 shows a compilation of the locations of herbarium specimen data, one-square kilometre sites, interviewed farms and of re-documentation sites. The compilation indicates that great parts of South Africa for which no herbarium collection exist were sampled in the course of the study. Also for Namibia, new information on the distribution of *Harpagophytum* can be contributed to the existing herbarium specimen data, in particular for the central regions of the country (Khomas Region) and the south-eastern parts of the Kalahari.

Focus of the field studies was the comparison of *Harpagophytum* in two types of land ownership, communally owned land and commercial, privately owned land. This approach was chosen as the result of a first study conducted in the frame of an "F+E Vorhaben" (Research & Development project) for the German Federal Agency for Nature Conservation (HACHFELD 1999), indicated that large differences between the resource abundance and the utilisation intensity of *Harpagophytum* are evident between both types of land ownership. In this study, further research aimed at a detailed documentation and better understanding of these differences. Yet, the gross over-simplification of the differentiation between communal and commercial land ownership has to be born in mind. Commercial farming systems may differ in the land use intensity with respect to the knowledge and capacity of the owner/farmer. The same is true for communal areas where traditional authorities may also have a tight control over the land management issues and the resources (HOFFMAN & ASHWELL 2001). This threat of over-simplification could be overcome as focus was put on several aspects of the landscape, the plant and it utilisation intensity within both types of land ownership.

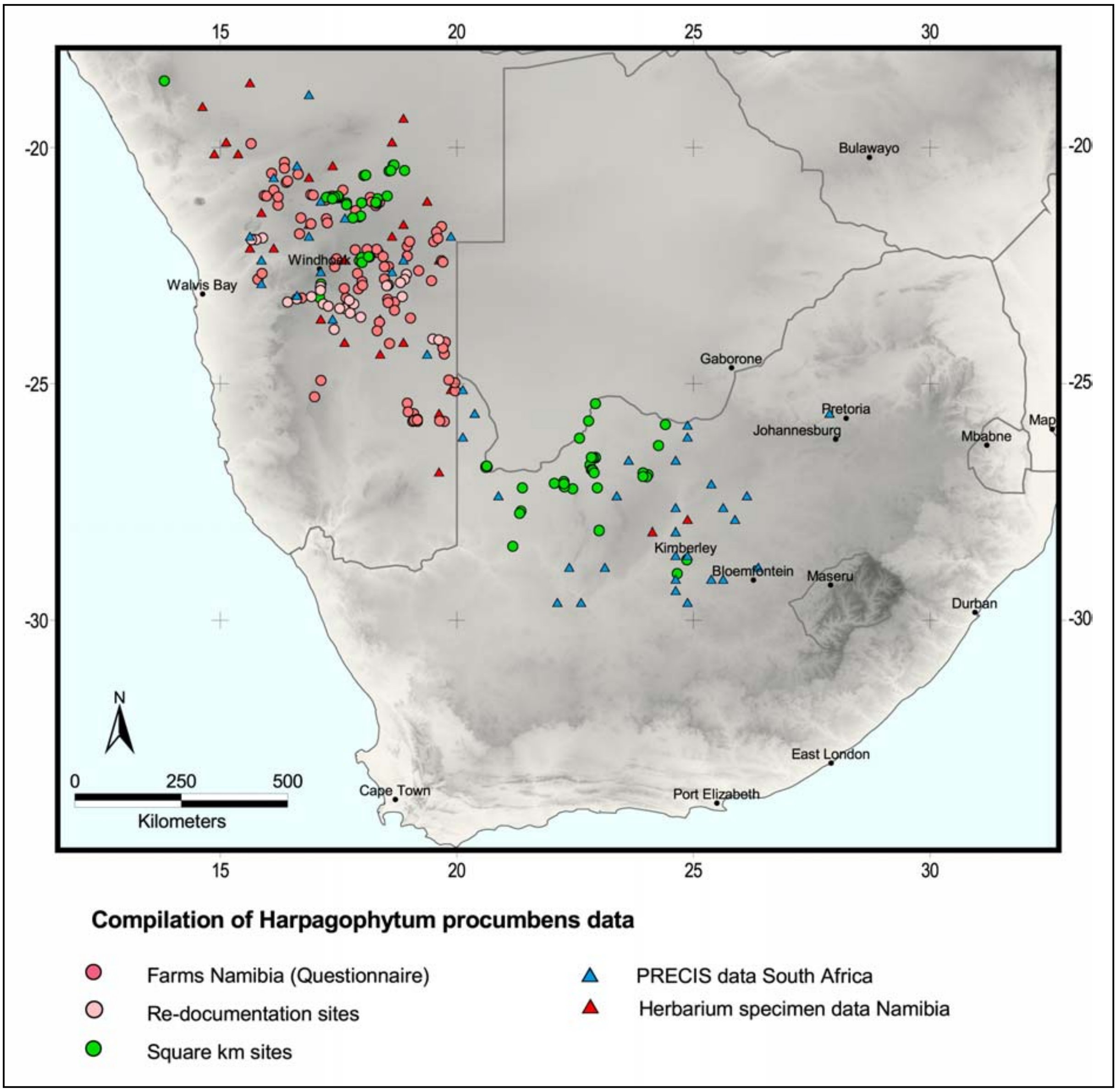


Fig. 65: Compilation *of Harpagophytum* data available for southern Africa.

Main objectives covered by the three types of field assessments were:

(1) Environmental conditions of *Harpagophytum*

(2) Impact of land use on *Harpagophytum*

(3) Spatial distribution and abundance of *Harpagophytum*

(4) Potential threats of *Harpagophytum* through harvesting

(5) Regeneration potential of *Harpagophytum*

Detailed discussions on the findings of the three approaches are discussed in the relevant chapters. Here, a synthesis of the main objectives is presented.

11.1 Environmental conditions of *Harpagophytum*

Four major aspects of environmental conditions, each with a potential impact on the occurrence and abundance of *Harpagophytum,* were assessed in the course of the three types of field study. Often, all four aspects were investigated:

(a) Habitat conditions	(ecology assessment, interviews)
(b) Soil properties	(ecology assessment, interviews)
(c) Precipitation	(ecology assessment, interviews, re-documentation)
(d) Vegetation	(ecology assessment, interviews, re-documentation)

(a) Habitat conditions

Seven habitat types were sampled throughout the study. These comprise plains, disturbed plains such as roadsides, Omurambas (periodically flooded plains), and dune habitats such as dune base, dune slope, dune crest and interdune areas.

Results of the ecological assessment and the interviews suggest that *Harpagophytum* is predominantly restricted to plain habitats. This preference is evident irrespective of the land ownership and country. 70% of the Namibian farmers stated plain habitats as most important habitat for the growth of *Harpagophytum*. Single *Harpagophytum* plant may also occasionally inhabit roadsides, Omurambas, dune base and lower dune slope habitats. This was supported by the questionnaire as only 10% of the farmers stated this as favourite habitat site. Dune slopes and in particular dune crest proved to be not suitable for the occurrence of the plant.

High abundances of *Harpagophytum* with patch aggregations are typically restricted to plain habitats. Only in the communal areas of Namibia and South Africa in Kalahari dune areas (where no plains occur) *Harpagophytum* patches may occasionally also occur on the interdune or dune base.

(b) Soil properties

Sand substrates represent the most prominent type of soil substrate for the occurrence of *Harpagophytum*. This is indicated by both, the results of the mapping and of the interviews, for which 64% of the Namibian farmers consider sand substrate as most suitable for the growth of *Harpagophytum*. While a varying content of loam or clay may also occur (17.4% of the farmers stated this), soils with a large stone or gravel content are not inhabited by *Harpagophytum*. Soil substrates may have various colours indicating a variation of pedogenesis and chemical properties. In particular yellow-red or red soil colours of the substrate were found at sites inhabited by *Harpagophytum*.

No significant differences with respect to soil chemical properties were found between sites with and without *Harpagophytum*. Neither the salt content nor the pH values differed significantly between different dune habitats indicating that these do not account for the occurrence of *Harpagophytum* on interdunes.

(c) Precipitation

No data on the climatic condition was collected on the research sites. Interpretations are only derived from mean annual precipitation amounts and from personal communications. In general, the abundance of *Harpagophytum* was found to increase with an increase of the mean annual rainfall amounts (Chapter 8) from south-west to north-east in Namibia and from north-west to south-east in the research areas of South Africa. In semi-humid areas with a large predictability of the rainfall, competition with other plant species seems to become an increasingly limiting factor.

This result is supported by the perception of the Namibian farmers: 72% of them see precipitation as responsible factor for the re-sprouting of *Harpagophytum* from the underground parent tuber. While most find the amount of rainfall more important than the date of the rainfall event, many find a combination of both to be responsible. A series of high rainfall years in the beginning of the 1970s probably lead to the occurrence of great densities of *Harpagophytum* at a first visit to herbarium collecting sites in the Rehoboth area of Namibia (Chapter 9). Yet, today, also in good rainfall years for most sites only a limited resource and no increase in the abundance of the plant was found in contrast to low rainfall years. No variation in *Harpagophytum* densities was found for scattered distributed plants between high and low rainfall years.

(d) Vegetation

Several vegetation types were sampled in the course of the study. Although these only represent large units and are themselves composed of small-scale patterns of various vegetation units depending on soil substrate, geology, relief and precipitation, the vegetation types reflect broad entities of typical dominance structures in the vegetation.

Namibia

The largest resource of *Harpagophytum* occurs in the Tree Savanna and Woodland, the northern parts of the Camelthorn Savanna, and the eastern parts of the Thornbush Savanna. Interview results indicate that also in the eastern Highland Savanna adjacent to the Camelthorn Savanna a common occurrence of *Harpagophytum* may be evident. A formerly dense but today completely diminished resource has been reported for old collections also in the north-eastern extension of the Mixed Tree Savanna and Shrubland near Rehoboth.

South Africa

Results from the square kilometre sites indicate the highest resource of *Harpagophytum* for the Kalahari Plains Thorn Bushveld. Single dense spots were also evident for the Kalahari Mountain Bushveld and the Kimberley Thorn Bushveld.

Results of the square kilometre sites show that the grass layer may play a competitive role for *Harpagophytum*. Single individuals of *Harpagophytum* may occur at all grass densities, while patches tend to be limited to an open grass matrix. This is also supported by the perception of Namibian farmers who find *Harpagophytum* predominantly on sparsely vegetated areas. In completely open areas such as in the direct vicinity to bore holes or cattle tracks disturbance seems to be too high for the survival of the plant.

While the results of the square kilometre sites indicate that the herb cover is not competitive with *Harpagophytum*, on one monitoring site, *Harpagophytum* was almost missing in a year when the Cucurbitaceae (*Acanthosycios naudinianus*) was dominant. This divergent observation indicate that further research is needed on the impact of certain herb species on *Harpagophytum*.

11.2 Impact of land use on *Harpagophytum*

Land use intensity differs not only between communal and private land but also within each type of land ownership. On the one-square kilometre research sites of communal areas typically a higher grazing pressure, used as an indicator for land use here, occurred in comparison to private farmland. It was found that both, frequency and abundance of *Harpagophytum,* are positively related to grazing pressure. Patches of the plant tend to be limited to high grazing pressures, while a scattered pattern may develop at all grazing intensities.

The results of the interviews correspond to these findings and suggest that *Harpagophytum* occurs on private Namibian farmland with a carrying capacity of 10-45kg/ha. Yet, clumps of the plant with densities of >50 individuals per hectare occur in areas with a higher carrying capacity (30-45kg/ha) indicating that at these sites higher stocking rates and a higher grazing pressure is present. Rotational grazing is carried out with the sites typically being grazed several times a year.

The grazing intensity may also favour the dissemination of the epizoochoric fruits of *Harpagophytum*, as several farmers report that these cling to the hoofs and tails of cattle, horses and occasionally sheep.

11.3 The spatial distribution and abundance of *Harpagophytum*

Information on the spatial distribution and abundance of *Harpagophytum* is available from all three field studies. From the results of the square kilometre sites a principle patterns of dispersion was identified that comprises a clumped pattern (patches), a scattered pattern or a lack of *Harpagophytum*.

When comparing the results of the interviews with those of the square kilometre sites, Namibian farmers have a perception of a lower resource available than indicated by the mapping results (Chapter 9). In particular with respect to large quantities and a frequent occurrence of *Harpagophytum,* only 10% of the farmers reported such amounts, while on almost half of the square kilometre sites such a high resource was evident. Contrarily, a scattered distribution pattern of *Harpagophytum* is less frequent on the square kilometre sites (15.2%) than on the interviewed farms (47.7%). The percentage of a common occurrence is approximately similar between both research approaches. In Chapter 10 this discrepancy was discussed and concluded that either the farmers were not familiar with the location of all patches on their farms, or that the questionnaire was not detailed enough so that the farmers gave an overall estimation of quantities on their farm and levelled out the higher quantities of occasional occurring patches, or that both data sets are not comparable due to different "plot" sizes.

Also from the re-documentation sites dense patches of *Harpagophytum* have been reported for some sites at the first collection.

Abundance in Regions and Provinces

Abundance and frequency of *Harpagophytum* differs between the different regions and provinces reflecting variations in the land ownership, precipitation amount, vegetation and substrate types.

For the private farmland of Namibia, greatest resource of *Harpagophytum* is evident for the Otjozondjupa Region (Tab. 57) as indicated in both, the finding of the square kilometre sites and the interviews. Also in the Omaheke Region, the Khomas Region and the eastern part of the Erongo Region large quantities of *Harpagophytum* may occur. Single individuals and a lack of the plant were evident for most regions. The questionnaires as well as the square kilometre sites supported this.

Tab. 57: Number of farms and 1km^2 sites on private farmland in seven regions of Namibia for which different density classes were identified by field sampling or interviews.

Density on farms **1 km^2-sites private Namibian land**	**No plants**	**0 ind.**	**Single ind.**	**1-49 ind.**	**Common**	**50-99 ind.**	**Large numbers**	**>100 ind.**
Erongo Region	–	–	3	–	2	–	1	–
Hardap Region	4	–	7	1	2	–	–	–
Karas Region	–	–	9	–	1	–	–	–
Kunene Region	–	–	1	–	–	–	–	–
Khomas Region	2	2	6	4	7	2	–	1
Omaheke Region	–	–	13		16	1	4	1
Otjozondjupa Region	–	1	12	11	3	2	2	7
Total	6	3	51	16	31	5	6	9

On communal land of Namibia, greatest resource was sampled in the Otjozondjupa Region (and here the Omaheke area), but it can also be expected that in the Omaheke Region large quantities may develop.

In South Africa, in both, communal and private land, the greatest resource was evident for the North West Province or the border of the Northern Cape Province to the North West Province.

11.4 Potential threats of *Harpagophytum* through harvesting

Next to the predominant impact by harvesting, potential threats of *Harpagophytum* may occur through grazing of the shoots at the beginning of the rainy season when only little other fodder is available or by conversion of suitable habitats to cropping fields or roads. Main focus of all three approaches of this study was put on the harvesting impact.

It was found that an exploitation of *Harpagophytum* is evident for both countries and types of land ownership, but concentrates on areas with a large resource. These are plain habitats which are characterised by a high grazing pressure on the vegetation. The potential resource of an area prior to the extraction of the secondary tubers was typically considerably higher.

Harvesting of the plant on private Namibian farmland was reported from approximately one third of the interviewed farmers. While typically harvesting is done by the farm worker for both, commercial and private use, also illegal harvesting practises occur to an increasing extent in particular in the greater vicinity of refugee camps in Namibia.

The re-documentation of old collecting sites on communal land in the Hardap Region (Mixed Tree and Shrub Savanna) of Namibia, indicate that very strong harvesting intensities with the application of detrimental harvesting techniques resulted in a persistent diminishing of *Harpagophytum*. Even decades after harvesting had stopped, no regeneration of the former populations was found in the research area. This finding was not dependent on rainfall amounts but was evident over the period of three years of monitoring Results of the square kilometre sites support this as it was found that the impact of harvesting often resulted in the conversion of dense clumps of *Harpagophytum* into a scattered distribution or a complete lack of the plant. This was in particular the case in the Thornbush Savanna in Namibia. Also half of the interviewed Namibian farmers assumed that applied harvesting techniques are not sustainable and that the whole plant is permanently removed from the soil. Yet, only 20% of the farmers think that the plant may be decreasing in their region over the coming decades. In the case of an uttered concern, natural phenomena as well as over-exploitation are seen as possible reasons.

11.5 Regeneration potential of *Harpagophytum*

Regeneration may take place on various levels of biological organisation, while the principle of replacement does not change (URBANSKA 1992). Regeneration comprises the fugitive strategies of deciduous trees, geophytes or annuals, the regenerative phases of individuals or populations, the regeneration of individuals after disturbance by herbivory or the replacement of entire populations of a species by another population of the similar species (or phytocoenosis etc.).

The avoidance of unsuitable environmental conditions and the translocation of photosynthetic resources by the development of the geophytic life form, is the most prominent regeneration strategy of *Harpagophytum*. Others, included in this study are reproduction, regeneration after grazing or low rainfall years and regeneration after anthropogenic disturbance by harvesting. The latter comprises the regeneration of single individuals as well as whole populations.

While monitoring *Harpagophytum* over the period of three years, similar plants were frequently flowering and producing fruits in each year. Yet, irrespective of the regular reproduction and high rainfall years, no regeneration of the populations by seedlings was visible. This finding was not dependent on the dispersion pattern and seed production of *Harpagophytum*. Also on 70% of the square kilometre sites on which *Harpagophytum* plants were found in the reproductive phase, no seedlings were observed in neither year of data collecting. Although a greater reproductive effort of single plant individuals was evident for the communal Okakarara area (Otjozondjupa Region), Namibia, in comparison to the private farmland of South Africa, no seedlings were observed.

The regeneration of *Harpagophytum* from year to year varies depending on precipitation amounts. This was not only the perception of the interviewed farmers but also found by the re-documentation of old colleting sites. It was observed that plant individuals may develop new shoots and flowers several times a year, if dry periods occur within the rainy season and cause the withering of existing shoots or in the case that the shoots are grazed. A regeneration of *Harpagophytum* populations may, however, not be possible when the entire population has been removed by destruction of the habitat. This was found for some square kilometre sites for which dense stands of the plant were reported before the conversion of the habitat to a crop field (maize field). Even several years after maize cropping had stopped, the vegetation had not recovered and also *Harpagophytum* had not re-entered the area.

The impact of harvesting is the most persistent one and regeneration after a severe harvesting impact may not be possible. This was reported by interviewed farmers who observed that since illegal extraction of tubers took place on their land formerly dense patches of *Harpagophytum* have not regenerated. The findings of the re-documentation of old collecting sites support this. No regeneration of formerly dense stands of the plant took place on sites which have been destructed by over-harvesting two to three decades ago.

11.6 Conclusions on the field studies in *Harpagophytum*

With respect to the aim of many studies to ensure the possibility of a continuous availability and utilisation of *Harpagophytum* also over the next decades, it can be concluded that several factors need to be considered. First and foremost, the current distribution of *Harpagophytum* needs to be known. The documentation of the square kilometre sites was able to contribute to this. Data of this study formed one basis for additional studies on a resource mapping of *Harpagophytum,* which have recently been carried out by M. Strohbach for CRIAA SA-DC in Namibia (STROHBACH 2002). Also in South Africa, a small-scale mapping project of *Harpagophytum* is initiated based on my findings for the following year 2003 (Raimondo, pers. comm.). This will continue with the sampling of additional vegetation types in South Africa, in particular towards the border of the distribution area of the species. Concurrent to the additional collection of environmental data, the understanding of the ecology of *Harpagophytum* will increase. Yet, more specific research is needed on the reproduction and patch forming of the plant.

Next to the described known focus areas of utilisation, the extent of the "dormant" resource of *Harpagophytum* on predominantly private farmland needs to be evaluated. This was one major focus of this study. Yet, as it could be shown that regeneration is not easy in *Harpagophytum*, it cannot be assumed that regeneration of over-exploited areas from the non-utilised areas is not easy to achieve. STROHBACH (2002) states in preliminary results of a harvesting monitoring study that there is a tendency of parent tuber diameters to be bigger in not or seldom harvested populations than in those which are frequently harvested indicating an effect of harvesting on regrowth rates. This is supported by the observation of exporters and middleman who report that lately the sliced material of *Harpagophytum* is of smaller size than it used to be some years ago. This indicates a reduction in the existence of old plants with large storage tubers in harvest areas (TRAFFIC 2000). From this result, the need to protect also the utilised areas from over-exploitation and the destruction of patches has to be formulated. This could be achieved by an increasing application of non-detrimental harvesting techniques. Nevertheless, success in regeneration will not only depend on the harvesting techniques applied and the season of harvest, but is also dependent on the habitat conditions of the area where the plant is extracted from, the precipitation amounts, grazing intensity and other disturbances as well as inter- and inner-specific competition in the years subsequent to harvesting. Although, fieldwork of this study was able to contribute to these topics, no detailed understanding has been achieved up to date. It is not yet possible to accurately define a sustainable utilisation of *Harpagophytum* except for the traditional utilisation by the San who only harvested half of the secondary tubers of each plant to leave a sufficient number of tubers for recovery in the following years.

12 Harvesting of *Harpagophytum*

While the harvesting of medicinal plants was traditionally limited to well-skilled traditional medicinal practitioners, who respected strict conservation measures for plant collecting, the recent trend towards increased commercialisation of medicinal plants in South Africa has resulted in frequent over harvesting of many medicinal plant species (CUNNINGHAM 1994). The relative importance of veld products varies with the potential income an individual can get from various other economic activities. Depending on the market possibilities, people in rural areas will – if they have a choice – concentrate on agriculture, gathering of wild plants or on other activities. Due to increased demands in medicinal plants, a greater range of people gets involved in gathering medicinal valuable plant parts. Consequently, a shift from selected traditional gatherers to untrained and often indifferent commercial gatherers with no other sources of income takes place (WILLIAMS, BALKWILL & WITKOWSKI 2000).

Also in *Harpagophytum* this trend is evident. The exploitation of the secondary tubers of *Harpagophytum* from the wild poses one of the greatest potential threats to the species. Dramatic increases in the exports of raw material led to a public concern about an over-exploitation of the resource. In order to understand how an over-exploitation may happen, it is important to understand the harvesting process including the motivation of the harvesters and the yield and price they can get for their harvest.

This chapter deals with the process of harvesting, the applied techniques and potential yield, the harvesters, the middlemen buying and transporting the harvested material to the exporter, and other notable operations related to the harvesting of *Harpagophytum*. Following a subchapter on the harvesting techniques, in each of the following three subchapters the current exploitation status with respect to *Harpagophytum* in the three range states Namibia, Botswana, and South Africa is discussed.

12.1 Methods

Data collecting for this chapter on the harvesting of *Harpagophytum* was started at the end of 1998 and continued throughout the study until mid of 2002. Information compilation is based on three main sources.

The applied methods are:

- Personal communications and interviews with various stakeholders (harvesters, exporters, Ministry officials, Extension officers from the Ministry of Environment and Tourism and NGOs).
- Comprehensive review of existing literature, unpublished reports etc.
- Personal observations of the harvesting process of *Harpagophytum* in the field. This was done while collecting data for the square kilometre sites.

In particular, Cyril Lombard and Dave Cole, from the NGO CRIAA SA-DC contributed valuable information to this chapter. In the text, the different sources of the data collection are highlighted.

Price calculations are based on officially available exchange rates for the mid of the respective year of calculation, typically the 1st of September (http://www.oanda.com/convert/classic). This time period was chosen as in general it lies after the main harvesting season when the selling of the tubers takes place.

12.2 Harvesting

12.2.1 Harvesting techniques

Harvesting techniques differ with respect to the person harvesting, the ethnic group and the region. Harvesting techniques are dependent on whether traditional knowledge of the plant exists in the harvesters community or with the single harvester, on the access to the resource, its availability and quantity as well as on the price paid for the harvested material. In Figure 66 a *Harpagophytum* plant is shown with its main tuber and several secondary storage tubers.

In general, two ways of harvesting can be distinguished:

(a) Harvesting can be done in an exploitative and detrimental mode with no consideration of a continuation of the resource availability or

(b) Harvesting can be done in a sustainable mode that ensures a regeneration of the resource.

Up to date there are several guidelines on how a sustainable harvesting of the secondary tubers of *Harpagophytum* should be carried out. However, no comprehensive studies have yet been carried out on the impact of different harvesting techniques on the regeneration potential of the species, especially when considering various rainfall scenarios, other environmental or anthropogenic influences. It has not yet been scientifically proved what this term exactly means and what needs really to be done in order to ensure permanent resource availability and resource regeneration over a long period of years. If exploitation level remains low such as it was when the plant is only harvested for traditional and non-commercial, this does not pose a problem. Only in the case of large-scale commercial exploitation this issue becomes increasingly important.

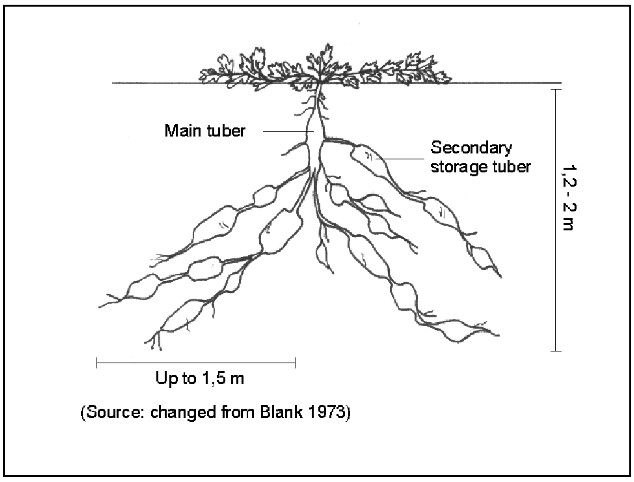


Fig. 66: Habitus of a *Harpagophytum* plant with main tuber and secondary storage tubers.

Traditionally, sustainable harvesting techniques were applied by the traditional users of the plant, the San. When harvesting the secondary tubers of *Harpagophytum*, they did not remove all root tubers of a plant, but limited their harvesting to only one half of the tubers. This was done by only digging half a circle around a plant individual and leaving the other half including the parent tuber untouched (STROHBACH

2001b). By this, it was ensured that the plant has enough water as well as carbohydrates stored in the secondary tubers to shoot new leaves and produce flowers and fruits in the next vegetation period.

One main principle of a sustainable harvesting and a potentially successful regeneration of a plant individual after extraction is that the main tuber is left untouched in the soil or is replanted after the harvesting.

Sustainable harvesting techniques are listed in order of declining sustainability:

- The soil around the plant is loosened with a stick, and the soil material is removed by hand to uncover the secondary root tubers. The use of a stick avoids the damage of the side roots and the mother tuber. After harvesting, the hole is closed up again (pers. observation North West Province, South Africa).
- The soil material around the plants is removed with a spade, starting at one side of the plant. The green shoots of the mother tuber remain untouched and the tuber is removed and set aside for the period of extraction or remains in the soil. After harvesting, the hole is closed again (pers. observation. Okakarara area, Namibia).
- Plants are completely removed from the soil, i.e. also the mother tuber is taken out which is not replanted after harvesting. However, as in a dense patch of *Harpagophytum* only single individuals are harvested, following a curvy line through the patch, many plants are left untouched. By this, a regeneration of the patch may be possible in the following years and under favourable environmental conditions (pers. observation, Okakarara area, Namibia).

In South Africa and Botswana, a method of rotational harvesting, called the quadrant system, is applied. For this, each harvesting area is divided in four parts and only one quadrant is being harvested within one season. This was implemented to give plants enough time to recover from harvesting and to produce new secondary tubers (van der Vyver, pers. comm.).

One farmer and exporter of *Harpagophytum* in South Africa stated that regeneration is favoured by harvesting, even if harvesting is not sustainable. He observed that new plants come up in the very vicinity of previously harvested plants in the following years. He concluded that the lack of competition by the harvested plant individual triggered the occurrence of another individual of *Harpagophytum*. No information was available though, if the new plants recently germinated or were only re-sprouting.

In order to ensure a constant level of resource availability over a number of years it is important to restrict harvesting to adult plants which have already reached the regenerative phase in their life span. Only when these are harvested after flowering and fruit-set, they can contribute to regeneration and the refilling of the seed bank of the soil.

Non-sustainable, detrimental harvesting techniques are characterised by the following:

- The digging of a big hole around the Harpagophytum plant of about 1-2m in diameter depending on the size and age of the plant and removal of the entire plant with tracing back all side roots with the secondary tubers.
- Large digging hole are left uncovered after the harvesting, posing a danger to livestock, game and other smaller animals to fall into it (pers. observations Osire, Otjozondjupa Region, Namibia).

Non-sustainable harvesting techniques are typically applied when harvesters are not well acquainted with the morphology and appearance of the plant because they may just have started harvesting it. This is for example the case if harvesters from other areas are engaged to harvesting *Harpagophytum*. It may also be applied by people who do not harvesting on their own land and thus do not care about a resource depletion (see Chapter 12.3).

12.2.2 Sustainability of harvest

There is an increasing concern by various stakeholders regarding the sustainability of the harvesting and trade in *Harpagophytum* in the three major range states. It is clear to various stakeholders that in localised areas the resource is in danger to become depleted owing to poor harvesting techniques and the intensity of harvesting. However, there is also concern that not enough is known about the national "macro" situation regarding the entire *Harpagophytum* resource base, and no proper baseline is available upon which conclusions to draw regarding the status of the plant (Lombard, pers. comm.). A first attempt to overcome this situation was the “First Regional Devil’s Claw Conference” held in Windhoek, Namibia, in February 2002, which aimed at a information exchange of all levels of stakeholders (Chapter 14). Also the findings of this study can contribute a better understanding of the resource base.

The issue of sustainability is further complicated by the fact that low rainfall can cause a lack of the plant just by the geophyte staying dormant without producing green shoots, while higher rainfall – which is highly variable from year to year – can cause a "come-back" of the plant especially if this is positively associated with overgrazing (see Chapter 8).

For Botswana information is derived from SEKWHELA (1994) and SEKWHELA & NTSEANE (1994). They cite that in areas where *Harpagophytum* commercial activities are well developed, a very low resource base of the plant is found which also exhibits disturbed population structures. Small plants representing a low age were predominantly found and indicate a selective removal of mid-range and high parent tuber sizes, high yield individuals respectively. Additionally, field observation in Botswana by SEKWHELA (1994) hind to a discrepancy between recommended harvesting methods and actual harvesting in the field. A high prevalence of uncovered holes reflecting missing plants, which were not sustainable harvested. SEKWHELA (1994) interprets these observations in the way that short-term benefit interests seem to be more important to the harvesters than future supplies. This, however, links to the fact that in no way the cash income from harvesting activities is sufficient for the harvesters to make a living, and thus the pressure to harvest great amounts is high (see Chapter 12.3).

In the three range states, attempts are made to train harvesters how to apply sustainable harvesting techniques. Although the range of harvesters who can be reached by theses may be limited, it presents a valuable first step and incentive.

- In Botswana, training is carried out by the main buyer of *Harpagophytum*, the non-profit organisation Thusano Lefatsheng.
- In Namibia, the NGO (CRIAA SA-DC) has produced a poster that pictures a sustainable harvesting procedure. The NGO also produced a small brochure that contains amongst other, also information on sustainable harvesting methods. Also, the NGO is actively involved in a Sustainably Harvested Devil’s Claw project (SHDC-project) in various villages in the Omaheke Region (Chapter 12.3.4).

- In South Africa, the incentive to compile and distribute information on sustainable harvesting techniques was given when the Ministry of Conservation and Environment of the North West Province was approached from the private sector at the end of 1999 (VAN DER VYVER 2002). Persons in the province can only be registered as harvesters after being trained in sustainable harvesting techniques by extension officers from the Ministry. Training consists of five parts, i.e. information on the plant, its monitoring, the procedure from the permit application to the selling, the market and the sustainable harvesting methods. In the course of a gtz project in South Africa, a CD was compiled with information on the sustainability of harvesting, which was distributed to the South African ministries (SCHNEIDER 1997).

Another important aspect of sustainability are post harvesting assessments that are initiated to control if sustainable harvesting techniques have been applied in the past harvesting season. The assessments typically include whether the harvesting holes have been closed properly and in the case of the quadrant system whether harvested limited their extractions to the specific quadrant. On farms participating in the Sustainably Harvested Devil's Claw project (SHDC-project) in Namibia, the assessments are carried out by CRIAA SA-DC. In South Africa and Botswana, extension officers of the Ministry are responsible for the post-harvesting assessments (VAN DER VYVER 2002, BEN 2002).

12.2.3 Yield

The yield of the harvesting of *Harpagophytum* depends on several factors:

- Environmental factors such as the habitat and the soil. In the case the soil is hard, which may be at a lack of rainfall or in the dry season, harvesting may be much more time consuming or not possible.
- Density of the resource available at the harvesting site
- Distance and time needed to get to the harvesting site
- Harvesting season and water content of the secondary tubers
- Population structure of *Harpagophytum*. Usually only large plant individuals with a large parent tuber (and a higher age) are harvested for these have developed more secondary tubers, but in the case of a limited resource also all other plants may be harvested and total yield will decrease.
- Age and vitality of the plant and thus the amount of secondary tubers a plant has developed have a major influence

Estimates of yield per plant differ between the various literature references (Tab. 58). They typically range from 0.2-1.5kg fresh tubers per plant. Occasionally yield may also be 4.1-5kg per plant. Tubers have a high water content of 70-85%, which is independent on rainfall and season (e.g. BRUINE et al. 1977, NOTT 1986, VON WILLERT et al. 2002.). According to this, at a water content of 80% total dry matter per plant will typically range between 0.04-0.3kg per plant (maximum 1kg/plant), while at a water content of 85% this would typically be between 0.03-0.23kg per plant (maximum 0.75kg/plant). Based on this, it can be calculated that typically between 3.3-25 plants (minimum of 1 plant) or 4.4-33.3 plants, respectively, have to be harvested to sum up to one kilogram of dry material.

Tab. 58: Yield fresh tubers per *Harpagophytum* plant.

Source	Yield / plant [kg fresh material]	Dried yield / plant [kg) at 80% water content	Dried yield / plant [kg] at 85% water content	No. plants harvested for 1kg dry material at 80% (85%) water content
VOLK (1964)	1.50	0.30	0.23	3.3 (4.4)
IHLENFELDT & HARTMANN (1970)	1.00	0.20	0.15	5 (6.7)
BLANK (1974)	5.00	1.00	0.75	1 (1.3)
BRUINE et al. (1977)	1.04	0.21	0.16	4.8 (6.3)
MÜLLER & MOSS (1982)	0.58	0.12	0.09	8.3 (11.1)
NOTT (1986)	5.00	1.00	0.75	1 (1.3)
STROHBACH (2001b)	0.20-0.80	0.04-0.16	0.03-0.12	25.0-6.3 (33.3-8.3)
VON WILLERT et al. (2002)	0.60	0.12	0.09	8.3 (11.1)

Time needed to harvest one plant is reported to be 10-20 minutes for a harvester community in the North West Province, South Africa (Motshoari, pers. comm.). Additional time is needed to reach the harvesting area, to close the harvesting hole and to slice and dry the tubers. It is reported that the harvesting of seven plants in the morning may be possible, while at good conditions a total of 20-30 plants may be harvested per day. On average, a yield of 15 plants may be harvested per day. Based on the calculations above, this means that in most cases between 0.6kg to 4.5kg of dried tubers or 7.5kg to 15kg of fresh material may be harvested per day. The impact of the yield on the monetary outcome of the harvesters is highlighted in the scheme of Figure 63.

According to NTSEANE (1993), a maximum of 50kg fresh tubers may be harvested per day. Yet, harvesting will not be possible every day, due to bad weather conditions or other activities the harvesters are involved into. NTSEANE (1993) found that the majority of harvesters in two districts of Botswana, harvesting for one to three months a year. NOTT (1986) states higher daily harvesting amounts for a farm in the Keetmanshoop area, where in the rainy season up to 150kg per day and person may be harvested (equals 5kg fresh weight/tuber), while in the dry season this is much less.

12.2.4 Further processing

Further processing comprises a limited number of steps that are carried out in the source countries while in the majority of cases the final product processing is done in the importing countries.

12.2.4.1 Processing steps undertaken by the harvester

- Cleaning: After the extraction of the secondary tubers from the soil, these are transported to a place where the harvested tubers are collected. There, the tubers are cleaned. Some harvesters also peal the skin of the tubers.
- Slicing: Tubers are sliced into 0.5mm thick pieces and dried for 2-3 days (pers. observation in various areas, Fig. 67). Dried material is difficult to cut up. Therefore, slicing is done with fresh root material (VOLK 1964, NOTT 1986).

- Drying: The drying is often done directly on the sand, which inheres the danger of sand grains sticking onto the slices. If available, the sliced material is dried on paper, cemented ground or in drying nets.
- Problems: Throughout the drying season drying material may become spoiled and mouldy due to rainfall and high humidity. To avoid this, additional but time consuming activities are undertaken. For instance, in a village in the North West Province, South Africa, the sliced raw material is spread on flattened cardboard boxes during the day and brought into a house during the night and in the case of rainfall (pers. observation). In other areas, material is packed into sacks during the night to avoid quality degeneration (pers. observation, Okakarara area, Namibia).
- Storage: After the drying, the sliced tubers are packed into sacks and stored until they are sold (KGATHI 1988). Sometimes quality problems may arise when dirty bags or bags with a formerly poisonous content are used for storage purposes
- In general, such processing steps are done by the harvester themselves, sometimes, however, middleman take over these steps.

One exporter in Namibia as well as another large-scale buyer in South Africa started to buy the whole tubers and to take over the cutting and drying process. They claim that this is done to increase cleanness and morphological quality of the material and to avoid adulterations with other root tubers. The company in South Africa runs a large truck with which the harvesting areas are approached directly. After the buying of the tubers, these are sliced and dried on large metal sheets under air circulation in the truck.

12.2.4.2 Concerns regarding processing

The fact that there is very little "value-adding" in the country is the reason for rising concerns of many stakeholders in Namibia. The fact is that almost all (perhaps even 100%) of the sliced and dried *Harpagophytum* roots is exported as raw material (Lombard, pers. comm.). This is even more the case when the whole tubers are sold and the slicing and drying is not done by the harvesters anymore. Several harvesters claimed that prices for tubers are too low and that they rather sell dried material (Motshoari, pers. comm., North West Province).

There is a "Devil's Claw Herbal Extract" (which is more accurately an alcoholic tincture) produced on a very small scale in Namibia and sold to health food shops and chemists (Lombard, pers. comm.). There is also a brand of "Harpago" tea produced in Namibia and one produced in Botswana by Thusano Lefatsheng (a non profit organisation), which is basically granulated sliced and dried *Harpagophytum* in a box (CAMPBELL 1999). Neither of these products are exported outside the region to any significant extent.

There have been discussions with some commercial parties involved in the trade regarding the establishment of an pharmaceutical extraction facility to add value in Namibia. However, the support services for such an operation are currently considered lacking. Furthermore, the processes of extraction of the active compounds, and the pharmaceutical applications thereof, have been patented by two German companies and one Asian company (see Chapter 14.7). This issue, and its implication with regard to provisions within the Convention on Biological Diversity, and for industrial development opportunities for the producing countries, is according to Lombard from the NGO CRIAA-SA-DC to be investigated by stakeholders in Namibia in the near future. A large scale crushing of the sliced and dried tubers in the source countries instead of the export of raw material could provide a first step towards more value adding.

Yet, concerns by importing German companies were risen that pharmaceutical companies overseas would not trust the pulverised quality of material pre-processed in Namibia.

12.2.5 Quality of harvested material

While *Harpagophytum procumbens* occurs in the southern and central parts of Namibia, *Harpagophytum zeyheri* grows in the more northern and north-eastern parts of Namibia where precipitation is higher. Both species have been and are harvested and traded as Devil's Claw in Namibia. Up to the beginning of 2003, various Pharmacopoeias in Europe and USA stipulated that *Harpagophytum* is derived from *H. procumbens* only (see Chapter 7). As the level of inclusion of *H. zeyheri* in export stocks was high, it was expected that the exclusion of *H. zeyheri* from trade would have implication for, amongst others, an increased exploitation pressure on the *H. procumbens* populations in particular in Namibia. However, recently both species may be traded as Harpagophyti radix and quality control does not have to deal with adulterations of both species anymore.

Material originating from Angola (which will certainly be *H. zeyheri*) is entering into export stocks in Namibia. Also for Botswana the trade of such mixtures of both species is possible, but no information on this was available.

The price paid to the harvesters is subject to various conditions:

(a) Prices vary depending on quality.

(b) Quality differs depending on the level of dryness of the sliced root material before it is packed into bags and stored until it is sold to the middleman.

(c) As weight loss means a loss of money to the exporters, many pay the harvesters also for the dryness of the material. Therefore, often the exporters clean and dry the material after buying and before exporting it. An additional weight loss of 15% may be reached by extra drying of the tubers by the exporter (KRAFFT 2002).

(d) Sand, dirt, other plant parts, or even adulterations with other species may be encountered with sliced roots of *Harpagophytum* in the storage bags and lower the price (Harms, pers. communication).

(e) Material may be stored into bags by the harvesters while it is still wet. This way it may get mouldy and fungi as well as aflatoxine may invest the material and lower the income for the exporter.

(f) The content of active ingredients may vary considerably. Yet, this cannot be distinguished by the harvester, middleman or exporter but is only determined in the laboratories overseas.

Information on the quality of the material is transferred back to the exporter. Based on the risks, exporters tend to rely on material from specific areas and harvesters or middlemen of which they can rely on high quality material.

Fig. 67: Harvest of *Harpagophytum*: a) farm worker harvesting *Harpagophytum* on private farmland in Namibia; b) pile of harvested secondary tubers in the Okakarara area of Namibia; c) various sizes of secondary tubers; d) rural harvesters slicing tubers in Cassel, South Africa; e) sliced tubers spread out to dry in the sun; f) dried tuber slices of *Harpagophytum*.

12.3 Namibia

12.3.1 Harvesting localities

In Namibia, harvesting predominantly takes place in the communal areas of the country, that is in the north eastern, eastern, middle, and to a lesser extent also in the southern and south eastern parts of the country (see Chapter 8). Harvesting in Namibia is generally not restricted to *Harpagophytum prcoumbens* areas, but also stretches out to the north to *Harpagophytum zeyheri* areas.

12.3.2 Harvesters

It is almost exclusively the case that the harvesters of *Harpagophytum* in Namibia are from the most marginalized and poverty stricken communities (HEATH 1999). The cash earned by these harvesters, although meagre by any standards, clearly plays an important role in household food security. For some harvesters this may be the only cash income earned at all. Even though most rural communities in the communal areas are poor by common standards there is division between the poor and the very poor. Generally, it is the very poor who actually harvest *Harpagophytum*. Ethnic issues, and land and resource tenure issues, play a negative role in the harvesting and rural level trade (Lombard, pers. comm.).

The exact number of harvesters is difficult to determine for Namibia. Estimates assume a number between 5,000 to 8,000 harvesters while the number of issued harvesting permits is considerably lower (COLE 2003).

Harvesters may come from various backgrounds:

- San people make up a significant percentage of the harvesters.
- Herero people harvesting *Harpagophytum* in the Hereroland, but often also employ other ethnic groups to harvest.
- In the communal Okakarara area of the Otjozondjupa Region people from the Kavango areas (Oshivambos) are employed by other ethnic groups (Herero people) to harvest *Harpagophytum*. In small groups of harvesters they go from communal “farm” to communal “farm” to harvest.
- In some areas Damara people are involved in harvesting activities
- Refugees from Angola living in several refugee camps within the private Namibian farmland frequently enter the commercial farm to illegally harvest *Harpagophytum* (various pers. comm.)
- Harvesting by farm workers on private commercial land also takes place although the amount of material procured from commercial farming is not known at present and can be neglected.

COLE (2003) states two principle ways of organisation of Namibian harvesters:

(a) Harvesters may operate on an individual basis and are independent. Typically they exploit the resource close to their household and sell their material directly to the exporter. The amount of material harvested individually is limited.

(b) Harvesters may be organised in groups. There is what appears to be an increasing trend in middlemen who organise teams of harvesters (often reported as being Oshiwambo, or even Angolan) and camp out in remote areas (Lombard, pers. comm.). The middlemen supply basic food and drink requirements for a week or so wherein the team intensively harvests a particular area. Middleman often deduce expenses for food and transport from the harvesters income. COLE (2003) assumes that these harvesters are unlikely to receive fair compensation for their efforts. Most of the material is harvested in this manner.

The organisation of harvesters to groups is a common procedure that may stretch over various groups of people involved in the harvesting. There are also reports of cases whereby middlemen organise unemployed youth, school children, or refugees, drive them to remote areas where they camp for several days or weeks. The area around where they camp is heavily harvested, with reports of severe over-harvesting in cases. The middleman returns later to collect the product and returns the workers to wherever they came from. This and related practices are currently a major cause for concern by the various stakeholders in Namibia such as the above stated neighbouring farms to refugee camps.

Lombard (pers. comm.) also states that there are frequent claims that the harvesters often receive as little as nothing for their product. Since a harvester's knowledge of, and contact with, a large trader or exporter may be non-existent, they most often need to put their trust in a middleman who in turn puts his trust in another middleman, etc. The middleman with transport and market contacts will probably not have much capital and will therefore take the goods on credit and probably without weighing. After selling the stock to a trader he or she will need to travel back to the area of procurement and pay the middleman or harvester. Assessment of the quality and the weight of the product may often be deferred until the middleman returns from the selling trip. Usually scales are not available at remote rural area level and the harvester probably does not know how much material he has "sold". As a result exploitative practices are common with the principle victims being the harvesters. This problem is also very common when people form other areas are employed to harvest. As these are paid per bag of extracted tubers irrespective of the invested time effort, harvesters report to that this favours unsustainable harvesting techniques.

In general, the manner and level of organisation of the harvesters has a great impact on the benefits they may receive from harvesting. It can be assumed that closely related to the monetary benefit is the impact on sustainability of the harvesting practises (COLE 2003).

12.3.3 Middlemen

Middleman buy and sell dried and sliced raw material of *Harpagophytum*. They typically buy from various harvesters and then sell the material to the exporter. Additionally, other middleman may only supply other middleman, prolonging the trade chain.

For Namibia, a number between 50-100 middleman can be estimated (COLE 2003).

According to Lombard (pers. comm.), the middleman who delivers to the exporter's premises may receive a varying price depending on the

- Visual and physical quality (dryness, cleanliness)
- Level of stocks already held by the buyer
- Market conditions such as demand or over-supply
- Relationship between the middleman and the exporters

Transport of *Harpagophytum* from the rural areas to the exporter is usually by a small pick-up car, or sometimes by larger vehicles. The operations of middlemen may be highly organised, regular and high-volume operations, or they may be part-time, opportunistic and small-scale. There are examples of exporters using their own transport to travel to areas where prepared stocks of *Harpagophytum* are expected or are pre-arranged by another middleman.

Sometimes the buyers are also religious figures or preachers with remote missions, or traditional leaders / Headmen, civil servants etc. (Lombard, pers. comm.). Lombard reports that reports of abusive behaviour by middlemen are not infrequent when travelling in some of the harvesting areas. Reports of conflict over resource access and tenure, and resource management, are made from time to time by harvesting communities. As the demand for the raw material has increased these reports have become more frequent.

COLE (2003) sees a clear link between the number of middleman, the number of primary producers (harvesters) and the exporters or product manufacturers. Benefits derived by the harvesters are closely related to that link, meaning that an increasing length of the trade chain or an increase of the market layers, respectively, is most likely to be reflected in the income generation of the harvesters.

Next to negative impacts of middleman, also positive impacts may be evident in the case that middleman link remote harvesters to the market chain and spread the knowledge on the commercial potential of *Harpagophytum*.

12.3.4 Notable Operations

The only public sector involvement in the trade of *Harpagophytum* in Namibia is the Sustainably Harvested Devil's Claw Project of CRIAA SA - DC (Namibia). In this project, since 1999 a minimum of 17 rural communities, representing approximately 250 households, are assisted to ascertain the quantity of their resource, to establish quotas for harvesting households, to harvest it sustainably, to produce as high a quality product as possible and to access the market as directly as it is economically and logistically feasible and sustainable thereby generating as much income at harvester level as possible. The production of *Harpagophytum* was certified "Organic"/"Biological"/"Environmentally Friendly" by the Soil Association, which is a British-based and internationally recognised agency for certifying organic products (HEATH 1999). With the certification, higher prices may be achieved on the market.

12.4 South Africa

Despite the large Kalahari sandveld area of South Africa surprisingly little *Harpagophytum* is actually harvested and traded from South Africa so far. In general, South African exporters often import material from Namibia to trade it on the European market. It is difficult to distinguish between quantities of *Harpagophytum* derived from South Africa and imported from Namibia or Botswana.

12.4.1 Harvesting localities

Harvesting in South Africa takes place in three Provinces of the country:

(a) North West Province: In the former Bophutotswana homeland, an area of approximately nine million hectare, main harvesting localities are located. Here, harvesting forms an important alternative option of income generation in particular as other agricultural activities are usually limited through unfavourable environmental conditions such as poor soil quality or low rainfall. It can be assumed that the political history of South Africa contributed to the current socio-economic situation of the people in the former homeland areas of the North West Province. Harvesting areas are communal land that is overseen by the local tribal chiefs (RAIMONDO et al. 2003).

(b) Northern Cape Province: There are few communal areas in the province. Former harvesting activities are reported from the Mir area south of the Kalahari Gemsbok Park for the 1970's. These were limited to national traditional healer markets. Harvesting from private commercial farmland can up to date be neglected, but may increase in future. In the vicinity of one exporter of *Harpagophytum*, interest may arise also on neighbouring farms to exploit the resource. In fact, one farm was sampled with the square kilometre approach on which harvesting by the exporter had taken place two years ago.

(c) Limpopo Province: RAIMONDO et al. (2003) state that extremely little harvesting takes place in the Limpopo Province. Both species of *Harpagophytum* occur in the area and are used as traditional medicines in a limited amount. According to the Limpopo Province Conservation Department officials, no large-scale illegal harvesting is evident.

12.4.2 Harvesters

Similar to Namibia, the harvesters of *Harpagophytum* in South Africa are from poor rural communities. They have little other options of income generation.

The harvesters profiles depend on the following:

- Ethnicity: Predominantly Tswana are involved in the harvesting of *Harpagophytum*. RAIMONDO et al. (2003) also report other ethnic groups such as Pedi, Xhosa, San people or occasionally also Venda, Northern Sotho and Shangaan to harvest.
- Age: RAIMONDO et al. (2003) found that most harvesters are aged between forty and sixty while younger people are rather employed on nearby private farms and urban centres.
- Gender issue: Personal observations in the North West Province indicate that it is the women who are harvesting the tubers. Traditionally the women are involved in the gathering natural resource. If men are involved in the harvesting of *Harpagophytum*, they typically clear the grass layer around the plants and help with the slicing of the tubers.
- Harvester's organisation: Harvesters often operate individually while extraction activities may be done in groups. In some villages harvesters are organised in groups. This is either done on the harvester's own initiative or by the initiative of the Ministry. Advantages of a communal harvesting effort are seen in the social aspects as well as in the possibility of a mutual monitoring of harvesting methods (RAIMONDO et al. 2003). Depending on the village, harvesters sell the material often in combined sellings per village or in single amounts.

In the North West Province legal harvesting with harvesters ID cards started in 2001 (VAN DER VYVER 2002). At that stage 250 harvesters were trained. In 2002, 800-1000 people in ten villages were harvesting *Harpagophytum* (van der Vyver, pers. comm.) while in 2003 there were 2381 trained and registered harvesters in the North West Province. It is not known to what extent also people not registered as harvesters are involved in harvesting. It can be assumed though that illegal harvesting does take place in the province. RAIMONDO et al. (2003) estimate a total between 2,700 and 3,000 harvesters in the North West Province, a number of 1,500 harvesters in the Northern Cape Province and between 50-100 harvesters in the Limpopo Province. In total, this sums up to a number of harvesters (between 3,500 to 4,500 people) that is almost comparable with that of Namibia.

12.4.3 Middleman

No information is available on possible middleman activities in South Africa. As most material comes from Namibia and is only re-imported into South Africa by South African exporter in order to be exported from there to overseas, middleman are not necessary for these steps. The buyers of *Harpagophytum* are in both known cases the exporter themselves, who approach the harvesters in regular terms to buy the raw material form them. In the North West Province, such transactions are frequently monitored by extension officers of the Ministry.

12.4.4 Notable operations

In general, only few exporters are known who derive their material from South Africa and do not import raw material from Namibia or Botswana. Until recently, two exporter were involved in the buying of *Harpagophytum*.

This is the operation of Mr. Gert Olivier, which is worth noting as he is interested in regional co-operation. His modus operandi is to work and co-ordinate with rural village Headman who in turn organise the harvesting with local rural people. His operation is briefly described at http://www.harpago.co.za. Together with several universities and two exporters a research project financed by the gtz was carried out (see Chapter 13 for details). Oliver also buys for another South African company, called Parcival.

Grassroots Natural Products, owned by Prof. Earl Graven, is notable in that they researched *Harpagophytum* genetic material from southern Africa in the early 1990's and apparently have made progress with regard to selection of high-yielding chemotypes and cultivation thereof by vegetative propagation on a 1 hectare plot in the Cape Province (Gouda).

As currently only a limited number of harvesters are active in the North West Province personal communications indicate that both buyers occasionally compete over the supply (Motshoari, pers. comm.). According to RAIMONDO et al. (2003) one exporter has recently dropped of the market. This has the effect of a monopolisation of prices to only one exporter, which most probably will have a negative impact on the harvester’s income.

12.5 Botswana

Next to Namibia the main resource of *Harpagophytum* is to be found in Botswana. However, trade structures within the country do not seem to be as diverse as in Namibia, not many companies are involved. No fieldwork has been conducted in Botswana, but two visits and several interviews together with a review of literature and other personal communications in Namibia and South Africa contribute to this chapter.

12.5.1 Harvesting localities

Harvesting is restricted to more or less definite areas within the distribution area of *Harpagophytum* in Botswana and is located predominantly in the communal areas. *Harpagophytum* is concentrated in the Kgalagadi sandveld of Botswana, which is the southern most provinces (NTSEANE 1993). The commercial trade in *Harpagophytum* started in 1978 in the south and south-eastern parts of the Kgalagadi District and moved later on to other areas (TAYLOR & MOSS 1982, BEN 2002). In particular in the Kgalagadi District harvesting pressure is reported to have been very high over the past years, leading recently to an obvious depletion of the resource in some areas (Dipholo, pers. comm.). According to Dipholo this resulted in a shift of harvesting activities from the heaviest exploited areas in the south-west to more eastern parts and thus the main focus of harvesting seems to move along the southern border of Botswana to the more eastern areas.

Currently in three districts, Kgalagadi, Kwaneng and Southern District, harvesting takes place, while the plant may occur in another four districts (MATLAHARE 2002).

Harvesting is mainly concentrated around the village area, only very few harvesters harvest outside their district or in other villages (NTSEANE 1993). Harvesting season is officially restricted to the first half of the year, but harvesting activities after August still take place to a great extent due to the need of cash income.

12.5.2 Harvesters

Currently, there are approximately 30 villages and 900 harvesters involved in the trade of *Harpagophytum* (RAIMONDO et al. 2003).

The socio-economic profile of the harvesters in Botswana is almost identical to that of Namibia. This includes the following:

- People in the very poor in rural areas, which are characterised by poverty and high rates of illiteracy of up to 75%.
- The majority of the harvesters are San (called Basarwa in Botswana), but also other minority groups such as Bakgalagadi and Coloureds are involved in harvesting.
- The gender issue is of great importance, i.e. most harvesters are women leading a female-headed household (VAN DER VLEUTEN 1998, MATLAHARE 2002).

The major source of livelihood is dependency on governmental help through Drought Relief Projects and other similar projects. Supplementary food income is achieved by hunting and gathering of wild or veld products (NTSEANE 1993). NTSEANE claims that the harvesting of *Harpagophytum* is cited as major source of cash income in all areas. Nevertheless in 1993 the maximum cash income of P250.00 (~ € 51.69) from a maximum of harvested *Harpagophytum* (150kg per year) was still below the Botswana Poverty Datum Line of BWP 275.00 (~ € 56.87) per year.

A great problem harvesters have to face in Botswana is the fact that in addition to low prices the market is not very reliable. NTSEANE (1993) states that in some years buyers (middleman of Thusano Lefatsheng) do not come. As a result the harvesters are stuck with the raw material and wild resources are reduced without being able to make a worthwhile contribution to the market. Other sources report the buying of raw material from the NGO but that payment to the harvesters is postponed until the NGO has sold their stock, which in some cases took very long time and let to the lost of trust in trade.

12.5.3 Middlemen

No information is available on possible middleman in Botswana. It is regarded unlikely though that many of them operate in Botswana as most of the export is restricted to the NGO of Thusano Lefatsheng. Of this NGO extension officers travel to the different harvesting areas inhabiting only the role of advisory and technical guidance (SEKHWELA & NTSEANA 1994). They do not buy and sell material for their own benefit. It is assumed by the authors, however, that the extension officers rather try to take the lead and form groups in the villages than guiding the community into the process of sustainable harvesting or self-organisation. Currently also Veld Products and Research, another NGO based in Botswana, gets increasingly involved in trade and research on *Harpagophytum*.

Personal communications with a South African exporter also indicate that material is exported to South Africa. In particular in areas close to the border between both countries, such trade contacts occur. As far as it is known, no middleman are involved, but the exporter directly come and buy the raw material.

12.5.4 Notable operations

In Botswana, main notable operation involved in the trade in *Harpagophytum* is the non-profit organisation Thusano Lefatsheng (TL). TL has to date a leading role in the development of *Harpagophytum* as marketable veld product and extension work is largely involved with the plant (Thusano Lefatsheng, no date).

Recently, also another NGO, Veld Products, Research & Development (VPRD) is increasingly involved in *Harpagophytum* research. Several studies in selected villages on the evaluation of densities and the monitoring of harvesting have been carried out by VPRD (e.g. VAN DER VLEUTEN 1998, PERKINS 1999). A future project together with TL and the University of Botswana on a countrywide mapping of *Harpagophytum* is planned but awaits further financing (SETSHOGO 2002).

12.6 Prices for raw material of *Harpagophytum*

The price paid for raw material of *Harpagophytum* is related to quality and supply. Yet, the greatest impact has the market and next to this, the strength of the currency in the range states. Prices may vary strongly between the years depending on the stock available and the demand from Europe. Prices paid for dried material of *Harpagophytum* show great differences between the amount paid to the harvesters, the middleman, and prices paid to the exporters by the buyers from overseas.

12.6.1 Prices paid to the harvesters

Available data on prices paid to the harvesters includes the following:

- In 1993, in Botswana, the price paid by the main buyer and NGO Thusano Lefatsheng was at BWP 5.00/kg (~ € 1.03). This was considered to be too low to make a living (NTSEANE 1993).

- Since 1995: Price development can only be described for Namibia. KRAFFT (2002), involved in the export of *Harpagophytum* from Namibia over the past 15 years, claims a price increase by more than 275%, which is considerably more than the inflation rate of the country at that time.
- 1997-1998: Demand seemed to be exceeded by supply and prices paid to middlemen in Namibia seldom reached more than N$ 8.00/kg (€ 0.8/kg).
- 1998-1999: Demand was at an all-time high and exporters competed for stocks from rural suppliers in Namibia. This led to an increase in the delivered price and prices were at N$ 14.00/kg to N$16.00/kg (€ 1.5-1.7/kg).
- 1999-2000: In Botswana, prices are known for the year 2000, when the main and non-commercially operating buyer Thusano Lefatsheng paid Pula 13/kg (€ ~1.9/kg).
- 2000-2001: In South Africa prices paid per kilogram averaged R 8.00/kg (~ € 1.0/kg).
- 2001-2002: Demand was high and competition occurred between the buyers in Namibia as well as in South Africa. Prices paid in South Africa increased considerably to R19.00/kg (~ € 2.0/kg). In Namibia prices paid in the villages taking part in the SHDC-project (Sustainably Harvesting Devil's Claw project) are currently at N$ 12.0/kg (€ 1.5/kg) (LOMBARD 2002).
- 2002-2003: For South Africa, preliminary results indicate a drop in the prices to R 16.00/kg (~ € 1.7/kg) (RAIMONDO et al. 2003). This is supposed to be due to the strengthening of the South African currency as well as due to the fact that one exporter stopped trading and now a monopoly of only one exporter rules the South African market.

There are numerous examples of harvesters being paid N$1.00-3.00/kg (€ 0.1-0.3/kg), or the equivalent in consumer goods (often alcohol) at inflated prices (Lombard, pers. comm.). There are examples of good practices whereby harvesters receive higher prices but these are apparently rare. Higher prices are being paid in connection with harvesting projects in Namibia, South Africa and Botswana. With these projects, buyers directly approach the harvesters and the chain of middleman is missing, which leads to higher prices being paid to the harvesters. Also, organic certification may be responsible for higher prices paid to the harvesters (see Chapter 14).

RAIMONDO et al. (2003) states the total current income per harvesting season in South Africa for 2000-2001 to be R 133,688.27 (€ 21,619.10) and for 2001-2002 to be R 1,799,689.66 (€ 234,707.00). This calculates to an average total income per harvester of R 108.43 (€ 17.53) in 2000-2001 or R 782.47 (€ 102.05) in 2001-2002. Also the tribal authorities participate in the selling of *Harpagophytum* as part of the price paid by the exporter goes to the tribal authority.

COLE (2003) lists the amount of money received by the harvesters in Namibia in 2002 to be on average between US $ 0.45-1.35/kg (€ 0.48-1.44/kg). For organic certified material he states a much higher income of US $ 2.5 (€ 2.68) per kilogram dry material.

From the time effort to harvest one individual of *Harpagophytum* from the wild, the yield of secondary tubers per plant and the time needed to slice and dry the tubers, the monetary outcome can be calculated (Fig. 68). As stated above, prices may differ considerably between bad trade practises with a very low monetary outcome to the harvesters (as found by Lombard) and fair prices paid in particular by Non-

Governmental Organisations. Based on the harvesting amounts used in the model, the annual cash income generated by the harvesting of *Harpagophytum* may range widely from less than 10 Euro to more than 400 Euro per year.

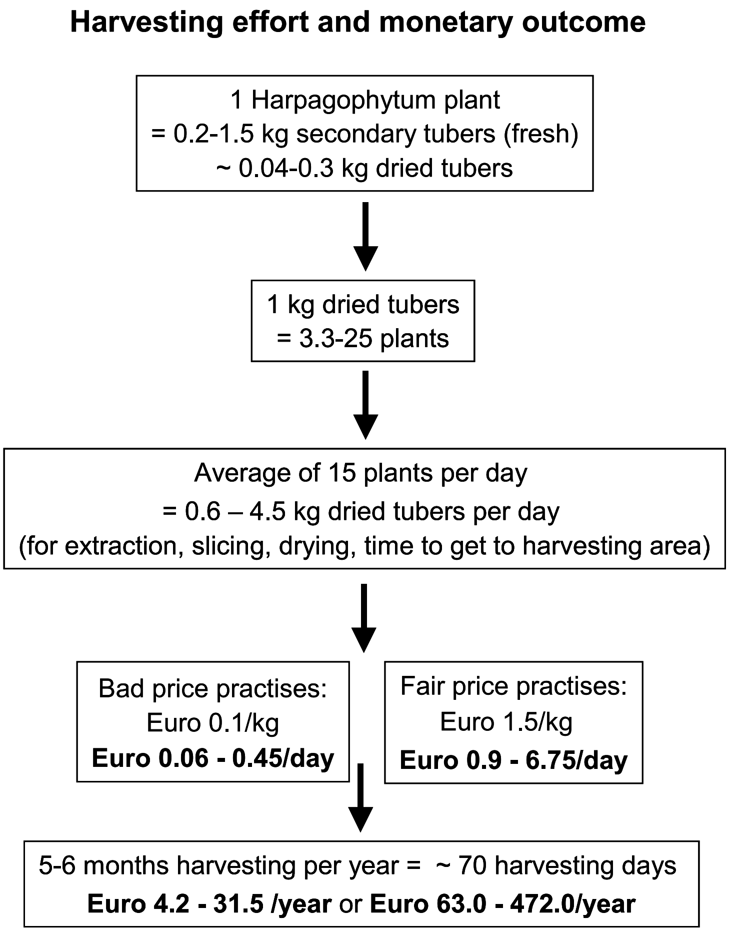


Fig. 68: Scheme of the effort and monetary outcome of the wild harvesting of *Harpagophytum* based on daily and annual yield as well as bad and fair price practises.

Considering the prices of the final retail products of *Harpagophytum*, it can be estimated that harvesters do not earn more than approximately 0.5% of the total trade value (COLE 2003).

12.6.2 Prices paid to the middleman

Data on the amount of money earned by the middleman for the buying and selling of *Harpagophytum* is very limited. Only in Namibia, a trade chain of one to various middleman seems to be well established. For Namibia, COLE (2003) states an amount received by the middleman for one kilogram of dried tubers of US $ 1.8 (€ 2.0).

12.6.3 Prices paid to the exporter

Similar to the prices paid to the harvesters, also prices achieved by the exporters vary with respect to the market situation.

For the year 2000, prices paid by the importers for half processed material were between US $ 2.30-3.28 (€ 2.6-3.7) per kilogram (GAIA/GRAIN 2000). For 1998, prices were slightly lower according to the TRAFFIC Network Report (MARSHALL 1998) with prices paid by importers of US $ 1.10-3.56 per kilogram. COLE (2003) emphasizes that organic certified material also brings higher prices to the exporter and not only to the harvesters. For 2002, he states an amount of US $ 4.2 (€ 4.7) per kilogram organic certified material in Namibia, while on average only US $ 3.2 (€ 3.6) was paid to the exporters of non-organic material of *Harpagophytum*.

The profit margin earned by the exporters calculates from the prices gained by the payments of the importers minus the amount of money paid to the harvesters, the employees to clean and repack the raw material on the exporters premises, the shipping and related costs.

12.6.4 Prices paid for retail products

At the retail level in the Western market much higher prices can be retained, and retail products of *Harpagophytum* can fetch as much as US $ 180.00 per kilogram. Consumers in the Unites States pay US $10 per diluted one ounce bottle of plant extract (GAIA/GRAIN 2000). This would correspond to more than US $ 700 per kilogram of *Harpagophytum* extract.

12.7 Summary and conclusions on the harvesting of *Harpagophytum*

Harvesting of the secondary storage tubers of *Harpagophytum* can be considered as the main threat to the species that clearly overweighs other threats such as grazing, trampling and invests by larvae or fungi. The impact of harvesting becomes increasingly significant when paired with harmful and non-sustainable harvesting techniques. Various authors give strong evidence that (i) non sustainable harvesting techniques have been applied in the past, (ii) over exploitation has locally occurred already, and (iii) increasing demand will be the major threat to the species in the future (e.g. MARSHALL 1998, STROHBACH-FRICKE 1995).

Another threat related to harvesting activities, is the fact that *Harpagophytum* so far suffered of an increasingly higher harvesting pressure since the other species of the genus, *H. zeyheri*, was not officially registered as medicinal plant and was therefore not authorised to be a component of the official drug (see Chapter 7). The consequence was a shift of exploitation from the entire distribution area of the genus in Namibia to only *Harpagophytum procumbens* areas within the last couple of years. This is the more alarming as it can be assumed that a plant needs at least 3-4 years even after a sustainable harvesting before a sufficient number of new storage tubers have developed to be harvested again.

Harvesters in all the three range states typically come from marginalized communities in remote areas and very often harvesting of *Harpagophytum* poses the only possibility of income to them. At least 9000 rural people in these countries rely on wild harvesting of *Harpagophytum* (WYNBERG 2002). Harvesters are typically not informed about the value of their resource and thus they have no influence on the prices but rely on the amount paid to them by the middlemen or exporters.

Open access to the resource in many areas paired with an unclear land tenure lead to a lack of identification with the resource. Improved resource owner rights could help harvester communities to manage their resource.

Effort to harvest the root tubers is high in particular in remote areas and when the resource is not nearby available. Approximately 3-25 plants have to be harvested to gain 1kg of dried tubers, which is currently worth – in the case of good market prices – € 1.5-1.9. However, prices may vary strongly between almost none to the mentioned price depending on the quality and the middleman.

Namibia

A great concern exists concerning a possible depletion of the resource. It is known from some localised areas that *Harpagophytum* populations have either decreased dramatically or even vanished completely. This is especially true for the communal areas rather than for the commercial areas of the country as harvesting predominantly focuses on communal areas where the main resource pool of the species is located. Next to the sustainability of applied harvesting methods, a great impact on a decrease has to be seen in the fact that the number of harvester has increased over the past years. Today not only the ethnic groups living in villages within the distribution area are involved in the harvesting, but also an increasing amount of people coming from outside these areas try to get into the market (this may be with or without permission of the traditional land owners). Taking also the years with low rainfall into account, it can be expected that the regeneration of *Harpagophytum* populations is the more aggravated. Yet, as large and currently not harvested areas also belong to the distribution area of *Harpagophytum* the resource pool is probably still existent in one area or the other.

South Africa

In South Africa commercialised harvesting of *Harpagophytum* is just recently picking up while the buying of material from Namibia and Botswana has long been carried out. Activities to harvest South African tubers of *Harpagophytum* started in the North West Province in 2001 and are continuously increasing since then. Prices seems to be more stable and less variable between the harvesters than in Namibia due the shorter trade chains and the lack of middleman. Instead, harvesting is monitored and regulated by the North West Department of Agriculture, Conservation and Environment (NW-DACE).

Botswana

Fears of a possible threat of *Harpagophytum* due to an increase in commercialisation driven by profit and market availability were risen by TITIEMA (1986) and NTSEANE (1993). Information from both, field observations and socio-economic studies, hint towards an over-exploitation despite the existence of government introduced recommended harvesting methods and other conservation measures (SEKHWELA & NTSEANE 1994). From this it has to be concluded that sustainable harvesting does not always seem to be applied properly. Due to local resource depletion, harvesting activities have undergone a spatial shift within Botswana. Yet, BEN (2002) and MATLAHARE (2002) claim a country-wide establishment of sustainable harvesting techniques while a greater resource potential exists that could be exploited with improved trade contacts.

13 Cultivation and vegetative propagation of *Harpagophytum*

13.1 Cultivation trials

The incentive to focus research on and implement large-scale cultivations of medicinal plants is dependent on the commercial demand of the species in question. Only if the demand for a product is large enough, an incentive is set which may lead to the establishment of large-scale plantations. Yet, so far there are few species in the global herbal medicine market for which yield from cultivated plants are considered more valuable than those from the wild (SHELDON, BALICK & LAIRD 1997). The example of wild American ginseng (*Panax quinquefolius*) indicates that market prices for wild collections may be ten times higher than for cultivated material. In American ginseng, this difference is due to the different perception of potency between wild and cultivated plants. Apart from perception, also measurable changes in the quality of a drug may occur when a plant is cultivated. This is typically due to cropping and irrigation on agricultural fields resulting in changes of environmental conditions in comparison to natural conditions in the wild. Additionally, not for all medicinal plant species, large-scale cultivation is possible.

In general, it can be differentiated between intensive cultivation and wild cultivation. While the intensive cultivation of *Harpagophytum* by commercial farming requires investments in the form of land, labour and time, the financial return may be larger and more concentrated than with wild cultivation. Contrarily, with wild cultivation various harvester groups tend to be involved and benefit will be spread among a greater number of harvesters. While attempts to cultivate *Harpagophytum* have long been made, only recently these proved to have a potential success.

In 1973, BLANK applied a method of vegetative propagation and found that regeneration from cuttings is generally not feasible. Other experiments with tissue cultures failed in the 1970s resulting in the assumption that such produced iridoid plants generally do not contain worthwhile amounts of these metabolites (e.g. ABOUT-MANDOUR 1977, CZYGAN & KRÜGER 1977, FRANZ et al. 1978). Only 20 years later, a semi-cultivation method was introduced by SCHNEIDER (1997, 1998), which combined naturally occurring plant stocks being harvested with shifting sustainable harvesting techniques. Also the withdrawal of *Harpagophytum* parent tubers from one area to replant them into another area has been attempted as wild semi-cultivation, offering the opportunity of easier access to the harvesting sites.

Small-scale cultivation trials with seeds of *Harpagophytum* were done by the NGO Thusano Lefatsheng in Botswana (Matlahare, pers. comm.) and by the National Botanical Research Institute in Namibia (POWELL & MOOLMANN 2000).

Recently, a number of trials on vegetative propagation and in-vitro cultures of *Harpagophytum* have been undertaken. The expressed need for cultivating is often based on the argument that cultivated sources will

- Offer a more consistent quality,
- Offer a lower risk of adulterations with other look-alike species,
- Be needed to meet the increasing demand of the market.

It is generally attempted to select high yield chemotypes for further cultivation. While the selection of high yield plants is used by some authors, who tested the harpagoside content of tuber samples throughout various sites in southern Africa (BETTI 1995, SCHMIDT et al. 1998, BETTI 2002), other scientists claim that similar variations in the content may occur within the secondary tubers of single plant individuals (VON WILLERT & SCHNEIDER 2001, VON WILLERT, SANDERS & OLIVIER 2002).

Another argument for cultivation is used by a "Private Public Partnership" project financed by the gtz (German Development Co-operation), where the term "conservation by cultivation" is used. The project (www.uni-muenster.de/biologie/pflanzenoekologie/science/willert-harpago.htm) was a co-operative approach carried out by three pharmaceutical companies, Bioforce (Switzerland), Salus-Haus (Germany), and Parceval (South Africa), two universities, i.e. the University of Westville (South Africa) and the University of Münster (Prof. von Willert, Germany), and a local farmer. The pronounced goals of the project were the establishment of a method for propagating and cultivating *Harpagophytum* to contribute to its conservation, to guarantee a continuous and sustainable supply, and to transfer gained knowledge to local communities of the Southern Kalahari, South Africa. Studies were based on eco-physiological, economical and pharmaceutical aspects. Cultivation success was achieved by seed germination and the replanting of young plants on linear fields for which a water-harvesting system was established. For this, agricultural fields were cleared in narrow stripes within the intact grass and tree savanna vegetation, upper soil layers were cleared after rain to avoid capillary rise of soil water and plant individuals were planted in the mid of the stripes. According to the involved farmer, after four years of experiments this type of cultivation proved to uneconomical due the very high labour costs. From this, RAIMONDO et al. (2003) concluded that large-scale may not be an economically viable land use option in the Kalahari.

Also in South Africa, E. Graven from Grass Roots Natural Products and Prof. B.-E. van Wyk are currently investigating and developing techniques to grow certain medicinal plants on commercial scale in South Africa (POWELL & MOOLMAN 2000). Graven is convinced that it is possible to produce up to 100.000kg per year of dried tubers from cultivated plants in the near future (GOUWS 1999). Recently, South African farmers were called upon to participate in cultivation projects of *Harpagophytum* (GOUWS 1999).

Experiments with in-vitro micro-propagation of *Harpagophytum procumbens* and *Harpagophytum zeyheri* proved to be successful by the regeneration of new plantlets from nodal cuttings and their acclimatisation to ex vitro conditions (LEVIEILLE 2002). Concentration of active ingredients showed comparable concentrations to wild plant material. No large-scale commercial application is currently planned though. Instead, the genetically homogenous plants are used to study the chemovariablity within the species and the distribution, biosynthesis and localisation of iridoids.

13.2 Quantity of *Harpagophytum* produced by cultivation

Information on the amount of secondary tubers of *Harpagophytum* that is derived from cultivation varies with respect to the source of information.

For the gtz-project conducted in South Africa, 500kg cultivated *Harpagophytum* tubers were harvested in 2002 (http://www.harpago.co.za). Success in cultivation led to the assumption that demand in secondary tubers of *Harpagophytum* by one of the involved companies will be met by cultivated material in the year 2003 (Franke, pers. communication).

Already some years ago, the supply of dried material from cultivation has been reported by SCHMIDT et al. (1998), who claimed to obtain the entire demand of root material for a drug preparation of a pharmaceutical company from cultivation projects in Namibia. This led to controversial discussions and one of the major Namibian exporters responded that secondary tubers are still exclusively harvested from the wild (KRAFFT 2000).

Also COLE (2003) claims that there is at present no major supply of commercially cultivated *Harpagophytum*. While Wynberg (pers. communication) expected exports of cultivated material to be approximately one ton for 2002, COLE (2003) estimated a production of no more than six tons for 2002.

13.3 Possible impacts of cultivation

Various concerns regarding the cultivation of *Harpagophytum* have been expressed by stakeholders and scientists (e.g. KRAFFT 2000, STRATHMANN AG 2001, HALLBAUER 2002, WYNBERG 2002). Important issues concerning the cultivation were summarised at the first Regional Devil's Claw Conference in February 2002.

These comprise three broad categories:

- Socio-economic issues such as the ownership of cultivation knowledge and the impact for the harvesters
- Technical issues such as growing techniques
- Economics and marketing issues such as the impact of cultivation on the price development (FIRST REGIONAL DEVIL'S CLAW CONFERENCE 2002)

What is clear, however, is that irrespective of the range of concerns, cultivation will not come to a stop. Therefore, an approach is needed that does not exclude neither type of production of dried material from secondary tubers.

One has to distinguish between different impacts of cultivation:

(a) Ecological impacts

This is a more local one and includes the problem of irrigation in a country scarce of water and characterised by high evaporation rates that may promote soil salination.

Other problems such as soil erosion may arise through ploughing. The infest of *Harpagophytum* root tubers with fungi in mono-specific cultivated fields led in one case to the death of a great percentage of plants (Horsthemke, pers. comm.). The impact of the subsequent use of herbicides and fungicides on the quality of the drug still awaits further research.

(b) Impacts on the quality

The quality concern of potentially lower iridoid contents of the tubers as a consequence of irrigation and high water content of the tubers were risen by various people. HALLBAUER (2002) for instance, claims that it is not known what influence cultivation has on the quality of the product, in particular as already variation in rainfall and the mode of storage have an effect on the quality of dried raw material. This, however, was falsified in studies carried out on plants in the southern Kalahari by VON WILLERT et al. (2002) in the course of the gtz-project. Yet, if this is also the case under different cultivation methods and environmental conditions has not been proved.

(c) Socio-economic impacts

Next to the important issue of benefit sharing (Chapter 14), socio-economic impacts of cultivation may have negative as well as positive impacts on rural harvesters.

- Negative effects: Successful commercial cultivation may have a negative effect on rural harvesters in the case that the market share of cultivated material (by others than the harvesters) exceeds that of wild material. COLE (2003) claims that for a variety of reasons "such as the unavailability of capital, technology and, in some cases, access to land" rural harvesters will most probably not be able to participate in a commercial cultivation of *Harpagophytum*.
- Positive effects: Cultivation may supplement wild harvested material and thus level out fluctuations in the natural occurrence of *Harpagophytum*. This may stabilize the market. Other positive effects could come up, if cultivation methods are such that they are appropriate also for communal land users and could offer them additional income opportunities. By this, wild resources could be harvested less frequently and regeneration may be ameliorated.

(d) Conservation impacts

Other concerns are related to trade issues in such that the price development for dried raw material may break down, when the supply is supplemented by cultivated material. With respect to conservation, such decreasing possibility of income generation by harvesting, may lead to a loss of the incentive to conserve and sustainable use wild populations of *Harpagophytum* by the harvesters.

Concluding, the principle stated on the First Regional Devil's Claw Conference can be applied that " there should be space and opportunities kept open for all modes of production – there should be not decision in principle, or policy, to exclude one type of production or another". However, this includes also that cultivation does not overwhelm and drive out indigenous harvesters.

14 Trade in *Harpagophytum*

The management of traditional medicinal plant resources can be considered as the probably most complex African resource management issue facing conservation agencies, health car professionals and resource users (CUNNINGHAM 1994). As the market for a medicinal plant species expands, traditional systems of management are in danger of being supplanted by business interests that are uninvested in regional futures (SHELDON, BALICK & LARID 1997). Also in *Harpagophytum*, strongly increasing extraction quantities indicate that traditional management systems are not applied anymore. Additional issues closely related to trade and market are patenting of plant extracts by pharmaceutical companies and questions of intellectual property rights, benefit sharing and value adding as well as in the case of an over-exploitation of a resource, conservation measures such as CITES.

In this chapter, the trade data and trade chains in *Harpagophytum* as well as information on companies involved in trade are presented. An analysis of the market and potential conservation measures for domestic and international trade are made.

14.1 Methods

Export data is in particular based on recent literature, while the analyses of the market situation and the effects of trade include a synthesis of personal communications, literature and the findings of own fieldwork.

A survey for the Federal Agency of Nature Conservation (BfN) was carried out in 2001 on the extent of German imports of *Harpagophytum*. For Germany as importing country does not have a trade monitoring system for *Harpagophytum* or other non-protected medicinal plants, and thus no trade data was available, this survey was initiated to implement the CITES Decision 11.111 (see Chapter on CITES below).

For the survey, a compilation of all German importing companies was carried out (HACHFELD 2002). Telephone interviews were conducted to collect information on import quantities and the importers' perception of

(a) The current and future development of the market,

(b) Their opinion of the impact of cultivation on the market and

(c) The impact of potential control measures.

(d) In many cases several parallel approaches were necessary such as the sending of an introducing letter by the BfN, sending emails or faxes.

Selected results of this survey are presented in this chapter. For the purpose of confidentiality only some results can be presented here. For this reason, information resulting from the interviews cannot be stated with its specific source.

14.2 Namibia

14.2.1 Export quantities

To export *Harpagophytum* material from Namibia, two different permits are necessary, a phytosanitary certificate and an export permit. Export quantities based on the export permits issued from the Ministry of Environment & Tourism from 1973 to 1986 are listed in the table below (Tab. 59). Data shows that these may vary considerably between the years.

Tab. 59: Exports of *Harpagophytum* from Namibia.
Source: Lindeque (Ministry of Environment & Tourism).

Export quantities	Export [kg]	Export quantities	Export [kg]
1973	28.161	1980	nd
1974	nd	1981	84.350
1975	180.000	1982	133.619
1976	180.000	1983	124.291
1977	190.000	1984	107.800
1978	nd	1985	183.370
1979	nd	1986*	81.078
*Jan-April 1986; nd = no data available			

Whereas in 1973, at the beginning of large-scale exports from Namibia, only 28t of raw material were exported, quantities increased rapidly, and only three years later six times the amount was exported (180t). This level was kept about constant throughout the following years up to 1986, irrespective of some small increases and decreases probably due to climate driven variations in supply. The lack of data between 1987 and 1991 corresponds well with the period when *Harpagophytum* harvesting activities decreased considerably due to an extensive drought in Namibia and decreasing demands from the market.

From the more recent export quantities based on issued export permits, a constant increase since 1993 is obvious (Fig. 69). In particular over the past years, since 1998, export has been rising dramatically. Export already reached the 600t mark in 1998 and was in that year about three times higher as in the previous year 1997. A drop occurred in the year 2000, when demand for a short period of time decreased considerably (see Chapter 14.7. on CITES). Already in 2001 a higher export was evident in comparison to 1998 and 1999. Highest export quantities so far were reached in 2002 with more than 1000 tons.

It can be expected that not only *Harpagophytum procumbens* material but also a significant portion of *Harpagophytum zeyheri* has been traded over the past years. It is not possible, however, to assign exact exports quantities of either species. In most cases, mixed shipping loads are exported and raw material is not separately labelled.

Subsequent to the strong increase in export figures, the income in foreign earnings is significant. For 2002, the sales value of *Harpagophytum* can be estimated to be worth US $ 2.7 million (COLE 2003).

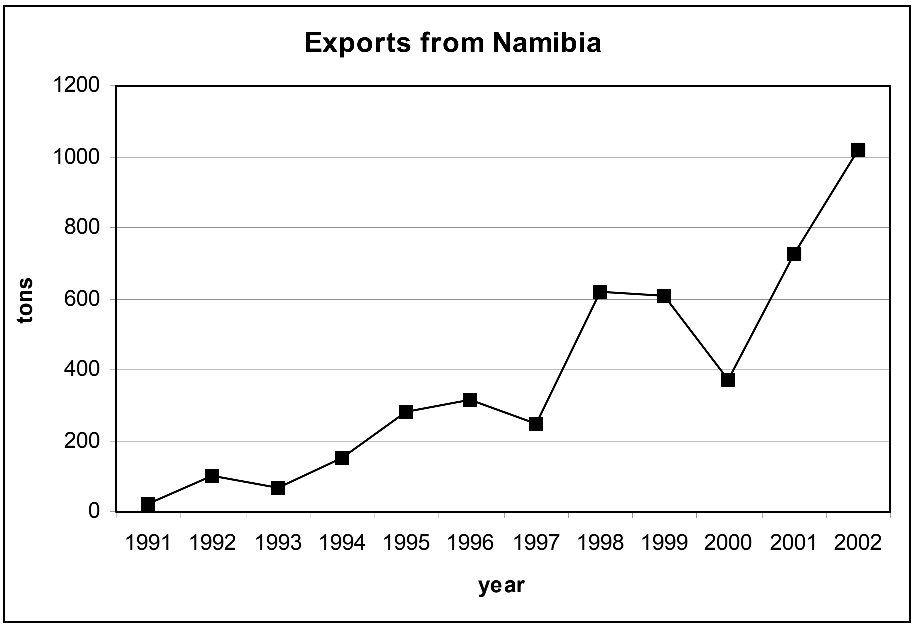


Fig. 69: Namibian exports of *Harpagophytum* from 1991-2002.
Sources: HAMUNYELA (2002), CITES Plant Committee (2003).

Of the total trade in all southern African countries, Namibia currently takes up 92% of the trade volume while South African participates with 3% and Botswana with 5% in the trade of *Harpagophytum* (http://www.cites.org/eng/cttee/plants/12/E-Minutes_PC12A3.pdf).

14.2.2 Exporting companies

The trade and export of *Harpagophytum* within and from Namibia is at present dominated by approximately six big private sector operators, and 2 or 3 smaller operators (Lombard, pers. comm.). The number of exporters rose from only 2 or 3 operators in the 1980s and early 1990s to about 10 in 1996 with a least 2 dropping out of the business since then. In 1998 the largest operator exported over 100 MT (directly to the EU and the USA) whilst the smallest exported only 1 container to South Africa. The bigger and longest established exporters are mostly German families; there is one Afrikaner farmer exporting large quantities (only to South Africa) and recently a local Damara buyer has begun exporting significant quantities (principally to South Africa).

In general, the number of exporters fluctuates from year to year. Due to the increased public awareness of the medicinal and monetary value of *Harpagophytum* over the past years an increasing number of exporters have entered the scene. COLE (2003) emphasises that in contrast to the harvesters, for the majority of exporters, the export of *Harpagophytum* is only an additional income that contributes typically between 2.5-25% of their income.

Each exporter operates on a slightly different basis. However, the main exporters will be well known to buyers. These buyers typically have a series of rural contacts (such as a shopkeeper) who in turn will have several remote rural contacts where the resource exists (Harms, pers. comm.). The shopkeeper or other business operators will be known as buyers to the harvesters. They may carry their product to his or her premises. The buyer will, when there is an economically viable amount of sliced, dried and bagged

Harpagophytum ready, travel and sell the material to the exporter. The exporter will often be able to pay cash on the spot for the load. The middleman, who often has no significant ready cash, will then pay the other middlemen who will then pay the harvesters.

Due to the request of the European market to buy only officially registered *Harpagophytum* material (*H. procumbens)*, some exporter show an increasing interest in reliable suppliers of the official raw material. This is reported by one major Namibian exporter who only buys material that comes from known and privately registered middleman who have in the past proved to sell *Harpagophytum procumbens* only. Nevertheless, it is by no other means possible to trace back where the harvested and through a chain of middleman sold material is actually coming from. As the purity and quality of material exported is only analysed in the importing country, and results are only known several months after the actual export, the exporter carries a certain risk concerning the composition of material he buys and exports. It has also been reported that other exporters explicitly buy and sell *H. zeyheri* as they claim an increasing demand also for this species, e.g. for the treatment of horse ailments.

Some of the exporters have very economical and efficient operations. The premises for grading, re-bagging and containerisation will be on their farm or at business premises in an urban area. Some exporters employ 2-3 workers for the manual grading (if necessary), re-bagging into new and printed woven plastic bags, storage and containerisation (Fig. 71). This operation is also "part-time" as their other business operations are extensive and the workers almost certainly have "duties" other than those relating to *Harpagophytum* work.

14.2.3 Countries of destination

Major importing countries are Germany, France and South Africa, but material also goes to Greece, Italy, Japan, Unites Kingdom, USA, Spain, Sweden and Venezuela (HACHFELD & SCHIPPMANN 1999). While France imported large amounts of *Harpagophytum* up to 1999, Germany represents the major importer today. Also greatest increase of imports is evident for Germany.

The importance of South Africa as an importer has increased since 1996 and is now one of the dominant buyers of *Harpagophytum* from Namibia. The demand for the material in Europe and also the USA is definitely increasing (Lombard, pers. comm.).

14.3 South Africa

14.3.1 Export quantities

Few official figures are available for the total export volumes of *Harpagophytum* from (or through) South Africa. In two provinces (Northern Cape Province, North West Province) harvesting takes place. But as both provinces operate independently, overall figures are difficult to obtain. It is also difficult to distinguish between re-imports from Namibia which are exported via South Africa and material originated from the country. While in 2001 material of *Harpagophytum* harvested in South Africa made up approximately 3% of the total South African trade volume, in 2002, this was already 10% (RAIMONDO et al. 2003).

For the harvesting season of 1999/2000, an amount of 6,900kg of harvested South African material is reported for the Northern Cape Province (TRAFFIC 2000).

In the harvesting season of 2000/2001, a total of 21,029kg *Harpagophytum* harvested in the North West Province of South Africa was exported (RAIMONDO & DONALDSON 2002).

In 2001/2002, exports increased significantly and more than 90,000kg were exported (POWELL 2001). An increase in quantities can be expected for the past harvesting season of 2003 as several new harvesters were registered and trained in the province.

14.3.2 Exporting companies

Seven exporters are known from South Africa (Lombard, Powell, van der Vyver pers. comm.). Most of them export material either from Botswana or Namibia, only three exporters are currently known to export nationally harvested material of *Harpagophytum.*

Traders and observers in Namibia suggest that this rising role of South African middlemen is at least partly due to them having better market contacts, and those selling *Harpagophytum* stocks to South African traders having relatively poor market contacts. Discussion with Namibian traders who export only or mainly to South Africa indicate that they have only a limited knowledge of *Harpagophytum* markets in the EU or the USA (Lombard, pers. comm.).

14.3.3 Countries of destination

It is estimated that the countries importing *Harpagophytum* material which is exported via South Africa are similar to those of the Namibian market, e.g. mainly France and Germany, but also Great Britain, Spain, and the USA. No exact data was available though.

14.4 Botswana

14.4.1 Export quantities

There are two different sources of quantitative export data available for Botswana. These are data from the issuing of harvesting permits (Fig. 70) and from export permits (Tab. 60). Large fluctuations in the issued harvesting permits are evident between the years, which range from a complete lack of permits (e.g. 1990) to a peak in 1995 over the extraction of 40t. Typically no more than 15t were annually extracted.

Yet, data of the harvesting permits does not always match with export data (Tab. 60). The stated export quantities for 1993-2001 ranged from 501kg to 33,506kg. They suggest higher exports for the years 1995 and 1998, but lower exports for the years 1994, 1999 and 2001. Although BEN (2002) states that there is also small-scale trade that is done locally and for which no data is available, differences between both sources of data seem to be larger than that.

According to KGATHI (1988), an average of 17,056kg of raw material per year was exported from Botswana between 1979 and 1985.

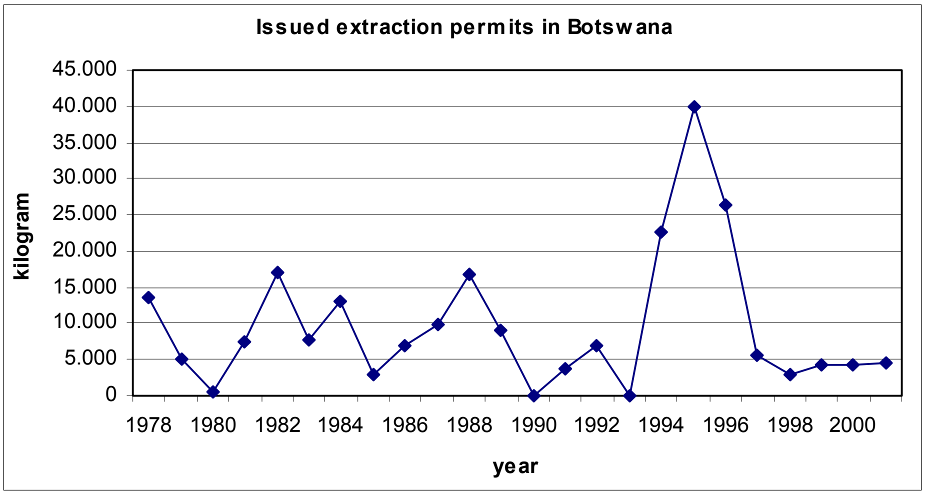


Fig. 70: Issued harvesting permits for *Harpagophytum* in Botswana for 1978-2001. Source: Agricultural Resource Board 2002, Gaborone.

Tab. 60: Exports of *Harpagophytum* from Botswana. Sources: Thusano Lefatsheng & Agricultural Resource Board 2002.

Year	Export [kg]
1993/ 94	18,000
1994/ 95	17,000
1995/ 96	19,500
1996/ 97	22,000
1997	5,493
1998	501
1999	2,050
2001	17,306

Personal communications indicate that there is still a great resource potential for trade purposes in Botswana and therefore an increase of export numbers can be expected in future. This would, however, depend on market connections.

14.4.2 Exporting companies

The principal exporter of *Harpagophytum* from Botswana is Thusano Lefatsheng. Thusano Lefatsheng is a rural development organisation set up to market veld products, including *Harpagophytum*, for the benefit of remote area dwellers. It is a non-profit making Trust (non governmental organisation). It has a commercial operations department, an extension department, and a research department. Over the past ten years it has conducted cultivation trials with *Harpagophytum* and has made significant efforts at instituting sustainable harvesting practices, even if this has not always been the outcome.

There is possibly a significant trade of *Harpagophytum* outside of the operation of Thusano Lefatsheng. The precise legal nature of this possible trade is not known (Lombard, pers. comm.). There are several other NGO stakeholders in Botswana. These include Permaculture Trust of Botswana and Veld Products

Research and Development, which are recently more involved in harvesting and scientific approaches to analyse harvesting effects.

Also South African exporters enter the market in Botswana to buy *Harpagophytum* although the extent of such purchases is not known.

14.4.3 Countries of destination

Raw material originating in Botswana is predominantly exported to South Africa. Certain quantities may also be sold to Namibia. Other countries of destination include Germany, South Korea.

MATLAHARE (2002) claims a serious lack of marketing information and information on market dynamics in Botswana. While in some year demand is completely lacking and no material can be bought from harvesters, in other years demand exceeds by far the stocks.

14.5 The market situation

Even though *Harpagophytum* is reported to be high in demand by traditional medicinal practitioners in Botswana and Namibia (MARSHALL 1998), trade in this species clearly focuses on international rather than on domestic markets. The material traded almost entirely consists of dried and sliced root tubers, which so far almost exclusively originates from the wild (see Chapter 13).

14.5.1 Europe

In Europe, the market for *Harpagophytum* is well developed especially in its western parts, i.e. France, Spain, Germany, and Great Britain. Material also goes to Belgium, Sweden, Greece, Italy, and Austria. No information is available on east European countries.

A survey with the German importers of *Harpagophytum* that was conducted for the BfN in the year 2001/2002 (HACHFELD 2002) revealed the following for Germany:

- 8-10 importing companies are active on the market.
- Some pharmaceutical companies import their material directly, while others rely on large-scale import companies. Also extracting companies may function as importers.
- Most interviewed importers stated that there are obvious variations in the availability of raw material.
- Importers see the variations in the raw material supply to be due to rainfall variations in the source countries, while they do not see any signs of a general scarcity of material.
- Importers find quality constraints that may be due to fungi and bacteria (that invest the sliced tubers, if these are not dried quickly enough) or due to mixed in slices of other plant species.
- Most companies have several opportunities to buy material from and do not rely on one exporter only.
- In early 2002, the supply was reported to be limited, which is assigned to low rainfall in Namibia. This finding is supported by the observation that several Namibian exporters are in the search for new sources of material.

- The majority of interviewed German companies anticipated that the market for *Harpagophytum* will not increase dramatically in future.

  While some importers claim that the maximum market share of *Harpagophytum* has been reached already, others found a stable demand or a slight increase possible. Only one company stated clearly that the market will increase. This company, however, was closely related to the recent launching of a new product.

The increase in particular of Namibian exports but also of South African exports of wild material in 2002 indicates that a considerable increase in trade has already taken place.

14.5.2 USA

Results of the interviews with German importers revealed that traders consider the USA market to be significantly under-developed at present (HACHFELD 2002):

- There are only very little direct imports of *Harpagophytum* into the USA, instead most material is imported via European companies.
- All interviewed companies stated that markets such as the USA and Asia would be potentially great opportunities but difficult to enter.
- Although small amounts of *Harpagophytum* are already exported to USA, licenses for pharmaceutical products are too expensive to cover the risk of this highly fluctuating market.
- For South America, the only importing country known so far is Venezuela (MARSHALL 1998).

14.5.3 Far East

German companies involved in the trade of *Harpagophytum* also consider the market potential of the Far East to be enormous and under-exploited (HACHFELD 2002). The only fragmentary information available at present is that exports to Japan take place (NOTT 1986, MARSHALL 1998).

14.5.4 Efforts to market *Harpagophytum*

The majority of interviewed German companies stated that to hold a constant share of the *Harpagophytum* market, great effort has to be invested into marketing.

The market of herbal products is often linked to the emotions of the consumers who like to buy "good stories" and myths with the product. In general, with herbal products, which are commonly marketed as "green" or as having beneficial links to indigenous people, consumers remain unaware of the real background, i.e. the biological and socio-economic implications of their purchases (LAIRD & PIERCE 2002).

In particular with *Harpagophytum,* various ways means of marketing strategies are followed. These comprise the traditional knowledge of the San people and the mythical stories around them being gatherers and hunters in the Kalahari is frequently used for marketing purposes.

Occasionally, partly odd exaggerations go along with this. For instance, recently advertisements for a *Harpagophytum* retail product were found which market their tablets as product from the tropical rainforest and use their sponsorship for the survival of endangered animal species in Asia to attract consumers.

Other pharmaceutical companies use the potentially bad conscience of the European consumers as marketing strategy and suggest that by buying wild harvested material the consumer will be responsible for the extinction of rural traditional medicines. They claim that their product is based on cultivated material and is thus delivering a great contribution to the conservation of the endangered plant species.

The impact of cultivation on the demand and development of the market is considered an important issue not only between the stakeholders in the range states, but also between the pharmaceutical companies and importers (HACHFELD 2002). As discussed in Chapter 13 on the possible impacts of cultivation, harvesters see a danger of a decreasing market share for material harvested from the wild. This would mean a decrease in cash income that would pose a great threat to the rural harvesters community who often rely entirely on this sole source of income.

The view of the importers on the impact of cultivation on the market varied with respect to their position concerning their activities in cultivation trials. Some are convinced that cultivation will benefit the wild populations and claimed that "conservation by cultivation" is the only solution for a quality control and a continuous resource flow. Others focus on the problems concerning cultivation such as a loss in harpagoside contents and an increase in parasites when watering the plants and a general lack of knowledge concerning the best harvesting periods and other standardisation methods. Some companies did not believe the announcements of successful cultivation projects, which claim to cover already the entire resource needs of the involved companies.

In general, the increase in demand for *Harpagophytum* can be attributed to

- The above listed intensified efforts in marketing initiatives by product manufacturers
- A broader market presence (from pharmacies to large supermarket chains in Germany) combined with lower retail prices in these supermarkets
- The increasing number of clinical research data
- An increasing number of people suffering from arthritis or similar locomotive disorders

COLE (2003), however, advises to be cautious with respect to the expectation of an ongoing increase in demand: The increase in prescription in Germany can be attributed to *Harpagophytum* being listed on Medical Aid schemes, which makes products claimable by users. Also France has recently de-listed almost 600 other herbal medicines from Medical Aid schemes and by this *Harpagophytum* products may be favoured at the moment.

Fig. 71: a-c) Cleaning and rebagging of secondary tubers of *Harpagophytum* on the premises of exporters in Namibia; d) sliced raw material and selected retail products made of *Harpagophytum.*

14.6 Effects of trade in *Harpagophytum*

Effects of commercial trade in *Harpagophytum* result first and foremost in the extraction of very large numbers of individuals from the wild. In Namibia, concerns about high harvesting intensities came predominantly from local people in the country (Hamunyela, Regional Devil's Claw Conference 2002).

14.6.1 Area to be harvested in Namibia to meet export quantities

Effects of trade can be calculated from the number of plants that have to be extracted from the wild and the area that is affected by harvesting to meet existing export quantities:

On the basis of several studies conducted in Namibia (Chapter 12) it was calculated that 4-6 plants have to be harvested to produce 1kg of dried tubers. This adds up to 4,000-6,000 plants that have to be extracted for one ton of dried tubers. Extrapolating these numbers to the annual export quantity of Namibia of more than 1,000 tons for the year 2002, this sums up to a number of over 4,000,000-6,000,000 plants.

Table 61 combines data collected in the field on the occurrence of *Harpagophytum* on one square kilometre sites with the dry yield of tubers per plant. It is assumed that the sampled square kilometres give a representative mixture of the occurrence patterns of *Harpagophytum* in the research area. Based on this, the number of plants that have to be extracted from Namibian communal areas to meet the export quantity of the year 2002 (~ 1,000 tons) and the area to be harvested is calculated. To include the variable occurrence of *Harpagophytum* on the research sites, the percentage of occurrence of different individual classes was considered (Chapter 8.4).

Tab. 61: Calculation of the area to be harvested at different densities of occurrence of *Harpagophytum* on communal land of Namibia to meet the export quantities of 2002.

Area to be harvested on communal land of Namibia to meet the export quantity of 2002							
Quantity classes counted on 24 transects of 100*2m	500 ind.	200 ind.	100 ind.	50 ind.	10 ind.	5 ind.	0 ind.
Percentage of occurrence in study	17.7%	17.6%	5.9%	0%	23.5%	11.8%	23.5%
Calculated total number of plants/1 km² based on 24 transects = 0,48% of 1km²	104,166	41,666	20,833	10,416	2,083	1,041	0
No. of square kilometer to be harvested for the export of 1000 tons 2002 based on <u>4 plants/1kg</u> dry material (= 4,000,000 plants)	38	96	192	384	1920	3842	-
No. of square kilometer to be harvested for the export of 1000 tons 2002 based on <u>6 plants/1kg</u> dry material (= 6,000,000 plants)	58	144	288	576	2880	5764	-
No. of square kilometer to be harvested based on percentual occurrence of quantity classes and on <u>4 plants/1kg</u> dry material	6.8	16.9	11.3	0	451.3	453.4	0
No. of square kilometer to be harvested based on percentual occurrence of quantity classes and on <u>6 plants/1kg</u> dry material	10.1	25.3	17.0	0	676.9	680.1	0

The number of plants that has to be extracted from the wild and the area to be affected by harvesting to reach the 1,000 tons of exported raw material depend on the population density of *Harpagophytum.*

While in very dense populations (500 individuals on 24 transects) only 38-58 square kilometres (3,800-5,800ha) would have to be harvested to meet export quantities, in a scattered occurrence of *Harpagophytum* (10 individuals/1km²), this would correspond to an area of 1,920 square kilometres (192,000ha) or 2,880 square kilometres (288,000ha) respectively.

When the results of the field studies on the frequency of occurrence of the seven quantity classes on Namibian communal land are taken, and it is assumed that harvesting takes place in each quantity class, Table 49 shows the following: At a dry yield of 4 plants/1kg *Harpagophytum* a total of 940 square kilometres (94,000ha) would have to be harvested for an export quantity of 1,000 tons. With a dry yield of 6 plants/1kg this would even add up to 1,410 square kilometres (141,000ha).

Considering that this area cannot be harvested again in the following years as the resource has to regenerate and has to produce new secondary tubers, an enormous area of resource is taken out of utilisation over a period of at least three years. This is only the case, if the resource is harvested sustainable, yet, if, this is not done, then very large areas of the distribution area of *Harpagophytum* is continuously lost for harvesting purposes and income generation.

14.6.2 Area to be harvested in South Africa to meet export quantities

VON WILLERT et al. (2002) have based a similar calculation on the findings of one farm in South Africa, where the weight of dry tubers was much lower (harvesting of 8.3-11.1 plants for 1kg dry material, see Chapter 12.2.3). Calculating from this, the South African export quantity of 90 tons in 2002 equals an amount of 747,000 plants that had to be harvested.

RAIMONDO et al. (2003) also calculated the number of harvested plants for South Africa using the dry weight of secondary tubers per plant. With their weighing of 21 plants in the North West Province of South Africa, in a very dry year, they found a dry weight of 0.045kg per plant (harvesting of ~22.2 plants for 1kg dry material). From that, for the 90 tons of exported raw material from South Africa in 2002, a number of 2,004,868 plants had to be harvested.

Table 62 combines data collected in the field on the occurrence of *Harpagophytum* on the square kilometre sites in South Africa with the dry yield of tubers per plant stated by the above authors. Only the communal areas of South Africa were used for the following calculations as commercial harvesting is only of importance there. It is again assumed that the sampled square kilometres give a representative mixture of the occurrence patterns of *Harpagophytum* in the research area. Based on this, the number of plants that have to be extracted from South African communal areas to meet the export quantity of the year 2002 (90 tons) and the area to be harvested is calculated. To include also the variable occurrence of *Harpagophytum* on the research sites, the percentage of occurrence of different individual classes was considered (Chapter 8.4).

In comparison to Namibia, less often very high number of *Harpagophytum* were encountered on the research sites (500 individuals). Again, area that has to be harvested increases with a decrease of the resource density.

Tab. 62: Calculation of the area to be harvested in varying dense occurrence of *Harpagophytum* on communal land of South Africa to meet the export quantities of 2002.

Area to be harvested on communal land of South Africa to meet export quantities							
Quantity classes counted on 24 transects of 100*2m	500 ind.	200 ind.	100 ind.	50 ind.	10 ind.	5 ind.	0 ind.
Percentage of occurrence in study	9.1	18.2	18.2	18.2	27.3	9.1	9.1
Total number of plants/1 km² based on 24 transects = 0,48% of 1km²	104,166	41,666	20,833	10,416	2,083	1,041	0.0
No. of square kilometres to be harvested for the export of 90 tons in 2002 based on 8.3 plants/1kg dry material = 747,000 plants (VON WILLERT et al. 2002)	7	18	36	72	359	718	-
No. of square kilometres to be harvested for the export of 90 tons in 2002 based on ~ 22.2 plants/1kg dry material = 2,004,868 plants (RAIMONDO et al. 2003)	19	48	96	192	962	1926	-
No. of square kilometres to be harvested based on % occurrence of quantity classes and on data of VON WILLERT et al. 2002	0.7	3.3	6.5	13.1	97.9	65.3	0
No. of square kilometres to be harvested based on % occurrence of quantity classes and on data of RAIMONDO et al. 2003	1.8	8.8	17.5	35.0	262.8	175.3	0

Great differences in the size of harvesting areas occur between the calculations of both authors. While based on VON WILLERT et al. (2002), in a high resource area seven square kilometres would suffice to extract the export quantity of 90 tons from the soil, according to RAIMONDO et al. (2003) 19 square kilometres would have to be affected by harvesting. Also at a low resource density the difference is evident and two and a half fold.

When considering the percentage of occurrence of different quantity classes on communal South African land (as found in this study, see Chapter 8.4), the findings of the authors result in very divergent total areas that were exploited in 2002. Based on the calculation of VON WILLERT et al. (2002) harvesting had to take place on a total of 186 square kilometres (18,600ha). According to RAIMONDO et al. (2003) this would be a significantly larger area of 510 square kilometres or 51,000ha.

Due to the significantly lower dry yield of *Harpagophytum* in comparison to Namibia, the area to be harvested for the South African export quantities of 2002 is considerably larger than in Namibia. Although the different data of literature seems to support that dry yield per plant of *Harpagophytum* is frequently lower in South Africa than in Namibia, this deserves additional attention. In particular, for the estimation of the long-term impact of harvesting and resource management planning in the communal areas of the North West Province where major harvesting activities take place, this is important.

Next to the effects of trade on the biological status of *Harpagophytum,* effects include the very important aspect of the socio-economy of the harvesters, their perspectives in future trade and cash-income.

14.7 Domestic and regional trade

Apart from the existing national harvesting and export permit system for Namibia and Botswana (see Chapter 15), there is a lack of instruments controlling regional trade between range states (e.g. from Namibia and Botswana to South Africa). Nevertheless, the trade with South Africa seems to become increasingly important but is not subject to any form of control or registration to date.

Personal communications indicate that for South Africa it is difficult to establish a country-wide control of imported *Harpagophytum* material from Botswana and Namibia. Many custom posts at the border of South Africa lie very isolated, and custom officers – even if trained in this respect – will never stay longer than a few months in these remote areas. The high fluctuation rate in officers makes a continuous level of recognition more than difficult (Koen, pers. comm.). Domestic transport and trade between the different provinces is difficult to track, as some exporters may be located in one province, while they buy their material in or import their material into another province. Yet, recently great efforts are being invested by the Northern Cape Province and the North West Province with respect to information exchange on trade and harvesting issues of *Harpagophytum*. A close co-operation exists between the provinces, which allows the assessment and partly also control of domestic trade (Powell, pers. comm.).

The need for a better organisation of trade in and between ranges states was acknowledged on the Regional Devil's Claw Conference in February of 2002. This was to avoid competition, unfair prices and market practises and to gain a better control over the resource available. Also with respect to cultivation, quantities of material to be produced by cultivated material in future and potential consequences to the income generation of harvesters were considered to be issues that needed regional attention. Based on this, the idea of a trade association was brought up which should include all stakeholders. In future, further steps in this direction are to be undertaken.

14.8 International Trade

For the successful international trade in *Harpagophytum* mutual trust between the importer and exporter is important. Various im- and exporters state that in particular with respect to quality this relationship is predominantly based on trust. This is in particular important as the quality of the material (harpagoside content and aflatoxin contamination) is only determined in the importing country while orders of material are paid in advance. There are reports on problems with low quality shipments from Namibia for which importers have been supplied with handpicked samples, which did not prove to hold the quality in the entire shipment. If imported material does not meet the standards called for in the pharmacopoeias the material is considered sub-standard and cannot be used anymore.

14.9 Organic certification

The organic certification of wild harvested *Harpagophytum* is one option to reach higher prices for raw material that could benefit the harvesters in the source countries.

In general, there are a number of well-established certification schemes for timber agricultural products. Four main categories of certification schemes exist for Non-wood forest products (NWFP). These are (a) forest management certification, (b) social certification, (c) organic certification, and (d) product quality certification (WALTER 2002).

Organic certification comprises wild crafted and semi-domesticated NWFP while the criteria specify that organically collected material (a) has to come from a stable and sustainable growing environment, (b) is harvested in a way not exceeding sustainable yields, (c) is derived from a clearly definable collecting area, (d) is not exposed to prohibited substances, (e) is collected in an area that shows an appropriate distance from conventional farming, pollution and contamination, and (f) is harvested by clearly identifiable operators (WALTER 2002).

One development project in Namibia, the Sustainable Harvesting Devil's Claw Project (SHDC-project) initiated by CRIAA SA-DC, chose the option of organic certification with the aim to provide harvesters with higher income and to provide buyers with a guarantee of sustainable resource utilisation and quality control.

Yet, a survey questionnaire sent to leading European *Harpagophytum* manufacturers as well as quantities of production of organic and non-organic *Harpagophytum* in Namibia revealed that the willingness of buyers to pay more for organic certified material is very limited (COLE 2003). In 2001, only one German buyer took over the entire organic produced *Harpagophytum* tubers paying higher prices than for other material while he no additional income through the certification accrued to him.

It seems that certification of *Harpagophytum* can only be valuable option and a working tool to provide higher income level to the harvesters, when the market and in particular the consumer recognises the connection between the production of the retail product and the livelihood of the producers. It is assumed that in order to market organic certified products, a high marketing effort is needed to increase the awareness of the consumer in that respect. Still, it remains unknown, whether many consumer who suffer from acute arthritis would be willing to pay higher prices for certified products, if parallel to certification not necessarily a higher effectiveness of the product is guaranteed.

Apart from the economic effects an organic certification may have on the harvesters, COLE (2003) stresses non-monetary benefits. Certification can contribute to improve knowledge of harvesters regarding the resource management (in particular in dry years). Next to the improved knowledge on sustainability, the training of harvesters in various fields that is needed prior to a successful certification can empower the community to recognise ownership, to strengthen the harvesters' bargaining position and to realise benefits, and to sharpen the harvester's perception and responsibility of their resource.

14.10 Intellectual property rights – patents

The TRIPs (Trade Related Aspects of Intellectual Property Rights) agreement forms one major part of the World Trade Organisation (WTO), which is a legally binding agreement to all signatory countries (www.wto.org). The TRIPs agreement addresses amongst others, the applicability of relevant international intellectual property agreements, the provision of adequate intellectual property rights, and the provision of effective enforcement measures for those tights. TRIPs also includes a regulatory approach concerning patents. For patents, TRIPs sets a 20-year patent protection for patented products or processes in almost all fields of technology.

The text of article 28.3b says that

> "Inventions may be excluded from patentability if permitted exclusions are for (…) plants and (other than micro-organisms) animals and essentially biological processes for the production of plants or animals (other than microbiological processes)…".

To license a patent on products or production steps these need to be (a) a novelty, (b) non-obviousness, i.e. involve an inventive step, and (c) usefulness (industrial applicability)

Patents are generally licensed to create an incentive for commercially based research and development. The development of new technologies or products is extremely costly and the exclusive user right by a patent holder is supposed to account for this effort. Yet, great international disputes evolved on this concept as it claimed that patenting creates monopolies and severely increases prices for food and medicine in particular for rural people. It is argued that false user rights are being put on intellectual properties, while the creativity of several centuries of collective and cultural innovation is neglected, which is however evident in the biodiversity today (e.g. SHIVA 2001, WOLFRUM et al. 2001). SHIVA claims that "Patents on life are so immoral, and so unjust, and so against nature and people, that is really only needs awareness in larger numbers for the whole thing to come to a stop".

Also in *Harpagophytum*, herbal medicine companies have patented methods to make extracts and pharmaceuticals. Recently, three patents have been issued of which two are held by German companies, i.e. Finzelberg Nachfolger GmbH (W09744051) and Willmar Schwabe (W09734565). Another patent holder is Choongwae Pharmaceutical of South Korea (US 5929038) (GAIA/GRAIN 2000).

Various stakeholders claim a lack of commitment from the importers or pharmaceutical companies to sharing the benefits that accrue to them (e.g. MATLAHARE 2002, WYNBERG 2002). These also include benefits from patent holders on extraction techniques. With the patent holder being not from the source countries and the allowances that have to be paid to use patented processes being too high to be afforded from these countries, no value adding by further processing can be achieved in the range states. It is argued that source countries by no means have the financial capability to develop alternative extraction techniques themselves and that due to the 20-year patent protection they have no chance to increase value adding in their countries. In general, the lack of technological transfer and capacity building is argued. Additionally, on the side of the harvesters and traditional users of the plant an acknowledgement of traditional knowledge, which originally led to the pharmaceutical application today is said to be missing.

Some stakeholders use the article 8j of the CBD (Convention on Biological Diversity) to stress that an equitable sharing of benefits, which arises from the commercial utilisation of the knowledge on the medicinal value of *Harpagophytum* should take place.

The article 8j of the CBD says that

> "Subject to its national legislation, respect, preserve and maintain knowledge, innovations and practises of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practises and <u>encourage</u>

the equitable sharing of the benefits arising form the utilisation of such knowledge, innovations and practises" (UNEP 1998).

The sharing of benefits implemented in the CBD is an important issue that conflicts with the TRIPs agreement on the protection of intellectual property rights. The sharing of benefits in form of free access to genetic resources and biotechnology cannot be taken for granted due to the patent rights implemented in the TRIPs agreement (WOLFRUM et al. 2001). Yet, from the point of view of the harvesters of *Harpagophytum* who are predominantly San people and traditional users of the plant other form of benefit-sharing (other than monetary) such as the transfer of technology is an issue that needs further attention.

14.11 Conservation measures – CITES

Extensive trade in wild flora or fauna may result in a threat of extinction of the traded species. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is the international binding tool (for signatory countries) to protect and monitor such endangered species. The convention offers three levels of protection depending on the level of threat posed by trade and the biological status of the species in question. While Appendix I prohibits any commercial trade of a species, species listed under Appendix II may be traded if certain scientific and legal criteria are satisfied. These include that the listed specimens are harvested in a legal and biologically sound manner and that valid CITES documentations are obtained prior to export. In order to be listed on Appendix I or II, approval is needed from the Parties. Appendix III, on the other hand, is a useful tool used unilaterally by countries seeking to complement domestic protection for native species by regulating exports and is assigned by each country individually (ROBBINS 2000).

Germany as being one of the major importers of *Harpagophytum* had proposed a listing of both species of *Harpagophytum* on Appendix II at the eleventh meeting of the COP11 (Conference of the Parties) to CITES held in Nairobi in April 2000. This proposal was based on the concern that *Harpagophytum* was not being sustainably utilised and that unless trade was monitored and regulated, the species may become seriously endangered. The other species, *Harpagophytum zeyheri,* was to be included for look-alike reasons. This concern was based on the results of an extensive study conducted for the German Federal Agency of Nature Conservation on the analyses of the trade potential and possible over-exploitation of *Harpagophytum* (HACHFELD 1999). Due to a lack of support among the range states, Germany withdrew the proposal. It was argued that the scientific evidence that *Harpagophytum* may be endangered was not yet sufficient and that in many areas also sustainable harvesting techniques are applied (CRIAA 2000). Concerns were risen with respect to negative impact of a CITES listing on the livelihood of the harvesters and a promotion of cultivation. As a result two decisions were passed at the COP11.

The decisions of the COP 11 were:

- Decision 11.63

  "In the light of increasing international trade in the roots of *Harpagophytum* spp. (Devil's Claw) the range and importing States should submit to the Secretariat all available information concerning the trade, management and biological status of *Harpagophytum* species and regulatory measures applying to them."

- Decision 11.111

  The Plants Committee shall:

  - Review information submitted to the Secretariat in accordance with Decision 11.63.
  - Summarise the biological and trade status of *Harpagophytum* species subject to international trade
  - Prepare a report on the biological and trade status of *Harpagophytum* species, at least six months before the 12th meeting of the Conference of the Parties, for consideration at that meeting.

Next to the above mentioned concerns regarding a potential CITES listing, a lack in communication was identified which was evident at several levels, i.e. between the national CITES authorities and the stakeholders who did not know what to expect from a potential listing, and between the regional CITES managements as well as with the CITES secretariat. It was furthermore anticipated that a listing would give the wrong impulse to the market and that buyers would restrain from buying wild harvested material. It was stressed at the First Regional Devil's Claw Conference held in Windhoek in February of 2002, that CITES would need to work in favour of the range states, i.e. to help to alleviate poverty and encourage the sustainable use of *Harpagophytum*. It should be used as a development tool rather than as a control tool.

Although a CITES Appendix II listing explicitly allows trade, it was assumed by stakeholders in the range countries that pharmaceutical companies would fear a severe decrease of the market as soon as the listing was implemented (e.g. CRIAA 2000, BEN 2002). A decrease in export quantities in 2001 was interpreted as a consequence of the German proposal, which had upset the market structures. However, when comparing these concerns with the perception of German importers, collected in a recent survey (HACHFELD 2002, see Chapter 14.5) it has to be concluded that these were not fulfilled. The majority of the interviewed companies were not of the opinion that the German CITES proposal had an influence on the market. They did see extra costs involved in the case of a listing though. Lower import quantities in 2000 were reported to have been solely due to large stocks available in the importing countries.

Although no listing of *Harpagophytum* was proposed for the next COP, on the twelfth meeting of the Plants Committee, CoP 12, the advisory board for CITES on plants, held in Leiden, the Netherlands in May 2002, the issue was considered to be too important to be completely withdrawn from the agenda. It was recognised that the inclusion of the species in any CITES decisions could contribute to the awareness that further research is needed on the ecology and utilisation of the plant and that by this funding for scientific projects may be facilitated.

A potential step that would be initiated and implemented by the range states could be to include *Harpagophytum* on Appendix III of CITES. This was recommended by CoP 12. For *Harpagophytum*, this would practically only mean that an export permit is required and that the specimen to be exported "was not obtained in contravention to the laws of that State for the protection of fauna and flora" (www.cites.org/eng/disc/text.shtml#V). To import *Harpagophytum* the presentation of a certificate of origin would be required together with the export permit of the country where the plant had been listed on Appendix III. The advantage of a listing could be that track of im- and exports are more easy to keep and that by these means a trade monitoring could easily be achieved. Participants of the National Devil's Claw Stakeholder Workshop in Namibia in November 2002 were against such listing at the moment (COLE 2003).

From the site of European importing countries, there is the possibility to include *Harpagophytum* into the Annex D of the EU Regulation 338/97 (SCHIPPMANN 2002). This regulation is one of two regulations that were implemented as the core of the European Community's wildlife trade legislation to fulfil CITES (http://europa.eu.int/comm/environment/cites/legislation_en.htm). The Regulation No. 338/97 deals with the protection of species of wild flora and fauna by regulating trade in these species. The regulation has four Annexes (Annex A-D). While in Annex A to C predominantly species of the CITES Appendix I, II and III are listed, in Annex D next to species for which the EU holds a reservation also some non-CITES species are listed. The decision to include a species into this Annex is taken by the Management Committee on the basis of a proposal by the Commission and after consultation of the Scientific Review Group. The purpose is to monitor significantly traded species, while no import permit but only an import declaration is required. Just recently, the proposal to include *Harpagophytum* in Annex D has been approved by the European Community.

14.12 Conclusions and summary on the trade in *Harpagophytum*

Trade in *Harpagophytum* takes place in the three range states with Namibia being the dominant exporting country. Namibia exports about 10-12 times the amount of the exports of Botswana. South Africa, on the other hand, predominantly imports and re-exports half processed material from Botswana and Namibia. Up to 2001, only very small amounts have been derived from domestically harvested material in South Africa, but trade picks up for 2002. In the three range states exports are expected to only slightly increase in future. It is clear that in future more material will come from cultivation, while the majority of raw material will still come wild collections. It is not yet known how the market share of cultivated material will develop.

Whereas exporters in Namibia come exclusively from the private sector, and comprise about 7-9 in number at the moment, in Botswana the dominant and officially only exporter is a non-profit organisation. In South Africa, trade is operated on private sector basis or by exporting pharmaceutical companies. Due to the fact that market contacts to the European and USA market are much better developed, South Africa is the main buyer for material from Botswana at the moment. Currently, only one main exporter is known to be involved in local harvesting activities in Botswana.

Domestic market structures for *Harpagophytum* do exist, but are considerably unimportant in comparison to especially the European market, but also to the USA market. For South America and the Far East market potential is considered to be still under-exploited.

Next to socio-economic issues effects of trade include the incentive to set control measurements for trade. The withdrawn CITES proposal and the resulting Decision 11.111 on *Harpagophytum* created a stronger awareness of the value of the resource and the need for further research. Although a need for more close co-operations was identified independently between the range states, it can be assumed that the proposal added an additional trigger to this. Also with respect to funding of scientific research proposals, the decision proved to be a good argument. In all three range states mapping project apply for funding or have already been initiated using also the argument of the CITES proposal.

15 Legislation in *Harpagophytum*

Legislative measures in the range states are responsible for domestic trade control, including the issuing of extraction permits, of permits for transport, phytosanitary permits and permits for the export of raw material of *Harpagophytum*. Not only with respect to trade, conservation and sustainability of *Harpagophytum*, the legislation plays an important role. Also with respect to the socio-economy of the harvesters legislation may have a great impact through the harvesting permitting system. In the following, legislation of the three range states is presented separately.

15.1 Methods

Methods on the legislation of *Harpagophytum* are predominantly derived from literature. Only in parts personal communications or interviews were also conducted on this topic.

15.2 Namibia

Harpagophytum is protected in Namibia under Schedule 9 of the Nature Conservation Ordinance of 1975. From 1975 onwards a permit was required for the collection, transport, possession and / or sale of *Harpagophytum*. As early as 1986 this system was considered to be ineffective and in reality only a permit to export has been required in recent years (NOTT 1986, MARSHALL 1998). In the mid of 1999 an interim harvesting permitting system was re-instated with the aim to stop unauthorised collecting in communal and private sectors and to provide the Directorate of Resource Management of Ministry of Environment and Tourism (MET) with more information on localities and quantities harvested and on the dynamics of trade in *Harpagophytum* (HAMUNYELA 2002).

Known exporters so far are routinely issued permits to export with often little other record keeping by exporters. The Division for Specialist Support Services (DSSS, the Namibia CITES Management Authority) within the MET is responsible for the issuing of export permits.

To export *Harpagophytum* from Namibia a phytosanitary certificate is required with the other necessary documents such as an invoice, waybill, permit, etc. Phytosanitary certificates are issued by the Ministry of Agriculture, Water and Rural Development (MAWRD) and are done so routinely rather than after a thorough inspection of the material.

A permit is also required for cultivation or research on *Harpagophytum*. Proposals in this respect are discussed with the Namibian Devil's Claw Working Group (NDCWG) and permits are then issued by the DSSS.

Stakeholders in Namibia consider the permit system to be both, poorly designed and poorly executed, and the MET and other government bodies and stakeholders are in the process of reviewing the relevant policy and legislation (Lombard, pers. comm.). The permit system is being evaluated as part of the Namibian National Devil's Class Situation Analysis, the results of which will be published soon (COLE 2003).

The recent re-instatement of the Nature Conservation Ordinance of 1975, including the reinforcement of collecting permit requirements by the MET / Directorate of Resource Management, is supposed to bring more insight into the exploitation level areas where most harvesting takes place. This way it is hoped to achieve an idea of harvesting and exploitation pressures and thus depletion potential in specific areas.

Another background recognised by the Ministry is the problem of land tenure and harvesting. With the need of a collecting permit, the harvester has to state the harvesting locality (land unit and district) and has to have the approval of the land owner to harvest. It is assumed that this is in particular of importance in the case of hired harvesters who enter communal areas without permission of the traditional authorities.

In Namibia, the official harvesting season starts at the end of the rainy season form 1st of March to 31st of October.

At the moment collecting permits are valid for one month only, after another month a report on the amount harvested has to be given. The problems herein lie not only in the issuing of the permits, e.g. who will issue them and how long distances the harvesters have to overcome in order to receive a permit having no means of transport, but also in the validity of the permits. The question is whether the period of one month will really be beneficial for the sustainability of *Harpagophytum*, or whether not the contrary may be true and harvester will harvest as much as possible within this one month trying to weigh out the effort of permit issuing? At the moment these contradiction are not satisfyingly solved according to P. Lindeque from the MET, but a permit with conditions like those mentioned above are considered better than no permit at all (Lindeque, pers. comm.).

15.3 South Africa

Harpagophytum was considered a protected plant by the Nature and Environmental Conservation Ordinance No. 19 of 1974 (POWELL 2002) in the former Cape Province of South Africa, which are today the provinces Northern Cape, North West Province and Eastern Cape. A recent proclamation confirmed the protected status of the species.

Over the past two years, great effort is being invested in the implementation of permit systems and training of the harvesters in the Northern Cape Province and the NW-Province (POWELL 2002, VAN DER VYVER 2002). Northern Cape and North West Province issue regulatory permits ensuring control over harvesting activities of *Harpagophytum*.

Until recently, in South Africa, the official harvesting season was in the rainy season, from November to May. Now, a new proclamation published in September 2003 in the Northern Cape Province excluded these months explicitly from the harvesting season, and no extraction permits will be issued for that period (GOVERNMENT GAZETTE 2003).

In the same proclamation a comprehensive legislative basis for procedures of permit applications and harvesting for *Harpagophytum* is set for the Northern Cape Province (GOVERNMENT GAZETTE 2003).

General conditions are that no harvesting is allowed in protected areas or nature reserves. For harvesters, a consent (memorandum of understanding) is needed from the landowner to harvest on his/her land. The permits and all relevant documents have to be present at all times and expired permits must be returned to the permit sections (POWELL 2002). Permit holders and landowners agree between themselves who does the monitoring for the duration of the permit and who thereafter. Monitoring results must accompany new permit application.

In the Northern Cape Province, additional strict guidelines for the harvesting techniques are implemented (GOVERNMENT GAZETTE 2003): Harvesting techniques must follow a four-year rotational system and only secondary tubers are allowed to be extracted. After harvesting the plants must be watered at least once and all visible seeds must be planted in the surrounding area. Also for scientific research on the plant a comprehensive permit proposal is necessary that includes a Resource Assessment and Management Report next to a permit application form that comprises a detailed description of the project and the research localities, the number of plants intended to be harvested, a field condition assessment, and a description of possible effects of harvesting on the environment and affected parties.

In the North West Province additional regulatory approaches were made concerning the sustainable harvesting of *Harpagophytum* as well as the trade (see Chapter on harvesting). These include a training of harvesters prior to the issuing of an extraction permit called harvesters ID in the province. In the case of misconduct various levels of warnings are implemented which start with a first warning of the harvester and end with the taking of the harvesters ID (VAN DER VYVER 2002). Regarding law enforcement, material harvested without permit has been confiscated in the past. However, the approach rather aims at a trustworthy relationship between harvesters and permit office.

Other permit applications (such as for research) are evaluated by the scientific section of the Directorate of Conservation and Environment and reviewed by the permit section before issuing.

As with all commodities a Phytosanitary certificate is required along with all other necessary documents for the export of *Harpagophytum* from South Africa.

15.4 Botswana

Harpagophytum procumbens is protected in Botswana under the Agricultural Resources Conservation Act (Cap. 35:06) of 1977 - Agricultural Resources (Grapple Plant) Regulations (Cap.35:06 Sub. Leg.) (Regulation 3 (1)). The current legislation is under review to encompass the latest developments in natural resource management (BEN 2002).

Permits to harvest are issued by the Agricultural Resources Board. They are valid for three months only in order to limit harvesting season and exploitation, respectively. The extraction permits are supposed to be issued after assessment of the resource by the Range Ecology Unit of the Ministry of Agriculture. However, this is reportedly not adhered to in practice. The CITES Management Authority in Botswana is the National Conservation Strategy (Co-ordinating) Agency.

Of potential interest to those considering the best method of *Harpagophytum* resource management, is Botswana's policy of giving harvesting permits to actual harvesters of the tubers. This policy claims to ensure the purchase of all tubers of *Harpagophytum* harvested under agreed permits and according to the predetermined annual quantities. These quantities follow the assessment of the resource and are defined down to district level. According to its policy, the non-government organisation Thusano Lefatsheng is committed to the sustainability of harvesting activities, and will in this context advise communities involved. These include the monitoring and evaluation of methods to determine population levels, the determination of appropriate harvesting techniques, the training and supervising of permit holding harvesters in harvesting techniques and in optimising harvesting quality.

A permit for the transfer of harvested *Harpagophytum* material from one owner to the next is required as well as an export permit. A Phytosanitary Certificate is required with the export of all *Harpagophytum* from Botswana.

A penalty for illegal or unlawful activities is also established.

15.5 Conclusions and Summary on the legislaton in *Harpagophytum*

Harpagophytum is protected in all three range states. Utilisation of the plant is possible in non-protected areas when the relevant permits have been issued and consent with the landowners is ensured. Approaches to sustainability by the stipulation of specific harvesting seasons are recently coherent in the range countries. Harvesting is only allowed in the dry season when the plant is dormant.

Recently, all three states have implemented approaches to monitor the exploitation of the resource to gain a better control of potential threats to the species by over-exploitation in specific areas. Strict conditions for the issuing of permits for harvesters as well as researchers (including companies who wish to cultivate the plant) are being implemented.

Potential future legislative measures for *Harpagophytum* were discussed in Chapter 14.6 which deals with the effects of trade in *Harpagophytum*.

16 Final discussion and conclusions

This study analysed the direct influence of human utilisation on the medicinal and endemic southern African plant species, *Harpagophytum procumbens* (referred to as *Harpagophytum* in the text).

In the following, conclusions are derived from the analyses of the resource availability, the current extent of harvesting, the socio-economy and trade in *Harpagophytum* for two of the three major range countries, Namibia and South Africa.

16.1 Spatial occurrence of *Harpagophytum*

Results of the study indicate that the medicinal plant *Harpagophytum procumbens* is not evenly distributed over southern Africa but concentrates on specific habitat types (predominantly plains), vegetation types (predominantly open savannas) and soil types (predominantly sand substrates). An increase in the abundance of *Harpagophytum* is positively related to rainfall amounts and land use intensity, in particular to the grazing pressure (see discussion of field study results in Chapter 11).

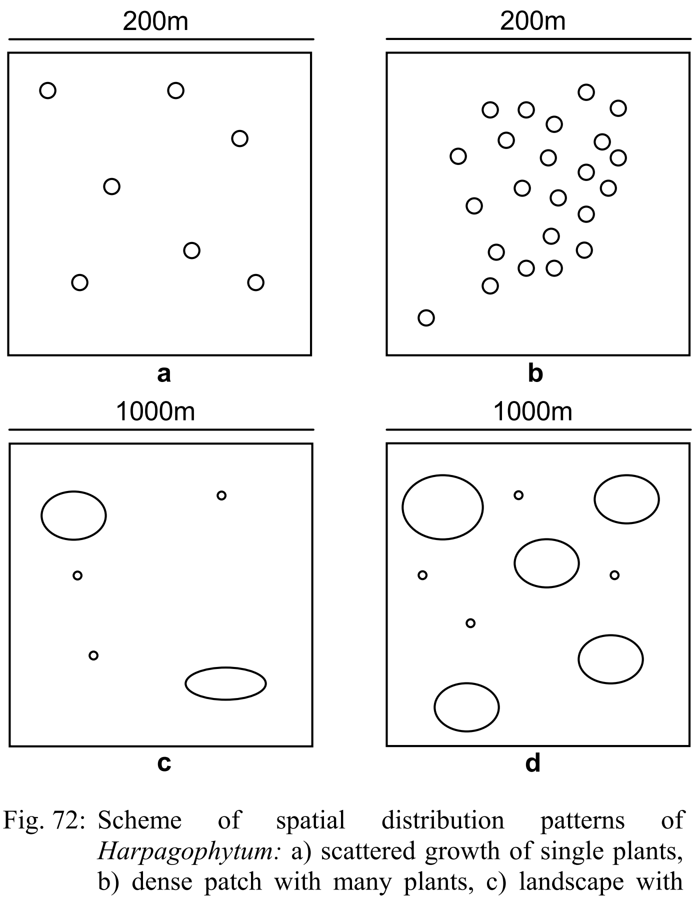


Fig. 72: Scheme of spatial distribution patterns of *Harpagophytum:* a) scattered growth of single plants, b) dense patch with many plants, c) landscape with two patches and single plants, d) landscape with many patches and single plants of *Harpagophytum*.

Distinct spatial patterns of *Harpagophytum* are evident on a small scale as well as on the landscape level (Fig. 72):

- *Harpagophytum* occurs typically as single individuals that grow scattered in the landscape (Fig. 72a).
- Dense aggregations, called patches, may develop in particular in areas with a high overall density of the species (Fig. 72b). Patches have an extension of few to several hundred metres.
- On private farmland, a scattered pattern of *Harpagophytum* prevails on the landscape level that is only occasionally accompanied by single patches (Fig. 72c).
- On communal land, in many areas patches of *Harpagophytum* are more frequent in the landscape (Fig. 72d).

16.2 Impact of non-sustainable harvesting on populations of *Harpagophytum*

Unsustainable harvesting practises can be considered as one of the greatest threats to medicinal plants in general (e.g. SHELDON, BALICK & LAIRD 1997). Study results indicate that regeneration in *Harpagophytum*, of single individuals or of populations, may require a very long time. The impact of harvesting on the ecology of *Harpagophytum* can be summarised with the scheme below (Fig. 73) that is in the following discussed for high and low resource areas separately:

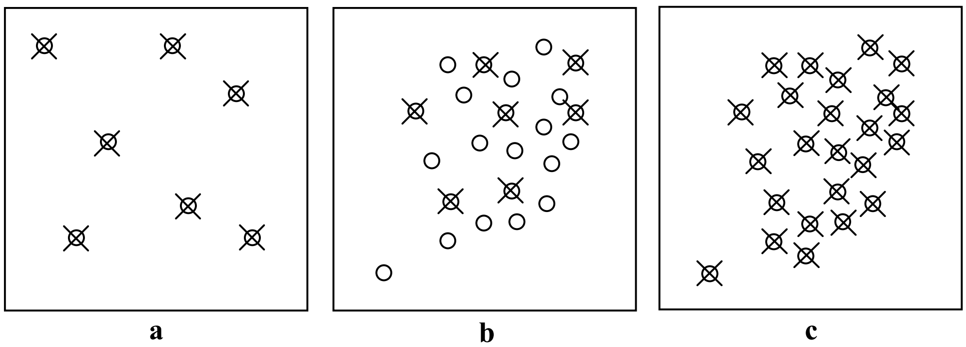


Fig. 73: Scheme of the impact of non-sustainable harvesting on spatial patterns of *Harpagophytum*: a) over-harvesting in a scattered occurrence of *H.*, b) conversion of a patch into a scattered occurrence through harvesting, c) destruction of a patch through over-harvesting.

16.2.1 Non-sustainable harvesting in high resource areas

In the case that in a high resource area the majority of plants were removed by unsustainable harvesting, the following was observed: Formerly dense populations of *Harpagophytum* had been completely destroyed by over-harvesting (Fig. 73c). The severely over-harvested areas did not recover over a period of several years or decades. No regeneration took place and no individuals of *Harpagophytum* occur in these areas today. Reasons are seen in the fact that for the re-establishment of a population in formerly abundant areas, a viable seed bank is needed or transport of seeds from neighbouring areas into the former patch areas has to take place.

In the case that in a patch only a limited number of plants is harvested, the patch will continue to exist (Fig. 73b). Yet, if a certain threshold in the number of harvested plants is surpassed, the patch will be converted into a scattered occurrence. It was frequently observed in Namibian communal harvesting areas that patches are not completely exploited but only a certain number of plants are uprooted.

It is not yet known and requires further research what the threshold value in the density of *Harpagophytum* is that can ensure a successful regeneration of a patch. Also, the time period needed for this is not yet understood. It is presumed that various factors will have an impact on this: (a) the extent and viability of the seed bank, (b) precipitation, (c) resource density in and transfer from neighbouring areas, (d) availability of dispersing vectors, that results in (e) a success of long distance transport of a number of seeds (fruits may function as trample burrs) to formerly over-harvested areas while parallel to that (f) other seeds are not successfully distributed, but remain and germinate close to the mother plants to build up a patchy population pattern. (g) Once germination occurs, inner- and inter-specific competition will play a major role for a successful establishment of individuals.

16.2.2 Non-sustainable harvesting in low resource areas

In the event that the incentive for harvesting *Harpagophytum* is so high that also scattered growing individuals are uprooted (Fig. 73a), the population is even more susceptible to local extinction. In a scattered distribution of the plant, already the uprooting of few plant individuals will result in the complete disappearance of the population. As reproduction rates showed to be correlated with plant densities, a considerably lower contribution of seeds to the soil seed bank will reduce the capacity to regenerate.

16.2.3 Impact of the harvesting season

The regeneration of single individuals after harvesting has not been investigated in the course of this study. While it can be expected that it will be driven by similar factors such as precipitation and land use intensity, additionally, the harvesting season will play an important role. While in Botswana and Namibia, the official harvesting season begins only after the flowering and fruit-set of *Harpagophytum* to allow the plant to reproduce, until recently in South Africa the rainy season was chosen as legal harvesting season. It was argued that the plants have a greater potential of regeneration during the vegetation period which could be essential for the recovery from the general disturbance by up-rooting and the removal of the secondary root tubers. However, in a recent proclamation of the Northern Cape Province of South Africa, harvesting within the rainy season is also prohibited and may only be conducted between June and October (GOVERNMENT GAZETTE 2003).

In order to evaluate whether *Harpagophytum* is threatened by over-harvesting in the long-term more scientific research should be carried out to understand the regeneration potential of the species, in particular in seed bank dynamics and germination. Once such understanding is brought forward, the sharing of results should not be limited to scientific publications, but for a successful and sustainable management it is indispensable to share and discuss results and upcoming management advices with the major stakeholders.

16.3 Incentives to get involved in the trade of *Harpagophytum*

In general, commercialisation of natural resources may be both necessary and potentially harmful to rural people as well as farmers. For the impact of commercialisation, the extent to which a stakeholder relies on the commercialised resource is important. The impact of harvesting on the development of wild *Harpagophytum* populations as well as the motivation of communal people and of commercial farmers to become involved in the commercial exploitation or the cultivation of *Harpagophytum* is similar in the three range countries. However, conditions to become involved in the commercial exploitation of *Harpagophytum* differ for both groups of people.

Private farmers

Interviews with private Namibian farmers indicate that

- A commercial exploitation is not viable when the resource is restricted to a scattered occurrence.
- The financial outcome of harvesting has to cover the investment to employ additional persons to harvest the plant and to slice and dry the tubers.
- Also, the loss of the harvested areas for other purposes of utilisation (such as grazing land) needs to be accounted for.

Nevertheless, many farmers expressed a general interest to become involved in harvesting. While it is generally expected that the interest in the harvesting of *Harpagophytum* on private farmland is highly dependant on the market situation (prices) and the density of the resource (the potential profit), rural harvesters react differently.

Rural harvesters

Rural harvesters are typically without any other source of cash income.

- They strongly rely on the harvesting of *Harpagophytum*.
- They usually do not have the choice to decide whether harvesting is profitable or not, but will harvest in order to secure their livelihoods.

In communal high resource areas (Fig. 72b) harvesting presents a good and viable option of income (when land tenure and access to the resource is ensured) while in low resource communal areas (Fig. 72a), a much greater effort would be needed to exploit *Harpagophytum*. The effort to be invested in harvesting is closely related to and has a negative impact on the sustainability of the harvesting techniques.

16.4 Spatial extent of harvesting

The estimation that for 1kg of dried tubers approximately between 4-6 plants (up to 25 plants) have to be harvested adds up to an amount of about 4,000,000-6,000,000 plants that are extracted for 1,000t of dried material (that are currently exported from Namibia per year). Based on the density pattern of *Harpagophytum* on Namibian communal land, this corresponds to an area of 94-141,000ha on which the plant is uprooted annually (see Chapter 14.6.1). Even in the case that all plants are harvested with sustainable methods and that environmental conditions of the following years are such that the plants are able to regenerate, these areas cannot be harvested in the following years. Instead, annually another 94-141,000ha would have to be exploited before new storage tubers have developed at the former harvesting site.

16.5 Impact of prices on wild harvesting and cultivation

Different price development scenarios may effect not only the involvement of different groups of people in the trade of *Harpagophytum,* but also the population status of the plant.

The supply of *Harpagophytum* secondary root tubers for the commercial market may be met by different groups of people and different ways of production:

- Rural harvesters exploit wild populations of *Harpagophytum*. They heavily rely on the cash income of the resource and produce the largest share of exported material today. An increasing number of harvesters is interested in taking up harvesting. Rural harvesters generally live in areas with the largest resource and patch density of *Harpagophytum (*Fig. 72b, d).
- Cultivation presents a new potential source of income in particular to commercial farmers. Cultivation is highly related to the possibility of gaining medium- to large-scale profit. It has already accomplished a small share on the market that can be expected to increase over the next years. Cultivation has not yet been successfully applied and distributed in communal areas. The reason lies in the fact that rural people being typically without explicit access to private land property, will not be able to implement large-scale cultivation.
- Commercial farmers are increasingly interested in additional possibilities for income generation such as the exploitation of wild populations of *Harpagophytum*. However, the majority has not yet marketed any raw material. It is expected that commercial farmer will only harvest, if trade yields enough profit. As the resource on private farmland is typically limited (Fig. 72a, c) the incentive has to be high.

Currently, approximately at total of almost 1,200 tons of dried tubers are exported from Namibia, Botswana and South Africa of which six tons have been produced by cultivation.

Interviews with German importers (which make up the greatest share of importers of *Harpagophytum*) indicate that the demand in the secondary root tubers of *Harpagophytum* will not continue to rise as strongly as it did in the past. The increasing efforts into cultivation, the initiatives of private farmers and the increasing number of harvesters, will rise the number and range of suppliers that will enter the market and that will impact the price development for raw material of *Harpagophytum*.

16.5.1 Decreasing market prices

If prices decrease on the market this will have the following impacts for the involved groups of people and the population status of the plant:

- Rural harvesters will continue to harvest as they depend on the cash income. Lower prices may result in an increased over-exploitation of the resource (Fig. 73a, c) to level out the loss in income. Only few harvesters (employed by middlemen to harvest) stated that they would restrain from harvesting if prices were too low to cover investments and labour input.

- Cultivation will only continue if methods have been successfully implemented and no further financial investments are involved. Cultivation will only continue as long as expenditure (for employees, water, land) is considerably lower than the calculated profit. It is assumed that no new farmers will get involved in cultivation.
- Commercial farmers will not get involved in harvesting.

Thus, it is unlikely in the case of decreasing prices that rural harvesters will be marginalised by competition with a supply of cultivated raw material. However, their income will nevertheless decrease parallel to the price development while effort in the harvesting stays the same (or might even increase when the resource is getting scarce). The population status of *Harpagophytum* will continue to be affects in the communal areas but not on private farmland.

16.5.2 Increasing market prices

If prices increase on the market this will have the following impacts for the involved groups of people and the population status of the plant:

- Rural harvesters will continue harvesting.

  More rural people will become interested in harvesting, which will increase the pressure on the resource. This will have a negative impact on the sustainability (even in the case that sustainable harvesting techniques are applied). As a result, patches of *Harpagophytum* are converted to patterns of single individuals or populations may even disappear completely (Fig. 73b or Fig. 73c). It is presumed that questions of land tenure and access to the resource will gain more importance. Irrespective of higher market prices it is unsure whether harvesters will receive more money. As they are generally not informed about the value of their product they have to rely on the prices offered by the buyers.
- Cultivation will expand. More farmers will become interested to cultivate *Harpagophytum* on their land.
- Commercial farmers will increasingly start with the exploitation of *Harpagophytum* on their land, when the monetary yield is higher than expenditures for additional financial effort.

  While it is expected that on farms with only a scattered occurrence of *Harpagophytum* (Fig. 72c), this will not be the case, in high resource areas the commercial harvesting of *Harpagophytum* will be profitable (Fig. 72b, 66d). As a result similar threats to the plant populations will come up as observed in the communal areas. It is, however, expected that with the exception of a high demand in short-term profit, private farmers also have other sources of income and thus can more easily afford to manage their resource on a sustainable basis (if they know how to do so). As generally less patches occur on private farmland (Fig. 72c), it is more likely that these are converted to a scattered pattern by harvesting.

Concluding, rural harvesters may face competition with other suppliers of raw material in the case of increasing prices for raw material on the market. As a consequence, their share of the market may decrease while they additionally may not benefit from the higher prices due to their lack of knowledge on the resource value.

In general, higher prices will lead to an increasing exploitation of the resource with an expansion of the harvesting areas not only in communal areas but also on private farmland. This will have an impact on the currently still "conserved" resources of *Harpagophytum* on private farmland. Issues of sustainability such as harvesting techniques, post harvesting assessments and harvesting quotas will gain increasing importance.

16.6 Different incentives to sustainability

It can be postulated that higher product values may not be equally shared among all stakeholders involved in the collection, processing, manufacturing, trade and marketing of Non-Wood Forest Products (WALTER 2002). Also in *Harpagophytum*, it is expected that with an increase in the value of *Harpagophytum* and even if rural harvesters supply a constant share of the market, they will not benefit to the same extent as other stakeholders.

Certification

One solution offers the certification of the gathering process of raw material. This approach has been followed up by one NGO in Namibia, CRIAA SA-DC, who successfully implemented organic certification for material harvested in specific harvesting areas in the communal Omaheke area of Namibia. By this, higher prices were achieved for the harvesters (LOMBARD 2002, COLE 2003).

Benefit sharing agreements

Additional solutions that could complement certification and link directly to the main objective of the CBD are benefit-sharing arrangements. These include "all forms of compensation for the utilisation of genetic resources whether monetary or non-monetary, in particular the participation in scientific research and development on genetic resources and the making available of the findings of such scientific research and development and the transfer of technologies" (SWISS STATE SECRETARY FOR ECONOMIC AFFAIRS 1999).

With regard to *Harpagophytum* it has been argued that benefit sharing does not take place in a sufficient manner among the harvesters in the range countries, neither monetary nor non-monetary. In particular, the licensing of extraction patents to European companies accounted for this.

CITES

While the proposal for a CITES Appendix II listing was also considered by some stakeholders to restrain benefit sharing, it nevertheless also pushed research activities and research funding in the region to a considerable extent. A listing of *Harpagophytum* on CITES Appendix III could be a future option for the source countries to retain national control of exports of raw material and sustainability.

16.7 Namibia

16.7.1 Population and utilisation status of *Harpagophytum*

Namibia has the highest exports of *Harpagophytum*. The fact that exports exceeded 1,000 tons in the year 2002 raised once more the concern of an over-exploitation of the species. Already since 1996, when export quantities reached the annual mark of 600 tons, increasing attention was driven to that issue. As the major share of root tubers is extracted from the wild and not from cultivation, export quantities are closely related to harvesting quantities.

Results of this study indicate the following:

- Harvesting focuses on the communal areas of Namibia, in particular on the Otjozondjupa Region and the Omaheke Region north east of the capital Windhoek.
- Parallel to the increase in export and harvesting quantities, also an increase in the area affected by harvesting is observed.
- While traditionally only in limited areas of the Otjozondjupa Region and the Omaheke Region indigenous groups of people harvested and utilised the plant, now an increasing awareness of the commercial potential of *Harpagophytum* led to a larger portion of land to be impacted by harvesting.
- Not only more people but also a greater range of ethnic groups is recently becoming involved in the exploitation of wild *Harpagophytum* populations in Namibia, most of them being marginalised and trying to meet their livelihood with the extraction of the root tubers.
- Corresponding to the involvement of more ethnic groups in the exploitation is a proportional decrease in the traditional knowledge on the ecology of the resource.
- The lack of traditional knowledge resulted in changes of the applied harvesting techniques. While traditionally, the San people who were the users of *Harpagophytum* for centuries, applied sustainable harvesting techniques, with the commercial exploitation increasingly techniques are applied that make a quicker and higher yield extraction possible. In many cases, such techniques are not sustainable and may endanger the regeneration of single individuals and populations of *Harpagophytum*.

Already in the 1970s, when harvesting was still locally limited to areas in the mid of the country near the town Rehoboth, sustainable harvesting techniques were not applied. Monitoring results of this study led to the conclusion of a formerly very intensive utilisation in that area and indicate that no regeneration of the natural occurrence of *Harpagophytum* has taken place since then.

For Namibia, it can be postulated that the high export quantities, the partly high harvesting intensity, the increasing number of harvesters and ethnic groups involved in the harvesting, and the loss of the traditional knowledge on the ecology of the plant paired with a frequent application of non-sustainable harvesting techniques increase the pressure on the wild resource of *Harpagophytum*.

Namibian communal areas

Yet, results of the study also indicate that not only the highest intensity of harvesting, but also the greatest resource potential is evident for Namibia in comparison to the other range countries Botswana and South

Africa. This is in particular true for the communal areas of Namibia where harvesting is most prominent and where patches of *Harpagophytum* occur most frequently in the landscape (Fig. 54d).

The reason for the high resource potential in the communal areas can be seen in

(a) natural habitat conditions of the area with

- increasing temporal and spatial rainfall reliability in the communal areas located towards the north east of the country,
- widely distributed sandy substrates (Kalahari soils) and a stronger rarity of rocky soils
- high frequency of vast plains, and

(b) the human impact on the environment in the area with

- comparatively large livestock numbers with
- high grazing intensities.

In general, the greater portion of Namibians lives in communal areas in comparison to private farmland. Parallel to that higher livestock numbers (cattle, sheep, goats) are evident in communal areas while different grazing systems are applied than on private farmland. Both can be considered to be responsible for the greater impact of grazing on the vegetation. Results indicate that high grazing intensities and subsequent to that a lower annual vegetation cover, in particular of grasses, is prominent in the sampled areas of communal land. The occurrence of *Harpagophytum* showed to be correlated to the low grass cover and high grazing pressure on the surrounding vegetation.

Namibian private farmland

While in the Namibian communal areas dense patches of *Harpagophytum* are more frequent, in other areas of the country, in particular on private farmland, more often a scattered occurrence of single individuals or a combination of single individuals and single patches is typical (Fig. 72c). The resource of *Harpagophytum* on private farmland, even if it is only scattered, can be regarded as natural resource pool of the species.

The reason for the lower natural resource potential on private farmland can be seen in

(a) natural habitat conditions of the area

- lower rainfall quantities in the main commercial farming areas towards the south and south west of the country,
- higher variability of soil types and substrates (less sandy substrates),
- higher variability of habitat types, and

(b) the human impact on the environment in the area with

- lower population density per area,
- clear ownership of land, and
- a generally lower impact of livestock on the vegetation.

The fact that on private farmland rotational grazing systems on fenced-in camps of a limited size and with regeneration phases between the grazing periods are more often established in comparison to the communal areas can be seen as one reason for the less obvious overgrazing on most of the sampled private farmland. Also, it can be expected that due to the fact that on privately owned farms less people have to meet their livelihood by livestock farming than on a comparable area on communal land, the pressure on the land is considerably lower. Clear ownership of the utilised land paired with generally higher education levels contribute to this. As a consequence a lower impact of grazing on the vegetation was found that is interpreted as on major reason for lower *Harpagophytum* densities of private farmland.

16.7.2 Regeneration potential

High harvesting intensities in some communal areas bring about the issue of sustainability and of regeneration. Both are closely correlated: Only with the application of sustainable harvesting techniques, a regeneration of the resource is possible.

The re-documentation of several sites for which old quantitative data on *Harpagophytum* was available indicate that regeneration after non-sustainable harvesting is difficult. Once the pattern of dense aggregations on the landscape level (Fig. 72d) is destroyed, a regeneration to more than a scattered occurrence of the species is hardly possible (Fig. 72a). The reproductive potential of single individuals even together with a long-living seed bank of *Harpagophytum* does not seem to suffice to rebuild the former population patterns.

Another ongoing study supported by the BfN focuses on the regeneration of *Harpagophytum* after the application of sustainable harvesting techniques on selected communal resettlement farms in the Omaheke Region of Namibia. Preliminary results of this co-operative project with the non-governmental organisation CRIAA SA-DC showed that regeneration does take place but is highly depend on rainfall amounts (STROHBACH 2001).

16.7.3 Conclusions on the resource status in Namibia

For Namibia, the following can be concluded:

- *Harpagophytum* is currently not in general threatened in Namibia.
- Yet, the resource has locally suffered a strong decrease due to over-harvesting. This is particularly true for areas with a high resource density (in the form of a high patch frequency), where at the same time the majority of harvesters substantially rely on the exploitation of the resource.
- As consequence of local resource reduction in the over-harvested areas, harvesters will have to overcome greater distances to reach new potential harvesting areas.
- An increasing competition over remaining high resource areas can be expected that is triggered by the increasing number of harvesters and the specific population pattern of *Harpagophytum*. The reason will lie in the fact that a dense occurrence of the resource requires a considerably lower harvesting effort than low resource areas where *Harpagophytum* individuals only grow with large distances between each other.

For Namibia, the scattered occurrence of *Harpagophytum* predominantly on private farmland but also in parts of the communal areas can be considered as natural resource depot that will avoid a general extinction of the species even in the case of severely increasing harvesting pressures. Yet, it can be expected that once the patchy pattern on the landscape level is destroyed in a specific area through unsustainable utilisation of the resource, regeneration even in the long-term will be difficult to not possible. Such failure in regeneration would have a severe impact on the livelihood of the harvesters as the monetary outcome from harvesting is already comparable low to the time effort invested even in the harvesting of even dense patches of *Harpagophytum*. It can be expected that harvesting will not be a viable option to meet the livelihood of rural people, if in future only medium to low resource areas were available. Also, it has to be expected that a degeneration of the resource will strongly impact the sustainability of applied harvesting techniques.

16.7.4 Recommendations for Namibia

Due to the fact that in Namibia a greater extent of and a longer tradition in harvesting as well as in the research on *Harpagophytum* exists, recommendations that can be made for the two range countries Namibia and South Africa correspond only in parts.

For Namibia, the following recommendations can be made:

(a) Harvesting issues

- The establishment of self-organised harvester communities should be encouraged that operate on a local basis instead of harvesters brought together by middleman to harvest in distant areas.
- Harvesting quotas should be implemented countrywide. Based on simple annual resource estimations in the field they could initiate sustainable communal resource management.
- The distribution on the knowledge of sustainable harvesting techniques should be improved in the communal areas. Also commercial farmer should be informed about appropriate harvesting techniques prior to the taking up of commercial harvesting.
- Awareness of the harvesters on the ecology of *Harpagophytum* should improve, in particular on the necessary regeneration phases of the plant in the annual cycle (to ensure successful reproduction) as well as between the years (time needed for recovery from harvesting and production of new secondary storage tubers).
- Post-harvesting assessments should be more widely implemented. More harvester communities should be involved to improve the understanding of harvesting impacts on the resource potential of their area.
- Land tenure issues should be clarified in particular in open and semi-open access systems of communal areas to avoid problems and competition over the resource with harvesters entering from outside. A clear "ownership" of the resource could strengthen the responsibility of individual harvesters or harvester communities in the communal areas.

(b) Market and trade issues

- Knowledge of quality standards (with regard to adulterations, dryness, cleanness, investment with fungi) and its control in the harvester communities could improve prices paid to the harvesters.

- A greater awareness of the value of the harvested tubers could strengthen the basis of the harvesters for price negotiations with the buyers.
- Fair prices paid to the harvesters could take pressure from the wild resources of *Harpagophytum.*

(c) Value adding

- Small-scale cultivation projects implemented on the communal level could improve sustainable utilisation of the wild resource. They could level out fluctuation in the harvesting quantities that are due to precipitation variations and thus ensure a more continuous income level to the harvesters.
- More certifications projects could impact positively on a sustainable utilisation of *Harpagophytum* through better prices paid to the harvesters. Long-term partnerships between harvester communities, buyers and manufacturers could benefit from this.

(d) Issues related to legislation

- Recording of quantities entering the country from Angola (*Harpagophytum zeyheri*) could avoid that such material is dealt with as Namibian material and adulterates Namibian exports and subsequently concerns of over-exploitation in the country.
- Although difficult, exporters should be encouraged to keep different record for either species of *Harpagophytum* to enable a differentiated estimation of the harvesting pressure on each species.
- Also the harvester permits should include a geographical restriction so that a differentiation between collecting quantities of both species is possible.
- In the case of increasing export numbers, one conservation measure would be to list both species of *Harpagophytum* on CITES Appendix III. In the case of constraints from Namibian stakeholders against such listing, an additional impact study (next to the interviews with German importers conducted in this study) with the main importers from overseas could clarify if potential negative impacts of a listing really exist.

(e) Research needs

- More scientific research on the regeneration and sexual reproduction of *Harpagophytum* is needed that should not serve pure scientific needs but should be passed on also to the major stakeholders, in particular the harvesters.
- More research on the impact of rainfall and other environmental impacts on *Harpagophytum* is needed. Focus areas should be the areas with the greatest impact of harvesting.

16.8 South Africa

16.8.1 Population and utilisation status of *Harpagophytum*

In South Africa, exports of raw material of *Harpagophytum* that is not imported and re-exported from the other source countries Namibia or Botswana but harvested within South Africa are still very limited. Just recently exports pick up and have reached 90 tons in the year 2002.

The reason for the lower export quantities are seen in the lack of a long-term tradition in the utilisation of the medicinal plant. Only since a few years, South Africa is involved in the commercial exploitation of *Harpagophytum*.

Subsequent to the up-to-date limited exploitation, results of this study indicate the following:

- The overall resource potential of *Harpagophytum* is considerably lower in South Africa than in Namibia. The species is not only distributed in a smaller area of the country, also the density patterns less often comprise a high frequency of patches of *Harpagophytum* in the landscape (Fig. 72c). Other habitat conditions, in particular a different climate (precipitation patterns) and different vegetation compositions are considered to be responsible for the general lower resource potential of *Harpagophytum* in South Africa.
- Largest occurrence of *Harpagophytum* is evident for the Kalahari Plains Thorn Bushveld in the North West Province.
- Similar to Namibia, the spatial growth patterns are denser in the communal areas than on private farmland.
- Also on South African private farmland predominantly a scattered occurrence of single individuals with only single patches is evident on the landscape level (Fig. 72c). The fact that this was observed for both countries separately underlines the impact of land ownership and land use on the occurrence of *Harpagophytum*.
- Harvesting is only evident in small parts of the South African distribution area of the species.
- The extent of harvesting is much lower than in Namibia and concentrates on the communal areas of the former Bophutotswana homeland, today the North West Province. Yet, lately more people are also seeking in South Africa for additional income generating possibilities from the harvesting of wild *Harpagophytum*.
- Corresponding to the lacking tradition in the exploitation of the resource, most of the ethnic groups and people currently involved in the harvesting do not have a traditional knowledge on the ecology of the plant. The fact that harvesting techniques are only newly introduced, may have both, a positive effect in the case that from the beginning sustainable extraction methods are learned and applied, or negative effects if this fails.

From the fact that VON WILLERT et al. (2002) and RAIMONDO et al. (2003) state a considerable lower dry yield of secondary tubers per plant in comparison to Namibia, it is concluded that more plants have to be harvested and a greater area is to be affected by harvesting to meet existing harvesting quantities in comparison to Namibia.

16.8.2 Regeneration potential

It was found that *Harpagophytum* shows a lower reproductive activity in South Africa in comparison to Namibia. A lower percentage of fruit set and consequently a lower contribution of seeds to the soil seed bank reflect this. This is in particular evident on private farmland. Together with the lower yields, this results in a comparatively stronger pressure on the existing wild resource.

16.8.3 Conclusions for South Africa

For South Africa the following can be concluded:

- The impact of harvesting on the wild resource of *Harpagophytum* is less strong and has lasted over a shorter period of time in South Africa in comparison to Namibia.
- Resource availability is more limited with a lower yield and a lower regeneration potential through reproduction.
- Therefore, it can be expected that commercial exploitation of the secondary tubers will also have a long-term impact on the wild populations while at the same time a comparably larger area is affected.

Although so far limited, the increase in exports and in the harvesting intensity, the increasing interest of harvesters and ethnic groups to get involved in the harvesting, and the lack of traditional knowledge on the sustainable utilisation and ecology of *Harpagophytum* sets a pressure on the wild resource of *Harpagophytum* also in South Africa.

16.8.4 Recommendations for South Africa

As less research has been conducted on the ecology of and harvesting impacts on *Harpagophytum* in South Africa, recommendations contain more of these topics and differ partly from those made for Namibia.

The following recommendations can be made for South Africa:

(a) Harvesting issues

- Harvesting quotas should be implemented that are based on simple annual resource estimations in the field. These could initiate communal sustainable resource management.
- The training of harvesters on the application of sustainable harvesting techniques should be continued.
- The self-organisation of harvesters should be strengthened including their awareness of the ecology of the plant, in particular on the necessary regeneration phases of the plant in the annual cycle (to ensure successful reproduction) as well as between the years (to recover from harvesting and produce new secondary storage tubers).
- Post harvesting assessments should be conducted in more areas. The harvesters should do the assessments and not the extension officers to increase the awareness of harvesting impacts.

(b) Market and trade issues

- Knowledge of quality standards (with regard to adulterations, dryness, cleanness, investment with fungi) and its control in the harvester communities could improve prices paid to the harvesters.
- More than one buyer should be on the market to avoid price control and encourage competition between buyers to the favour of the harvesters.
- A greater awareness of the value of the harvested tubers would strengthen the basis for price negotiations of the harvesters.
- Fair prices paid to the harvesters could take pressure from the wild resources of *Harpagophytum.*

(c) Value adding

- Certifications could also in South Africa impact positively on sustainable utilisation of *Harpagophytum*. Long-term partnerships between harvester communities, buyers and manufacturers could benefit this.

(d) Issues related to legislation

- Recording of harvested material should be improved as not all harvested material is currently recorded.
- In the case that no national means of export recording is being implemented, provinces need to improve export monitoring. Important is also the data exchange between the provinces to detect up-coming trends in exports.
- In the case of increasing export numbers, one conservation measure would be to list both species of *Harpagophytum* on CITES Appendix III.

(e) Research needs

- Monitor potential resource utilisation of *Harpagophytum* in the Northern Cape Province in the case that harvesting picks up in the communal areas of this province (e.g. the Mier area).
- Assess occurrence of *Harpagophytum* also in the Limpopo Province to be able to evaluate impacts of potential future increases in harvesting.
- Scientific research is urgently needed on the long-term impact of harvesting on *Harpagophytum* also for South Africa.
- Research is also needed on the impact of different harvesting techniques on the survival and regeneration of *Harpagophytum*. Due to different environmental conditions, it cannot be expected that results for Namibia are easy applicable also to South Africa.

16.9 Conclusions or is *Harpagophytum* threatened?

SCHIPPMANN, LEAMANN & CUNNINGHAM (2003) used the seven forms of rarity described by RABINOWITZ (1981) to assess how different wild medicinal and aromatic plants may be affected by harvesting pressures. According to RABINOWITZ a species that has a narrow distribution, is strictly habitat specific and has a small population size everywhere, is most susceptible to be over-harvested. When this system is applied to the results found for *Harpagophytum*, the opposite conclusions have to be drawn: (i) *Harpagophytum* has a relatively wide distribution area and occurs widely spread over the semi-arid parts of southern Africa, (ii) *Harpagophytum* is only habitat specific in that it favours plain habitat types, which however are the most frequent habitat types of savanna ecosystems in the distribution area. Typical habitat types of *Harpagophytum* comprise plains, dune bases, interdunes, disturbed or undisturbed plains and may be of a various sandy substrate ranging from sandy to loamy soils. (iii) *Harpagophytum* does not have a small population size everywhere but may have both, large, dense populations in some areas and small, scattered populations in other areas. Following RABINOWITZ (1981) only little concern is necessary regarding the rarity of *Harpagophytum*.

The second important factor for the assessment of harvesting impacts on a wild species is its susceptibility or resilience to collection pressure (SCHIPPMANN, LEAMANN & CUNNINGHAM 2003). Certain plant characters such as the growth rate, reproductive system and life form together with the plant part that is commercially exploited may contribute to a low resilience of a species to over-collection. Although perennial (which would generally account for a lower susceptibility), *Harpagophytum* having a geophytic growth form is highly dependent on rainfall. This dependency has an impact on various biological plant characters and restricts (i) the annual shoot production and photosynthesis rate, (ii) the general growth rate also of the underground plant parts, (iii) sexual reproduction, and (iv) the germination rate that is furthermore restricted by morphological and chemical dormance structures in the seeds. From this and the fact that in *Harpagophytum* the plant parts of commercial value are secondary root tubers (and not annually produced plant parts such as fruits or leaves), it can be expected that the resilience of *Harpagophytum* towards over-harvesting is very limited.

Concluding, for *Harpagophytum* both criteria, the system of RABINOWITZ and that of susceptibility, contradict each other. While from the biological provisions and the plant parts used, attention should be given to the susceptibility of *Harpagophytum* to over-harvesting, from the geographical distribution pattern and the environmental requirements of the species, no severe and general threat can be formulated.

These theoretical considerations correspond well to the findings of this study in that they reflect that while locally to regionally some populations of the species have undergone a dramatic decrease due to over-harvesting, in various areas the resource is still evident with partly a high abundance. Thus, it can be concluded that *Harpagophytum* is not in general threatened by extinction. However, the recommendations and research needs formulated above could contribute to a better understanding and the establishment of a long-term sustainable resource management of the species.

17 Executive Summary

In this study, the southern African endemic plant species *Harpagophytum procumbens* (Pedaliaceae family) was used to analyse the influence of utilisation of biological resources on biodiversity. *Harpagophytum* is an internationally traded plant species that is marketed for its medicinal properties to treat ailments such as arthritis. Over the past decade, an increase in the market value of *Harpagophytum procumbens* has resulted in increasing export quantities of the species in the three major range countries Namibia, South Africa and Botswana. In 2003, over one thousand tons of dry material has been exported from the three range countries. Due to the fact that plant material is predominantly gathered from the wild and that medicinal properties are restricted to the secondary root tubers, issues of sustainability are closely linked to the commercialisation of *Harpagophytum procumbens*.

This study assessed the ecology and utilisation of *Harpagophytum procumbens.* Several aspects were investigated which range from the assessment of important ecological parameters, the analyses of the current extent and impact of harvesting on wild populations, the perception of landowners and harvesters on the biological status of *Harpagophytum procumbens* to the assessment of socio-economic aspects. Several field approaches complemented each other, i.e. next to a comprehensive mapping on the occurrence and ecological requirements of *Harpagophytum procumbens*, a countrywide interview with Namibian farmers and a monitoring of selected sites over a period of three years was carried out. Most of the study was conducted in two of the three range states, Namibia and South Africa.

Occurrence in Namibia and South Africa

In Namibia, the highest resource potential as well as the highest level of utilisation is evident in two major vegetation types of the country, that are the communal areas in the Tree Savanna and Woodland and the Camelthorn Savanna in the Otjozondjupa Region. *Harpagophytum procumbens* was also sampled in another four regions and five vegetation types, but except for the Thornbush Savanna where partly large quantities were found, the species occurs in these only with a limited density. In particular towards the more arid and western part of the distribution area bordering the Namib Desert, plant densities are limited. North of the 19th degree latitude, in the more humid parts of the country with over 400mm annual rainfall, the distribution of *Harpagophytum procumbens* partly shows introgressive populations with the other *Harpagophytum* species, *H. zeyheri,* and is finally completely substituted by the latter.

In South Africa, a generally lower resource density was evident in comparison to Namibia. The resource availability and utilisation intensity was highest in the communal areas of the Kalahari Plains Thorn Bushveld of the North West Province while in the Northern Cape Province the resource was typically limited (with exception of areas belonging also the Kalahari Plains Thorn Bushveld and which are located adjacent to the North West Province). The plant was also sampled in another five vegetation types in the two provinces, however, except for some eastern parts of the Shrubby Kalahari Dune Bushveld, plant densities in these were limited.

Population patterns

It is shown that the occurrence of *Harpagophytum procumbens* is typically patchy comprising single plant populations of various sizes and various distances in between. These range from (i) a very scattered occurrence of single individuals on the landscape level, with several hundred metres between each plant, over (ii) various combinations of such scattered population dispersions that are mixed with aggregations (of a varying density), to (iii) a prevalence of dense aggregations on the landscape level that are connected through the occurrence of single plant individuals. Patchy aggregations of *Harpagophytum procumbens* may have a size between few metres to few hundred metres. On the landscape level, these three growth patterns of the populations occur next to each other while the spatial extension of each may vary strongly. Estimates of an over-all resource of the species for a vegetation type, a region or even a country are therefore very difficult.

Ecology

Harpagophytum procumbens occurs not evenly distributed over southern Africa but concentrates on specific environments: The favourite habitats are open plains and interdune areas that are only little undulated and are inhabited by open vegetation types (predominantly open savannas). The soils are predominantly composed of sand substrates that may have a loamy component.

An increase in the abundance of *Harpagophytum procumbens* is positively related to rainfall amounts and land use intensity, in particular to the grazing pressure. Results show that the type of landownership reflects the grazing pressure and composition of the vegetation and has therefore a great impact on the occurrence and density of the species. The lack of competitiveness, the low germination rate that is scattered over a long period of time, and the difficulties in the establishment of seedlings lead to a generally low population renewal in the species. In combination with the strong grazing pressure evident in many parts of the high resource areas and with years of low rainfall, these ecological restraints form a fragile equilibrium in which *Harpagophytum procumbens* populations can survive. This study indicates that this equilibrium may be stable and populations of dense aggregations may persist, if rainfall does not stay below a minimum over a too long period of time and if no other detrimental influences are evident. Such an potentially detrimental influence is the harvesting of the secondary root tubers of the species.

Utilisation of *Harpagophytum*

Harvesting of the secondary storage tubers of *Harpagophytum procumbens* can be considered as the main threat to the species. Results indicate that harvesting concentrates on those areas where a high resource density is evident. In both countries, these are typically the communal areas.

Harvesting of the secondary root tubers of *Harpagophytum procumbens* has a great impact on the status and the composition of populations in the species. As typically only plants of a certain age indicated by a certain minimum size of the main tuber are uprooted to achieve a maximum yield of secondary tubers per plant, this results in long-term changes in the composition of the plant populations. Paired with the low germination rates and a low establishment of seedlings, the renewal of harvested populations is difficult. The severity of these natural conditions is linked to the harvesting intensity and applied harvesting techniques, the time allowed for the population to recover between the harvesting seasons and the inherent structure and vitality of the harvested population.

It could be shown that the impact of harvesting varies with respect to the small-scale spatial patterns of *Harpagophytum procumbens* and the intensity of their exploitation. While patches can recover more easily from harvesting (when not all plants are uprooted), in scattered populations the impact is more severe.

An utilisation of wild populations of *Harpagophytum procumbens* is generally evident for great parts of the study area. Especially on communal land, and up to date only limited on private farmland harvesting takes place. Harvesting techniques may be sustainable or detrimental. It was found that although great effort has recently been implemented to create awareness to apply sustainable harvesting techniques, in many areas non-sustainable harvesting has resulted in a decrease of the resource. A severe over-utilisation of the plant that paired with the application of detrimental exploitation resulted in changes in the population structure of *Harpagophytum procumbens* were however only found for some areas.

From this it is concluded that so far harvesting is not threatening the population status of *Harpagophytum procumbens* in general. Nevertheless, it is expected that the application of non-sustainable harvesting techniques and the still increasing export quantities may impact the population status of the species in the medium to long-term.

Cultivation

Due to the complex biology of the species, the cultivation of *Harpagophytum procumbens* is not easy. Cultivation is restricted to few commercial farms in Namibia and South Africa and contributes up to date only a very small share to the market. Approximately six tons of material derived from cultivation have been exported in 2003. However, it is expected that if cultivation expands and gains a greater share of the market while being limited to commercial farmers, it may severely impact the possibilities of income generation of communal harvesters.

Socio-economy and trade

Next to biological parameters also the socio-economy of the harvesters, the trade structures and the legislation have an impact on the sustainability of *Harpagophytum procumbens*. A sustainable utilisation of the species is closely related to the prices paid to the harvesters and the incentives created by this to manage the resources properly. The majority of the harvesters of *Harpagophytum* are from marginalised communities who live in remote areas where high resources of *Harpagophytum procumbens* occur. Very often the harvesting of the plant poses the only possibility of cash income to the harvesters.

Over the past years parallel to the increase in the market value and the exports, more harvesters who also come from a greater range of ethnic groups have become involved in the exploitation of the secondary tubers. This has the effect that (i) harvesters who only now learn about the commercial value of *Harpagophytum procumbens* do typically lack the traditional knowledge on the ecology of the species and are not familiar with sustainable harvesting techniques. (ii) Parallel to the increasing number of harvesters the competition over and the pressure on the resource increases and (iii) a larger portion of land is affected by harvesting per year.

As interviews with German importers indicate that the market for *Harpagophytum procumbens* may not expand considerably over the next years, and as it can be expected that increasingly also cultivated material will enter the market, the impact of this development needs to be further monitored with respect to the biological status and sustainability of *Harpagophytum procumbens*. Over the past years, issues regarding sustainability have become increasingly important such as the distribution of adequate harvesting techniques, harvesting quotas and post-harvesting assessments. Such recommendations are formulated at the end of this study for Namibia and South Africa separately. The recommendations also comprise possibilities of value adding such as certification and small-scale cultivation, legislation related issues such as record keeping and the possibility of additional conservation measures in both countries. Research needs that could complement the current knowledge on *Harpagophytum procumbens* are also listed.

18 Zusammenfassung

Mit rund 35.000 Taxa stellen Medizinalpflanzen den größten Anteil der weltweit durch den Menschen genutzten Pflanzenarten. 28% aller Pflanzenarten werden laut Weltgesundheitsorganisation (WHO) für medizinale Zwecke verwendet und machen so einen großen Prozentsatz der globalen pflanzlichen Biodiversität aus. Ein erheblicher Anteil an Wirkstoffen aus Medizinalpflanzen wird heutzutage noch aus Wildsammlungen gewonnen, da synthetische Herstellungen zu teuer bzw. für viele Bevölkerungsgruppen nicht zugänglich sind. Bei Pflanzen, die überwiegend außerhalb der Ursprungsländer gehandelt werden, kann die internationale Nachfrage zu einer unkontrollierten Ausbeutung und somit zu einer erheblichen Abnahme der Populationsgrößen und -dichten führen. Dies ist insbesondere gegeben, wenn nicht leicht nachwachsende Pflanzenteile, wie z.B. Wurzeln, die medizinisch wirksamen Bestandteile enthalten.

Ein Beispiel hierfür ist *Harpagophytum procumbens,* eine im südlichen Afrika endemisch vorkommende, traditionelle Medizinalpflanze der San und das Studienobjekt dieser Arbeit. Seitdem die Art seit ca. 1960 auf dem internationalen Markt gehandelt wird, ist ein Anstieg der Sammlung von Wildmaterial und eine starke Zunahme der Nachfrage insbesondere auf dem europäischen Markt zu verzeichnen. Heute werden Exportmengen von über 1.000t getrocknetem Rohmaterial pro Jahr erreicht, die v.a. aus Namibia, aber auch aus Botswana und Südafrika stammen. Der handelsbedingte Rückgang und die damit möglicherweise einhergehende Gefährdung der natürlichen Ressource führte 1999 gemeinsam mit dem generellen Wissensdefizit über die Ökologie und Verbreitung der Art zu diesem, vom Bundesamt für Naturschutz geförderten Forschungsprojekt.

Im Mittelpunkt der Studie stehen Fragen nach dem Status der Ressource, einem potentiellen Rückgang der natürlichen Populationen durch Wildsammlung und die Nachhaltigkeit der Nutzung. Hierzu wurden 96 Ein-Quadratkilometer große Untersuchungsflächen auf privatem und kommunalem Farmland in Namibia und Südafrika beprobt, Interviews mit Namibianischen Farmern und eine Wieder-Begutachtung von ehemaligen Aufsammlungsstellen durchgeführt, sowie eine Analyse der Sozioökonomie der Sammler, der Handelsstrukturen (unter besonderer Berücksichtigung der deutschen Importe) und der geltenden Gesetzgebungen in den drei Ursprungsländern durchgeführt. Folgende Fragen konnten mit dieser Arbeit beantwortet werden: (a) Wie ist das Vorkommen und der Ressourcenstatus von *Harpagophytum procumbens*? (b) In welchen räumlichen Mustern und Dichten tritt *Harpagophytum procumbens* auf? (c) In welchen Gebieten liegen die Schwerpunkte der Nutzung, und (d) lassen sich Unterschiede in der Nutzung der Wildbestände zwischen Gebieten mit kommunalem und privatem Landbesitz feststellen? (e) Welche Sammelmethoden können eine nachhaltige Nutzung der Ressource sicherstellen? (f) Wie ist die Struktur der Handelsketten sowie die Höhe und Tendenzen der Ein- und Ausfuhrmengen?

Der Einfluss der Ernte auf die Wildpopulationen schwankt in Abhängigkeit von der Erntemethode und -intensität, der Ethnie und dem Wissen der Sammler, sowie der Nachfrage und der Ressourcenverfügbarkeit. Für die Ernte werden die sekundären Speicherknollen von *Harpagophytum procumbens* ausgegraben, in dünne Scheiben geschnitten und getrocknet. Das so getrocknete Rohmaterial wird über Zwischenhändler an Exporteure verkauft. Für die Sammler von *Harpagophytum procumbens*, die verschiedenen Ethnien angehören und zumeist in abgelegenen Gegenden mit kommunalem Landbesitz leben, stellt das Sammeln der Wildbestände häufig die einzige Einkommensquelle dar. Dabei beschränkt sich die Möglichkeit des Verdienstes auf die Regenzeit, da die geophytischen Pflanzen nur dann durch ihre grünen, am Boden kriechenden Triebe erkennbar sind.

Die größte Ressource von *Harpagophytum procumbens* wurde für Namibia nachgewiesen. Dabei ist die Verteilung der Ressource innerhalb des Verbreitungsgebietes keineswegs homogen, sondern variiert in den verschiedenen Vegetationstypen in Abhängigkeit vom Niederschlagsregime, den Habitat- und Bodenverhältnissen sowie der Nutzung. In beiden Ländern liegt der größte Anteil der Ressource in ein bis zwei Vegetationstypen der Kommunalgebiete.

Die Wildsammlungen von *Harpagophytum procumbens* konzentrieren sich auf die Gebiete mit der größten Ressourcenverfügbarkeit, wobei für Namibia eine deutlich stärke Sammelaktivität als für Südafrika nachgewiesen wurde. Wie der Vergleich der Individuenzahlen auf 100*2m langen Transekten innerhalb einer Untersuchungsfläche von je einem Quadratkilometer gezeigt hat, ist eine große Ressourcen-verfügbarkeit immer auch auf einen hohen Anteil an aggregiert auftretenden Individuen zurückzuführen. Solch aggregiertes Vorkommen von *Harpagophytum procumbens* tritt dabei lokal auf und erstreckt sich nicht über die gesamte Untersuchungsfläche des Quadratkilometers.

Die stärkste Sammelaktivität existiert in den Kommunalgebieten Namibias, wo auch die Mehrheit der Sammler lokalisiert ist. Auch auf privatem Farmland Namibias findet eine stellenweise starke Ernteaktivität statt. In Südafrika ist der Nutzungsdruck bisher deutlich geringer, auch dort wird insbesondere in den Kommunalgebieten geerntet. Auf privatem Farmland Südafrikas wurden nur sehr vereinzelt Hinweise auf Ernteaktivitäten gefunden. Auffällig ist, dass es in allen Untersuchungsregionen Gebiete gibt, für die entweder keine Nutzung oder eine sehr starke Nutzung nachgewiesen werden konnte.

Es konnte anhand von Dauerbeobachtungen gezeigt werden, dass die Regeneration von beernteten Populationen von *Harpagophytum procumbens* in der Regel schwierig ist. Insbesondere, wenn ein bestimmter Schwellenwert-Anteil einer Population durch Sammeln entfernt wurde, kann erwartet werden, dass eine generative Regeneration durch Samenkeimung zunehmend erschwert wird. Es hängt von verschiedenen Faktoren, wie dem Fruchtansatz, der Samenproduktion und der Nähe von anderen *Harpagophytum procumbens* Populationen ab, ob eine Wiederbesiedlung von ehemaligen dichten Vorkommen möglich ist.

Verschiedene Nutzungsintensitäten von verschieden dicht räumlich verteilten Populationen wurden mit der Entwicklung des Marktes und der Sozioökonomie der Sammler in Zusammenhang gebracht. Auf diese Weise wurde bewertet, unter welchen Bedingungen (bei verschiedene Populationsdichten, höhere Nachfrage, Preisanstieg) der Populationsstatus von *Harpagophytum procumbens* durch Übernutzung gefährdet wird. Es zeigt sich, dass der Handel einen großen Einfluss nicht nur auf die Nachhaltigkeit der angewandten Erntemethoden, sondern auch auf das Verhältnis zwischen Anbau und Wildsammlung hat. Obwohl der Export von Rohmaterial aus kommerziellem Anbau von *Harpagophytum procumbens* bisher zu vernachlässigen ist, kann erwartet werden, dass dieser bei zunehmender Nachfrage des Marktes ansteigt und somit die Einkommensmöglichkeiten und unter Umständen sogar die Existenzgrundlage der kommunalen Sammler beeinträchtigt. Eine Reihe von Empfehlungen für eine nachhaltige Nutzung werden aufgestellt, wie zum Beispiel die Empfehlung von Sammelquoten, Erntekontrollen, die Verbreitung des Wissens über nachhaltige Sammelmethoden und eine bessere Identifizierung der Sammler mit der Ressource, die mit eindeutigen Eigentumsverhältnissen dieser einher gehen. Hierzu zählen Vorschläge zur Dauerbeobachtung von Exportmengen und einer potentiellen Unterschutzstellung von *Harpagophytum procumbens* unter CITES Annex III. Wichtige Forschungsdefizite für Namibia und Südafrika, insbesondere im Hinblick auf den Einfluss der Erntemethoden und der Regeneration, werden aufgezeigt.

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20 Attachments

Attachment A:	*Harpagophytum* documentation sheet
Attachment B.1:	Vegetation types of Namibia (GIESS 1970) with number of one-square kilometre sites
Attachment B.2:	Vegetation types of South Africa (LOW & REBELO 1996) with number of one-square kilometre sites
Attachment C.1:	Kruskall-Wallis Anova by ranks for transects with >10 individuals on 1km^2-sites
Attachment C.2:	Kruskall-Wallis Anova by ranks for transects with 1-9 individuals on 1km^2-sites
Attachment C.3:	Kruskall-Wallis Anova by ranks for transects with no individuals on 1km^2-sites
Attachment C.4:	Kruskall-Wallis Anova by ranks on the utilisation intensity on 1km^2-sites
Attachment D:	Field Data on the square kilometre sites
Attachment E:	Field Data on re-documentation sites
Attachment F:	Interviews – questionnaire
Attachment G:	Map of research sites in different soil units of South Africa differentiated into quantity classes per square kilometre

Attachment A: *Harpagophytum* data sheet

Date:	Region:	District:	Locality:

Transect walk No **GPS reading (start):** S E	Habitat type Hill crest Midslope Footslope Valley floor	Oshana Wash River bank River terrace Dry river bed	Dune base Dune slope Dune crest Interdunal street Shifting dunes	Plain Other:	**Soil type and colour**
GPS reading (end): S E	Disturbances None Fire Other: Clearing	**Grazing** Cattle Goats Sheep	Grazing intensity:		
		Vegetation type: desert shrubland grassland thornbush savanna open/closed other:			
Notes (e.g. distance from next village)		**Total herb cover (%)**	**Total grass cover (%)**	**Total shrub cover (%)**	**Total tree cover (%)**
No small plants: (<10cm)	**No big plants:** (>10cm)	species list	species list	species list	species list
No. flowers					
No. young fruits					
No. old fruits					
No. holes					

Attachment B.1: Vegetation types of Namibia (GIESS 1970) with number of one-square-kilometre research sites

Biom	Vegetation type	Remarks	Number of sites
Savanna	Mixed Tree and Shrub Savanna (Southern Kalahari)	Most areas covered by longitudinal red sand dunes, harder soils occur in dune valleys and pans. Typical vegetation comprises Acacia haematoxylon, A. erioloba, A. reficiens, Boscia albitrunca and perennial grasses.	7
Savanna	Camelthorn Savanna (Central Kalahari)	Open savanna with Acacia erioloba. Common shrubs are A. mellifera, A. hebeclada, Grewia flava etc. Woodland patches with Terminalia sericea occur on white sand or red loamy sand.	11
Savanna	Tree Savanna and Woodland (Northern Kalahari)	In eastern Ovamboland, Kavango River and Waterberg Plateau. Characterised by Baikiaea plurijuga, Pterocarpus angolensis, Burkea african etc.; on harder soils also Acacia erioloba, Lonchocarpus nelsii and Boscia albitrunca	5
Savanna	Highland Savanna	Common in Khomas Hochland and Windhoek Bergland, characterised by Acacia hereroensis, A. reficiens, A. hebeclada, Combretum apiculatum etc.	6
Savanna	Thornbush Savanna (Tree and shrub savanna)	Typical in Central regions, characterised by grassland with trees (mainly Acacia spp.) and bigger shrubs in dense or open clumps of varying size	20
Savanna	Mopane Savanna	Savanna type of the Kaokoland, NW-Namibia, dominated by the tree or shrub Colophospermum mopane	1
Savanna	Dwarf Shrub Savanna	Occurs in the monotonous regions of southern Namibia, dominated by Karoo shrubs and grasses. Typical species are Rhigozum trichotomum, Acacia nebrownii, Boscia foetida etc.	–
Savanna	Mountain Savanna and Karstveld	Within the Karstveld vegetation type Sandveld patches with Combretum apiculatum and Dichrostachys cineria as well as flats between mountains with Terminalia sericea, Acacia spp., Lonchocarpus nelsii can be suitable habitats for Harpagophytum.	–
Nama Karoo	Semi Desert and Savanna Transition (Escarpment zone)	Characterised by many endemic species, with various Commiphora spp.	–

Attachment B.2: Vegetation types of South Africa (Low & Rebelo 1996) with number of one-square-kilometre research sites

Biome	Vegetation type	Short description of vegetation type	Number of sites
Savanna	Thorny Kalahari Dune Bushveld	Restricted to parallel dunes of the Kalahari Gemsbok National Park in N-Cape; grazed by game	–
Savanna	Shrubby Kalahari Dune Busveld	Dunes with scattered pans in most of the Kalahari Gemsbok Park, area north of Upington, east to Olifantshoek and Van Zylsrus in N-Cape	15
Savanna	Kalahari Plains Thorn Bushveld	Deep, loose sand with undulating to flat sandy plains in N-Cape and NW-Province.	17
Savanna	Karroid Kalahari Bushveld	Flat gravelly plains with sandy calcareous tufa substrate in north and northwest area of Upington, and Noenieput-Rietfontein area, N-Cape.	3
Savanna	Kalahari Mountain Bushveld	Rocky, shallow soils on hills in vicinity of Olifanthoek, Kuruman, and northwards to Sonstraal, N-Cape	4
Savanna	Kimberely Thorn Bushveld	Deep, sandy to loamy sand underlain by calcrete in Kimberely area, N-Cape, Schweizer-Reneke area, NW-Province, and western parts of Free State	3
Savanna	Kalahari Plateau Bushveld	Confined to different soils on the plateau in NW- Province and N-Cape in the Vryburg-Kuruman-Griekwastad area	4

Attachment C.1: Kruskall-Wallis ANOVA by ranks for transects with >10 individuals on the 1km²-sites

Independent variable: research area

Kruskal-Wallis test: H (3, N= 310) = 22,36473 p =,0001

	Code	Valid N	Sum of Ranks
farm NA	100	76	9674,5
comm NA	101	111	20684
farm ZA	102	51	7382,5
comm ZA	103	72	10464

Independent variable: habitat type

Kruskal-Wallis test: H (3, N= 310) = 9,400095 p =,0244

	Code	Valid N	Sum of Ranks
Plain	100	299	47150
dune base	101	4	385,5
interdune	103	3	531,5
omuramba	105	4	138

Independent variable: grazing intensity

Kruskal-Wallis test: H (4, N= 304) = 16,38242 p =,0026

	Grazing intensity classes	Valid N	Sum of Ranks
Group 1	0	14	2011
Group 2	1	31	3324
Group 3	2	75	10655,5
Group 4	3	114	19848,5
Group 5	4	70	10521

Independent variable: vegetation types Namibia

Kruskal-Wallis test: H (4, N= 187) = 23,04011 p =,0001

	No. Veg.types	Valid N	Sum of Ranks
Group 1	5	1	8,5
Group 2	7	53	4240
Group 3	8	8	332,5
Group 4	11	63	5860
Group 5	12	62	7137

Independent variable: vegetation types South Africa

Kruskal-Wallis test: H (2, N= 115) = 1,632708 p =,4420

	No. Veg.types	Valid N	Sum of Ranks
Group 1	28	15	859,5
Group 2	30	92	5230,5
Group 3	32	8	580

Independent variable: soil substrate type

Kruskal-Wallis test: H (1, N= 310) = 2,511783 p =,1130

	Code	Valid N	Sum of Ranks
loamsand	100	66	9240
sand	101	244	38965

Independent variable: grass cover Kruskal-Wallis test: H (9, N= 157) = 20,32488 p =,0160

	Cover classes	Valid N	Sum of Ranks
Group 1	1	49	4566
Group 2	3	6	679,5
Group 3	4	5	300
Group 4	7	5	444,5
Group 5	8	5	476,5
Group 6	10	31	2406
Group 7	12	6	281
Group 8	25	16	1278,5
Group 9	40	18	1073,5
Group 10	50	16	897,5

Attachment C2: Kruskall-Wallis ANOVA by ranks for transects with 1-9 individuals on the 1km²-sites

Independent (grouping) variable: Research area

Kruskal-Wallis test: H (3, N= 564) = ,3554343 p =,9493

	Code	Valid N	Sum of Ranks
farm NA	100	229	65398
comm NA	101	60	16919
farm ZA	102	127	34966
comm ZA	103	148	42047

Independent (grouping) variable: HABITAT TYPE

Kruskal-Wallis test: H (6, N= 560) = 19,25204 p =,0038

	Code	Valid N	Sum of Ranks
Plain	100	476	138563,5
dune bas	101	27	6282
dune slo	102	15	2336
interdun	103	27	6257
roadside	104	7	1846
omuramba	105	4	1202,5
dune cre	106	4	593

Independent (grouping) variable: GRAZING INTENSITY

Kruskal-Wallis test: H (4, N= 529) = 11,30404 p =,0234

	Grazing intensity classes	Valid N	Sum of Ranks
Group 1	0	45	12253,5
Group 2	1	82	20667,5
Group 3	2	240	59249
Group 4	3	81	23880
Group 5	4	81	24135

Independent (grouping) variable: NO_VEGETATION TYPE NAMIBIA

Kruskal-Wallis test: H (5, N= 284) = 15,27474 p =,0093

	No. Veg.types	Valid N	Sum of Ranks
Group 1	7	129	19012,5
Group 2	8	52	7517,5
Group 3	11	31	5485,5
Group 4	12	53	6616,5
Group 5	13	18	1687
8, 13	100	1	151

Independent (grouping) variable: NO_VEGATION TYPES SOUTH AFRICA

Kruskal-Wallis test: H (3, N= 255) = 10,78160 p =,0130

	No. Veg.types	Valid N	Sum of Ranks
Group 1	28	103	12056,5
Group 2	29	11	885
Group 3	30	134	18740
33/30	101	7	958,5

Independent (grouping) variable: SOIL SUBSTRATE

Kruskal-Wallis test: H (1, N= 562) = 1,156402 p =,2822

	Code	Valid N	Sum of Ranks
loamsand	100	165	48299,5
sand	101	397	109903,5

Independent variable: grass cover

Independent (grouping) variable: GRASSCOV

Kruskal-Wallis test: H (8, N= 256) = 9,308989 p =,3169

	Cover classes	Valid N	Sum of Ranks
Group 1	10	45	5891,5
Group 2	20	39	5863
Group 3	25	33	3682
Group 4	28	6	734,5
Group 5	30	51	5831
Group 6	35	27	3862,5
Group 7	50	42	5565,5
Group 8	65	9	1066
Group 9	90	4	400

Attachment C.3: Kruskall-Wallis ANOVA by ranks for transects with no individuals on the 1km²-sites

Independent (grouping) variable: RESEARCH AREA

Kruskal-Wallis test: H (3, N= 968) = 0,000000 p =1,000

	code	Valid N	Sum of Rank
farm NA	100	318	154071
comm NA	101	159	77035,5
farm ZA	102	231	111919,5
comm ZA	103	260	125970

Independent (grouping) variable: HABITAT TYPE

Kruskal-Wallis test: H (6, N= 960) = 0,000000 p =1,000

	code	Valid N	Sum of Ranks
Plain	100	743	357011,5
dune bas	101	58	27869
dune slo	102	67	32193,5
interdun	103	58	27869
roadside	104	4	1922
omuramba	105	2	961
dune cre	106	28	13454

Independent (grouping) variable: GRAZING INTENSITY

Kruskal-Wallis test: H (4, N= 895) = 0,000000 p =1,000

	code	Valid N	Sum of Rank
Group 1	0	54	24192
Group 2	1	256	114688
Group 3	2	396	177408
Group 4	3	123	55104
Group 5	4	66	29568

Independent (grouping) variable: VEGETATION TYPES NAMIBIA

Kruskal-Wallis test: H (6, N= 473) = 0,000000 p =1,000

	No. Veg.types	Valid N	Sum of Rank
Group 1	5	3	711
Group 2	7	202	47874
Group 3	8	53	12561
Group 4	11	17	4029
Group 5	12	113	26781
Group 6	13	69	16353
8, 13	100	16	3792

Independent (grouping) variable: VEGETATION TYPES SOUTH AFRICA

Kruskal-Wallis test: H (2, N= 371) = 0,000000 p =1,000

	No. Veg.types	Valid N	Sum of Rank
Group 1	28	211	39246
Group 2	30	120	22320
Group 3	32	40	7440

Independent (grouping) variable: SOIL SUBSTRATE TYPE

Kruskal-Wallis test: H (2, N= 964) = 0,000000 p =1,000

	Code	Valid N	Sum of Rank
loamsand	100	312	150540
sand	101	651	314107,5

Independent variable: grass cover

Independent (grouping) variable: GRASSCOV

Kruskal-Wallis test: H (9, N= 417) = 0,000000 p =1,000

	Cover classes	Valid N	Sum of Ranks
Group 1	3	11	2299
Group 2	10	47	9823
Group 3	15	37	7733
Group 4	17	3	627
Group 5	18	8	1672
Group 6	35	54	11286
Group 7	40	114	23826
Group 8	50	58	12122
Group 9	60	75	15675
Group 10	90	10	2090

Attachment C.4: Kruskall-Wallis ANOVA by ranks on the utilisation intensity on the 1km²-sites

Independent (grouping) variable: RESEARCH AREA

Kruskal-Wallis test: H (3, N= 972) = 81,96360 p =,0000

	Code	Valid	Sum of Ranks
farm Namibia	1	360	196575,5
communal Namibia	2	195	103128
farm South Africa	3	181	68811
communal South Africa	4	236	104363,5

Independent (grouping) variable: HABITAT TYPE

Kruskal-Wallis test: H (6, N= 967) = 26,56499 p =,0002

	Code	Valid	Sum of Ranks
Plain	100	865	424786
dune bas	101	32	13583,5
dune slo	102	19	11582
interdun	103	30	10810,5
roadside	104	7	2422
omuramba	105	10	3460
dune cre	106	4	1384

Independent (grouping) variable: VEGETATION TYPES NAMIBIA

Kruskal-Wallis test: H (6, N= 555) = 44,10561 p =,0000

	No. Veg.types	Valid	Sum of Ranks
Group 1	5	6	1005
Group 2	7	226	71156,5
Group 3	8	66	15728,5
Group 4	11	98	22610,5
Group 5	12	140	40293,5
Group 6	13	18	3328,5
8, 13	100	1	167,5

Independent (grouping) variable: VEGETATION TYPES SOUTH AFRICA

Kruskal-Wallis test: H (6, N= 417) = 120,3768 p =,0000

	No. Veg.types	Valid	Sum of Ranks
Group 1	28	119	21899,5
Group 2	29	16	6245,5
Group 3	30	236	49939,5
Group 4	31	11	1969
Group 5	32	22	3938
Group 6	33	1	179
33/30	101	12	2982,5

Independent (grouping) variable: GRAZING INTENSITY

Kruskal-Wallis test: H (6, N= 966) = 61,94041 p =,0000

	Grazing Intensity class	Valid	Sum of Ranks
Group 1	0	63	27861
Group 2	1	148	82966
Group 3	2	355	183010,5
Group 4	3	206	94948,5
Group 5	4	156	61067

Attachment D: Field Data on the square kilometre sites

no. of site	research area	no. tran-sects	Latitude (dec.degrees)	Longitude (dec. degrees)	total no. plants	no. transects diff. quantity classes						no. small plants	no. large plants	no. flow-ers	no. fruits	no. holes
						0 ind	1-4 ind	5-9 ind	10-20 ind	21-50 ind	>50 ind					
1	farm NA	10	-22,88888889	17,11933333	16	4	5	1	-	-	-			0	51	0
2	comm NA	17	-23,17658333	17,09361111	3	16	1	-	-	-	-			1	0	0
3	comm NA	20	-23,27722222	17,07983333	0	20	-	-	-	-	-			0	0	0
4	comm NA	18	-23,31183333	17,17044444	13	12	6	-	-	-	-			5	0	0
5	farm NA	4	-23,36333333	17,27972222	3	2	1	1	-	-	-			0	0	5
6	farm NA	5	-23,40400000	17,51791667	0	5	-	-	-	-	-			0	0	0
7	farm NA	1	-23,50383333	17,74741667	0	1	-	-	-	-	-			0	0	0
8	farm NA	15	-23,58666667	17,96744444	6	14	-	1	-	-	-			1	16	0
9	farm ZA	25	-26,76619444	20,63394444	8	22	2	1	-	-	-			1	10	0
10	farm ZA	24	-26,77413889	20,61330556	7	19	5	-	-	-	-			5	0	0
11	farm ZA	25	-26,77655556	20,60716667	19	18	6	-	1	-	-			4	2	3
12	farm ZA	23	-26,75263889	20,61511111	11	19	4	-	-	-	-	2		0	1	0
13	farm ZA	1	-26,74400000	20,62380556	7	1	-	-	-	-	-			1	1	0
13b	comm ZA	22	-26,74138889	20,62288889	348	18	4	-	-	-	-			75	442	40
14	farm ZA	17	-26,82661111	22,84272222	13	1	4	1	4	4	3			5	10	0
15	farm ZA	6	-26,82425000	22,83994444	26	5	-	-	1	-	-			2	11	12
16	farm ZA	14	-26,83405556	22,86752778	507	8	3	2	1	-	-			5	394	1
17	farm ZA	24	-27,21266667	22,95983333	566	1	3	4	7	8	1	81	13	34	147	12
18	comm ZA	23	-26,55844444	22,83672222	213	1	3	-	7	9	3	5	9	16	84	31
19	comm ZA	26	-26,56591667	22,91872222	347	2	8	8	5	3	-			0	99	2
23	farm NA	24	-21,03263889	17,49202778	38	1	-	9	9	5	-			0	1	0
24	farm NA	18	-21,02177778	17,48805556	4	5	10	3	-	-	-			0	0	0
25	farm NA	24	-21,06180556	17,49630556	0	21	3	-	-	-	-			0	0	4
26	comm NA	24	-21,06608333	17,39880556	1	21	3	-	-	-	-			0	0	17
27	comm NA	14	-21,07738889	17,37175000	14	8	5	1	-	-	-			0	2	0
28	farm NA	5	-21,20844444	17,66961111	198	1	3	1	-	-	-	0	1	1	96	0
29	farm NA	6	-21,17136111	17,66047222	67	-	-	-	2	2	2			0	7	24
30	farm NA	14	-21,16758333	17,98033333	0	-	6	4	4	-	-			0	0	16
31	comm NA	24	-21,00925000	18,29669444	11	16	8	-	-	-	-	0	1	0	2	13
32	comm NA	17	-21,02819444	18,52538889	0	7	10	-	-	-	-			0	0	0
33	comm NA	4	-21,15897222	18,77536111	27	4	-	-	-	-	-			6	1	0
34	comm NA	9	-18,58675000	13,81558333	112	3	4	1	1	-	-	1	11	0	111	5
35	farm NA	31	-22,88888889	17,11933333	14	11	11	6	1	2	-	2	9	0	4	0
36	comm NA	24	-23,31177778	17,16958333	74	15	9	-	-	-	-	14	15	6	67	9
37	farm NA	24	-22,43452778	17,98633333	192	9	7	6	2	-	-	13	18	0	30	26
38	farm NA	24	-21,05766667	17,45586111	25	3	10	4	5	1	1	1	9	0	0	39
39	farm NA	24	-21,05194444	17,46836111	66	9	12	1	2	-	-	3	8	0	3	6
40	farm NA	22	-21,04944444	17,41366667	166	12	6	2	1	1	-	30	23	0	20	267
41	farm NA	24	-21,06280556	17,36736111	39	1	2	4	4	13	-	3	6	0	9	25
42	farm NA	24	-21,04894444	17,24650000	141	10	10	2	1	1	-	16	17	2	21	110
43	farm NA	24	-21,04236111	17,25416667	2	3	6	7	4	3	1	0	2	0	0	16
44	farm NA	20	-21,03972222	17,27416667	509	11	9	-	-	-	-	5	20	0	94	22
45	farm NA	24	-21,16944444	17,65952778	1	4	2	5	4	5	4	0	1	0	0	7
46	farm NA	23	-21,17750000	18,30252778	14	17	6	-	-	-	-	1	6	0	0	2
47	farm NA	23	-21,16333333	18,28861111	146	16	6	1	-	-	-	0	11	0	29	54
48	farm NA	24	-21,07747222	18,31919444	10	9	8	3	1	1	2	0	2	0	0	4
49	farm NA	22	-21,46583333	17,94125000	15	18	3	1	-	-	-	0	6	0	24	0
50	farm NA	14	-21,45261111	17,96852778	0	8	5	1	-	-	-			0	0	0
51	farm NA	20	-21,43411111	17,95219444	46	20	-	-	-	-	-	3	11	2	3	1
52	farm NA	19	-21,48355556	17,79833333	74	8	8	2	1	-	-	6	11	0	3	16
53	farm NA	24	-22,42952778	17,99288889	26	9	8	3	4	-	-	1	9	0	5	2
54	farm NA	24	-22,39408333	17,93719444	94	14	7	3	-	-	-	2	16	9	4	2
55	farm NA	22	-22,30847222	18,13066667	166	6	7	6	3	-	-	17	16	0	1	2
56	farm NA	24	-22,31875000	18,15272222	49	8	7	2	2	5	-	13	12	0	0	4
57	farm NA	24	-22,32872222	17,98752778	885	10	9	3	2	-	-	96	24	1947	45	416
58	comm NA	24	-20,59008333	18,02950000	1035	-	-	1	2	8	13	50	24	5199	207	4
59	comm NA	24	-20,57550000	18,06969444	672	-	-	-	1	18	5	239	22	326	208	36
60	comm NA	22	-20,47997222	18,60505556	377	-	4	2	5	5	6	29	20	76	166	118
61	comm NA	21	-20,36477778	18,66788889	376	1	2	3	4	10	1	49	19	51	71	15
62	comm NA	24	-20,36675000	18,64419444	159	5	3	4	4	6	2	25	18	22	24	0
63	comm NA	24	-20,48047222	18,89650000	493	6	4	4	9	1	-	155	19	45	31	76
64	comm NA	24	-20,49355556	18,56375000	139	5	-	4	5	5	5	1	2	0	72	1

no. of site	research area	no. tran-sects	Latitude (dec.degrees)	Longitude (dec. degrees)	total no. plants	no.transects diff. quantity classes						no. small plants	no. large plants	no. flow-ers	no. fruits	no. holes
						0 ind	1-4 ind	5-9 ind	10-20 ind	21-50 ind	>50 ind					
65	farm ZA	18	-26,72261111	22,81166667	60	8	4	1	2	3	-			1	16	10
66	farm ZA	24	-26,89338889	22,89094444	215	8	6	4	2	-	-			3	24	0
67	comm ZA	24	-26,57341667	22,86986111	29	2	2	4	7	3	-	12	12	18	20	0
68	farm ZA	24	-26,15547222	22,58433333	9	13	9	2	-	-	-			0	5	0
69	farm ZA	17	-25,79508333	22,77841667	43	14	3	-	-	-	-	4	6	0	125	1
70	farm ZA	24	-25,42522222	22,92161111	168	17	3	2	2	-	-	38	19	40	46	27
71	comm ZA	24	-26,56913889	22,92313889	18	4	7	5	5	3	-	7	8	25	29	0
72	farm ZA	23	-27,11169444	22,06155556	95	15	7	1	-	-	-	32	17	8	61	0
73	farm ZA	24	-27,12205556	22,25788889	39	6	11	5	1	1	-	10	10	39	5	0
74	farm ZA	24	-27,19061111	22,26200000	268	14	7	2	1	-	-	154	22	143	73	6
75	farm ZA	24	-27,18463889	22,25705556	24	2	8	6	4	3	1	22	24	3	7	168
76	comm ZA	24	-28,43613889	21,17525000	0	9	2	4	7	2	-	0	24	0	0	0
77	farm ZA	24	-28,35811111	21,18783333	0	24	-	-	-	-	-	0	24	0	0	0
78	farm ZA	24	-28,40752778	21,23394444	6	24	-	-	-	-	-	5	24	12	3	4
79	farm ZA	24	-27,69794444	21,35286111	6	21	2	1	-	-	-	6	24	0	0	0
80	farm ZA	24	-27,74958333	21,31658333	33	20	4	-	-	-	-	25	19	5	17	0
81	farm ZA	19	-27,20641667	21,38244444	63	7	11	1	-	-	-	32	24	6	16	0
82	farm ZA	24	-27,11822222	22,25200000	133	15	4	4	-	1	-	61	24	25	44	0
83	farm ZA	24	-27,07086111	22,25483333	132	14	4	2	2	1	1	34	24	81	507	0
84	farm ZA	24	-27,22452778	22,44147222	0	13	4	2	4	1	-	0	1	0	0	0
85	farm ZA	1	-27,25836111	22,46980556	0	1	-	-	-	-	-	0	2	0	0	0
86	farm ZA	2	-27,25319444	22,45594444	0	2	-	-	-	-	-	0	1	0	0	0
87	farm ZA	1	-27,24541667	22,45300000	0	1	-	-	-	-	-	0	24	0	0	0
88	comm ZA	47	-28,80813889	24,67097222	24	47	-	-	-	-	-	8	24	3	0	0
89	comm ZA	24	-28,72141667	24,85658333	257	15	7	1	1	-	-	53	16	4	8	0
90	farm ZA	16	-29,00991667	24,64497222	323	3	4	1	3	4	1	29	24	139	296	0
91	farm ZA	24	-28,10691667	23,00105556	39	7	4	4	3	4	2	22	7	0	1	8
92	comm ZA	7	-26,97886111	24,00375000	52	2	1	1	3	-	-	1	12	0	2	18
93	comm ZA	13	-26,97016667	23,93311111	122	6	4	1	1	1	-	22	24	8	85	70
94	comm ZA	24	-26,89408333	23,92577778	122	7	8	2	4	2	1	16	24	0	95	0
95	farm ZA	24	-26,31466667	24,25030556	9	6	7	6	5	-	-	2	24	0	0	0
96	farm ZA	24	-26,92852778	24,03361111	0	23	-	1	-	-	-	0	10	0	0	0

no. of site	no. transect on diff. habitat types						no. transects		vegetation type (Low & Rebelo1996) (Giess 1970)	transects diff. grazing intensity classes					vegetation cover (mean of transects)			
	dune base	dune crest	dune slope	inter dune	omur amba	Plain	loamy sand	sand		c 0	c1	c2	c 3	c4	mean herb cover [%]	mean grass cover [%]	mean shrub cover [%]	mean tree cover [%]
1	-	-	-	-	-	-	-	10	Highland Savanna	-	-	-	-	-	70,0	10,0	0,0	3,0
2	-	-	-	-	-	17	-	17	Mix. Tree & Shrub Sav.	-	-	-	-	-	3,0	32,8	10,0	0,4
3	-	-	-	-	-	20	-	20	Mix. Tree & Shrub Sav.	-	-	9	2	-	1,6	45,5	7,1	2,5
4	3	1	6	-	-	8	-	18	Mix. Tree & Shrub Sav.	-	-	18	-	-	16,0	29,6	4,4	4,2
5	-	-	-	-	-	4	-	4	Mix. Tree & Shrub Sav.	-	-	4	-	-	3,0	90,0	0,5	2,0
6	-	-	-	-	-	5	-	5	Mix. Tree & Shrub Sav.	-	-	5	-	-	1,1	46,0	6,4	0,0
7	-	-	-	-	-	1	-	1	Mix. Tree & Shrub Sav.	-	-	1	-	-	1,0	50,0	5,0	0,0
8	5	-	5	4	-	-	-	15	Mix. Tree & Shrub Sav.	-	-	15	-	-	1,0	50,0	2,0	2,4
9	7	5	5	8	-	-	-	25	Shrub. Kal. Dune Bushv.	-	25	-	-	-	6,1	24,7	3,7	0,1
10	9	2	8	5	-	-	-	24	Shrub. Kal. Dune Bushv.	-	24	-	-	-	4,0	12,3	4,5	0,2
11	5	1	2	17	-	-	-	25	Shrub. Kal. Dune Bushv.	-	25	-	-	-	4,7	13,2	4,1	0,0
12	5	2	6	10	-	-	-	23	Shrub. Kal. Dune Bushv.	-	23	-	-	-	2,4	25,3	2,4	0,0
13	7	1	5	10	-	-	-	23	Shrub. Kal. Dune Bushv.	-	-	23	-	-	3,0	16,0	5,4	0,4
13b	-	-	-	-	-	17	-	17	Kal. Plains Thorn Bushv.	-	-	15	2	-	2,7	35,2	1,7	0,1
14	-	-	-	-	-	6	-	6	Kal. Plains Thorn Bushv.	-	-	6	-	-	1,5	38,5	2,0	0,0
15	-	-	-	-	-	14	-	14	Kal. Plains Thorn Bushv.	-	-	14	-	-	3,3	36,1	1,6	0,0
16	-	-	-	-	-	24	-	24	Kal. Plains Thorn Bushv.	-	-	-	24	-	5,6	25,8	4,5	0,0
17	-	-	-	-	-	23	1	22	Kal. Plains Thorn Bushv.	-	-	-	1	22	2,1	9,4	13,6	0,4
18	-	-	-	-	-	26	-	26	Kal. Plains Thorn Bushv.	-	-	-	6	20	3,8	11,0	11,5	0,2
19	-	-	-	-	-	24	-	24	Thornbush Savanna	-	24	-	-	-	9,0	43,6	13,2	0,8
23	-	-	-	-	-	18	-	18	Thornbush Savanna	-	-	18	-	-	3,2	66,1	12,8	0,6
24	-	-	-	-	-	24	-	24	Thornbush Savanna	-	24	-	-	-	8,5	62,7	12,5	4,2
25	-	-	-	-	-	24	-	24	Thornbush Savanna	-	24	-	-	-	7,9	44,8	12,2	0,3
26	-	-	-	-	-	14	-	14	Thornbush Savanna	-	14	-	-	-	6,5	52,1	18,9	0,0
27	-	-	-	-	-	5	-	5	Thornbush Savanna	-	-	5	-	-	2,0	72,0	23,0	0,8
28	-	-	-	-	-	6	-	6	Thornbush Savanna	-	-	6	-	-	5,0	65,0	15,0	0,0
29	-	-	-	-	-	14	-	14	Thornbush Savanna	-	-	14	-	-	2,0	59,3	11,0	0,0
30	-	-	-	-	-	24	-	24	Thornbush Savanna	-	-	12	12	-	3,1	43,5	25,0	0,1
31	-	-	-	-	-	17	-	17	Thornbush Savanna	-	-	17	-	-	9,1	13,5	41,6	0,3
32	-	-	-	-	-	4	-	4	Tree Sav. & Woodland	-	-	-	4	-	1,5	15,0	24,5	0,0
33	-	-	-	-	-	9	-	9	Mopane Savanna	-	-	-	9	-	1,6	12,8	12,9	0,0
34	-	-	-	-	-	31	13	18	Highland Savanna	-	-	-	-	-	34,3	44,5	0,8	1,8
35	2	1	9	-	-	12	-	24	Thornbush Savanna	-	-	24	-	-	19,6	39,6	2,5	1,9
36	-	-	-	-	-	24	-	24	Highland Savanna	-	-	24	-	-	7,5	51,9	9,1	0,8
37	-	-	-	-	-	24	24	-	Thornbush Savanna	-	-	24	-	-	4,5	25,5	22,5	0,2
38	-	-	-	-	-	24	24	-	Thornbush Savanna	-	-	24	-	-	4,3	28,5	15,9	0,8
39	-	-	-	-	-	22	22	-	Thornbush Savanna	-	-	22	-	-	7,7	20,5	16,3	1,6
40	-	-	-	-	-	24	24	-	Thornbush Savanna	-	-	24	-	-	5,3	34,0	24,6	0,0
41	-	-	-	-	-	24	20	4	Thornbush Savanna	-	24	-	-	-	3,6	31,4	22,8	1,6
42	-	-	-	-	-	24	-	24	Thornbush Savanna	-	24	-	-	-	7,5	37,5	12,8	1,8
43	-	-	-	-	-	20	-	20	Thornbush Savanna	-	20	-	-	-	9,6	38,8	25,7	1,3
44	-	-	-	-	-	24	14	10	Thornbush Savanna	-	-	24	-	-	6,9	21,1	22,5	0,3
45	-	-	-	-	-	23	23	-	Camelthorn Savanna	-	-	23	-	-	0,9	63,0	18,3	0,0
46	-	-	-	-	-	23	21	1	Camelthorn Savanna	-	-	23	-	-	1,0	42,3	20,3	1,0
47	-	-	-	-	-	24	12	12	Camelthorn Savanna	-	-	24	-	-	1,6	48,3	20,9	0,0
48	-	-	-	-	-	22	20	2	Thornbush Savanna	-	22	-	-	-	2,5	39,4	17,2	0,0
49	-	-	-	-	-	14	14	-	Thornbush Savanna	-	-	14	-	-	1,2	59,4	0,0	0,1
50	-	-	-	-	-	20	19	1	Thornbush Savanna	-	-	20	-	-	5,5	32,7	18,8	0,1
51	-	-	-	-	-	19	15	4	Thornbush Savanna	-	-	19	-	-	4,6	31,1	13,2	0,0
52	6	-	-	-	-	18	5	19	Highland Savanna	-	-	24	-	-	17,8	36,3	8,5	0,6
53	-	-	-	-	-	24	11	13	Highland Savanna	-	-	24	-	-	4,3	58,2	7,5	1,0
54	-	-	-	-	-	22	14	8	Camelthorn Savanna	-	22	-	-	-	11,8	59,5	3,1	0,8
55	-	-	-	-	-	24	8	16	Camelthorn Savanna	-	24	-	-	-	11,0	50,0	8,8	0,2
56	-	-	-	-	-	24	7	17	Camelthorn Savanna	-	-	24	-	-	5,0	47,1	6,5	0,0
57	-	-	-	-	-	24	-	24	Camelthorn Savanna	-	-	3	21	-	7,6	4,8	18,1	0,1
58	-	-	-	-	-	24	-	24	Camelthorn Savanna	-	-	-	24	-	4,3	0,8	18,9	0,0
59	-	-	-	-	-	22	-	22	Tree Sav. & Woodl.	-	-	-	22	-	3,2	0,6	17,8	0,0
60	-	-	-	-	-	21	-	21	Tree Sav. & Woodl.	-	-	8	13	-	4,9	25,7	15,3	0,0
61	2	-	-	1	-	21	-	24	Tree Sav. & Woodl.	-	-	-	14	10	24,9	5,5	12,1	0,0
62	-	-	-	-	12	12	24	-	Tree Sav. & Woodl.	-	-	-	-	24	14,4	8,4	6,7	0,0
63	-	3	-	-	-	21	-	24	Tree Sav. & Woodl.	-	-	-	8	16	12,9	2,7	17,1	0,0
64	1	-	-	-	-	17	2	16	Kal. Plains Thorn Bushv.	-	-	18	-	-	3,9	39,6	5,7	1,7

no. of site	no. transect on diff. habitat types						no. transects		vegetation type (Low & Rebelo1996) (Giess 1970)	transects at diff. grazing intensity classes					vegetation cover (mean of transects)			
	dune base	dune crest	dune slope	inter dune	omur amba	Plain	loamy sand	sand		c 0	c1	c2	c 3	c4	mean herb cover [%]	mean grass cover [%]	mean shrub cover [%]	mean tree cover [%]
65	-	-	-	-	-	20	2	18	Kal. Plains Thorn Bushv.	-	-	20	-	-	4,7	26,4	7,8	0,7
66	-	-	-	-	-	-	-	-	Kal. Plains Thorn Bushv.	-	-	-	-	-	8,2	29,5	11,5	0,3
67	-	-	-	-	-	-	-	-	Kal. Plains Thorn Bushv.	-	-	-	-	-	9,0	26,6	11,2	0,3
68	-	-	-	-	-	17	-	17	Kal. Plains Thorn Bushv.	-	-	17	-	-	1,9	28,8	4,8	1,0
69	-	-	-	-	-	24	-	24	Kal. Plains Thorn Bushv.	-	-	-	24	-	1,1	29,8	5,4	1,4
70	-	-	-	-	-	24	-	24	Kal. Plains Thorn Bushv.	-	-	-	24	-	3,1	35,5	17,5	1,6
71	-	1	2	2	-	18	-	23	Shrub. Kal. Dune Bushv.	-	-	23	-	-	3,2	23,2	1,6	0,1
72	-	1	-	-	-	23	4	20	Shrub. Kal. Dune Bushv.	-	-	-	6	18	6,7	22,4	7,8	1,5
73	-	-	-	-	-	24	-	24	Shrub. Kal. Dune Bushv.	-	-	6	3	15	2,3	17,7	6,2	1,4
74	1	1	-	-	-	22	-	24	Shrub. Kal. Dune Bushv.	-	-	-	1	23	4,6	19,1	4,3	0,8
75	3	-	10	1	-	10	-	21	Karoo. Kal. Dune Bushv.	5	10	3	-	-	1,2	31,2	16,7	0,0
76	-	-	-	-	-	24	23	-	Karoo. Kal. Dune Bushv.	1	12	-	-	-	1,9	39,7	5,8	0,0
77	-	-	-	-	-	24	23	-	Karoo. Kal. Dune Bushv.	1	-	-	15	-	0,4	28,0	7,7	0,0
78	11	2	5	6	-	-	-	24	Shrub. Kal. Dune Bushv.	-	-	-	24	-	2,5	30,4	8,5	0,0
79	7	2	8	7	-	-	-	24	Shrub. Kal. Dune Bushv.	-	-	-	-	24	2,5	27,6	12,9	0,2
80	5	2	2	10	-	-	-	19	Shrub. Kal. Dune Bushv.	-	-	-	19	-	2,7	25,0	13,8	0,0
81	1	1	2	-	-	20	-	24	Shrub. Kal. Dune Bushv.	-	-	-	24	-	9,9	34,2	7,0	0,3
82	5	2	3	7	-	7	3	21	Shrub. Kal. Dune Bushv.	-	-	-	-	24	3,3	37,3	15,6	0,0
83	-	-	-	-	-	24	24	-	Kal. Mountain Bushveld	-	-	24	-	-	2,8	49,1	7,0	1,5
84	-	-	-	-	-	1	1	-	Kal. Mountain Bushveld	-	-	1	-	-	20,0	30,0	5,0	0,0
85	-	-	-	-	-	2	2	-	Kal. Mountain Bushveld	-	-	2	-	-	32,5	12,5	16,5	3,5
86	-	-	-	-	-	1	1	-	Kal. Mountain Bushveld	-	-	1	-	-	6,0	45,0	15,0	0,0
87	-	-	-	-	-	47	-	47	Kal. Thorn Bushveld	-	47	-	-	-	8,7	53,0	5,5	2,4
88	-	-	-	-	-	24	24	-	Kal. Thorn Bushveld	24	-	-	-	-	1,4	68,4	0,6	0,1
89	-	-	-	-	-	16	16	-	Kal. Thorn Bushveld	16	-	-	-	-	7,9	50,6	3,2	0,2
90	-	-	-	-	-	24	24	-	Kal. Plains Thorn Bushv.	-	-	-	-	24	24,5	15,3	28,4	0,1
91	-	-	-	-	-	7	-	7	Kal. Plateau Bushveld	-	7	-	-	-	19,3	24,3	15,0	2,5
92	-	-	-	-	-	13	1	12	Kal. Plateau Bushveld	-	-	-	-	-	22,5	22,5	10,7	2,5
93	-	-	-	-	-	24	18	6	Kal. Plains Thorn Bushv.	23	-	-	-	-	16,7	38,7	4,3	0,1
94	-	-	-	-	-	24	11	13	Kal. Plains Thorn Bushv.	22	2	-	-	-	16,3	48,1	7,0	1,9
95	-	-	-	-	-	24	24	-	Kal. Plateau Bushveld	-	-	24	-	-	8,4	73,8	11,4	2,3
96	-	-	-	-	-	10	-	10	Kal. Plateau Bushveld	10	-	-	-	-	8,9	59,6	13,7	3,1