

DINTERIA

Namibia Scientific Society
Namibia Wissenschaftliche Gesellschaft



Contributions to the Flora and Vegetation of Namibia
Beiträge zur Flora und Vegetation von Namibia

Number
Nummer **35**
NOVEMBER
2015

DINTERIA

Number 35, NOVEMBER 2015

[Editor: Peter Cunningham, Environment & Wildlife Consulting, Namibia – E-mail: pckkwrc@yahoo.co.uk]

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Cover Illustration: *Hermania stricta* (desert rose; Wüstenrose). Photograph by Peter Cunningham

A plant checklist for the Bismarckberge in the central highlands of Namibia

Antje Burke¹, Silke Rügheimer² & Leevi Nanyeni²

¹EnviroScience
P. O. Box 90230
Klein Windhoek
Namibia

E-mail: antje@enviro-science.info

²National Botanical Research Institute
P/Bag 13184
Windhoek
Namibia

Abstract

A plant survey in the Bismarckberge, the eastern extension of the Auas Mountains near Windhoek, during the rainy season 2014 increased the species list for the quarter degree square 2217CB by 35%. Although this quarter degree square falls within an area generally considered well covered floristically, the enrichment of the species list shows that dedicated plant surveys are well worth the effort, even in well-collected areas. The plant species recorded in the Bismarckberge can be considered a subset of the flora of the Auas Mountains, as no species were restricted to the Bismarckberge only.

Keywords: biogeography, central highlands, mountain flora, savanna

Introduction

The Auas Mountain Range in the Khomashochland has been identified one of the most important areas for biodiversity in central Namibia (Irish 2002). Plant collecting on the main mountain range has been undertaken repeatedly and produced a fairly comprehensive plant inventory for the Auas Mountains (Burke & Wittneben 2008). However, the eastern-most extension of the range – the Bismarckberge, which is separated by about 10 km from the main mountain chain – had not been previously surveyed. The quarter degree square (QDS) in which the Bismarckberge are located, has been reasonably well collected. However, the data held at the Specimens Database of the National Botanical Research Institute (NBRI) are not sufficiently detailed to separate plants growing on these mountains from those on the plains, or on the eastern-most extension of the continuous Auas Mountain Range – Auasende – which is also positioned in this QDS. Therefore a plant survey of the Bismarckberge was warranted and a plant inventory of these mountains is presented here.

Study area

The Bismarckberge in the Khomashochland in central Namibia form part of the Auas Mountain Range, although they are separated from the main mountain chain by approximately 10 km of *Acacia* dominated plains. These mountains fall into the quarter degree square 2217CB. The mountains are largely composed of Precambrian quartzites and other metasedimentary rock types of the Hakos and Rehoboth Groups (Miller 2002). The weather-resistant quartzites remained after the surrounding softer sediments were eroded over around 500 million years. The mountains ascend up to 400 m above the surrounding plains, with the highest peak at 2299 m amsl and cover about 15 km².

The general climate is semi-arid and the mean annual rainfall ranges between 300 and 400 mm. Due to the high altitude, temperatures are moderate in summer (average maximum: 30-32°C), but cold in winter, with frost occurring on average 10-20 days per annum (Mendelsohn *et al.* 2002).

The Bismarckberge are located in highland savanna and the general vegetation is described as highland shrubland (Burke *et al.* in Mendelsohn *et al.* 2002). Shrubs are the most conspicuous components, but a low cover of trees and a high diversity of grasses and herbs add to the species spectrum (Figures 1 & 2).



Figure 1. African wild olive (*Olea africana*), next to Silke Rügheimer, grows in the upper reaches of the Bismarckberge. In the foreground, plenty of camphor bush (*Tarchonanthus camphoratus*), and generally a dense cover of shrubs is prevalent on the top of the mountain (©A. Burke).



Figure 2. The footslope and mid-section of the Bismarckberge are characterised by gentle slopes, with steep sections only in the upper reaches (©A. Burke).

Methods

Plant surveys were undertaken during the period 11 February to 24 March 2014 during an above-average rainy season in Windhoek. Over 500 mm had been recorded in the Bismarckberge during the season from November to the last survey date at Hohe Warte (H. Köhler, pers. comm. 2014), the nearest rainfall station to the mountains and 447 mm were finally recorded in Windhoek during January-December 2014.

Plant collections focused on species not yet represented in the herbarium's collection, but the species list presented here also includes, for completeness, observational records of plants which have not been collected.

The following questions were addressed by this paper:

1. Is it still worth collecting in relatively well researched quarter degree squares – i.e. did the surveys add new species not recorded in QDS 2217CB before, in terms of (a) specimen collections and (b) observations?
2. Are there plants of particular interest in the Bismarckberge?

Results and discussion

A total of 268 species were listed for the quarter degree square 2217CB prior to the survey conducted in 2014. Our survey added 94 new species, 35 of which were collected (Appendix 1; Table 1). This included common plants such as *Acacia erioloba*, *A. hebeclada*, *Cleome monophylla* and *Dichrostachys cinerea*, but also less common species such as *Euphorbia monteiri* and *E. spartaria*. These latter, rarer species are not necessarily restricted to high altitudes, but are less common in the highland savanna. The plant surveys in 2014 increased the species list for this quarter degree square by 35%. The 59 observed (only) species were not collected because insufficient material was available at the time of the survey, largely because reproductive structures (flowers or fruit) were missing. Plant surveys of areas believed to be well-collected are therefore still productive, particularly after a good rainy season.

Table 1. Number of plant species recorded prior and after the plant surveys at Bismarckberge in 2014.

| 2217CB up to 2013 | 2217CB in 2014 | New collected species | Additional observed species |
|--------------------------|-----------------------|------------------------------|------------------------------------|
| 268 | 362 | 35 | 59 |

Overall, the plants found on Bismarckberge are typical species of the highland savanna around Windhoek, enriched by some plants of higher altitude, which are also found on the Auas Mountains. Examples of the latter are the grass *Brachiaria serrata*, the bulbs *Babiana longicollis* and *Hypoxis obtusa*, the tree *Osyris lanceolata* and the shrubs *Heteromorpha papillosa*, *Monsonia burkeana* and *Wahlenbergia denticulate* (Figures 3-5).



Figure 3. The iris-like bulb, *Hypoxis obtusa*, is rare in Namibia, but occurs throughout southern Africa (©A. Burke).



Figure 4. The attractive low shrub *Monsonia burkeana* is endemic to Namibia, and only found in higher altitudes (©A. Burke).



Figure 5. The striking iris *Ferraria glutinosa* was one of the few bulbs recorded during the plant survey in the Bismarckberge in 2014 (©A. Burke).

Based on current records, the Bismarckberge support 205 plant species, all of which also occur in the Auas Mountains (Burke & Wittneben 2008), and the Bismarckberge can thus be considered a less diverse outpost of mountain flora of the Auas Mountains. More plant species are recorded in the Auas Mountains, but they also cover a larger area than the Bismarckberge and reach a higher altitude.

Although many bulb species had already disappeared at the time of the survey, two attractive Iridaceae were found in flower – *Ferraria glutinosa* and *Moraea polystachya* – both savanna species that also occur in Botswana and South Africa.

Unavoidably the flora of the Bismarckberge also includes some introduced species that are now considered naturalised. The herbs *Achyranthes aspera*, *Bidens biternata*, *Chenopodium schraderianum*, *Pupalia lappacea* and *Schkuhria pinnata* are some such examples. Three of these have very effective means of seed dispersal by attaching to fur and clothes which could well explain their successful spread.

The majority (55 %) of the Bismarckberge flora consists of plants widespread in southern Africa, but there are also 19 plants endemic to Namibia. *Aptosimum arenarium*, *Anisopappus pinnatifidus*, *Eragrostis scopelophila*, *Euphorbia spartaria*, *Geigeria plumosa* and *Heteromorpha papillosa* are some examples. Of note are also some species typical of southern Namibia, usually found in the winter-rainfall influenced area, such *Diospyros ramulosa* and *Hermbsstaedtia glauca*.

Although the species list presented here is reasonably comprehensive, our survey did not cover bulbs (Amaryllidaceae, Liliaceae *sens. lat.* and Iridaceae) well, because these were either past blooming or not yet in flower during the surveys. These are certainly underrepresented. Also not all aspects of the mountain, and particularly steep sections, were accessible, and there may well be additional species that have not yet been recorded here. The presented species list provides a plant inventory for land-owners and land users and can be used to guide further research, collecting and development planning.

Acknowledgements: We are grateful to have been granted permission to work on the farms Hohe Warte and Etango Ranch and thank Heike Köhler, Volker Grellmann and the manager of Etango Ranch for their support. The Ministry of Environment & Tourism granted permission for this research and we thank our reviewer for insightful comments which improved the manuscript.

References

BURKE, A., DU PLESSIS, W. & STROHBACH, B. 2002. Vegetation types in Namibia. Supplementary data to Environmental Atlas of Namibia, Ministry of Environment and Tourism, Windhoek.

BURKE, A. & WITTNEBEN, M. 2008. A preliminary account of the vegetation of the Auas Mountains. *Dinteria* 30: 41-91.

IRISH, J. 2002. Namibian mountains: biodiversity potential based on topography. Report to the Mountain Ecosystem Working Group of the Namibian National Biodiversity Programme, 34 pp.

MENDELSON, J., JARVIS, A., ROBERTS, C. & ROBERTSON, T. 2002. Atlas of Namibia. David Philip Publishers, Cape Town, 200 pp.

MILLER, R. MCG. 2002. Simplified geological description of Namibia's mountains. Report to the Mountain Ecosystem Working Group of the Namibian National Biodiversity Programme, Windhoek, 12 pp.

Appendix 1. Plant species of the Bismarckberge east of Windhoek (E = Namibian endemic, i = introduced, nE = near endemic).

| | |
|------------------------------------------------------------------------------|----|
| <i>Acacia erioloba</i> E.Meyer | |
| <i>Acacia hebeclada</i> DC subsp. <i>hebeclada</i> | |
| <i>Acacia hereroensis</i> Engl. | |
| <i>Acacia mellifera</i> (Vahl) Benth. subsp. <i>detinens</i> (Burch.) Brenan | |
| <i>Acacia reficiens</i> Wawra subsp. <i>reficiens</i> | |
| <i>Achyranthes aspera</i> L. var. <i>aspera</i> | |
| <i>Acrotome pallescens</i> Benth. | |
| <i>Aerva leucura</i> Moq. | |
| <i>Aizoon giessii</i> Friedr. | E |
| <i>Andropogon chinensis</i> (Nees) Merr. | |
| <i>Anisopappus pinnatifidus</i> (Klatt) O.Hoffm. ex Hutch. | nE |
| <i>Antheophora pubescens</i> Nees | |
| <i>Anthospermum rigidum</i> Eckl. & Zeyh. subsp. <i>pumilum</i> (Sond.) Puff | |
| <i>Aptosimum arenarium</i> Engl. | E |
| <i>Aptosimum lugardiae</i> (N.E.Br.) E.Phillips | |
| <i>Aristida adscensionis</i> L. | |
| <i>Asparagus cooperi</i> Baker | |
| <i>Asparagus laricinus</i> Burch. | |
| <i>Babiana longicollis</i> Dinter | E |
| <i>Bidens biternata</i> (Lour.) Merr. & Scherrf | i |
| <i>Blepharis leendertziae</i> Oberm. | |
| <i>Boophone disticha</i> (L.f.) Herb. | |
| <i>Boscia albitrunca</i> (Burch.) Gilg & Gilg-Ben. | |
| <i>Brachiaria nigropedata</i> (Munro ex Fical. & Hiern) Stapf | |
| <i>Brachiaria serrata</i> (Thunb.) Stapf | |
| <i>Bulbine capitata</i> Poelln. | |
| <i>Bulbostylis hispidula</i> (Vahl) R. Haines | |
| <i>Cenchrus ciliaris</i> L. | |
| <i>Chamaecrista biensis</i> (Steud.) Lock | |
| <i>Chascanum pinnatifidum</i> (L.f.) E.Mey. | |
| <i>Cheilanthes dinteri</i> Brause | |

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|----------------------------------------------------------------------------------------|----|
| <i>Cheilanthes marlothii</i> (Hieron.)Schelpe | |
| <i>Chenopodium schraderianum</i> Roem.& Schult. | i |
| <i>Chloris virgata</i> Swartz | |
| <i>Cineraria canescens</i> J.J.Wendl ex Link var. <i>flabellifolia</i> Harv. | |
| <i>Cleome gynandra</i> L. | |
| <i>Cleome monophylla</i> L. | |
| <i>Cleome oxyphylla</i> Burch. var. <i>oxyphylla</i> | |
| <i>Cleome rubella</i> Burch. | |
| <i>Coccinea rehmannii</i> Cogn. | |
| <i>Coccinia sessilifolia</i> (Sonder) Cogn. | |
| <i>Combretum apiculatum</i> Sonder subsp. <i>apiculatum</i> | |
| <i>Commelina africana</i> var. <i>krebsiana</i> (Kunth) C.B. Clarke | |
| <i>Commelina benghalensis</i> L. | |
| <i>Commicarpus pentandrus</i> (Burch.) Heimerl | |
| <i>Commiphora pyracanthoides</i> Engl. | |
| <i>Convolvulus sagittatus</i> Thunb. var. <i>sagittatus</i> | |
| <i>Corallocarpus welwitschii</i> (Naud.) Hook.f.ex Welw. | |
| <i>Crassula tabularis</i> Dinter | |
| <i>Cucumis africanus</i> L.f. | |
| <i>Cucumis meeusei</i> C.Jeffrey | |
| <i>Cymbopogon caesius</i> (Hook.& Arn.) Stapf | |
| <i>Cyperus fulgens</i> C.B. Clarke | |
| <i>Cyphostemma congestum</i> (Baker) Desc. ex Wild & R.Drumm. | |
| <i>Cyphostemma hereroense</i> (Schinz) Decs.ex Wild. & Drumm. | |
| <i>Danthoniopsis ramosa</i> (Stapf) Clayton | |
| <i>Dichrostachys cinerea</i> subsp. <i>africana</i> Bren. & Brum. var. <i>africana</i> | |
| <i>Dicoma anomala</i> Sond. subsp. <i>anomala</i> | |
| <i>Digitaria eriantha</i> Steud. | |
| <i>Diospyros ramulosa</i> (E.Meyer ex A.DC.) De Winter | |
| <i>Dombeya rotundifolia</i> (Hoechst.) Planch. | |
| <i>Dyschoriste pseudirecta</i> Mildbr. | |
| <i>Echinochloa holubii</i> (Stapf) Stapf | |
| <i>Ehretia alba</i> Retief & A.E.van Wyk | |
| <i>Elephantorrhiza elephantina</i> (Burch.) Skeels | |
| <i>Elephantorrhiza suffruticosa</i> Schinz | |
| <i>Enneapogon cenchroides</i> (Roem.& Schult.) C.E.Hubb. | |
| <i>Enneapogon scoparius</i> Stapf | |
| <i>Eragrostis echinochloidea</i> Stapf | |
| <i>Eragrostis lehmanniana</i> Nees var. <i>lehmanniana</i> | |
| <i>Eragrostis nindensis</i> Fical.& Hiern | |
| <i>Eragrostis rigidior</i> Pilg. | |
| <i>Eragrostis scopelophila</i> Pilger | E |
| <i>Eragrostis superba</i> Peyr. | |
| <i>Eriocephalus dinteri</i> S.Moore | E |
| <i>Eriocephalus luederitzianus</i> O. Hoffm. | |
| <i>Euclea undulata</i> Thunb. var. <i>myrtina</i> (Burch.) Hiern | |
| <i>Euphorbia monteiri</i> Hook. f. subsp. <i>monteiri</i> | nE |
| <i>Euphorbia spartaria</i> N.E.Br. | E |
| <i>Evolvulus alsinoides</i> (L.) L. var. <i>linifolius</i> (L.) Baker | |
| <i>Felicia muricata</i> (Thunb.) Nees subsp. <i>muricata</i> | |
| <i>Ferraria glutinosa</i> (Bak.)Rendle | |
| <i>Fingerhuthia africana</i> Lehm. | |
| <i>Galenia africana</i> L. | |
| <i>Geigeria ornativa</i> O.Hoffm. | |

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|-----------------------------------------------------------------------------------------|---|
| <i>Geigeria plumosa</i> Muschl. | E |
| <i>Gisekia africana</i> (Lour.) Kuntze var. <i>africana</i> | |
| <i>Gladiolus permeabilis</i> Delaroche subsp. <i>edulis</i> (Burch.ex Ker-Gawl.) Oberm. | |
| <i>Gomphocarpus fruticosus</i> (L.) Aiton f. | |
| <i>Grewia flava</i> DC. | |
| <i>Grewia flavescens</i> Juss. var. <i>flavescens</i> | |
| <i>Gymnosporia linearis</i> (L.f.) Loes. subsp. <i>lanceolata</i> E.Mey. ex. Sond. | |
| M.Jordaan | |
| <i>Helichrysum obtusum</i> (S. Moore) Moeser | |
| <i>Helichrysum tomentosulum</i> (Klatt) Merxm. subsp. <i>tomentosulum</i> | |
| <i>Heliophila minima</i> (Stephens) Marais | |
| <i>Heliotropium ciliatum</i> Kaplan | |
| <i>Hermannia comosa</i> Burch. Ex DC | |
| <i>Hermannia modesta</i> (Ehrenb.)Mast. | |
| <i>Hermannia tomentosa</i> (Turcz.) Schinz ex Engl. | |
| <i>Hermbstaedtia glauca</i> (J.C.Wendl.) Rchb. ex Steud. | |
| <i>Hermbstaedtia odorata</i> (Burch.) T.Cooke var. <i>odorata</i> | |
| <i>Heteromorpha papillosa</i> C.Towns | E |
| <i>Heteropogon contortus</i> (L.) Roem. & Schult. | |
| <i>Hibiscus fleckii</i> Guerke | E |
| <i>Hibiscus palmatus</i> Forsskal | |
| <i>Hibiscus pusillus</i> Thunb. | |
| <i>Hibiscus sulfuranthus</i> Ulbr. | E |
| <i>Hilliardiella oligocephala</i> (DC.) H.Rob. | |
| <i>Hirpicium gazanioides</i> (Harv.) Roessl. | |
| <i>Hoffmannseggia burchellii</i> (DC.) Benth. ex Oliv. subsp. <i>burchellii</i> | |
| <i>Hyparrhenia hirta</i> (L.) Stapf | |
| <i>Hypertelis salsoloides</i> (Burch.) Adamson var. <i>salsoloides</i> | |
| <i>Hypoestes forskalii</i> (Vahl) R.Br. | |
| <i>Hypoxis obtusa</i> Ker Gawl. | |
| <i>Indigofera alternans</i> DC. | |
| <i>Indigofera colutea</i> (Burm.f.) Merr. var. <i>colutea</i> | |
| <i>Indigofera damarana</i> Merxm. & A. Schreiber | |
| <i>Indigofera heterotricha</i> DC. | |
| <i>Indigofera vicioides</i> Jaub.& Spach var. <i>vicioides</i> | |
| <i>Ipomoea holubii</i> Baker | |
| <i>Ipomoea obscura</i> (L.) KerGawl. var. <i>obscura</i> | |
| <i>Ipomoea oenotheroides</i> (L.f.) Raf ex Hallier f. | |
| <i>Ipomoea sinensis</i> (Desr.) Choisy subsp. <i>sinensis</i> | |
| <i>Jamesbrittenia lyperioides</i> (Engl.) Hill. | E |
| <i>Kalanchoe brachyloba</i> Welw. ex Britten | |
| <i>Kyllinga alba</i> Nees | |
| <i>Kyllinga welwitschii</i> Ridley | |
| <i>Kyphocarpa angustifolia</i> (Moq.)Lopr. | |
| <i>Laggera decurrens</i> (Vahl) Hepper & J.R.I.Wood | |
| <i>Lantana dinteri</i> Moldenke | E |
| <i>Leonotis ocymifolia</i> (Burm.f.) Iwarsson var. <i>raineriana</i> | |
| <i>Limeum argute-carinatum</i> Warwa & Peyr. var. <i>argute-carinatum</i> | |
| <i>Limeum fenestratum</i> (Fenzl) Heim. var. <i>fenestratum</i> | |
| <i>Limeum sulcatum</i> (Klotzsch) Hutch. var. <i>sulcatum</i> | |
| <i>Lycium bosciifolium</i> Schinz | |
| <i>Lycium eenii</i> S.Moore | E |
| <i>Manuleopsis dinteri</i> Thell. | E |
| <i>Melhanian damarana</i> Harv. | |

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| <i>Melianthus comosus</i> Vahl | |
| <i>Melinis repens</i> (Willd.) Zizka subsp. <i>repens</i> | |
| <i>Mollugo cerviana</i> (L.) Ser.ex DC. var. <i>cerviana</i> | |
| <i>Monechma divaricatum</i> (Nees) C.B.Clarke | |
| <i>Monelytrum luederitzianum</i> Hack. | |
| <i>Monsonia angustifolia</i> E.Mey. ex A. Rich. | |
| <i>Monsonia burkeana</i> Planch. ex Harv. | |
| <i>Monsonia glauca</i> Knuth | |
| <i>Moraea polystachya</i> (Thunb.) Ker Gawl. | |
| <i>Nelsia quadrangula</i> (Engl.) Schinz | |
| <i>Nidorella resedifolia</i> DC. subsp. <i>resedifolia</i> | |
| <i>Ocimum americanum</i> L. var. <i>americanum</i> | |
| <i>Olea europaea</i> L. subsp. <i>africana</i> (Mill.) P.S.Green | |
| <i>Ornithoglossum vulgare</i> B.Nord. | |
| <i>Oropetium capense</i> Stapf | |
| <i>Osteospermum montanum</i> Klatt | E |
| <i>Osteospermum muricatum</i> E. Mey. Ex DC subsp. <i>muricatum</i> | |
| <i>Osyris lanceolata</i> Hochst. & Steud. | |
| <i>Otoptera burchellii</i> DC. | |
| <i>Oxalis depressa</i> Eckl. & Zeyh. | |
| <i>Oxalis purpurascens</i> Salter | |
| <i>Oxygonum alatum</i> Burch. var. <i>alatum</i> | |
| <i>Pavonia burchellii</i> (DC.) R.A. Dyer | |
| <i>Pegolettia retrofracta</i> (Thunb.) Kies | |
| <i>Pellaea calomelanos</i> (Sw.) Link var. <i>calomelanos</i> | |
| <i>Pennisetum foermeranum</i> Leeke | NE |
| <i>Pentarrhinum insipidum</i> E.Meyer | |
| <i>Peucedanum upingtoniae</i> (Schinz) Drude | |
| <i>Phyllanthus pentandrus</i> Schumach. & Thonn. | |
| <i>Plectranthus hereroensis</i> Engl. | |
| <i>Pogonarthria squarrosa</i> (Roem.& Schul.) Pilg. | |
| <i>Pollichia campestris</i> Aiton | |
| <i>Polydora poskeana</i> (Vatke & Hildebr.) H.Rob. sens lat | |
| <i>Polygala uncinata</i> E.Mey. ex Meisn. | |
| <i>Pseudogaltonia clavata</i> (Mast.) E. Phillips | |
| <i>Pupalia lappacea</i> (L.) A.Juss. var. <i>lappacea</i> | i |
| <i>Rhynchosia totta</i> (Thunb.) DC var. <i>totta</i> | |
| <i>Rumex sagittatus</i> Thunb. | |
| <i>Schkuhria pinnata</i> (Lam.) Kuntze ex Thell. | i |
| <i>Schmidtia pappophoroides</i> Steud. | |
| <i>Searsia lancea</i> (L.f.) F.A.Barkley | |
| <i>Searsia marlothii</i> (Engl.) Moffett | |
| <i>Searsia tenuinervis</i> (Engl.) Moffett | |
| <i>Selago alopecuroides</i> Rolfe | |
| <i>Sesamum capense</i> Burm.f. | |
| <i>Sida chrysantha</i> Ulbr. | |
| <i>Solanum delagoense</i> Dunal | |
| <i>Solanum incanum</i> L. | i |
| <i>Solanum multiglandulosum</i> Bitter | |
| <i>Sporobolus fimbriatus</i> (Trin.) Nees | |
| <i>Sutera patriotica</i> Hiern | |
| <i>Tagetes minuta</i> L. | i |
| <i>Talinum cafferum</i> (Thunb.) Eckl. & Zeyh. | |
| <i>Tarchonanthus camphoratus</i> L. | |

Tephrosia rhodesica Bak. fil. var. *rhodesica*
Tetragonia calycina Fenzl
Themeda triandra Forssk.
Thesium xerophyticum A.W.Hill E
Tragus racemosus (L.) All.
Tribulus terrestris L.
Tribulus zeyheri Sond. subsp. *zeyheri*
Tricholaena monachne (Trin.) Stapf & C.E.Hubb.
Trochomeria macrocarpa (Sonder) Hook.f. subsp. *vitifolia*
Urochloa brachyura (Hack.) Stapf
Ursinia nana DC. subsp. *nana*
Wahlenbergia denticulata (Burch.) A. DC.
Ziziphus mucronata Willd. subsp. *mucronata*

An overview of grass species used for thatching in the Zambezi, Kavango East and Kavango West Regions, Namibia

Ben J. Strohbach¹ & H.J.A. (Wally) Walters²

¹School of Natural Resources and Spatial Sciences, Polytechnic of Namibia
P/Bag 13388
Windhoek
Namibia
E-mail: bstrohbach@polytechnic.edu.na

²Oshikango Thatching and Building cc
P. O. Box 6058
Uniedal
7612
Stellenbosch
South Africa

Abstract

The trade with indigenous plant products has increased over the past years, contributing considerable to the household economies of rural people. Likewise, the trade with thatch grasses in north eastern Namibia has grown to a multi-million dollar industry, with a considerable amount being exported to neighbouring Angola. However, confusion still exists as to which grass species are harvested, where they grow, and in what quantities. With this paper, the main thatching species, Eragrostis pallens, Cymbopogon caesius and Hyperthelia dissoluta, together with other potential thatching species, are shortly described according to characteristics important for the thatching industry. Recommendations are made to improve the sustainability of the industry.

Key words: *Cymbopogon caesius, Eragrostis pallens, Hyperthelia dissoluta*, indigenous plant product trade, thatch grass, thatch quality

Introduction

The indigenous plant product sector has developed in recent years to become an important contributor to income generation in the rural economies of Namibia (Cole 2014). The thatch grass industry is but one of these: An annual sales volume of 1.2 million bundles is estimated for the Kavango, and in many years the demand is greater than the supply. Thatch grass is sold at between N\$7 and N\$10 per bundle by the local harvesters (Walters 2014). A project is currently initiated by the Ministry of Trade and Industry (MTI), through the Namibia Development Corporation (NDC), to establish a thatch grass hub in Rundu, with the aim to formalise and stabilize the trade with thatch grass in the north-eastern Regions of Namibia (NDC 2013).

Considerable confusion exists on the species used for thatching, with e.g. *Aristida stipitata* (a short, much-branched grass) being praised as a prime thatching grass under the name 'nangondwe' (cf. NDC 2013; Walters 2014). Such confusion can be attributed to the initial incorrect capturing of local names during specimen collection for herbarium purposes, and was over time multiplied in various publications taken as authoritative for the Namibian Flora (Müller 1984, 2007; Klaassen & Craven 2003; Craven & Kolberg 2012). In many cases, the grasses are only known by their local names, or an incomplete identification (e.g. Gunson 1999).

At the same time, the habitat of the grasses in question, as well as the abundance/availability of these, is greatly unknown. Identification guides (Gibbs Russell *et al.* 1990; van Oudtshoorn 1999; Müller 2007) generally provide only a very sketchy overview of the habitat, whilst vegetation descriptions aim at giving a general description of dominant and characteristic species as well as structure of the vegetation, rather than the full composition and abundance of species (e.g. De Sousa Correia & Bredenkamp 1986; Burke 2002; Strohbach & Petersen 2007; Lushetile 2009; Strohbach 2013a, 2014). In many cases, including the Zambezi Region, only an overview description is available, lacking detailed phytosociological descriptions (Mendelsohn & Roberts 1997; Burke & Strohbach 2000; Strohbach 2001; Mendelsohn & el Obeid 2003).

The purpose of this study was to ascertain the identification of thatch grasses collected, sold and used in the Kavango West, East and Zambezi Regions, and to present some basic characteristics of these grasses. Furthermore, general comments and recommendations towards the development of a sustainable thatch grass industry are presented.

Natural Environment

Eastern and especially north-eastern Namibia are dominated by sands of the Kalahari basin. Riverine systems of the Okavango, Kwando, Zambezi and Chobe River systems locally define the landscape (Mendelsohn & Roberts 1997; Mendelsohn *et al.* 2002; Mendelsohn & el Obeid 2003, 2004).

In the Kavango West and East Regions, the Okavango River forms a deep ravine cutting through the landscape (Schneider 1986; Gröngroft 2013; Strohbach 2013a). Most of the population lives near the Okavango River, with easy access to water, and natural resources provided by the riverine and wetland ecosystems (Mendelsohn & el Obeid 2003). The thatching grass industry developed along the B8 tarmac road towards Rundu as well as nearby Divundu (Walters 2014). The people living here are more impoverished than those living along the river, and are highly dependent on living from various forest products (timber as well as non-timber products). Here the main habitat for collecting thatch grasses is the Kavango woodlands. Detailed descriptions of this vegetation are presented by De Sousa Correia & Bredenkamp (1986), Burke (2002), Strohbach & Petersen (2007) and Strohbach (2013). The Bwabwata National Park, now entirely part of the Kavango East Region, is covered by a dune - interdune mosaic with Kavango woodlands (Mendelsohn & Roberts 1997).

The Zambezi Region is strongly influenced by the riverine systems of the Kwando, Zambezi and Chobe Rivers. These form extensive floodplain systems in the eastern and southern parts of the Region. Only the far northern part of this Region is dominated by pure Kalahari sands with associated woodlands. The central parts (between Kongola and Katima Mulilo) form a transition between these Kalahari sands and the wetland systems, and are dominated by various forms of Mopane savanna. Only limited detailed vegetation descriptions, mainly of the Kalahari Woodlands at Sachinga Livestock Development Centre, are available (Lushetile 2009).

Thatch quality characteristics

No formal quality criteria exist for thatch grass or thatch reed (Long 1978; Horn 2006). The length of the culm would be an obvious criteria; for Cape thatching reed (*Thamnochortus* spp.) a culm length of 2 m is regarded as a standard quality characteristic (Horn 2006). The durability of the thatch is considered as a major factor by owners and producers, and is

influenced by the hardness of the culm, the ripeness of the culms at the time of harvesting, but also chemical components like tannins (Van Voorthuizen & Odell 1976; Horn 2006).

During discussions with several harvesters, but also with other stakeholders, the following possible criteria for thatch grass quality were developed:

Length

Grass culms are to be at least 1 m long, preferably longer than 1.5 m

Diameter

Extremely thin culms would mean a lot more material need to be collected. Thinner culms also have a higher surface: volume ratio, resulting in a higher risk for fungal attack and rotting. Thick culms, on the other hand, would mean less effective water-proofing, requiring a thicker thatch layer.

Straightness of the culms

The straighter, the easier to thatch with. Bent, knotty or branching culms are unsuitable for effective thatching.

Is the culm hollow or not?

Hollow culms can easily be flattened, or can splinter and break. This will make the roof loose, and highly susceptible for rot or loss of material. Related to this would be factors like how easily the culm bends or breaks, as well as the general hardness (degree of lignification) of the culm. Especially snapping at nodes has been observed at some species.

Does the culm contain essential oils or not?

From observations and anecdotal evidence by the harvesters it became evident that e.g. *Cymbopogon excavatus* provides a highly durable thatch, most likely due to the fact that it contains essential oils. These essential oils are also insect-repelling (Bissinger & Roe 2010; Nerio *et al.* 2010; Maia & Moore 2011; Kalita *et al.* 2013).

Methods

During a field visit between 13 and 17 May 2015, a large number of thatch grass collectors were visited in the Zambezi, Kavango East and Kavango West Regions. At each collector, available grass bundles were inspected and the different species collected identified. For this purpose, samples were taken and pressed for further identification in the National Herbarium of Namibia (WIND). Identification in the herbarium was done with the aid of the available collection, as well as standard reference books available (Merxmüller 1966; Launert 1971; Gibbs Russell *et al.* 1990; Müller 2007).

Whilst inspecting the grass bundles, the collectors were asked for the vernacular names of different grasses found in the bundles. In many cases, they were also asked to point out these grasses in the veld. Questions were also asked regarding the availability of these grasses, the quality of these grasses and preferences for use.

Additional information to the grass species, including English (E), Afrikaans (A), Silozi (L), Rukwangali (R), Shishambyu (Sh) and Thimbukushu (T) vernacular names, were obtained from the literature (Klaassen & Craven 2003; Müller 2007; Craven & Kolberg 2012; Clayton *et al.* 2014). Care was taken that the vernacular names provided by the literature did not contradict names provided by the collectors in this report. Abundance and distribution data (as far as available) was obtained from the Namibian phytosociological database (Strohbach & Kangombe 2012), in particular sub data sets collected/used for Strohbach & Petersen (2007), Lushetile (2009) and Strohbach (2011, 2012, 2013a).

For a number of species a few culms were harvested and dried in an oven at 50°C. After drying, the diameter of these culms was determined with the aid of a veneer calliper. For this

purpose, repeat measurements were done on the internodes of several sections of these culms. In several cases, where no samples were taken, measurements were taken from specimens at the National Herbarium of Namibia.

Grass species used for thatching

Several grass species have been indicated in the past as thatching species from the north-eastern parts of Namibia. Not all are suitable or actually used as thatch. In the discussion below, these species are discussed in relation to some of the basic characteristics important for the thatching industry. A comparison of culm diameter is presented in Figure 1. Nomenclature follows Klaassen & Kwembeya (2013).

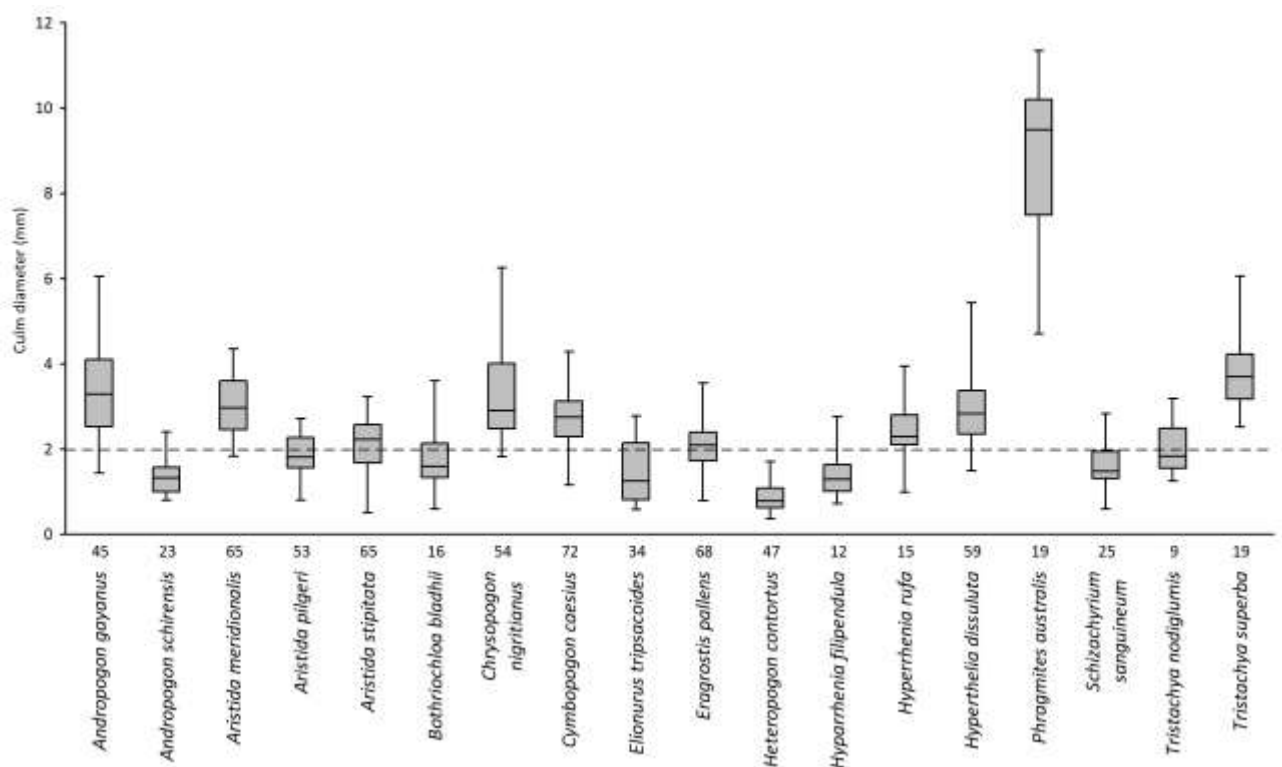


Figure 1. Comparative culm diameter of 18 grass species used for thatching purposes in Kavango West, East and Zambezi Regions. The number of measured samples is indicated next to the x axis, before the species name. The dotted line at 2 mm diameter indicates an arbitrary ideal minimum culm thickness for thatching.

Andropogon gayanus

Blue-grass (E); ngumbe (Sh); nengere (T)

Perennial grass, up to 3.6 m high. The culm diameter ranges between 1.4 and 6.1 mm, averaging at 3.4 mm (± 1.08 mm) (measured on herbarium specimens).

The straight culms are used by San for arrow shafts (Müller 2007). It has been found occasionally on heavier soils, often associated with calcrete, but never at great abundance (Strohbach & Petersen 2007; Strohbach 2013a). It has not been reported by Lushetile (2009).

This grass was very seldom found in collected bundles in the Zambezi Region, and is generally not exploited for thatch.

Andropogon schirensis

hairy blue-grass (E)

Perennial grass, with unbranched culms, ca 1.8 m high (Müller 2007). Culm diameter ranges between 0.8 and 2.4 mm, averaging at 1.4 mm (± 0.41 mm) (based on herbarium specimens).

Often confused with the branching *Andropogon chinensis* (Figures 2a & b). It has not been reported by Lushetile (2009).

This grass is seldom seen and was only occasionally found in the collected bundles in the Zambezi Region. It is generally not targeted as a grass for collection as thatch.



Figures 2a & b. Inflorescence (left) and habitat (right) of *Andropogon schirensis*.

Aristida meridionalis

Giant bristle-grass (E); leeusteeekgrass (A)

Tufted perennial, with basal leaves, up to 2 m high (Müller 2007). Average observed height is ca 1.5 m. The culm is remarkably straight, unbranched with a very smooth appearance (Figure 3). Culm diameter ranges between 1.8 and 4.4 mm, averaging at 3.1 mm (± 0.68 mm). In the field it was observed that the culm easily snaps at the nodes.

Aristida meridionalis occurs widespread in sandy and loamy soils, often in dense patches, but is not dominant (Lushetile 2009; Strohbach 2013a). A considerable amount of this species was observed along the road verges in Zambezi Region and to a lesser extend in Kavango East, Kavango West and Otjizondjupa Regions.

This grass is not harvested for thatch.



Figures 3 a & b. Inflorescence (left) and habitat (right) of *Aristida meridionalis*.

Aristida pilgeri

Pilger's bristle-grass (E); murkankumbu (T)

A tufted perennial grass, with unbranched culms ca 1.5 m tall (Müller 2007) (Figures 4a & b). Culms range between 0.8 and 2.7 mm in diameter, averaging at 1.9 mm diameter (± 0.45 mm). The grass is regarded as a very brittle grass, easily breaking when trampled (Müller 2007).

Aristida pilgeri occurs occasionally in sandy soils, often washed sandy soils of *omirimbi* or on dry floodplains, but never in great abundance (Strohbach 2011, 2012, 2013a).

The grass is occasionally harvested for thatch in the Zambezi and Kavango East Regions, but not in great quantities.



Figures 4a & b. Inflorescence (left) and habitat (right) of *Aristida pilgeri*.

Aristida stipitata

Dune/sandveld bristle-grass (E); tjoke-tjoke (R)

This species is incorrectly referred to as 'nangondwe' in current literature (Klaassen & Craven 2003; Müller 2007; Craven & Kolberg 2012).

A much-branched, woody grass, referred to as perennial in the literature (Gibbs Russell *et al.* 1990; Müller 2007), but generally assumed to be annual (Strohbach & Strohbach 2004; Strohbach 2013b). The many branches result in a strongly zigzagged culm, up to 0.6 m tall (Figures 5a & b). Culm diameter ranges between 0.5 and 3.2 mm, averaging at 2.1 mm (\pm 0.58 mm).

Aristida stipitata is a wide-spread pioneer species in especially the sandy soils of the Kalahari basin in eastern and north-eastern Namibia. It often dominates under over-grazed conditions (Strohbach & Strohbach 2004; Strohbach & Petersen 2007; Strohbach 2013a, 2014).

Due to its short growth, and much-branched culms, it is not regarded as a good thatching grass. However, the woodiness of the culms, and the ease of collecting it in great quantities, makes it a much-used grass for covering temporary shelters, even hut roofs, by the local population in Kavango East and West Regions. The grass is packed onto the roof in dense mats, rather than properly thatched.



Figures 5a & b. Inflorescence (left) and habitat (right) of *Aristida stipitata*. Habit picture from the Dordabis area.

Bothriochloa bladhii

Smelly grass (E); vleistinkgras (A); namunuka (L)

A tufted perennial grass, often with bent culms, up to 1.5 m tall (Gibbs Russell *et al.* 1990; Müller 2007; Clayton *et al.* 2014) (Figures 6a & b). Culm diameter ranges between 0.6 and 3.6 mm, averaging at 1.8 mm (± 0.78 mm) (based on herbarium specimens). The leaves have a strong phenolic smell when rubbed, indicating a possible resistance to rotting in the culm. Due to its smell, the grass is generally regarded as unpalatable to grazers (Müller 2007).

Bothriochloa spp. is known to occur in water-logged soils like vleys and pans. They however avoid standing water (Müller 2007). Their distribution is thus patchy, localized, but very dense in such patches. It has not been reported by Lushetile (2009).

This species has been reported to be used for thatching at Ibbu village in the southern Zambezi Region. It was not observed in any grass bundles for sale.



Figures 6 a & b. Inflorescence (left) and habitat (right) of *Bothriochloa bladhii*.

Chrysopogon nigritanus

(synonym: *Vetiveria nigritiana*)

Vetiver (E); sivamba (L), iskaka, zikaka

A tufted perennial grass, growing to 2 - 3 m tall (Gibbs Russell *et al.* 1990; Clayton *et al.* 2014). The culms are unbranched, and on average 3.4 mm in diameter (± 1.23 mm) (range: 1.8 - 6.3 mm) (Figures 7a & b).

Chrysopogon nigritanus is a wetland grass species, growing on fringes of inundated floodplains and in shallow water. It forms a valuable winter grazing once the floods have receded. During the flooding period it forms part of the refuge for fish fry and for species breeding on these seasonally inundated floodplains and is thus a keystone species in these aquatic ecosystems (Bethune 1991).

This species is used for thatch and palisades mostly by people living close to the Okavango River in the Kavango East and West Regions. It is not sold commercially, and should, due to its keystone function in the aquatic ecosystem, also not be commercially developed as thatch grass.



Figures 7a & b. Inflorescence (left) and habitat (right) of *Chrysopogon nigritanus*.

Cymbopogon caesius

(synonym: *Cymbopogon excavatus*)

Broad-leaved turpentine grass (E); kasisi (L)

A tussocky, tufted perennial, with many broad leaves along the culm. The culms generally grow up to 1.5 m tall (Müller 2007; Clayton *et al.* 2014), but have been observed along road verges to reach up to 1.8 to 2 m height (Figures 8a-d). The culm diameter ranges between 1.2 and 4.3 mm, averaging at 2.7 mm (± 0.64 mm). The genus *Cymbopogon* is known for its essential oil content (an oil similar to citronella oil), which is strongly insect-repelling (Nerio *et al.* 2010; Maia & Moore 2011; Kalita *et al.* 2013; Rehman *et al.* 2014).

Cymbopogon caesius occurs occasionally in the veld, never at high quantities (Lushetile 2009). It was observed in patches along the road verges. According to local grass harvesters in the Zambezi Region, it occurs in abundance in the southern parts of this Region, most likely in the Liambezi-Linyanti grasslands (Mendelsohn & Roberts 1997). This could not be ascertained during the field visit.

Kasisi has been described as a long-lasting, high quality thatching grass by the local community. It does not seem to be generally available in the thatch industry market – likely as a result of restricted availability and high local demand. A thatched roof at Omega (in the Bwabwata National Park) was said to have lasted for well over 30 years, before recently being replaced by a tin roof. The grass material which was taken from the roof indicated a 50/50 mixture of *kasisi* (*Cymbopogon caesius*) and *mahengehenge* (*Hyperthelia dissoluta*). It seemed that the essential oils in *Cymbopogon caesius* helped to prevent rot including the other grass culms in the mixture.

Should the production of thatch grass from *Cymbopogon caesius* be further developed, the possibility to harvest the leaves, and produce oil similar to citronella oil as a by-product should be investigated. As this grass does not seem to occur in great abundance, it should be investigated whether this species can be planted for commercial production, making use of numerous fallow fields in the area.





Figure 8. Inflorescence (a and b) and habitat (c) of *Cymbopogon caesius*. (b) Inflorescence as it appears stripped and is found in thatching bundles. (d) A roof of a hut at Ibbu being thatched with *kasisi* (*Cymbopogon caesius*).

Elionurus tripsacoides

A tufted perennial grass, ca 1.2 to 1.5 m tall (Clayton *et al.* 2014). The culm diameter ranges between 0.6 and 2.8 mm, averaging at 1.5 mm (± 0.69 mm) (measured on herbarium specimens). This species occurs occasionally in the deep sandy soils of the Kavango woodlands (Strohbach & Strohbach 2004) (Figures 9a & b). No record is known from the Zambezi Region (Lushetile 2009), but it is likely to occur here.

Elionurus tripsacoides has been found once in a mixed bundle of thatch for sale near Katima Mulio, but does not seem to be generally harvested for thatch.



Figures 9a & b. Inflorescence (left) and habitat (right) of *Elionurus tripsacoides*.

Eragrostis pallens

Broom grass (E); besemgras (A); nangondwe (R)

A tall, densely tufted perennial grass, growing to between 1.5 and 1.8 m tall. The culms are straight and unbranched (Müller 2007; Clayton *et al.* 2014) (Figures 10a-d). Culm diameter ranges between 0.8 and 3.6 mm, averaging at 2.1 mm (± 0.53 mm).

Eragrostis pallens is a wide-spread grass in the Kavango woodlands (Strohbach & Strohbach 2004; Strohbach & Petersen 2007; Strohbach 2013a), but never in dense stands. It has also been reported from the Zambezi Region (Lushetile 2009; Strohbach 2011, 2012), as well as from further south in the Kalahari ecosystems (Strohbach 2013b, 2014). The fact that this grass occurs wide-spread means that there is a considerable resource available; at the same time, due to its low density, it also means a considerable effort to walk to collect these grasses.

Nandongwe (*Eragrostis pallens*) is harvested as the prime thatching grass in the Kavango East and West Regions (including San communities in the Bwabwata National Park). It has also been reported as one of the main thatching grasses of northern Botswana in the sandy areas (Van Voorthuizen & Odell 1976). It is not harvested in Zambezi Region at all. The local population in Kavango also do not use this grass for thatching as this grass can be sold, and is thus more important as a source of income than to be used as building material.

Harvesting of this species starts as early as April each year, continuing to late winter, even spring (July to NOVEMBER). Of great concern is the fact that the grass is still green in April and May (being the bulk harvesting season), meaning that both the culms and the seeds have not ripened fully at the time of harvesting. The unripe culms mean that lignification of the cells has not been completed, making the grass soft and potentially susceptible to easy rotting (Van Voorthuizen & Odell 1976; Dabo *et al.* 1997). Unripe seeds mean that these (a) do not fall easily from the inflorescence when harvesting, and (b) are basically unripe and likely not viable for germination during the next season.

As this grass forms the bulk of the thatch grass industry in Namibia, and is also exported to neighbouring Angola, it should be investigated whether it is not feasible to cultivate this grass. For this purpose fallow (or abandoned) fields on the upper river terrace (with nutrient-poor sandy soils) could be utilised.



Figures 10a & b. Inflorescence and habitat of *Eragrostis pallens* (a & b). (c) Cleaning of nangondwe bundles at Omega; (d) Approximately 700 bundles of nangondwe (*Eragrostis pallens*) ready for sale along the B8 tarmac road to Divundu.

Heteropogon contortus

Spear grass (E); assegaaigras (A); ehege hege (R)

A short tufted, perennial grass, growing ca to 50 cm tall (Müller 2007). The culms are generally straight, but depending on genotype and age of grass, could be branched. Culm diameter ranges between 0.4 and 1.7 mm, averaging at 0.9 mm (± 0.32 mm).

Heteropogon contortus occurs widespread and in great densities along the roads in the Zambezi Region. The species occurs also in the Kavango Regions, mainly in loamy soils. However, it is not common in the veld, neither in the Zambezi nor the Kavango Regions (Strohbach & Strohbach 2004; Strohbach & Petersen 2007; Lushetile 2009; Strohbach 2011, 2013a).

As the grass leaves are more or less as long as the culms (up to 30 cm long), the culms cannot be cleanly cut without a large number of grass leaves. The very short and very thin culms are also not very suitable for thatching. The species is not used by the local population for thatching purposes.

Hyparrhenia filipendula

Fine Thatching Grass (E); fyn tamboekiegras (A); tengenya (L)

An upright, perennial grass, ca 1.5 to 1.8 m tall. Culm diameter ranges between 0.7 and 2.8 mm, averaging at 1.4 mm (± 0.54 mm) (measured on herbarium specimens). It is of limited distribution in the Zambezi Region and mainly associated with the floodplain areas around (especially to the south) Lake Liambezi (Strohbach 2011) and occasionally also along road verges.

It is not known to be used as a thatch grass in the Zambezi Region.

Hyparrhenia rufa

Yellow-spike thatching grass (E); geelaar tamboekiegras (A); mutenganya (L), latenganya

A tall, perennial grass, growing between 2 and 3 m tall. The culms are generally straight and unbranched (Müller 2007) (Figures 11a & b). Culm diameter ranges between 1.0 and 4.0 mm, averaging at 2.4 mm (± 0.77 mm). This species is easily confused with *Hyperthelia dissoluta*.

Like *H. filipendula*, this grass is limited to the heavier soils in the southern Zambezi Region around Lake Liambezi, possibly also within the Liambezi-Linyanti grasslands (Mendelsohn & Roberts 1997). It occurs at higher abundance than *H. filipendula*, but is still not wide-spread. Because of its length and relative higher abundance, it is used occasionally for thatch, although limited.



Figures 11a & b. Inflorescence (left) and habitat (right) of *Hyparrhenia rufa*.

Hyperthelia dissoluta

Yellow thatching grass (E); geel tamboekiegras (A); tengere (R), mahengehenge (L)

A tall, perennial grass, growing between 2 and 3 m tall. The culms are generally straight and unbranched (Müller 2007) (Figures 12a & b). Culm diameter ranges between 1.0 and 5.4 mm, averaging at 2.9 mm (± 0.70 mm). This species is easily confused with *Hyparrhenia rufa*.

Hyperthelia dissoluta occurs widespread, often at high densities, along road verges throughout Zambezi, Kavango East and West as well as Otjozondjupa Regions. Within the Kavango, it is often limited to the lower parts of the landscape in/nearby *omirimbi*, etc., indicating that this species favours heavier loamy soils rather than the pure sands of the Kalahari. Its abundance in the veld could not be ascertained. It has not been reported by Lushetile (2009) and infrequently by Strohbach (2011).

H. dissoluta (*Mahengehenge*) is collected widespread throughout the Zambezi Region, and is the main commercial thatch species in this Region. From a quality point of view, however, it is not highly regarded by the local population as it does not last as long as *Cymbopogon caesius* (*kasisi*).



Figures 12a & b. Inflorescence (top) and habitat (bottom) of *Hyperthelia dissoluta*.

Phragmites australis

Common reed (E); mbu (R)

A bamboo-like species (also belonging to the Poaceae, or grass family), the common reed grows in shallow water along the margins of the Kavango River and other permanent rivers like the Zambezi and Chobe mostly in areas which are more or less permanently inundated (Strohbach 2013a). It grows between 3 and 4 m tall, and the hollow culm ranges between 4.7 and 11.3 mm in diameter (Figure 13). Average culm diameter is 8.7 mm (± 1.95 mm). A related species, *Phragmites mauritanica*, also occurs here, but is less common, generally shorter and the culms are not as straight (more geniculate).

Phragmites australis is generally not used for thatch, but rather for palisades around huts, due to its length. The very thick culm means that water proofing with this species is difficult, requiring an extra thick layer of material for effective thatching. The culms are hollow, meaning that they splinter easily, or collapse if tightened too hard on a thatch roof.

Another concern is that the reed beds in the Kavango, Zambezi and Chobe Rivers are the breeding grounds for fish in these aquatic ecosystems and reducing this will mean a reduced fish population, which is under threat by overfishing (Bethune 1991; Hay *et al.* 1996).



Figure 13. Habitat of *Phragmites australis*.

Schizachyrium sanguineum

Red autumn grass (E)

A slender, perennial grass, ca 1.2 m tall (Müller 2007). The grass has a conspicuous copper-red to maroon appearance (Figure 14). The culms range in diameter between 0.6 and 2.8 mm, averaging at 1.6 mm (± 0.56 mm) (measured on herbarium specimens).

The distribution is limited to the moister, loamier soils near riverine systems in the Zambezi Region. The abundance of this grass could not be established. It has occasionally been found in bundles of thatch grass (mixed thatch) near Linyanti.



Figure 14. Inflorescence of *Schizachyrium sanguineum*.

Tristachya nodiglumis

Mwange, mwangetonga

A tufted perennial grass, growing between 0.6 and 2 m tall (mostly below 1.5 m) (Clayton *et al.* 2014) (Figure 15). The culm diameter ranges between 1.3 and 3.2 mm, averaging at 2.0 mm (± 0.69 mm) (measured on herbarium specimens). The culm is hollow.

Tristachya nodiglumis has been observed on sandy soils within the Mopane habitats in the Zambezi Region. The habitat preferences and abundance of this species could not be determined during the field trip. This grass has been found a number of times in bundles collected near the Gunkwe mulapos in Central Zambezi, as well as the Kwando valley woodlands of the western Zambezi Region.



Figure 15. Inflorescence of *Tristachya nodiglumis* as seen in the thatch bundles.

Tristachya superba

Giant russet grass (E)

A tufted perennial grass, with culms growing up to 2.5 m tall (Clayton *et al.* 2014). The culms are very straight, generally leafless and hollow (Figures 16a-c). The culm diameter ranges between 2.5 and 6.1 mm, averaging at 3.8 mm (± 0.95 mm) (measured on herbarium specimens).

Tristachya superba occurs in the Kavango woodland habitats on very sandy soils. It is widespread, but less abundant than *Eragrostis pallens*. This grass is used for making sleeping mats and as drinking straws by the local communities around Omega. It is generally not used as thatch.



Figures 16a-c. Inflorescence (top) and habitat (middle) of *Tristachya superba* (a and b) and examples of sleeping mats made with this grass species (bottom).

General observations

Grass quality

Most grass species have a culm diameter of between 2 and 4 mm, and are thus relatively thin compared to the industry standard of between 3 and 4 mm (Long 1978; CSIR 1998; Horn 2006). *Andropogon schirensis*, *Aristida pilgeri*, *Bothriochloa bladhii*, *Elionurus tripsacoides*, *Heteropogon contortus*, *Hyparrhenia filipendula*, *Schizachyrium sanguineum* and *Tristachya nodiglumis* are very thin (mostly <2 mm diameter), whilst *Phragmites australis* is extremely thick (Figure 1). *Andropogon gayanus*, *Chrysopogon nigritanus* and *Tristachya superba* have a very broad range of culm thickness (varying on a single culm), thus making them relative unsuitable for thatching purposes. *Aristida stipitata* and *Heteropogon contortus* are also too short for thatching and *Aristida stipitata* is also heavily branched without straight culms.

The strength of the culms could not be tested within the scope of this paper. In terms of general observations, it is felt that *Eragrostis pallens* is harvested too early in the season (it is still green at the time of harvesting), indicating that lignification of the culm has likely not been completed. This makes the culm weak, weaker than what it could have been. A longer growth/ripening period for this grass will possibly also result in somewhat thicker culms – many of the harvested material was less than 2 mm in diameter. *Aristida pilgeri* is known to be a brittle grass (Müller 2007), making it also potentially unsuitable for thatching. A similar tendency has been observed from *Aristida meridionalis*, which is not used for thatching at all by the local community.

Harvesting practises

In most cases, the grass is cut with a sickle. In some cases, grasses with roots attached were found in the grass bundles, which is an unsustainable practise (Figures 17a & b).

During interviews with the harvesters, it was indicated that the harvesting is done very low, just above ground level. This, coupled to the fact that harvesting in the Kavango Region starts very early during the season (during mid April), is potentially also an unsustainable practise. Perennial grasses store their nutrients in rhizomes and roots near or below the soil surface during the dry season. With the onset of the rainy season, these nutrients are released and can facilitate growth. As the growing season ends (normally with the onset of the first cold in May), nutrients are translocated back to the root system (Danckwerts *et al.* 1989; Tainton 1999). If harvested too early, the translocation of nutrients has not been completed (if it has started), and coupled to a very low cutting, means that the grass tuft is subject to severe defoliation equivalent to severe overgrazing. Such heavy defoliation has been proven to damage the grass sward, meaning that grass plants die (Danckwerts & Stuart-Hill 1988; Danckwerts *et al.* 1989; O'Connor 1991, 1993) and are replaced by unsuitable/unpalatable annual grasses. This is especially so for the Kavango Region, where *Aristida stipitata* could become dominant and cannot be commercially exploited for thatch (and is also used only for short-term/temporary structures by the local population).



Figures 17a & b. Unsustainable harvesting practises include (a - top) pulling out the grasses with their roots, rather than cutting the grasses with a sickle, as well as (b - bottom) harvesting these grasses too early, in an unripe stage, before seeds have fallen. Here a bundle of *Eragrostis pallens*.

Another concern of harvesting the grasses too early is the fact that the seeds are generally not ripe when harvesting. This is evident from the fact that most flower packets are still attached when cleaning commences, and many of these flower packets remain even within the cleaned grass bundles when ready for sale. This could affect propagation and production of the particular grass species while unripe seeds are also highly unlikely to germinate.

The possibility to cultivate thatch grass as an alternative crop has not yet been investigated. Cultivation of Cape dekriet (*Thamnochortus insignis*) has been successful in the southern Cape, and has in this way increased the production and sustainability of the industry dramatically (Horn 2006). Such a practise could increase the yield of high-quality grasses like *Cymbopogon caesius*, which is not known to grow in high abundances within their typical habitat. In both the Zambezi and Kavango East Regions, a number of abandoned/fallow fields are available, which can be exploited for the cultivation of such thatch grasses. In the Kavango East Region, *Eragrostis pallens* should be considered for planting, as it occurs on the nutrient-poor soils of the Kavango woodlands.

Additional, related products

Cymbopogon caesius contains an essential oil, which is likely to have insect-repelling properties. Collecting the leaf matter during thatch harvesting could potentially be used for further processing for such oil. This could develop into a considerable side-industry to the thatch industry although the feasibility of this still need to be determined, including the quality and quantity of such oils.

Many communities in the harvesting area also harvest wood in various forms – e.g. droppers, poles, fire wood are the most common timber products offered for sale in the area. The poles are mainly harvested from *Baikiaea plurijuga* (Rhodesian teak) – the preferred timber species in the area – although the poles on offer are generally short (2-3 m long) and not very straight. Droppers seem to be sourced from *Terminalia sericea* (as indicated by the intense yellow colour of the wood), and range between 1.2 and 1.5 m in length which could be suitable for fencing purposes, but are also both too short, and not straight enough, for construction purposes.

Threats

The development of the wood industry in conjunction with the thatching grass industry is viewed as highly problematic. Both *Baikiaea plurijuga* and *Pterocarpus angolensis* (teak / kiaat) are classified as near-endangered due to continuous overexploitation in Namibia (Loots 2005). Deforestation on the predominantly sandy soils could result in severe nutrient loss (specifically denitrification through the excessive heating of soil surface) (Schlesinger & Peterjohn 1991; Schlesinger & Pilmanis 1998). This in turn could lead to desertification, potentially influencing the production of grasses (not increased as by popular belief) (Schlesinger *et al.* 1990). Such processes would accelerate the ongoing desertification processes due to global climatic change, which in turn could lead to the remobilisation of the sand surface (wind erosion and wind deposition) (Thomas *et al.* 2005).

Fire is a threat to the grass harvesting industry. Several harvesters indicated that neighbouring villages threaten their grass harvesting operations when setting early fires. The fire season starts during late May/early June each year, but the most fires (and most intense fires) only occur during August and September each year (Le Roux 2011).

Recommendations

In conclusion, a number a recommendations can be made to assure the sustainable development of this industry for the benefit of the rural population. These recommendations are grouped as general recommendations, based on observations made during this study, as well as known grassland and ecosystem management principles. The second group of recommendations are recommendations for further research topics, where information needs have been identified.

General recommendations

- (i) **Register trade names, and set industry standards for these:** Three grasses have been identified as the most important grasses for thatch: *Cymbopogon caesius* (*kasisi*), *Hyperthelia dissoluta* (*mahengehenge*) and *Eragrostis pallens* (*nangondwe*). These three vernacular names lend them ideally as trade names and should be registered as such – i.e. as part of access and benefit sharing efforts (Cole 2014). At the same time, basic industry standards can be set for these – i.e. purity of the collection; specific minimum lengths of culms; harvesting standards; etc. A second obvious step would be to determine quality standards – this would be a research task to determine the quality (e.g. physical strength, durability, susceptibility to decomposition, etc.). With time, other grass species (e.g. *Hyparrhenia rufa*, *Tristachya nodiglumis*) could also be branded while mixed species bundles should be avoided as far as possible.
- (ii) **Harvesting of wetland grasses:** Harvesting of *Phragmites australis*, *Phragmites mauritanica*, *Chrysopogon nigritanus* and *Bothriochloa bladhii* should be limited and definitely not commercialised. This is recommended in order to protect the wetland habitats, and ultimately the fish resource in the river systems, which form an important protein source for the local population.
- (iii) **The trade in wood products:** This should not be encouraged. The Directorate of Forestry has a control function in this regard, but is battling to effectively implement this function due to the vastness of the area. Further commercialisation of this trade will mean that it will become difficult to control and will result in extensive desertification of the Kalahari sands. Due to their general lack in nutrients, these sands are already highly susceptible to desertification (Schlesinger *et al.* 1990; Thomas *et al.* 2005).
- (iv) **Sustainable harvesting techniques need to be implemented:** These include: (a) cutting culms with a sickle (or other mechanical means), but not pulling tufts from the soil; (b) cutting between 5 and 7 cm above the ground, not at ground level; (c) harvesting later in the season – i.e. earliest from mid-May onwards and (d) removing as many as possible seed packets at the place of cutting. With time, a community-driven monitoring system (similar as has been implemented with the devil's claw harvesting – see e.g. Strohbach 2003) should be implemented to monitor the resource availability, and to allocate harvesting areas to particular families.
- (v) **Community awareness and training of harvesters:** This is necessary to successfully implement the above recommendation, especially regarding industry standards and sustainable harvesting. This will include community capacity building in order to establish trader's associations.

Recommendations for further research

- (i) **The resource availability needs to be determined:** This includes both determining the preferred habitat of particular species, especially in the Zambezi Region, as well as quantifying the resource in terms of density and extent. A second step will be to develop a simple monitoring procedure which can be applied by the community to monitor and manage their resource.
- (ii) **The sustainability of harvesting, including seedling establishment:** This needs to be determined and is closely linked to the previous recommendation – i.e. how healthy is the grass population; how is it affected by repeated (annual)

harvesting; how well is recruitment of seedlings taking place; and how viable are seeds, especially if harvested too early?

- (iii) **Quality characteristics of different grass species needs to be determined:** This includes the average and minimum culm length with and without the inflorescence (values presented in this report are based on available literature); the culm strength in terms of bending, snapping and splintering under normal thatching procedures; as well as the susceptibility of these culms to rot and decomposition effects by sun and rain. Part of these characteristics will be regular material quality testing procedures as applied in the building industry (or at least applied to grass culms), part will be anatomical studies in order to determine the degree of lignification, and a large part will be decomposition studies both in the laboratory as well as on simulation thatch frames. It is also advisable to repeat these tests with both unripe (early harvest) and ripened (late harvest) culms.
- (iv) **The potential to mix sources, or to treat culms with specific chemicals, in order to prevent rotting and/or reduce fire risk:** Evidence from the Omega thatch roof indicates that a mixture of two grass species (including *Cymbopogon caesius* culms) considerably extended the life time of the grass roof (Figure 18). It needs to be empirically tested whether this observation is valid, and if, what the ideal mixture ratios would be to ensure maximum durability at minimal costs (considering that *Cymbopogon caesius* is presently only harvested in the southern Zambezi Region, and has thus the greatest transport cost). The use of chemicals as fire retardants on thatch roofing is still controversial, yet the technology is available. Similar chemicals will be available to prevent rot, and the grasses are in any case chemically treated to prevent the spreading of foot-and-mouth disease (Namibia Development Corporation 2013; Walters 2014). Empirical studies are needed to determine the effect of these different treatments on the durability of the grasses.
- (v) **The feasibility to establish secondary industries with essential oils from *Cymbopogon caesius*:** Essential oils derived from *Commiphora* spp. and *Colophospermum mopane* are well developed elsewhere in Namibia (Cole 2014). The fact that *Cymbopogon caesius* contains similar oils related to citronella oil is however little known in Namibia. This oil has known insect repellent properties and could lead to an important secondary industry to the thatch grass industry especially when considering that the leaves of this grass are currently treated as a waste product (and likely to be burned after cleaning of the culms).
- (vi) **The possibility to plant specific grass species, as an alternative cash crop, needs to be determined:** At present, the grass harvesting relies on cheap labour, often school children during their April/May school holidays (the reason why harvesting is starting in April already). Furthermore, these rural areas have a large impoverished jobless population; marginal fields, and no other source of income but collecting and selling grass. Due to the sparse growth of these grasses, the harvesting of grass is very slow and labour intensive. The current availability of cheap labour is bound to change over time, eventually resulting in less thatch grass available to the industry. It thus is advisable to start experimenting early with the planting of especially the high-value grasses to ensure a continued, sustainable production. The availability of land for this purpose should not be a problem, as numerous fields in marginal soils (e.g. along the river terrace of the Okavango River) are lying fallow. Planting of grass will stabilise these fallow lands again. However, the clearing of new fields for the purpose of planting thatch grass should be avoided.



Figure 18. A community hall at Omega (Bwabwata National Park) thatched with a mixture of *kasisi* and *mahengehenge* (*Cymbopogon caesius* and *Hyperthelia dissoluta*) in the 1980's. Except for loss of material due to improper maintenance, the condition of the thatch is surprisingly good.

References

- BETHUNE, S. 1991. Kavango River Wetlands. *Madoqua* 17: 77–112.
- BISSINGER, B.W. & ROE, R.M. 2010. Tick repellents: Past, present, and future. *Pestic. Biochem. Physiol.* 96: 63–79.
- BURKE, A. 2002. Present Vegetation of the Kavango. *J. Namib. Sci. Soc.* 50: 133–145.
- BURKE, A. & STROHBACH, B.J. 2000. Review: Vegetation Studies in Namibia. *Dinteria* 26: 1–24.
- CLAYTON, W.D., VORONTSOVA, M.S., HARMAN, K.T. & WILLIAMSON, H. 2014. RBG Kew: GrassBase - The Online World Grass Flora. URL <http://www.kew.org/data/grassbase/index.html>
- COLE, D. 2014. The commercialisation of indigenous natural plant products in Namibia. Venture Publications, Windhoek, Namibia.
- CRAVEN, P. & KOLBERG, H. 2012. A provisional list of local names for Namibian plants. (Unpublished report). Windhoek.
- CSIR, 1998. A Guide to Good Thatching Practice. Boutek Report, No. BOU/E9806. Division of Building and Construction Technology of the CSIR, Pretoria.
- DABO, S.M., TALIAFERRO, C.M. & COLEMAN, S.W. 1997. Anatomical and histological factors affecting the ruminal degradation of stem tissues in *Bothriochloa* species. *Anim. Feed Sci. Technol.* 67: 299–309.
- DANCKWERTS, J.E. & STUART-HILL, G.C. 1988. The effect of severe drought and management after drought on the mortality and recovery of semi-arid grassveld. *J. Grassl. Soc. South. Afr.* 5: 218–222.
- DANCKWERTS, J.E., TEAGUE, W.R. & HOBSON, F.O. 1989. Plant growth and response to defoliation. *Grazing Management: A strategy for the future*. Department Agriculture and Water Supply, Pretoria.
- DE SOUSA CORREIA, R.J. & BREDENKAMP, G.J. 1986. A reconnaissance survey of the vegetation of the Kavango, South West Africa. *J. SWA Wiss. Ges.* XL/XLI: 29–45.

- GIBBS RUSSELL, G.E., WATSON, L., KOEKEMOER, M., SMOOK, L., BARKER, N.P., ANDERSON, H.M. & DALLWITZ, M.J. 1990. Grasses of southern Africa. *Memoirs of the Botanical Survey of South Africa* No. 58. National Botanic Gardens / Botanical Research Institute, Pretoria.
- GRÖNGRÖFT, A. 2013. Mashare - Landscape. *Biodivers. Ecol.* 5: 101.
- GUNSON, K. 1999. The sustainability of use and economic valuation of wetland plant resources in the Eastern Caprivi floodplains, Namibia. University of Cape Town.
- HAY, C.J., VAN ZYL, B.J. & STEYN, G.J. 1996. A quantitative assessment of the biotic integrity of the Okavango River, Namibia, based on fish. *Water SA* 22: 263–283.
- HORN, J.A.M. 2006. Volhoubaarheid van die kommersiële benutting van inheemse dekriet (*Thamnochortus insignis*) in die Suid-Kaap. Masters Thesis, Department Agricultural Management, Nelson Mandela Metropolitan University, Port Elizabeth.
- KALITA, B., BORA, S. & SHARMA, A.K. 2013. Plant essential oils as mosquito repellent-a review. *Int. J. Res. Dev. Pharm. Life Sci.* 3: 741–747.
- KLAASSEN, E.S. & CRAVEN, P. 2003. Checklist of grasses in Namibia. Southern African Botanical Diversity Network report No. 20. National Botanical Research Institute and SABONET, Windhoek : Pretoria.
- KLAASSEN, E.S. & KWEMBEYA, E.G. (Eds.). 2013. A Checklist of Namibian Indigenous and Naturalised Plants. *Occasional Contributions* No. 5. National Botanical Research Institute, Windhoek.
- LAUNERT, E. 1971. Gramineae. *Flora Zambesiaca* 10.
- LE ROUX, J. 2011. The Effect of Land Use Practices on the Spatial and Temporal Characteristics of Savanna Fires in Namibia (Ph.D. thesis) Universitätsbibliothek der Universität Erlangen-Nürnberg, Erlangen.
- LONG, K. 1978. Introductory Guide to Thatching. National Building Research Institute of the CSIR, Pretoria.
- LOOTS, S. 2005. Red Data Book of Namibian Plants. Southern African Botanical Diversity Network Report, No. 38. SABONET, Pretoria and Windhoek.
- LUSHETILE, K. 2009. Vegetation description of Sachinga Livestock Development Centre and Surroundings, Caprivi, Namibia (B.Sc.Honours Mini Dissertation), University of Pretoria, Pretoria.
- MAIA, M.F. & MOORE, S.J. 2011. Plant-based insect repellents: a review of their efficacy, development and testing. *Malar. J.* 10: 11.
- MENDELSON, J., JARVIS, A., ROBERTS, C. & ROBERTSON, T. 2002. Atlas of Namibia. David Phillips Publishers, Cape Town.
- MENDELSON, J. & OBEID, S. EL. 2003. Sand and Water. A profile of the Kavango Region. Struik Publishers & RAISON, Cape Town & Windhoek.
- MENDELSON, J. & OBEID, S. EL. 2004. Okavango River. The flow of a lifeline. Struik Publishers & RAISON, Cape Town & Windhoek.
- MENDELSON, J. & ROBERTS, C. 1997. An environmental profile and Atlas of Caprivi. Directorate of Environmental Affairs, Namibia.
- MERXMÜLLER, H. (Ed.). 1966. Prodrum zur Flora von SWA. J. Cramer Verlag, Lehre.
- MÜLLER, M.A.N. 1984. Grasses of South West Africa/Namibia. Directorate of Agriculture and Forestry, Windhoek.
- MÜLLER, M.A.N. 2007. Grasses of Namibia, 2nd ed. Ministry of Agriculture, Water and Forestry, Windhoek.
- NAMIBIA DEVELOPMENT CORPORATION 2013. Kavango Thatch Grass & Home Industry Hub Project Document. Ministry of Trade and Industry, Windhoek.
- NERIO, L.S., OLIVERO-VERBEL, J. & STASHENKO, E. 2010. Repellent activity of essential oils: A review. *Bioresour. Technol.* 101: 372–378.
- O'CONNOR, T.G. 1991. Local Extinction in Perennial Grasslands: A Life-History Approach. *Am. Nat.* 137: 753–773.
- O'CONNOR, T.G. 1993. The influence of rainfall and grazing on the demography of some African savanna grasses: a matrix modelling approach. *J. Appl. Ecol.* 30: 119–132.

- REHMAN, J.U., ALI, A. & KHAN, I.A. 2014. Plant based products: Use and development as repellents against mosquitoes: A review. *Fitoterapia* 95: 65–74.
- SCHLESINGER, W.H. & PETERJOHN, W.T. 1991. Processes controlling ammonia volatilization from Chihuahuan Desert soils. *Soil Biol. Biochem.* 23: 637–642.
- SCHLESINGER, W.H. & PILMANIS, A.M. 1998. Plant-soil interactions in deserts. *Biogeochemistry* 42: 169–187.
- SCHLESINGER, W.H., REYNOLDS, J.F., CUNNINGHAM, G.L., HUENNEKE, L.F., JARELL, W.M., VIRGINIA, R.A. & WHITFORD, W.G. 1990. Biological feedbacks in Global Desertification. *Science* 247: 1043–1048.
- SCHNEIDER, M.B. 1986. Notes on Terrace Soils of the Kavango River, northern SWA/Namibia. *J. SWA Wiss. Ges.* XL/XLI: 199–213.
- STROHBACH, B. 2011. Environmental Impact Assessment on the proposed 330 kV Power Line from Katima Mulilo to Ngoma: Impact on the Vegetation. Unpublished report. Enviro Dynamics cc and NamPower, Windhoek.
- STROHBACH, B. 2012. Environmental Impact Assessment on the proposed irrigation scheme and water supply canal: Impact on the Vegetation. Unpublished report. Colin Christian Associates and Namibia Agriculture & Renewables, Windhoek.
- STROHBACH, B.J. 2001. Vegetation Survey of Namibia. *J. Namib. Sci. Soc.* 49: 93–124.
- STROHBACH, B.J. 2013a. Vegetation of the Okavango River valley in Kavango West, Namibia. *Biodivers. Ecol.* 5: 321–339.
- STROHBACH, B.J. 2013b. Vegetation of the Eastern Communal Conservancies in Namibia: III. Annotated checklist. *Dinteria* 33: 3–42.
- STROHBACH, B.J. 2014. Vegetation of the Eastern Communal Conservancies in Namibia: I. Phytosociological descriptions. *Koedoe - Afr. Prot. Area Conserv. Sci.* 56.
- STROHBACH, B.J. & KANGOMBE, F. 2012. National Phytosociological Database of Namibia. *Biodivers. Ecol.* 4: 298.
- STROHBACH, B.J. & PETERSEN, A. 2007. Vegetation of the central Kavango woodlands in Namibia: An example from the Mile 46 Livestock Development Centre. *South Afr. J. Bot.* 37: 391–401.
- STROHBACH, B.J. & STROHBACH, M.M. 2004. An annotated plant specieslist for the Mile 46 LDC and surrounding area in central Kavango, Namibia, with some notes on species diversity. *Dinteria* 29: 55–78.
- STROHBACH, M., 2003. National Devil's Claw Situation Analysis - Resource Survey. Internal report. CRIAA SA-DC, Windhoek.
- TAINTON, N.M. (Ed.). 1999. Veld Management in South Africa. University of Natal Press, Pietermaritzburg.
- THOMAS, D.S.G., KNIGHT, M. & WIGGS, G.F.S. 2005. Remobilization of southern African desert dune systems by twenty-first century global warming. *Nature* 435: 1218–1221.
- VAN OUDTSHOORN, F. 1999. Guide to Grasses of southern Africa, 2nd ed. Briza, Pretoria.
- VAN VOORTHUIZEN, E.G. & ODELL, M. 1976. Thatching in Botswana: The Social-Ecology of Traditional Construction. *Botsw. Notes Rec.* 165–174.
- WALTERS, H.J.A. 2014. Kavango Thatch Grass Logistics Centre Reports. Oshikango Thatching and Building cc for NDC, Windhoek / Stellenbosch.

Seed germination of Namibian woodland tree species

Vera De Cauwer & Rebecca Younan

Department of Geospatial Sciences and Technology, Polytechnic of Namibia, 13 Storch Street,
Windhoek, Namibia
E-mail: greenmap@iway.na
E-mail: younanrebecca@gmail.com

Abstract

Assisted regeneration allows for selecting desired tree qualities, such as drought resistance and good timber or fruit quality. It is also a valuable forest management tool for species with slow growth - such as most canopy tree species of northern Namibia - and limited natural regeneration, such as Pterocarpus angolensis and Guibourtia coleosperma. Few nursery experiments with dry woodland tree species from northern Namibia have been published. This study aimed to test seed treatments of six indigenous tree species to improve germination rates. The seeds were incubated in germination chambers at 30°C and 26°C to establish the effects of different temperatures on germination. In general, Dialium engleranum and G. coleosperma were found to germinate well, while Erythrophleum africanum and P. angolensis germinated moderately and Schinziophyton rautanenii poorly. Nicking of D. engleranum, E. africanum and P. angolensis was found to significantly improve these species' germination rates. Soaking was noted as an inappropriate pre-treatment for both E. africanum and P. angolensis. Surface sterilisation and other pre-treatments such as nicking and soaking decreased mean germination time of G. coleosperma seeds. Seeds of all species, except G. coleosperma, need to exceed two weeks under germination conditions. E. africanum and S. rautanenii were found to have very long lasting storage durability with germination of twelve year old seeds. These results may inform seed handling practises in nurseries and the field to advance successful assistance of regeneration.

Keywords: germination, pre-treatments, Miombo woodland, Northern Kalahari woodland, *Dialium engleranum*, *Erythrophleum africanum*, *Guibourtia coleosperma*, *Pterocarpus angolensis*, *Schinziophyton rautanenii*

Introduction

Assisted regeneration of tree species is a valuable forest management tool for species with slow growth and reduced natural regeneration. It also allows selecting desired tree qualities, such as drought resistance and good timber or fruit quality. Limited natural regeneration has been reported for several dry woodland tree species from southern Africa, especially *Pterocarpus angolensis* (Figure 1) but also *Guibourtia coleosperma* (Caro *et al.* 2005; Phiri *et al.* 2012; van Daalen 1991). Forest inventories in the Namibian Northern Kalahari dry forests and woodlands show that regeneration of these species is under-represented compared to mature tree composition (Kamwi 2003; Kanime 2003; Kanime & Laamanen 2002). More studies are needed to clarify to what extent this endangers the woodlands' future, and to what extent this is caused by fires and changing global climate (De Cauwer 2012; Geldenhuys 1977; Pröpper *et al.* 2015). Effects of reduced natural regeneration will

take a long time to become obvious as most of the canopy trees in Namibia's woodlands grow very slowly (Fichtler *et al.* 2004; Van Holsbeeck 2015). For example it takes *P. angolensis* on average about 93 years to reach the minimum diameter harvest size of 45 cm (Pröpper *et al.* 2015).



Figure 1. *Pterocarpus angolensis* trees near Nkurenkuru, Kavango West (©V. De Cauwer).

Unfortunately, nursery experiments in Namibia with indigenous woodland trees have been limited or were never published (P. Graz pers. com.). A few studies were done that yielded variable results and are only the first steps towards establishing germination protocols (Moses 2012; Van der Heyden 2014). Work outside Namibia is limited and concentrates mainly on *P. angolensis* and *Schinziophyton rautanenii* (Chisha-Kasumu *et al.* 2006; Chisha-Kasumu *et al.* 2007; Jøker *et al.* 2000; Keegan *et al.* 1989; Ronne & Jøker 2006).

The aim of this study was to assess the suitability of pre-germination treatments and to establish simple germination protocol for some indigenous Namibian trees. Treatments of seeds or pods are required to break dormancy and initiate germination and are required by many savanna tree species. Common treatments include soaking of seeds; burning of pods; exposure to smoke; mechanical or acid scarification; treatments with plant chemicals and combinations of these treatments. Six tree species were tested during this study; namely *Dialium engleranum*, *Erythrophleum africanum*, *Guibourtia coleosperma*, *Pterocarpus angolensis* and *Schinziophyton rautanenii*. The selected pre-germination treatment protocols are intended to suit conditions outside laboratories, to allow replication by unskilled persons and do not require special equipment or chemicals. Our main purpose is to provide well documented information that can be applied in future germination experiments in Namibia.

Materials and Methods

Most seeds were collected in northern Namibia (Hamoye, Kaisosi and Masivi) by the Namibian Directorate of Forestry (DoF) between 2003 and 2015. Seed lots originated from a single year and place of collection and were stored below 18°C. For *P. angolensis* and *S. rautanenii*, seeds were also collected by the authors in 2013 near Cuangar, in southern Angola, and south of Mashare in Kavango East, Namibia and stored below 25°C. Seeds of *Terminalia sericea* collected in 2013 were also provided by DoF, but all appeared to be non-

viable and were discarded from the experiment. Seed storage was under similar conditions to earlier Namibian studies (Moses 2012; Van der Heyden 2014).

All work was done at the National Botanic Research Institute (NBRI) in Windhoek. Pre-germination treatments included: soaking in cold, warm and hot water for 24 hours; nicking; combinations of the two; no surface sterilisation and long-term soaking for one week (Table 1). Each treatment was replicated three times with ten seeds per replicate, and five times with six seeds for large seeded *S. rautanenii*. For *P. angolensis* each treatment was only replicated twice because the seed lot was limited (Figure 2). Nicking referred to a small incision made with a scalpel through the seed coat, away from the embryo point. For *S. rautanenii* the incision had to be made with a saw. Cold soaking was done between 23°C and 28°C. Warm and hot soaking was tested as a pre-treatment for *D. engleranum*, *E. africanum* and *G. coleosperma* at 50°C and with boiling water respectively.

Table 1. Overview of all pre-germination treatments and replicates per species.

| At 30°C | | | | | | | |
|--------------------|----------------------|---------------------|-----------------------|----------------------|-------------|----------------------|-------------|
| Treatment | <i>D. engleranum</i> | <i>E. africanum</i> | <i>G. coleosperma</i> | <i>P. angolensis</i> | | <i>S. rautanenii</i> | |
| | | | | 2013 | 2014 | 2013 | 2013 |
| Nick | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | |
| Control | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | |
| Soak cold | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | |
| Nick and soak cold | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | |
| Nick and soak warm | 3x10 | 3x10 | 3x10 | | | | |
| Nick and soak hot | 3x10 | 3x10 | 3x10 | | | | |
| Soak warm | 3x10 | 3x10 | 3x10 | | | | |
| Soak hot | 3x10 | 3x10 | 3x10 | | | | |
| No sterilisation | 3x10 | 3x10 | 3x10 | | | | |
| Soak long | | | | | | 5x6 | |
| Nick and soak long | | | | | | 5x6 | |
| At 26°C | | | | | | | |
| Nick | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | 2x6 |
| Control | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | 2x6 |
| Soak cold | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | 2x6 |
| Nick and soak cold | 3x10 | 3x10 | 3x10 | 2x10 | 2x10 | 5x6 | 2x6 |
| Nick and soak warm | 3x10 | 3x10 | 3x10 | | | | |
| Nick and soak hot | 3x10 | 3x10 | 3x10 | | | | |
| Soak warm | 3x10 | 3x10 | 3x10 | | | | |
| Soak hot | 3x10 | 3x10 | 3x10 | | | | |
| No sterilisation | 3x10 | 3x10 | 3x10 | | | | |
| Soak long | | | | | | 5x6 | |



Figure 2. Pods and seeds of *Pterocarpus angolensis* (©R. Younan).

Prior to incubation, all seeds, apart from the no sterilisation set, were surface sterilised in a solution of one part 15% Sodium Hypochlorite and four parts distilled water (volume). They were submerged in the solution for 5 minutes then rinsed with distilled water five times. Seeds were placed on sterilised 9cm diameter Petri dishes with two MN 618 filter papers at the bottom. Petri dishes were watered with 5ml of distilled water and closed with Parafilm "M". Replicates were placed in a germination chamber at 30°C (+/-2°C) with a 12 hour light and dark regime. In the second part of the experiment the same procedure was repeated at 26°C. The Petri dishes were checked for germination progress daily and watered when dry. Seeds with clearly emerged radicals were determined as germinated. Germination was monitored over a minimum of 14 days for each trial. Between the two temperature regimes the handling of mouldy seeds was altered. During the 30°C experiment it was realised that seeds germinate despite developing mould on the surface. Discarding seeds due to mould was detrimental to maximum germination. Therefore, in the 26°C experiment only severely mouldy seeds were discarded.

A sample of seeds remaining ungerminated after 14 days at 26°C were subjected to a Tetrazolium test for viability, using a 0.5% solution, produced from 1g of Tetrazolium salt and 200ml of distilled water. Seeds were soaked at room temperature in distilled water for 24h, split and incubated in Tetrazolium solution for 24h at room temperature in the dark, after which they were rinsed and assessed.

Germination capacity was calculated for each species as the cumulative percentage of daily germination after two weeks (Dayamba *et al.* 2014). The mean germination time was the mean number of days since sowing till germination after two to three weeks. Species were tested for significant differences in germination capacity and mean germination time in function of temperature, pre-treatments and, for *P. angolensis* and *S. rautanenii*, origin. First, the data was tested for homoscedasticity and normality with the Fligner-Killeen and Shapiro-

Wilk tests respectively. Species with normal distributed data and homogeneity of variance were subjected to a two-way analysis of variance (ANOVA). When no significant interaction was observed between factors, the ANOVA was followed by a Tukey's post-hoc analysis ($p < 0.05$) (Dayamba *et al.* 2014). For data that did not show homoscedasticity or normality, even after transformation, a non-parametric Kruskal-Wallis test was performed to verify significance of treatment, temperature and origin effects. Post-hoc test of Kruskal-Wallis consisted of pairwise comparisons with the Wilcoxon rank sum test using a Bonferroni adjustment ($p < 0.05$). Analysis was performed in R.

Results and Discussion

An overview of the effect of temperature on the germination capacity is presented in Table 2. Differences in germination success between the two temperature regimes must be considered primarily in relation to allowing mouldy seeds to germinate at 26°C while they were discarded in the 30°C experiment. As a result, over-all germination capacity was higher at 26°C than at 30°C, although this difference was only significant for two species. Across all treatments, *G. coleosperma* had the highest germination capacity, in accordance with findings by Moses (2012) (Figure 3). The percentage of *P. angolensis* seeds that germinated was far lower than the 47% obtained by Van der Heyden's (2014). This can be attributed to the fact that the latter study followed germination of the seeds for a much longer time (almost one year). Another factor that could have contributed is the use of younger pods (1 to 2 years younger than this study).

Table 2. Germination capacity and mean germination time across treatments for all species studied at both temperature regimes. Significant differences between temperature regimes are indicated for $p < 0.5$ (*) and $p < 0.01$ (**).

| | Germination capacity (%) | | | | Mean germination time (days) | | | |
|----------------------------------|--------------------------|------|-------|--------------|------------------------------|------|-------|--------------|
| | Mean | 30°C | 26°C | Significance | Mean | 30°C | 26°C | Significance |
| <i>Dialium englerianum</i> | 41 | 35 | 47 ** | | 7.4 | 6.4 | 8.2 | |
| <i>Erythrophleum africanum</i> | 20 | 21 | 19 | | 8.0 | 7.0 | 9.0 * | |
| <i>Guibourtia coleosperma</i> | 91 | 87 | 96 | | 7.3 | 7.3 | 7.3 | |
| <i>Pterocarpus angolensis</i> | 23 | 14 | 31 * | | 6.6 | 6.2 | 7.0 * | |
| <i>Schinziophyton rautanenii</i> | 7 | 7 | 6 | | 10.8 | 12.4 | 9.7 | |



Figure 3. Germinated seed of *Schinziophyton rautanenii* (front) and *Guibourtia coleosperma* (background) (©R. Younan).

Mean germination time is not affected by the different handling of mould and was in general higher at 26°C than at 30°C (Table 2). *S. rautanenii* germinated almost two days faster at 26°C than at 30°C degrees, but the difference was not significant and more tests are needed to find the optimal temperature. The shortest mean germination time was found for *P. angolensis* and *D. engleranum* at 30°C. *S. rautanenii* had the lowest germination capacity and longest germination time in both temperature regimes. This is in agreement with literature that indicates that larger seeds germinate slower than small ones and that *S. rautanenii* germinates with difficulty (Moses 2012; Murali 1997).

The species that showed significant effects for the effect of treatments on germination capacity were *D. engleranum*, *E. africanum* and *P. angolensis*. All treatments that included nicking of *D. engleranum* resulted in significantly higher germination rates (Figure 4). MacDonald & Omoruyi (2003) found that only hot water soaking could improve germination rates for another *Dialium* species. In this study, none of the soaking treatments showed significant improvements. However, as soaking in hot water may cause damage to the seed; it may be advisable to soak *D. engleranum* at lower temperatures in accordance to advice from the DoF. Nicking of *E. africanum* seeds resulted in significantly higher germination

(38%) compared to the treatments with the lowest germination rates: the non-surface sterilised seeds (8%) and seeds that had been nicked and soaked with cold water (12%). The combinations of nicking and soaking in water often resulted in bloated seeds with a soft core. This was not conducive for germination, as especially *E. africanum* would quickly develop mould from within. For *P. angolensis*, nicking of seeds gave significantly better results than nicking and soaking or soaking only (Figure 5).

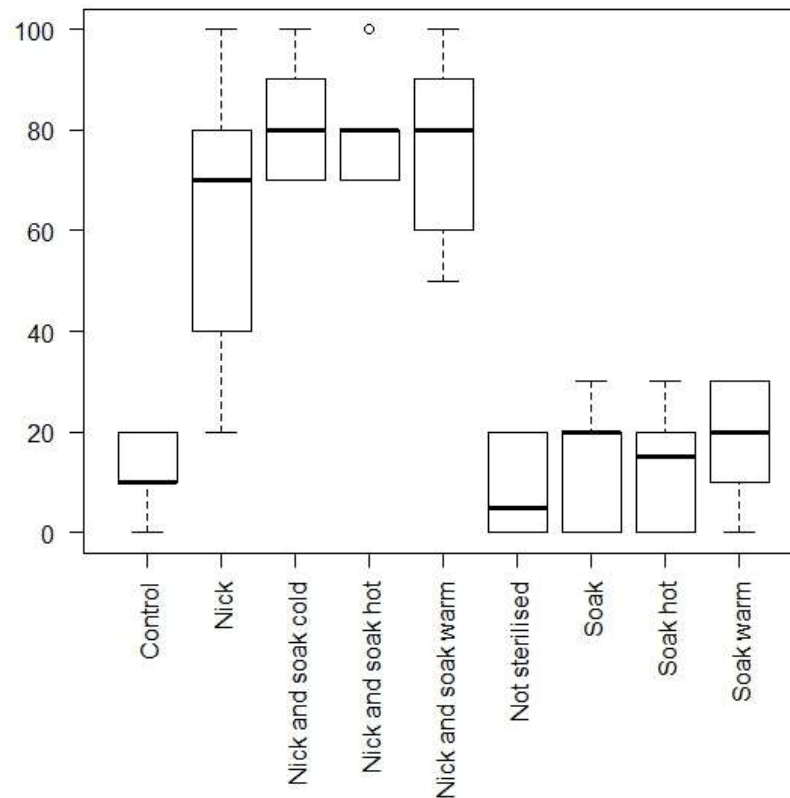


Figure 4. Germination capacity (%) of *Dialium engleranum* for the different treatments.

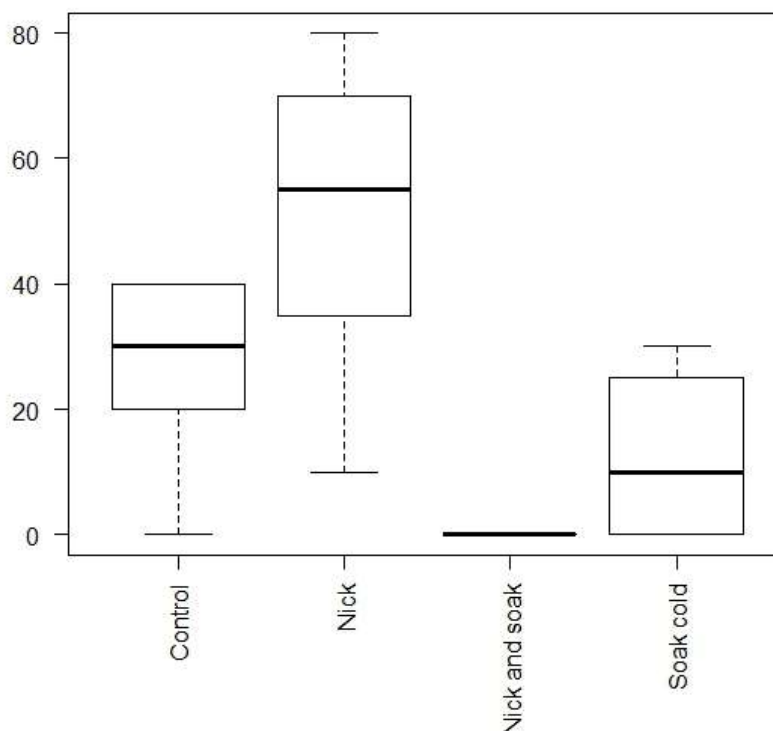


Figure 5. Germination capacity (%) of *Pterocarpus angolensis* for the different treatments.

None of the treatments used on *S. rautanenii* seeds appeared to be effective. Contrary to Ronne & Jøker (2006), soaking and nicking *S. rautanenii* seeds did not improve their germination in comparison to nicking only. According to Keegan *et al.* (1989), only ethylene can break *S. rautanenii*'s dormancy.

Origin of the *P. angolensis* and *S. rautanenii* seeds, and consequently different storage temperatures, did not have a significant effect on germination capacity nor mean germination time. Treatments did have a significant effect on mean germination time for two species. Germination of *G. coleosperma* took 11 days for the control and non-sterilised seeds compared to an average of 6 days for all other treatments. For *P. angolensis*, germination took on average 10 days for the cold soaked seeds compared to 5 or 6 days for nicking or nicking and soaking.

The Tetrazolium test revealed most seeds that hadn't germinated were viable. As the amount of non-germinated seeds was still high except for *G. coleosperma*, it can be stated that for the other species either the two week period was too short or the pre-treatments did not sufficiently break dormancy.

Seed viability of most seeds was remarkable. *E. africanum*, collected in 2003, still reached germination rates of 20%. Some seeds of *S. rautanenii* also sporadically germinated after twelve years in storage. This species can thus remain viable in storage for much longer than previously assumed (Peters 1987; Ronne & Jøker 2006). The storage durability of *P. angolensis* of at least three years as reported by Jøker *et al.* (2000) was confirmed. No literature on the effects of seed storage for several years for the other species could be found.

According to the findings, the following procedures are recommended to improve germination success:

- nicking of *D. engleranum* seeds, and optionally soaking for 24h in either cold or warm water;
- nicking of *E. africanum* seeds;
- nicking of *P. angolensis* seeds;
- optional surface sterilisation and other treatments of *G. coleosperma* seeds, especially to decrease germination time;
- nicking and a combination of nicking and soaking may promote germination of *S. rautanenii* to a certain extent, but further improvement of pre-treatments will be necessary;
- for all species studied, except *G. coleosperma*, seeds should be kept in an environment conducive to germination for longer than two weeks to achieve the maximum germination potential.

Future studies may want to investigate the germination response on more temperature regimes, as well as different day lengths and do so for a period of at least one to two months. Such an approach would allow taking the natural conditions into account better. The relationship of viability and seed floating should be further studied, especially as it is a more feasible alternative to the very expensive Tetrazolium testing. Van der Heyden (2014) found seeds of *P. angolensis* that sank to germinate better.

Other studies are now starting to build on the results of this study to improve germination and seedling development protocols for indigenous tree species and to find the most suited methods to assist regeneration in the trees' natural habitat. Much more work is needed to investigate their potential for enrichment planting in the forest, for agroforestry and intercropping and hereby meeting socio-economic needs.

Acknowledgements: This study is part of the project "Forest regeneration, growth, threats and trends in different forest types" of the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL task 038). The authors are grateful to the National Botanic Research Institute of Namibia for providing the facilities in which the study was conducted and the Directorate of Forestry for providing the seeds.

References

- CARO, T.M., SUNGULA, M., SCHWARTZ, M.W. & BELLA, E.M. 2005. Recruitment of *Pterocarpus angolensis* in the wild. *Forest Ecology and Management* 219: 169–175.
- CHISHA-KASUMU, E., PRICE, A.H. & WOODWARD, S. 2006. In vitro shoot multiplication and rooting from seedling explants of *Pterocarpus angolensis* in Zambia. *The Southern African Forestry Journal* 208 (1): 31–37. <http://doi.org/10.2989/10295920609505259>
- CHISHA-KASUMU, E., WOODWARD, S. & PRICE, A. 2007. Comparison of the effects of mechanical scarification and gibberellic acid treatments on seed germination in *Pterocarpus angolensis*. *Southern Hemisphere Forestry Journal* 69: 63–70. <http://doi.org/10.2989/SHFJ.2007.69.1.9.171>
- DAYAMBA, S.D., SANTI, S. & SAVADOGO, P. 2014. Improving seed germination of four savanna-woodland species: effects of fire-related cues and prolonged soaking in sulphuric acid. *Journal of Tropical Forest Science* 16–21.
- DE CAUWER, V. 2012. Modelling of distribution and environmental requirements of Kiaat (*Pterocarpus angolensis*), an important Southern African timber tree species. Presented at the KUL Seminar, Leuven, Belgium.

- FICHTLER, E., TROUET, V., BEECKMAN, H., COPPIN, P. & WORBES, M. 2004. Climatic signals in tree rings of *Burkea africana* and *Pterocarpus angolensis* from semiarid forests in Namibia. *Trees* 18: 442–451.
- GELDENHUYS, C.J. 1977. The effect of different regimes of annual burning on two woodland communities in Kavango. *South African Forestry Journal* 103: 32–42.
- JØKER, D., MSANGA, H.P. & SCHMIDT, L. 2000. *Pterocarpus angolensis* DC (No. 36). Danmark: Danida Forest Seed Centre.
- KAMWI, J.M. 2003. Woody Resources Report of Hans Kanyinga Community Forest.
- KANIME, N. 2003. Woody Resource Report of Ncamangoro Community Forest.
- KANIME, N. & LAAMANEN, R. 2002. Mashare forest inventory report.
- KEEGAN, A.B., KELLY, K.M., VAN STADEN, J. & GILLILAND, M.G. 1989. The Ultrastructural and Biochemical Changes Associated With Dormancy Breaking in *Ricinodendron rautanenii* Schinz. Seeds Following Ethylene Treatment. *Journal of Plant Physiology* 133(6): 747–755. [http://doi.org/10.1016/S0176-1617\(89\)80084-7](http://doi.org/10.1016/S0176-1617(89)80084-7)
- MACDONALD, I. & OMORUYI, O. 2003. Effect of seed pre-treatment on germination of two surface types of *Dialium guineense*. *Seed Technology* 25(1): 41–44.
- MOSES, R. 2012. Seed physiological aspects of large seeded species of the Kavango woodland, Namibia (B.Sc.Honours), University of Pretoria.
- MURALI, K.S. 1997. Patterns of Seed Size, Germination and Seed Viability of Tropical Tree Species in Southern India. *Biotropica* 29(3): 271–279. <http://doi.org/10.1111/j.1744-7429.1997.tb00428.x>
- PETERS, C.R. 1987. *Ricinodendron rautanenii* (Euphorbiaceae): Zambezian wild food plant for all seasons. *Economic Botany* 41(4): 494–502.
- PHIRI, M., CHIRWA, P., WATTS, S. & SYAMPUNGANI, S. 2012. Local community perception of joint forest management and its implications for forest condition: the case of Dambwa Forest Reserve in southern Zambia. *Southern Forests: A Journal of Forest Science* 74(1): 51–59. <http://doi.org/10.2989/20702620.2012.686203>
- PRÖPPER, M., GRÖNGRÖFT, A., FINCKH, M., STIRN, S., DE CAUWER, V., LAGES, F., ...JUERGENS, N. (EDS.). 2015. The Future Okavango - Findings, Scenarios, and Recommendations for Action. Research Project Final Synthesis Report 2010-2015. Hamburg & Windhoek: University of Hamburg - Biocentre Klein Flottbek.
- RONNE, C. & JØKER, D. 2006. *Schinziophyton rautanenii* (No. 114). Danmark: Danida Forest Seed Centre.
- VAN DAALEN, C.J. 1991. Germination of *Pterocarpus angolensis* seed. *South African Journal of Forestry* 158: 33–36.
- VAN DER HEYDEN, F. 2014. Germination experiments with the southern African tree species *Pterocarpus angolensis*: in-vivo and in-vitro. University of Ghent, Gent, Belgium.
- VAN HOLSBEECK, S. 2015. Annual diameter growth of *Pterocarpus angolensis* (Kiaat) and other woodland species in Kavango, Namibia (M.Sc. Thesis). University of Ghent, Gent, Belgium.

***Prosopis* encroachment along the Fish River at Gibeon, Namibia. I. Habitat preferences, population densities and the effect on the environment**

B.J. Strohbach, C. Ntesa, M.W. Kabajani, E.K. Shidolo & C.D. D'Alton

School of Natural Resources and Spatial Sciences
Polytechnic of Namibia
P/Bag 13388
Windhoek, Namibia
E-mail: bstrohbach@polytechnic.edu.na

Abstract

Prosopis species have been introduced into Namibia in the early 20th Century, and have since invaded especially the riverine ecosystems. Within the frame of the project "A Water Secure Future for Southern Africa" a baseline study to the *Prosopis* infestation near Gibeon was undertaken to determine the effect of the infestation on the ecosystem, and to propose possible ways to combat this infestation.

For this paper a baseline floristic survey of the invested areas is presented, using the Braun-Blanquet survey method. In addition the population density was determined using a belt transect method over 4 x 100 m. Mapping using aerial photographs from 2010 with a ground resolution of 0.5 m was done to determine the spatial extent of the identified habitat types (commonage, floodplains, river bed, and riparian thickets).

Three plant communities were identified: *Acacia nebrownii* shrubland within the upper slope of the commonage, *Tetragonia schenkii* shrublands on the floodplains, and *Tamarix usneoides* woodland along the river banks and in the fountain area. The latter can be subdivided into three units based on structure and habitat. The population of *Prosopis* at Gibeon is strongly regenerating with the smaller trees and shrubs (<3 m) dominating the stands. The river bank habitat (riparian thickets) had the highest density of over 2,500 *Prosopis* plants/ha followed by the fountain habitat with over 900 *Prosopis* plants/ha. Water use by the plants was estimated for the individual habitats based on the measured densities and size class distribution, and the total water use by *Prosopis* for the study area is estimated at 1.2 M m³ per annum for the study area.

Prosopis plants have largely replaced the natural vegetation along the Fish River, with only remnants of the original vegetation remaining. This invasion poses a major threat to the ecosystem and its functioning. The water used by the alien vegetation is considerably higher than natural vegetation would have used, and it is estimated that roughly 18% of the potential influx of the new Neckartal Dam in the lower Fish River is lost due to the *Prosopis* infestation.

Keywords: Alien invasive species; ecohydrology; Nama-Karoo; riparian thickets.

Introduction

Three species of *Prosopis* were introduced in Namibia during the early 20th Century, being *Prosopis chilensis*, *Prosopis glandulosa* (with two subspecies, *P. glandulosa* subsp.

glandulosa and *P. glandulosa* subsp. *torreyana*) and *Prosopis velutina*. It is believed that a German settler planted the first *Prosopis* trees for shade and as fodder trees for domestic animals such as cattle, donkeys, horses, goats and sheep. By 1912 the tree was reported to have established itself in the wild (Brown *et al.* 1985; Smit 2005). The first invasion of *Prosopis* in Namibia was recorded in 1950, when a group of farmers took over a large part of Southern and Central Namibia (Smit 2005). It has spread rapidly since in areas such as the Swakop River (Visser 1998) as well as the Nossob and Auob Rivers (Brown *et al.*, 1985). In the mean time, *Prosopis* species are labelled as the invasive species of greatest concern in Namibia (Brown *et al.* 1985; Bethune *et al.* 2004; Smit 2005).

Prosopis is able to flourish in wide spectra of rainfall patterns with mean annual rainfall ranging from 100 mm or less, up to 1,500 mm (Pasiecznik *et al.* 2001). However, they are less likely to be found in areas with mean annual rainfall more than 1,000 mm. *Prosopis* spp. have a wide ecological amplitude and are adapted to a wide range of soil types from dune sands to cracking clay (Pasiecznik *et al.* 2001). *Prosopis* are found mostly growing in soils such as sandy arenosols, shallow limestone and even in poor saline or alkaline soils, but more commonly on gravely leptosols. *Prosopis* usually colonises disturbed, eroded, over-grazed or drought affected areas (Smit 2005).

Prosopis are known to be phreatophytic plants (Le Maitre *et al.* 1999; Hultine *et al.* 2003; Smit 2005; van den Berg 2010), meaning they obtain a considerable amount of their water from the unsaturated zone above the water table in the soil. *Prosopis* are able to survive in areas with extremely low rainfall or a lengthy period of aridity, provided that the taproot is able to reach the groundwater within its first few years. The habitat of *Prosopis* has been described as areas with relative deep soil with underground water table close to the surface such as river banks, pans and depressions. The density of *Prosopis* invasion has been found to be highest close to river banks and decreases away from the river (Schachtschneider & February 2010). Various studies (Boyer & Boyer 1989; Smit 2005; van den Berg 2010) have indicated *Prosopis* as a wasteful water consumer. Levitt *et al.* (1995) measured water consumption for 3 m tall *Prosopis alba* trees and found that they use between 0.35 and 5.5 l/day.

Visser (1998) found that in the Swakop River, *Prosopis* density was increasing at the expense of local plant species richness. The species that are mostly affected are ephemeral river species such as *Acacia erioloba* in the Nossob River and *Faidherbia albida* in the Swakop River (Bethune *et al.* 2004).

As part of the project 'A Water Secure Future for Southern Africa', within the Orange-Senqu River Basin, the Desert Research Foundation of Namibia (DRFN), with funding from the United States Agency for International Development (USAID), is seeking solutions for the invasion problem of *Prosopis* at Gibeon along the Fish River in central southern Namibia. This paper attempts to understand the population dynamics of *Prosopis* and other woody species in the study area as well to appreciate any degradation, major threats, and conservation needs within the study area, and to determine possible remedial actions, which includes harvesting of fire wood. With this first paper, the preferred habitats of *Prosopis*, the density of the *Prosopis* stands, as well as their effect on the riparian ecosystem, are described.

Study area

The study was conducted at Gibeon (S 25°07.5', E 17°46.0') in the Hardap region along the Fish River (Figure 1), which is part of the Orange-Fish River Basin in the southern central part of Namibia (Strohbach 2008).

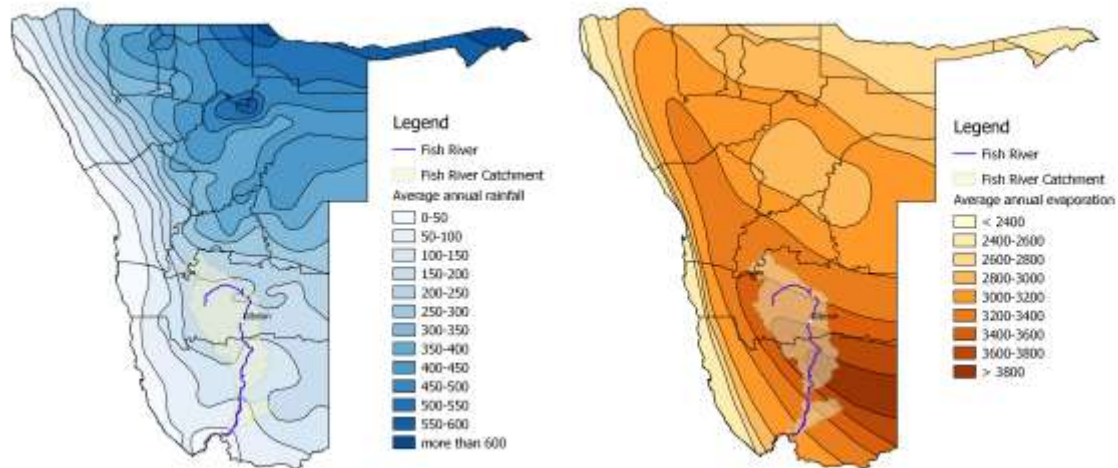


Figure 1. Location of Gibeon, in relation to the Fish River catchment (shaded) and the prevailing climate. (a) Mean annual precipitation (mm) and (b) mean annual evaporation (mm). Source: Mendelsohn *et al.* (2002); Strohbach (2008).

Climate

The south central areas of Namibia are characterised by a typical subtropical desert climate (Bw) following Köppen (1936). The mean annual rainfall ranges between 150 and 200 mm, with a 70% – 80% coefficient of variation (Mendelsohn *et al.* 2002). It rains predominantly during late summer, between February and April (Botha 1996). This region is among the hottest regions in the country, with average maximum temperature soaring to well above 36°C in summer and average minimum temperature sinking to below 2°C in winter. Evapotranspiration for this area ranges between 3,400 and 3,600 mm per annum (Mendelsohn *et al.* 2002).

Geology and soils

The Fish River catchment falls within the Nama Group in southern Namibia (Geological Survey 1980). This geological group consists of fluvial red sandstone as well as limestone with beds of lime and shales (Swart 2008; Tordiffe 2010), which were formed around 530-550 million years ago (Tordiffe 2010).

The soils on the undulating to rolling landscapes are generally shallow, on bedrock, with a high skeletal content. These Leptosols have only a very limited water holding capacity, and can therefore only support limited vegetative growth. Along the river, sedimentary deposits by the river form Fluvisols, which are deeper, and potentially nutrient-rich (ICC *et al.* 2000; Mendelsohn *et al.* 2002).

Natural vegetation

Gibeon falls within the northern Nama-Karoo biome along the Fish River. This biome is characterised by open short shrubs and grasses which make up most of the perennial vegetation. Big trees are rare and are mostly limited to rivers (Irish 2008). Giess (1998) describes the vegetation as being dominated by *Parkinsonia africana*, *Rhigozum trichotomum* and a variety of other dwarf shrub species, whilst *Stipagrostis* species are dominating as grasses. Only limited detailed vegetation descriptions are available for the Dwarf shrub savanna at the Nico Nord observatories to the south-east, as well as the farm Haribes to the north of the study area (Jürgens *et al.* 2010; Strohbach & Jankowitz 2012). For the Fish River Valley, specifically the riparian forest at the Fish River, no descriptions are available.

Environmental challenges

Some challenges experienced in an arid environment like Gibeon, include overgrazing due to livestock (Kruger 2001), potentially leading to desertification. Secondary land degradation can also be caused by alien invasive species such as *Prosopis*, initially taking advantage of the disturbances. *Prosopis* however aggressively invades the area at the expense of native species, in this way transforming the habitat and reducing the plant species diversity (Bethune *et al.* 2004; van den Berg 2010). Within this arid environment, water scarcity due to low rainfall, is a recurring problem. This is aggravated by invasive *Prosopis* spp., which are known to extract excessive amounts of water from the soil, even reducing water flow (Le Maitre *et al.* 2000; Nie *et al.* 2012; Dzikiti *et al.* 2013).

Assessment methods

Biodiversity assessments

In order to assess the plant diversity, at each plot a relevé (i.e. a Braun-Blanquet type survey) was compiled following standards set for the Vegetation Survey of Namibia project (Strohbach 2001, 2014; Mueller-Dombois & Ellenberg 2002; Kent 2012). For this purpose, a 20 x 50 m plot was set out. The position of this plot was determined with a Garmin eTrex 20 GPS (set to WGS 84), the general landscape and habitat features were described and a photo was taken. Following this, all identifiable plant species were recorded. Herbarium specimens from unknown species were collected, for later identification in the National Herbarium of Namibia (WIND). For each recorded species, the typical growth form and an estimated canopy cover (as abundance measure) were recorded.

The relevés were captured in TurboVeg (Hennekens & Schaminée 2001), using the Namibian species list (Klaassen & Kwembeya 2013) as base. This data has been incorporated into the National Phytosociological database of Namibia (Dengler *et al.* 2011; Strohbach & Kangombe 2012) (AF-NA-001). The actual relevé data from these plots forms the basis for long-term monitoring of the biodiversity (Westfall & Greeff 1998; Strohbach 2012).

The relevé data was exported to Juice (Tichý 2002) and grouped with Modified TWINSpan (Roleček *et al.* 2009). From these groups, a summary composition in the form of a synoptic table was obtained. At the same time, characteristic/dominant species for each habitat could be determined.

Mapping

Habitat types were mapped using aerial photographs from 2010 with a ground resolution of 0.5 m. Two images, 2517BA-15 and 2517BB-11 were used for this. Habitat types were identified by visual interpretation and manually digitised with QGIS Valmeira Edition (QG/S 2014). The study area was defined as the town of Gibeon, as well as the river-associated habitats along the Fish River adjacent to Gibeon, from ca 3 km upstream of Gibeon, to 5 km downstream up to the bridge across the Fish River. Although the vegetation of the fountain area is in composition similar to the riparian vegetation, these two were mapped separately due to the fact that these represent different ecosystems in the area. Once the mapping was completed, the area of each habitat type was calculated.

Density of *Prosopis* stands

In order to determine the density of *Prosopis* in the different habitats, a transect count over 4 x 100 m (i.e. 400 m²) was done of all woody species at each plot, with the exception of the floodplain plots. Here, the density of *Prosopis* was found to be too low for effective counting on these transects. For the transect count, the trees and shrubs were counted per size classes as follows: 0 - 1 m; 1 - 2 m; 2 - 3 m; 3 - 4 m; 4 - 5 m; 5 - 8 m; > 8 m. This data was summarised as trees (> 3 m) and shrubs (< 3 m).

Estimated water use of *Prosopis*

Water use by trees is dependent on three factors: the tree species and its intrinsic capacity to utilize water, the total leaf area of the plant as well as the climate (daily temperature, wind speed, humidity, etc.) (Cable 1977; Levitt *et al.* 1995; Wullschleger *et al.* 1998). Levitt *et al.* (1995) developed a water use coefficient for *Prosopis alba* in Tucson, Arizona, under similar, if slightly cooler, climatic conditions as the present study area. Their coefficient is calculated as follows:

$$K_{\text{trees}} = T / ET_0 \quad [1]$$

where T is the transpiration of the particular tree (in mm*day⁻¹) and ET₀ is the base evapotranspiration of the environment (in mm*day⁻¹)

T for the particular species can be calculated either as a function of the total leaf area (TLA) or a function of the projected canopy area (PCA) as follows:

$$T_{\text{TLA}} = H_2O / TLA \quad [2]$$

or

$$T_{\text{PCA}} = H_2O / PCA \quad [3]$$

where H₂O refers to the measured water use in litres per day. Both T_{TLA} and T_{PCA} have units of mm*day⁻¹.

Based on these formulas, the water use per tree can be calculated as follows:

$$H_2O = TLA * ET_0 * K_{\text{TLA}} \quad [4]$$

or

$$H_2O = PCA * ET_0 * K_{\text{PCA}} \quad [5]$$

From personal observations it was clear that *Prosopis chilensis* represented at least 80% of the *Prosopis* population within the study area, with *P. velutina* and *P. glandulosa* (in sequence of importance) making up the remainder of the population. *P. chilensis* has a very similar growth form and similar leaf size to *Prosopis alba* (Pasiecznik *et al.* 2004). It is thus assumed, that water use coefficients for of the *Prosopis* population found in the current study area will be similar to the water use coefficient of *Prosopis alba*.

Crown dimensions, following BECVOL (Smit 1989a, 1989b, 2014), were measured for 56 sample trees. A linear regression was calculated between the crown diameter and the tree height (Figure 2) for these sample trees. This regression was used to calculate average crown diameters for the size classes used for determining the density of the *Prosopis* stands (Table 1) in this study, based on the mid points of these size classes.

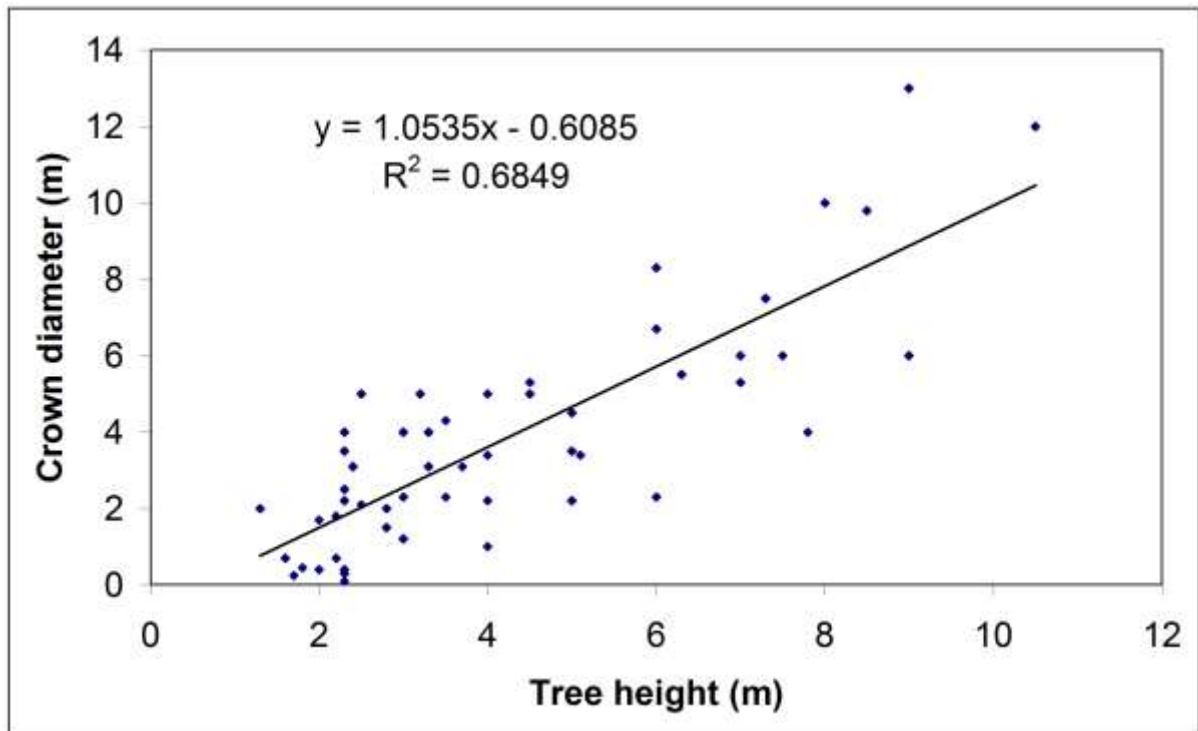


Figure 2. Relationship between tree height and crown diameter of 56 *Prosopis* trees measured for woody biomass determinations (Strohbach *et al.* in prep.).

Levitt *et al.* (1995) provide a range of PCA measurements for their sample trees, which were about 3 m tall. An average PCA of 0.4892 m² was calculated for these 3 m tall trees. Based on the relative differences of the crown diameter, the PCA was adjusted for each size class used in this study. Using formula [5] above, with K_{CPA} 1.56, as well as ET_0 at 9.589 mm*day⁻¹ (derived from Mendelsohn *et al.* 2002), an estimated water use per tree per day could be calculated for these size classes (Table 1). With this estimated water usage per plant, the total estimated water usage could be extrapolated for each habitat, based on the density measurements.

Table 1. Projected crown area and estimated water usage for different size classes of *Prosopis* in the study area, based on data from Levitt *et al.* (1995).

| Size class (m) | Size class midpoint (m) | Average crown diameter (m) | Relative crown diameter | Adjusted Projected Crown Area (m ²) | Estimated water use per plant per day (l) |
|----------------|-------------------------|----------------------------|-------------------------|-------------------------------------------------|-------------------------------------------|
| 0-1 | 0.7 | 0.129 | 0.051 | 0.025 | 0.379 |
| 1-2 | 1.5 | 0.972 | 0.381 | 0.186 | 2.857 |
| 2-3 | 2.5 | 2.025 | 0.794 | 0.388 | 5.954 |
| | 3* | 2.552 | 1.000 | 0.489 | 7.503 |
| 3-4 | 3.5 | 3.079 | 1.206 | 0.590 | 9.052 |
| 4-5 | 4.5 | 4.132 | 1.619 | 0.792 | 12.149 |
| 5-8 | 6.5 | 6.239 | 2.445 | 1.196 | 18.343 |
| > 8 | 9.5 | 9.400 | 3.683 | 1.802 | 27.635 |

* Standard size of trees measured by Levitt *et al.* (1995).

Results

Vegetation description

Twenty-five plots were sampled during the period 28 to 30 July 2014. A total of 60 species, representing 20 families and 47 genera were observed from the 25 relevés sampled. The Poaceae family was the most abundant with 17 species followed by the Fabaceae with eleven species and Asteraceae with seven species. Three species of *Prosopis*, being *P. chilensis*, *P. glandulosa* and *P. velutina* were recognised.

The classification of the relevés revealed three plant communities in the study area, being *Acacia nebrownii* shrublands within the upper slopes of the commonage, *Tetragonia schenkii* shrublands on the floodplains and finally the *Tamarix usneoides* woodlands along the river banks and in the fountain area. The detailed composition of these communities is presented in the form of a synoptic table in Table 2.

Table 2. Synoptic table showing the fidelity¹ as well as the average percentage cover of species occurring in the three plant communities.

| | phi coefficient of fidelity | | | Average percentage cover | | |
|-------------------------------------|-----------------------------|-------------|---------------------|--------------------------|-------------|---------------------|
| Group No. | 1 | 2 | 3 | 1 | 2 | 3 |
| No. of relevés | 4 | 5 | 16 | 4 | 5 | 16 |
| Habitat | commonage | floodplains | riparian & fountain | commonage | floodplains | riparian & fountain |
| <i>Acacia nebrownii</i> | 95.5 | --- | --- | 27.8 | 0 | 24 |
| <i>Melolobium</i> species | 81.6 | --- | --- | 0 | 0 | 0 |
| <i>Enneapogon desvauxii</i> | 79.5 | --- | --- | 0 | 0 | 0 |
| <i>Rhigozum trichotomum</i> | 63.2 | --- | --- | 0.3 | 0 | 0 |
| <i>Euphorbia</i> species | 63.2 | --- | --- | 0 | 0 | 0 |
| <i>Parkinsonia africana</i> | 63.2 | --- | --- | 1 | 0 | 0 |
| <i>Aristida adscensionis</i> | 60.8 | --- | --- | 8.8 | 1 | 1 |
| <i>Eragrostis nindensis</i> | 53.3 | --- | --- | 0 | 0 | 0 |
| <i>Tragus racemosus</i> | --- | 100 | --- | 0 | 0.6 | 0 |
| <i>Tetragonia schenkii</i> | --- | 80.2 | --- | 0 | 41.6 | 1.4 |
| <i>Schmidtia kalahariensis</i> | --- | 75.3 | --- | 0 | 0 | 0 |
| <i>Chloris virgata</i> | --- | 59.2 | --- | 0 | 0 | 0 |
| <i>Pechuel-Loeschea leubnitziae</i> | --- | 55.5 | --- | 0 | 0 | 0 |
| <i>Tamarix usneoides</i> | --- | --- | 81.6 | 0 | 0 | 16.3 |
| <i>Senecio windhoekensis</i> | --- | --- | 72.5 | 0 | 0 | 0.6 |
| <i>Acacia karroo</i> | --- | --- | 53.5 | 0 | 0 | 7.2 |
| <i>Stipagrostis hochstetteriana</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Schkuhria pinnata</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Stipagrostis uniplumis</i> | --- | --- | --- | 0.3 | 0 | 0.1 |
| <i>Lycium</i> species | --- | --- | --- | 0 | 0 | 3.5 |

¹ Fidelity refers to the degree a particular species is "true" to a particular community (i.e. occurring in all sample plots of a particular community, but not in sample plots belonging to other communities). The measure given is the phi coefficient of fidelity (Chytrý *et al.* 2002). Values from 60 and higher are regarded as highly diagnostic.

| | | | | | | |
|---------------------------------|-----|-----|-----|-----|-----|------|
| <i>Eragrostis lehmanniana</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Galenia papulosa</i> | --- | --- | --- | 0 | 6.8 | 0.4 |
| <i>Cyperus marginatus</i> | --- | --- | --- | 0 | 0 | 5 |
| <i>Forsskaolea</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Calicorema capitata</i> | --- | --- | --- | 0 | 0 | 3 |
| <i>Chenopodium</i> species | --- | --- | --- | 0 | 1 | 1 |
| <i>Enneapogon cenchroides</i> | --- | --- | --- | 0.7 | 1.3 | 0.3 |
| <i>Flaveria bidentis</i> | --- | --- | --- | 0 | 0 | 0.4 |
| <i>Acacia mellifera</i> | --- | --- | --- | 3 | 0 | 0 |
| <i>Sesamum</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Stipagrostis namaquensis</i> | --- | --- | --- | 0 | 0 | 3.5 |
| <i>Mesembryanthemum</i> species | --- | --- | --- | 0 | 3.8 | 2.7 |
| <i>Stipagrostis obtusa</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Lotononis platycarpa</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Prosopis</i> species | --- | --- | --- | 4 | 4 | 24.7 |
| <i>Senecio</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Zygophyllum simplex</i> | --- | --- | --- | 0 | 0.3 | 2.6 |
| <i>Lycium eenii</i> | --- | --- | --- | 1 | 0 | 4.2 |
| <i>Dicoma</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Dactyloctenium aegyptium</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Cynodon dactylon</i> | --- | --- | --- | 0 | 0.3 | 2.3 |
| <i>Acacia erioloba</i> | --- | --- | --- | 0 | 0 | 10 |
| <i>Acacia erubescens</i> | --- | --- | --- | 5 | 0 | 0 |
| <i>Blepharis</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Setaria verticillata</i> | --- | --- | --- | 0 | 0 | 1.3 |
| <i>Euclea pseudebenus</i> | --- | --- | --- | 0 | 0 | 7 |
| <i>Salsola kali</i> | --- | --- | --- | 0 | 0 | 1.7 |
| <i>Jamesbrittenia canescens</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Monechma</i> species | --- | --- | --- | 0 | 0 | 0.7 |
| <i>Boscia foetida</i> | --- | --- | --- | 1 | 0 | 1.7 |
| <i>Aizoon</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Suaeda</i> species | --- | --- | --- | 0 | 0 | 12.5 |
| <i>Eragrostis trichophora</i> | --- | --- | --- | 0 | 0.3 | 0.2 |
| <i>Cucumis</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Cleome</i> species | --- | --- | --- | 0 | 0 | 0 |
| <i>Kleinia longiflora</i> | --- | --- | --- | 0 | 0 | 1 |
| <i>Sericorema sericea</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Datura inoxia</i> | --- | --- | --- | 0 | 0 | 0 |
| <i>Eragrostis porosa</i> | --- | --- | --- | 0 | 0.4 | 0.1 |
| <i>Gymnosporia senegalensis</i> | --- | --- | --- | 0 | 0 | 0 |

1. *Acacia nebrownii* shrublands

Four plots have been classified into this community, with a total of 23 species observed in these. The *Acacia nebrownii* shrublands are found on the high-lying outskirts of the

settlement areas commonly referred to as “commonage” (Figure 3 and Table 2). The community is characterised by diagnostic deciduous shrubs and dwarf shrubs *Acacia nebrownii*, *Melolobium* sp., *Rhigozum trichotomum*, *Parkinsonia africana* and grasses *Aristida adscensionis*, *Enneapogon desvauxii* and *Eragrostis nindensis*. The habitat are rolling to moderately steep hill slopes, generally with shallow, stony soils on Dwyka shales (Geological Survey 1980). Although *Acacia nebrownii* also occurs in another plant community (i.e. *Tamarix* woodland) it is highly abundant in this shrubland. The leaves of *Acacia nebrownii* were browsed by livestock and it may be for this reason that the local people let it grow in abundance. The presence of *Aristida adscensionis* as dominant species, in addition to the relative high abundance of *Prosopis* spp. and *Acacia nebrownii*, is a sign of degradation and bush encroachment, replacing the more open dwarf shrubland dominated by *Enneapogon desvauxii*, *Eragrostis nindensis* and *Stipagrostis* spp., which are known as subclimax and climax grasses in the area (Jürgens et al. 2010; Müller 2007).



Figure 3. An example of the *Acacia nebrownii* shrublands as found in the commonage between the houses and other town buildings.

2. *Tetragonia schenkii* shrublands

Eight plots have been classified into this community, with a total of 27 species having been observed in these. The *Tetragonia schenkii* shrublands are found in the flood plains of the Fish River with deep alluvial deposits. They are characterised by shrubs of endemic *Tetragonia schenkii* and the annual grasses *Chloris virgata*, *Tragus racemosus* and *Schmidtia kalahariensis* (Figure 4 and Table 2). These grass species are of low grazing value and are seen as indicators of poor veld conditions. They mainly grow in disturbed, overgrazed or bush encroached areas (Müller 2007). The community is dominated by *Tetragonia schenkii*, *Prosopis* spp., *Galenia papulosa* and *Mesembryanthemum* sp. These are, with the exception of *Prosopis* spp., all leaf-succulent species, giving the community a distinct succulent character, which is a sign that the water availability is limited and highly seasonal. *Prosopis* plants are only sparsely distributed within this plant community. Because of this, their density could not be adequately determined with the belt transect method.



Figure 4. The *Tetragonia schenkii* shrublands on the floodplains of the Fish River.

3. *Tamarix usneoides* woodlands

Thirteen plots have been classified into this community, with a total of 24 species having been observed here. The community is characterized by *Prosopis* spp., *Tamarix usneoides*, *Euclea pseudebenus*, *Acacia karroo*, *Acacia erioloba*, *Acacia nebrownii*, *Lycium eenii*, as well as *Zygophyllum simplex*, *Mesembryanthemum* sp. and *Senecio windhoekensis* as the main species for the herbaceous layer (Figure 5 and Table 2).





Figure 5. The vegetation on the river bank (top), the fountain habitats (middle), and the river beds (bottom) belong collectively to the *Tamarix usneoides* woodlands.

Although they did not vary much floristically, three different vegetation communities could be recognised in the field according to their habitat and structure, being the dense thickets along the fountain areas, the riparian woodlands on the river banks and the sparse vegetation of the river beds and floodplains subject to regular flooding and water flow.

Large parts of the fountain area have high salt contents in the soils. This, as well as shallow rocky soils, that makes the soil unfavourable for many woody species as well as for most grass. Due to the constant supply of spring water, though, *Prosopis* spp. flourishes in these areas. Another indicator of such constant water supply is *Cyperus marginatus*.

The riparian vegetation along the river banks do not differ significantly in composition or structure from the vegetation of the fountain area, with the exception of the more constant occurrence of *Euclea pseudebenus* and the fact that the vegetation is more dense. Some huge *Prosopis* trees, with a stem diameter of well over 1 m, were found here. These old trees are an indication that the infestation by this alien invasive could date back to the early 20th Century (this, however, could not be verified). The habitat is generally deep alluvial sands, with a shallow water table.

The river bed vegetation has a similar composition to the previous two communities, but due to the fact that these are subjected to flowing water at least once per year, is comparatively sparse, especially with the number of *Prosopis* being conspicuously low.

Because of the differences in habitat, and also differences in structure and density, these three sub-communities are treated separately in the subsequent discussion.

Biodiversity of the plant communities

Comparing the species diversity of the different plant communities, it becomes clear that the open properties within the town of Gibeon (the "commonage") as well as the fountain thickets support the highest species richness, with the river bed vegetation having the lowest richness. The floodplain vegetation has a very uniform species composition (dominated by *Tetragonia schenkii*), whilst the river banks are highly variable in species richness. This could be due to these areas having a considerable environmental variability from close- to further away from the river (Figure 6a).

The Simpson's diversity index (a dominance index) tells a different story: The river bed vegetation show a comparatively high variability, compared to the diversity of the riparian thickets (Figure 6b). The riparian thickets are relatively uniform in their diversity, indicating a high level of dominance (by *Prosopis* spp.) in this community. Also the fountain area shows a generally high level of dominance, but with higher variability. This is borne out by the density of trees, in particular *Prosopis* spp.: roughly half of the tree cover within the riparian, fountain and river bed vegetation is provided by this alien invasive, severely limiting the growth of other species (Figure 7). The woody cover in the river bed area is obviously relatively low. A number of large *Acacia karroo* trees were observed to be dead in the fountain and riparian communities, whilst even large *Acacia erioloba* trees showed signs of reduced growth due to the severe competition by *Prosopis* trees and shrubs for water and growing space (Figure 8). Other typical riparian species like *Ziziphus mucronata* and *Euclea pseudebenus* were observed as juvenile plants, but very seldom as large trees or shrubs. Only the weedy *Acacia nebrownii*, a relative small shrub, seemed to thrive here, albeit at far lower densities than in the commonages. The population of *Prosopis* at Gibeon is strongly dominated by the smaller trees and shrubs (< 3 m) (Table 3), indicating a strongly regenerating/expanding population.

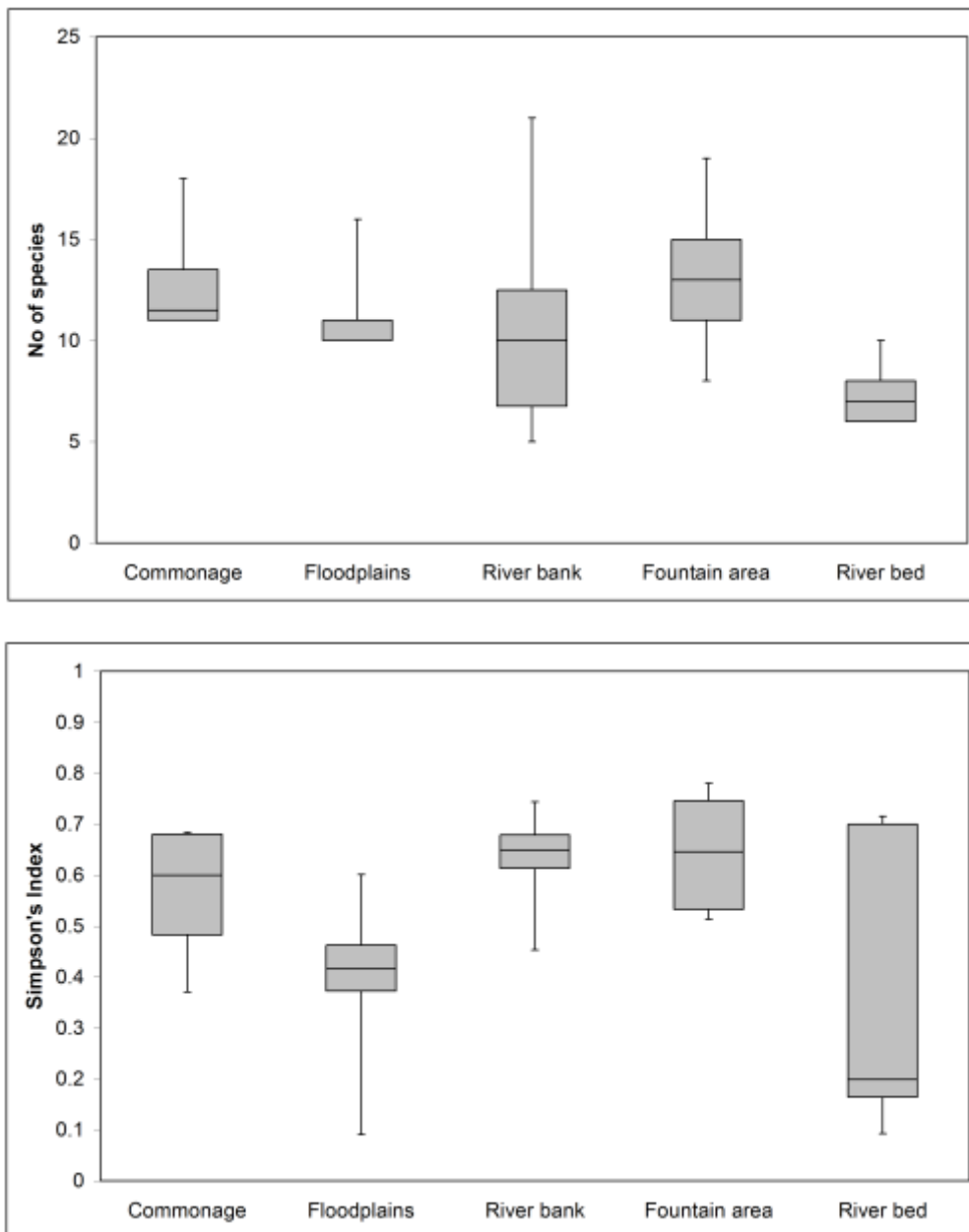


Figure 6. Box-and-whisker plots of the species richness of the various communities (top); Box-and-whisker plots of Simpson's Diversity Index of the individual plots within each community (bottom).

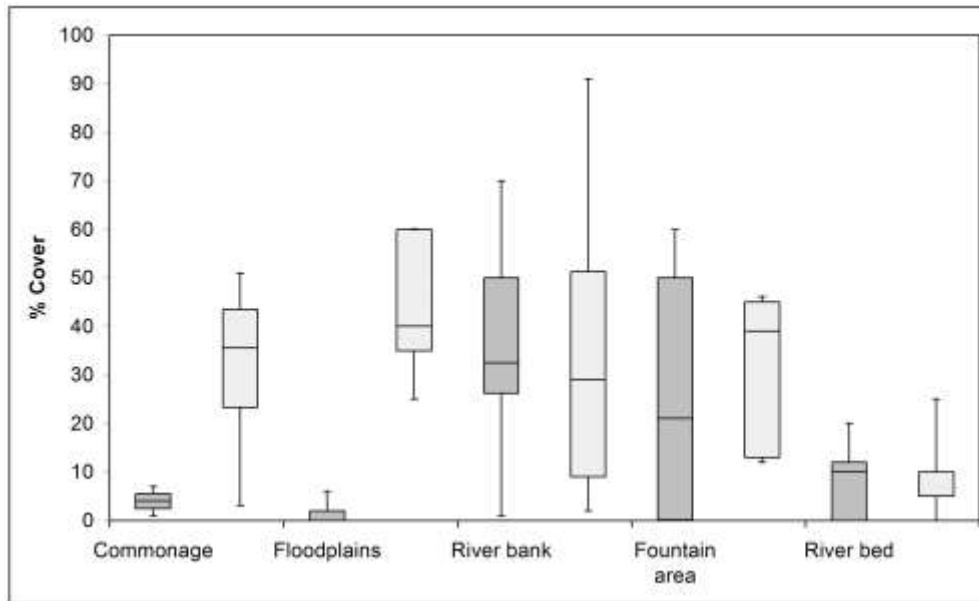


Figure 7. Percentage canopy cover of *Prosopis* spp. (dark grey/left boxes) and in relation to it, by indigenous woody species (light grey/right boxes), in the various plant communities.



Figure 8. Large *Acacia erioloba* tree within the fountain vegetation with strongly reduced foliage, indicating severe hardship due to competition from *Prosopis* stands surrounding it.

Table 3. Area of different vegetation types within the Gibeon study area, with approximate tree and shrub densities.

| Landscape | Area (ha) | <i>Prosopis</i> shrub density | <i>Prosopis</i> tree density | Other shrub species | Other tree species |
|-----------------------|-------------------------|-------------------------------|------------------------------|---------------------|--------------------|
| | (Total area: 678.47 ha) | (plants/ha) | | (plants/ha) | |
| Commonage | 142.35 | 470 | 25 | 106 | 0 |
| Floodplains | 277.03 | No data | | No data | |
| Fountain vegetation | 44.30 | 925 | 144 | 279 | 8 |
| River bank vegetation | 113.45 | 2510 | 425 | 422 | 75 |
| Riverbed | 101.35 | 125 | 58 | 417 | 0 |

Mapping

The habitat map is shown in Figure 9, and the area covered by each habitat within the study area in Table 3.

The town of Gibeon has considerable “brown space”, i.e. unoccupied erven amongst its houses. Especially in the western part of the town, a fair amount of *Prosopis* shrubs (very few trees) were observed in this ‘brown space’. This could be due to the spreading of seeds through humans and livestock alike, taking advantage of an already degraded environment. A particular large piece, south along the main road (ca 92 ha), did not show much of a *Prosopis* infestation, except for the road verges (and from the aerial photographs, adjacent to the old sewage plant).

Considering that tree removal has to be undertaken for effective control, and harvesting of wood is a definite option, cognisance has to be taken of limitations by the Forestry Act (Government of Namibia, Act 12 of 2001). This dictates that no felling of trees may take place within a 100 m strip of the river bank. For this purpose a 100 m buffer zone was demarcated around the actual river bed. The 100 m buffer zone surrounding the Fish River covers about a third of the riparian vegetation. This area is also the densest *Prosopis* population (due to proximity to the river).

Estimated water use by *Prosopis* in the study area

The estimated water use for a single, 3 m high *Prosopis* tree of 7.5 l/day for the Gibeon area (Table 1) is within range of the measured water use of a 3 m high *Prosopis alba* tree in Arizona (up to 5.5 l/day) (Levitt *et al.* 1995). The difference can likely be attributed to a harsher climate at Gibeon, as reflected by the high rates of evaporation. The projected water use, based on the density data of *Prosopis* spp. within each habitat, is presented in Table 4.

Table 4. Estimated water use by *Prosopis* plants within the different habitats.

| | Area (ha) | Water use by <i>Prosopis</i> | | |
|---------------|-----------|------------------------------|------------------------------|-------------------------------|
| | | l per day per ha | total m ³ per day | total m ³ per year |
| Commonage | 142.35 | 1,216.2 | 173.1 | 63,192.9 |
| Floodplains | 277.03 | No data | | |
| River bank | 44.30 | 34,273.8 | 1,518.3 | 554,189.5 |
| Fountain area | 113.45 | 5,599.5 | 635.3 | 231,869.0 |
| River bed | 101.35 | 10,286.9 | 1,042.6 | 380,592.0 |
| Totals | 678.47 | 51,376.4 | 3,369.3 | 1,229,793.4 |

Levitt *et al.* (1995) indicated that the water use co-efficiency of *Prosopis* based on the projected crown area (K_{PCA}) is less reliable than K_{TLA} . However, no suitable measurements to calculate water use based on K_{TLA} were made in the field. Thus an intrinsic error can be assumed to the above calculations. Should this work ever be repeated or improved on, it will make sense to both recalibrate the TLA for the *Prosopis* species in Namibia, as well as measure the evapotranspiration rates of these species to obtain an improved K_{TLA} value.

Discussion and Conclusion

Ecological implications of *Prosopis* encroachment

The highest density of *Prosopis* spp. in comparison to other woody species is found in the riparian habitat along the Fish River at Gibeon. This alien invasive has significantly replaced the natural vegetation in the area. Virtually no knowledge is available on the original vegetation of the central Fish River. However, for the Farm Haribes the vegetation along the Lower River is described by Strohbach & Jankowitz (2012) as short open woodland dominated by *Ziziphus mucronata*, with a well-developed understorey of shrubs and grasses. In comparison, the river banks at Gibeon had virtually no herbaceous understorey (Figure 5a); whilst the typical river species were either only present as seedlings or saplings (*Ziziphus mucronata*) or as stunted or dead remains of trees (*Acacia karroo*). Even deep-rooted species like *Acacia erioloba* (Canadell *et al.* 1996; Moustakas *et al.* 2006) are severely affected by the competition with *Prosopis* plants (Figure 8). *Prosopis* is also known to be allelopathic (Noor *et al.* 1995), thus preventing seedlings of other species to establish. Only *Tamarix usneoides* seems able to withstand the encroachment by these invasive species reasonably.

The negative impact of *Prosopis* on natural vegetation is supported by Wise *et al.* (2012) and Shackleton *et al.* (2015) who reported that in South Africa stands of *Acacia erioloba* died as a direct result of *Prosopis* invasions that lowered the water table. Auala *et al.* (2012) indicated that *Acacia erioloba* (both seedlings and large trees) were found in areas in the Auob Basin where *Prosopis* was cleared out compared to areas where *Prosopis* was not cleared.

Being a phreatophyte, *Prosopis* is known to use an immense amount of water, more than many other species (Le Maitre *et al.* 2002; Huxman *et al.* 2005). Its root system allows it to efficiently utilise both surface and ground water to depths of >50 m (Wise *et al.* 2012; Shackleton *et al.* 2015). To put the water use of *Prosopis* into perspective, the following two examples are given:

- (i) The total annual water use of the City of Windhoek is about 22.6 M m³ (Uhlendahl *et al.* 2010) The total annual water use of *Prosopis* at the study area (1.2 M m³)

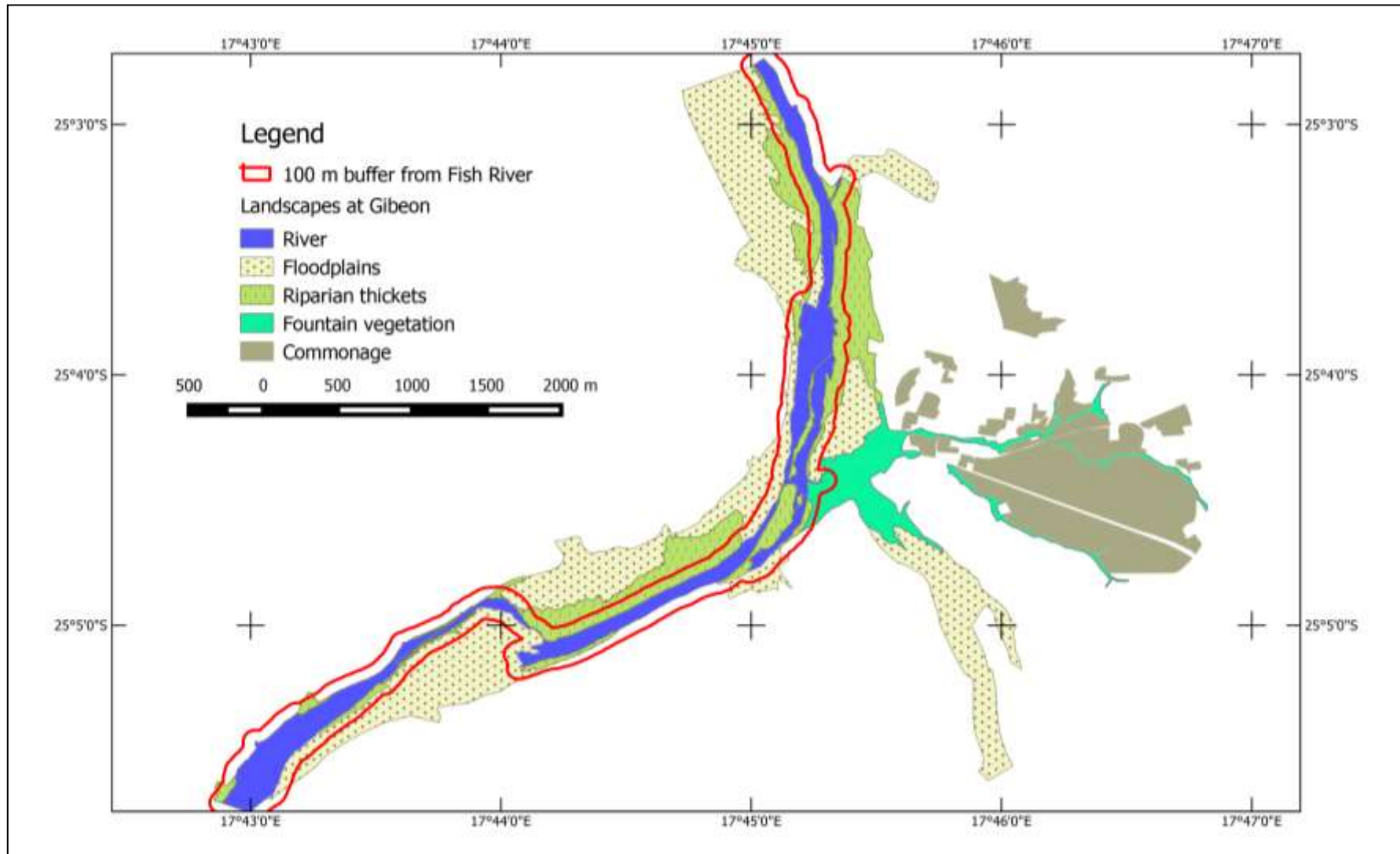


Figure 9. Habitat map of the Fish River valley areas around the town of Gibeon.

The unmapped areas in most cases represent the rolling Nama-Karoo landscape of southern Namibia surrounding Gibeon. The red outline represents the 100 m wide buffer area dictated by the Forestry Act.

- (i) represents 5.4% of this. This translates to a five times higher water consumption per unit area than Windhoek.
- (ii) Natural vegetation along the Kuiseb River has been measured to use 202,000 m³ per annum per 1 km stretch of river (Bate & Walker 1993). This vegetation consists of a mixture of *Acacia erioloba*, *Faidherbia albida*, *Euclea pseudobenus* and *Tamarix usneoides*. We can assume that the original vegetation of the Fish River bank had a similar composition, with the exception that *Faidherbia albida* would be replaced by *Acacia karroo*. The river meanders over roughly 320 km between the Hardap Dam and the new Neckartal Dam. If natural vegetation with similar water use as in the Kuiseb River would prevail, it would use roughly 64.7 M m³ per annum. However, a 100 m wide strip of *Prosopis*-infested vegetation next to the same distance of the river would use 219.4 M m³ per annum – a difference of 154.8 M m³ per annum more than natural vegetation. This difference presents 18.1 % of the projected capacity of the Neckartal Dam (857 M m³) (Salini Impregilo 2013).

In addition, *Prosopis* is known to increase rapidly: the population expands at 18% per annum, resulting in the invaded area to double every five years (Smit 2005). Therefore, if the infestation of *Prosopis* along the Fish River is not managed, the situation will likely exacerbate and *Prosopis* invasions may alter the hydrology of the Fish River. This could have major impacts on the new Neckartal Dam development.

The obvious choice for the management will be harvesting of trees, but must also include the removal of saplings (no harvestable woody biomass). In collaboration with the Directory of Forestry, a way needs to be devised how to reduce the number of *Prosopis* trees along the river bank within the 100 m buffer zone, without endangering this bank through erosion during flash floods.

References

- AUALA, H., CLOETE, C., GOTTLIEB, T., HAIMBILI, E., HEMBAPU, N., KABAJANI, M., NDJAMBA, J., SHEKUNYENGE, A., SHIPANI, H. & SHUUYA, T. 2012. An analysis of the environmental and socio-economic impacts of *Prosopis* in the Auob and Nossob Basins, Namibia (Summer Land Care Programme II). Desert Research Foundation of Namibia & Gobabeb Research & Training Centre, Windhoek & Gobabeb.
- BATE, G.C. & WALKER, B.H. 1993. Water relations of the vegetation along the Kuiseb River, Namibia. *Madoqua* 18:85–91.
- BETHUNE, S., GRIFFIN, M. & JOUBERT, D.F. 2004. National Review of Invasive Alien Species (Consultancy to collect Information on: Invasive Alien Species in Namibia for SABSP (Southern Africa Biodiversity Support Programme)). Discussion report. Directorate of Environmental Affairs, Ministry of Environment and Tourism, Windhoek, Namibia.
- BOTHA, L. 1996. Rainfall as an indicator of the agroclimate of Namibia. M.Dip.Tech. (Meteorology) thesis, Faculty of Engineering, Technikon Pretoria, Pretoria.
- BOYER, D.C. & BOYER, H.J. 1989. The status of alien invasive plants in the major rivers of the Namib Naukluft Park. *Madoqua* 16:51–58.
- BROWN, C.J., MACDONALD, I.A.W. & BROWN, S.E. 1985. Invasive alien organisms in South West Africa/Namibia. South African National Scientific Programme Report, No. 119. Foundation for Research Development, Pretoria.
- CABLE, D.R. 1977. Seasonal Use of Soil Water by Mature Velvet Mesquite. *Journal of Range Management* 30: 4–11.
- CANADELL, J., JACKSON, R.B., EHLERINGER, J.B., MOONEY, H.A., SALA, O.E. & SCHULZE, E.-D. 1996. Maximum rooting depth of vegetation types at the global scale. *Oecologia* 108: 583–595.
- CHYTRÝ, M., TICHÝ, L., HOLT, J. & BOTTA-DUKAT, Z. 2002. Determination of diagnostic species with statistic fidelity measures. *Journal of Vegetation Science* 13: 79–90.
- DENGLER, J., JANSEN, F., GLÖCKLER, F., PEET, R.K., DE CÁCERES, M., CHYTRÝ, M., EWALD, J., OLDELAND, J., LOPEZ-GONZALEZ, G., FINCKH, M., MUCINA, L., RODWELL, J.S., SCHAMINÉE, J.H.J. &

- SPENCER, N. 2011. The Global Index of Vegetation-Plot Databases (GIVD): a new resource for vegetation science. *Journal of Vegetation Science* 22: 582–597.
- DZIKITI, S., SCHACHTSCHNEIDER, K., NAIKEN, V., GUSH, M., MOSES, G. & LE MAITRE, D.C. 2013. Water relations and the effects of clearing invasive *Prosopis* trees on groundwater in an arid environment in the Northern Cape, South Africa. *Journal of Arid Environments* 90: 103–113.
- GEOLOGICAL SURVEY. 1980. South West Africa / Namibia: Geological Map 1: 1 000 000.
- GIESS, W. 1998. A Preliminary Vegetation Map of Namibia. *Dinteria* 4: 1–112.
- GOVERNMENT OF NAMIBIA, 2001. Forestry Act, 2001.
- HENNEKENS, S.M. & SCHAMINÉE, J.H.J. 2001. TURBOVEG, a comprehensive data base management system for vegetation data. *Journal of Vegetation Science* 12: 589–591.
- HULTINE, K.R., CABLE, W.L., BURGESS, S.S.O. & WILLIAMS, D.G. 2003. Hydraulic redistribution by deep roots of a Chihuahuan Desert phreatophyte. *Tree Physiology* 23: 353–360.
- HUXMAN, T.E., WILCOX, B.P., BRESHEARS, D.D., SCOTT, R.L., SNYDER, K.A., SMALL, E.E., HULTINE, K., POCKMAN, W.T. & JACKSON, R.B. 2005. Ecohydrological Implications of Woody Plant Encroachment. *Ecology* 86: 308–319.
- ICC, MAWRD & AECl. 2000. Project to support the Agro-Ecological Zoning Programme (AEZ) in Namibia. Main Report. Institut Cartogràfic de Catalunya (ICC), Namibian Ministry of Agriculture, Water and Rural Development (MAWRD) and Spanish Agency for International Co-operation (AECl), Windhoek.
- IRISH, J. 2008. Biological characterisation of the Orange-Fish River Basin, Namibia, Unpublished report, Ephemeral River Basins in Southern Africa (ERB) Project, Desert Research Foundation of Namibia, Windhoek.
- JÜRGENS, N., HAARMAYER, D.H., LUTHER-MOSEBACH, J., DENGLER, J., FINCKH, M. & SCHMIEDEL, U. (Eds.). 2010. Patterns at Local Scale: The BIOTA Observatories. Biodiversity in southern Africa. Klaus Hess Publishers, Göttingen & Windhoek.
- KENT, M. 2012. Vegetation Description and Analysis. A practical approach, 2nd edition. ed. Wiley-Blackwell, Chichester, UK.
- KLAASSEN, E.S. & KWEMBEYA, E.G. (Eds.). 2013. A Checklist of Namibian Indigenous and Naturalised Plants. *Occasional Contributions No. 5*. National Botanical Research Institute, Windhoek.
- KÖPPEN, W. 1936. Das Geographische System der Klimate. Handbuch der Klimatologie. Bornträger Verlag, Berlin.
- KRUGER, A.S. 2001. Coping in a fragile environment. The SARDEP experience. Sustainable Animal and Range Development Programme, Ministry of Agriculture, Water and Rural Development, Windhoek.
- LE MAITRE, D.C., SCOTT, D.F. & COLVIN, C. 1999. Review of information on interactions between vegetation and groundwater. *Water SA* 25: 137–152.
- LE MAITRE, D.C., VERSFELD, D.B. & CHAPMAN, R.A. 2000. The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment. *Water SA* 26: 397–408.
- LE MAITRE, D.C., VAN WILGEN, B.W., GELDERBLOM, C.M., BAILEY, C., CHAPMAN, R.A. & NEL, J.A. 2002. Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. *Forest Ecology and Management* 160:143–159.
- LEVITT, D.G., SIMPSON, J.R. & TIPTON, J.L. 1995. Water use of two landscape tree species in Tucson, Arizona. *Journal of the American Society for Horticultural Science* 120: 409–416.
- MENDELSON, J., JARVIS, A., ROBERTS, C. & ROBERTSON, T. 2002. Atlas of Namibia. David Phillips Publishers, Cape Town.
- MOUSTAKAS, A., GUENTHER, M., WIEGAND, K., MUELLER, K.-H., WARD, D., MEYER, K.M. & JELTSCH, F. 2006. Long - term mortality patterns of the deep - rooted *Acacia erioloba*: The middle class shall die! *Journal of Vegetation Science* 17: 473–480.
- MUELLER-DOMBOIS, D. & ELLENBERG, H. 2002. Aims and Methods of Vegetation Ecology, Reprint of First Edition. ed. The Blackburn Press, Cladwell, New Jersey.
- Müller, M.A.N. 2007. Grasses of Namibia, 2nd ed. Ministry of Agriculture, Water and Forestry, Windhoek.

- NIE, W., YUAN, Y., KEPNER, W., ERICKSON, C. & JACKSON, M. 2012. Hydrological impacts of mesquite encroachment in the upper San Pedro watershed. *Journal of Arid Environments* 82: 147–155.
- NOOR, M., SALAM, U. & KHAN, M.A. 1995. Allelopathic effects of *Prosopis juliflora* Swartz. *Journal of Arid Environments* 31:83–90.
- PASIECZNIK, N.M., HARRIS, P.J.C. & SMITH, S.J. 2004. Identifying tropical *Prosopis* species: a field guide. HDRA Publishing, Coventry. UK.
- QGIS. 2014. Open Source Geospatial Foundation (OSGeo).
- ROLEČEK, J., TICHÝ, L., ZELENÝ, D. & CHYTRÝ, M. 2009. Modified TWINSpan classification in which the hierarchy respects cluster heterogeneity. *Journal of Vegetation Science* 20:596–602.
- SALINI IMPREGILO 2013. Neckartal Dam Project [WWW Document]. URL <http://www.salini-impregilo.com/en/projects/in-progress/dams-hydroelectric-plants-hydraulic-works/neckartal-dam-project.html>
- SCHACHTSCHNEIDER, K. & FEBRUARY, E.C. 2010. The relationship between fog, floods, groundwater and tree growth along the lower Kuiseb River in the hyperarid Namib. *Journal of Arid Environments* 74: 1632–1637.
- SHACKLETON, R.T., LE MAITRE, D.C. & RICHARDSON, D.M. 2015. *Prosopis* invasions in South Africa: Population structures and impacts on native tree population stability. *Journal of Arid Environments* 114: 70–78.
- SMIT, G.N. 1989a. Quantitative description of woody plant communities: Part II. Computerized calculation procedures. *Journal of the Grassland Society of southern Africa* 6: 192–194.
- SMIT, G.N. 1989b. Quantitative description of woody plant communities: Part I. An approach. *Journal of the Grassland Society of southern Africa* 6: 186–192.
- SMIT, G.N. 2014. BECVOL 3: an expansion of the aboveground biomass quantification model for trees and shrubs to include the wood component. *African Journal of Range and Forage Science* 31: 179–186.
- SMIT, P. 2005. Geo-ecology and environmental change: An applied approach to manage *Prosopis*-invaded landscapes in Namibia. Ph.D. thesis, University of Namibia, Windhoek.
- STROHBACH, B.J. 2001. Vegetation Survey of Namibia. *Journal of the Namibia Scientific Society* 49: 93–124.
- STROHBACH, B.J. 2008. Mapping the major catchments of Namibia. *Agricola* 18:63–73.
- STROHBACH, B.J. 2012. Providing relevant, useful information on Namibian Vegetation Types. *Agricola* 22: 7–39.
- STROHBACH, B.J. 2014. Vegetation Survey of Namibia: Conceptualisation and implementation of a nation-wide vegetation survey serving practical land management needs. Department of Biology, Faculty of Mathematics, Informatics and Natural Sciences, University of Hamburg, Hamburg.
- STROHBACH, B.J. & JANKOWITZ, W.J. 2012. Phytosociology of the Farm Haribes in the Nama-Karoo Biome of southern Namibia. *Koedoe - African Protected Area Conservation and Science* 54: 8–20.
- STROHBACH, B.J., KABAJANI, M.W., NTESA, C., NDJAMBA, J., SHEKUNYENGE, A. & AMUTENYA, J.U., in prep. *Prosopis* encroachment along the Fish River at Gibeon, Namibia. II. Harvestable wood biomass.
- STROHBACH, B.J. & KANGOMBE, F. 2012. National Phytosociological Database of Namibia. *Biodiversity & Ecology* 4: 298.
- SWART, R. 2008. An earth science review of the Orange-Fish River Basin, Namibia. Unpublished report, Ephemeral River Basins in Southern Africa (ERB) Project, Desert Research Foundation of Namibia, Windhoek.
- TICHÝ, L. 2002. JUICE, software for vegetation classification. *Journal of Vegetation Science* 13: 451–453.
- TORDIFFE, E.A.W. 2010. Groundwater monitoring in the Orange-Fish River Basin, Namibia: Recommendations towards establishing a monitoring system. Unpublished report, Ephemeral River Basins in Southern Africa (ERB) Project, Desert Research Foundation of Namibia, Windhoek.
- UHLENDHAL, T., ZIEGELMAYER, D., WIENECKE, A., MAWISA, M.L. & DU PISANI, P. 2010. Water consumption at household level in Windhoek, Namibia. Institute for Culture Geography, Albert Ludwigs University Freiburg, Windhoek & Freiburg.

- VAN DEN BERG, E.C. 2010. Detection, quantification and monitoring *Prosopis* spp. in the Northern Cape Province of South Africa using Remote Sensing and GIS. M in Environmental Sciences thesis, Potchefstroom Campus of the North-West University, Potchefstroom.
- VISSER, J.N. 1998. Effect of *Prosopis glandulosa* on natural vegetation in Lower Swakop River. Unpublished Report, Polytechnic of Namibia, Windhoek.
- WESTFALL, R.H. & GREEFF, A. 1998. A national grid of vegetation monitoring sites. *South African Journal of Science* 94: 150–151.
- WISE, R.M., VAN WILGEN, B.W. & LE MAITRE, D.C. 2012. Costs, benefits and management options for an invasive alien tree species: The case of mesquite in the Northern Cape, South Africa. *Journal of Arid Environments* 84: 80–90.
- WULLSCHLEGER, S.D., MEINZER, F.C. & VERTESSY, R.A. 1998. A review of whole-plant water use studies in tree. *Tree physiology* 18: 499–512.

***Prosopis* encroachment along the Fish River at Gibeon, Namibia. II. Harvestable wood biomass.**

B.J. Strohbach¹, M.W. Kabajani¹, C. Ntesa¹, J. Ndjamba², A. Shekunyenge²
& J.U. Amutenya¹

¹School of Natural Resources and Spatial Sciences
Polytechnic of Namibia
P/Bag 13388
Windhoek, Namibia

²Desert Research Foundation of Namibia
P. O. Box 20232
Windhoek, Namibia
E-mail: bstrohbach@polytechnic.edu.na

Abstract

Prosopis infestation along the Fish River in southern Namibia poses a considerable threat to the environment; in particular, it reduces the water flow/water yield in the river. In this paper we propose that the trees be removed and utilised as firewood, which would also generate an income to the local community. For this, an average wood biomass per tree size class is established, and the total harvestable wood biomass for the Gibeon area (about a 5 km river stretch at Gibeon) is estimated to be as much as 2,900 tons of wood.

Harvesting for firewood alone will not curb the infestation, though. Saplings and coppice from the felled stumps need to be removed as well. It is suggested to treat felled stumps with arboricides applied directly to the stumps. Foliar application and/or soil application of arboricides are not recommended, due to the danger of these leaching through the soil and either contaminating the water in the Fish River and/or killing trees from the natural vegetation.

Gradual removal of *Prosopis*, combined with active revegetating of the natural vegetation is also recommended for the river bank area. In this way the natural vegetation can be replaced, without threatening the bank through erosion. Overall, this long-term project should be developed as a public-private partnership between the community of Gibeon (and other communities along the Fish River) as well as the Directorates of Forestry, Hydrology and Water Environment of the MAWF.

Keywords: Alien invasive control; fire wood harvesting; wood biomass

Introduction

Prosopis species were introduced to Namibia as early as 1897 for shade and as a fodder tree for domestic animals such as cattle, donkeys, horses, goats and sheep (Smit 2005) and has since aggressively invaded riverine systems throughout the arid and semi-arid parts of Namibia and southern Africa (Brown *et al.* 1985; Henderson 2001; Bethune *et al.* 2004; Smit 2005; van den Berg 2010). *Prosopis* spp. has also been found to densely encroach the Fish River valley as part of the Orange catchment, including the area around Gibeon (Strohbach *et al.* in prep.; Ntesa *et al.* 2014). As alien invasive, it does not only threaten and destroy the indigenous vegetation, but also uses extensive ground water reserves. It is estimated that the present invasion of *Prosopis* along

the Fish River between the Hardap Dam and the newly developed Neckartal Dam could use as much water as 18% of the total capacity of the Neckartal Dam (Strohbach *et al.* in prep.).

Prosopis is used for a variety of products in many countries (both as an indigenous species as well as an exotic), including pods as fodder for domestic animals as well as for human consumption – e.g. making beverages, wine, flour for bread and biscuits, etc. The wood of large trees is used for furniture and timber, whilst smaller trees and shrubs provide fencing material. Leaf litter can be used to improve soil quality. Furthermore, *Prosopis* bark is also used as a source of tannins (for tanning hides), dyes and fibres while *Prosopis* flowers produce good quality honey. In the Sahel and in some arid parts of India, *Prosopis* is used for sand-dune control (wind breaks and fences), stream bank stabilisation and watershed management. Furthermore, the plants are used to reclaim or rehabilitate degraded or altered arid lands. *Prosopis* is also known as an excellent source of fuel wood, and is often used to produce charcoal (Felger & Moser 1971; Lyon *et al.* 1988; Marangoni & Alli 1988; Fagg & Stewart 1994; Lea 1996; Felker *et al.* 2003; Pasiecznik *et al.* 2004; Smit 2005; Choge *et al.* 2007; Sirmah *et al.* 2008; Escobar *et al.* 2009; van den Berg 2010; Auala *et al.* 2012; Oduor & Githiomi 2013).

In Namibia a variety of products and services are derived from *Prosopis*, including pods which are used for human and livestock consumption, shade around homesteads as well as fuel wood. In Leonardville an industry developed around *Prosopis*, including wild silk scarves made from cocoons collected from *Prosopis* trees, as well as wood for furniture, timber and charcoal. Moreover, in Brakwater north of Windhoek, there is a small-scale plant where *Prosopis* wood is processed for furniture purposes (Smit 2005; Auala *et al.* 2012).

Although these trees provide some advantages in arid environments, their aggressive growth and extreme water use makes them a serious environmental threat especially in river beds. For this reason, the Desert Research Foundation of Namibia (DRFN) with funding from the United States Agency for International Development (USAID) is implementing a project: 'A Water Secure Future for Southern Africa'. The project's goal is to build governance capacity through mainstreaming the Ecosystem Approach (EA) in Integrated Water Resources Management (IWRM) in the Orange-Senqu River Basin. As part of this initiative, a management plan to control the *Prosopis* infestation in the Fish River Valley was developed. The aim of this paper is to provide a baseline on the available woody biomass within the study area, as an option to create an incentive to actively remove the invasive trees and shrubs.

Methods

The study area has been described in depth by Ntesa *et al.* (2014) and Strohbach *et al.* (in prep.). Three vegetation types, on five different habitats, have been described in these studies (See elsewhere in this current journal – Ed.). The current assessment of standing biomass is based on these five habitat types.

Volume and harvestable wood biomass per tree

In order to be able to determine standing harvestable woody biomass of the *Prosopis* stands in these five habitats, the harvestable woody biomass per tree/shrub of various height classes had to be determined. A minimum stem diameter of 50 mm was defined as "harvestable" biomass. This represents the minimum wood thickness generally harvested for charcoal production (Düvel 1985), and would also be acceptable for sale as fire wood.

A random selection of 56 trees of various sizes (from sapling to mature trees) was measured following the standard measurements for Biomass Estimates from Canopy Volume (BECVOL) (Smit 1989, 2014). This was done in order to obtain a relationship between tree height and tree volume. Furthermore, from these measured trees, 16 were selected (again representing various tree sizes) for felling with a chain saw. The harvestable woody biomass was removed from the felled tree, individually packed, dried in the sun for a week and weighed.

In order to determine the drying rate of the *Prosopis* wood after cutting, repeated re-weighing of a selection of samples was done over a period of two months after initial weighing.

An exponential regression between tree height and harvestable biomass was obtained. This regression was used to determine an average harvestable woody biomass weight per size class, which could be used to determine the harvestable woody biomass for particular stands/habitats in the direct vicinity of Gibeon.

Standing harvestable biomass

In order to determine the standing harvestable biomass of *Prosopis* in the different habitats, a transect count over 4 x 100 m (i.e. 400 m²) was done of all woody species at each of the 25 plots sampled for the biodiversity assessment (Strohbach *et al.* 2015.). For this transect count, the trees and shrubs were counted per the size classes (Table 1).

For each size class, the midpoint was taken as “typical” height. From this typical height, a “typical” tree volume and a “typical” harvestable woody biomass were calculated using the regression equations derived previously (Table 1). The final yield values were adjusted downward with 30% to allow for the drying of the wood.

Using the typical harvestable wood biomass per size class, the harvestable woody biomass per ha could be calculated from the transect data, by averaging the densities per plot, per habitat.

Using the areas calculated for each habitat, as determined from the map presented by Strohbach *et al.* (in prep.), a prediction was made as to the harvestable woody biomass for the various habitats and the entire townlands.

Results

Tree biomass

The relation between tree canopy volume and tree height is depicted in Figure 1. Although not a perfect fit, the regression indicates that the tree height can be taken as a reliable proxy for the total tree volume, with the advantage, that the tree height is relatively easy to measure compared to the measurements needed for tree volume.

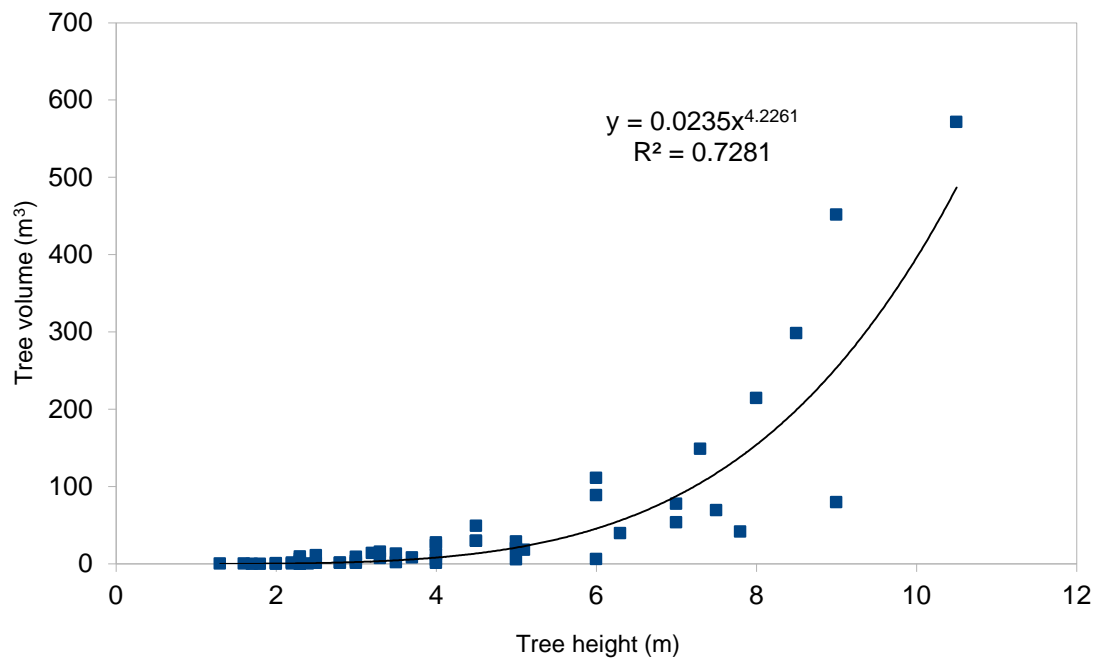


Figure 1. Relationship between *Prosopis* tree height and the tree canopy volume, as determined by the BECVOL method.

The relationship between tree height and harvestable wood biomass is depicted in Figure 2, based on the measured wood biomass of the 16 harvested trees. An exponential regression line was fitted, giving the most reliable results. With this regression equation, an estimated woody biomass per size class could be calculated. As no trees smaller than 2 m height were found in the field with harvestable-size stems, the size classes below 2 m height were taken as having none, even though the regression predicts at least 2.2 kg wood for a 1 m sapling. These estimated harvestable wood biomass quantities per height class are depicted in Table 1.

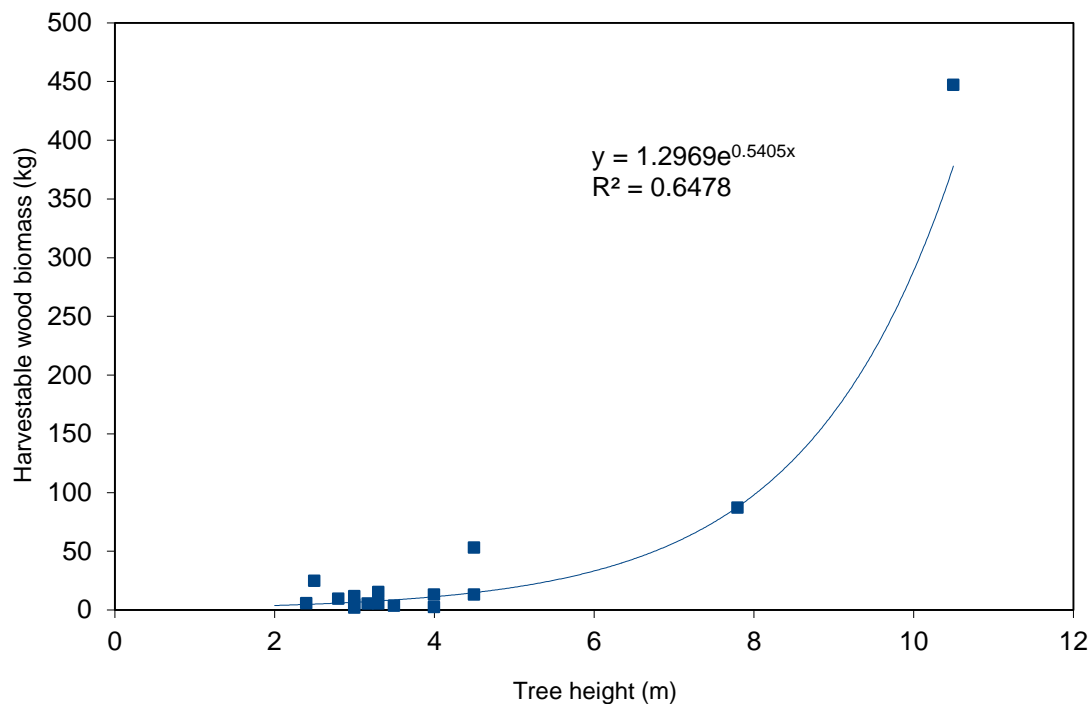


Figure 2. The relationship between harvestable wood biomass and tree height of *Prosopis* species at Gibeon.

Table 1. Size classes, with their midpoints, estimated volume and estimated harvestable biomass, used in the survey and subsequent analysis. Saplings below 2 m height were assumed not to have any harvestable wood biomass.

| Height class | Class midpoint (m) | Tree canopy volume (m ³)* | Harvestable wood biomass (kg)** |
|--------------|--------------------|---------------------------------------|---------------------------------|
| 0-1 m | 0.5 | 0.001 | 1.7 (taken as 0 kg) |
| 1-2m | 1.5 | 0.130 | 2.9 (taken as 0 kg) |
| 2-3 m | 2.5 | 1.129 | 5.0 |
| 3-4 m | 3.5 | 4.681 | 8.6 |
| 4-5 m | 4.5 | 13.540 | 14.8 |
| 5-8 m | 6.5 | 64.050 | 43.5 |
| >8 m | 9 | 253.392 | 168.0 |

* Regression: $y = 0.0235x^{4.2261}$, $R^2=0.7281$

** Regression: $y = 1.2969e^{0.5405x}$, $R^2=0.6478$

Drying of wood

The drying time is highly dependent on the size of the cut wood, and whether the stumps are further split. From the limited repeat weighing, an ideal drying time of between six and eight weeks should be allowed. By this time the wood would have lost between 10% and 20% of its initial weight (Figure 3), improving the burning properties (and thus the quality of the firewood) dramatically. Because of this obvious loss in weight, the estimated harvestable wood biomass was reduced by 20% for further yield calculations.

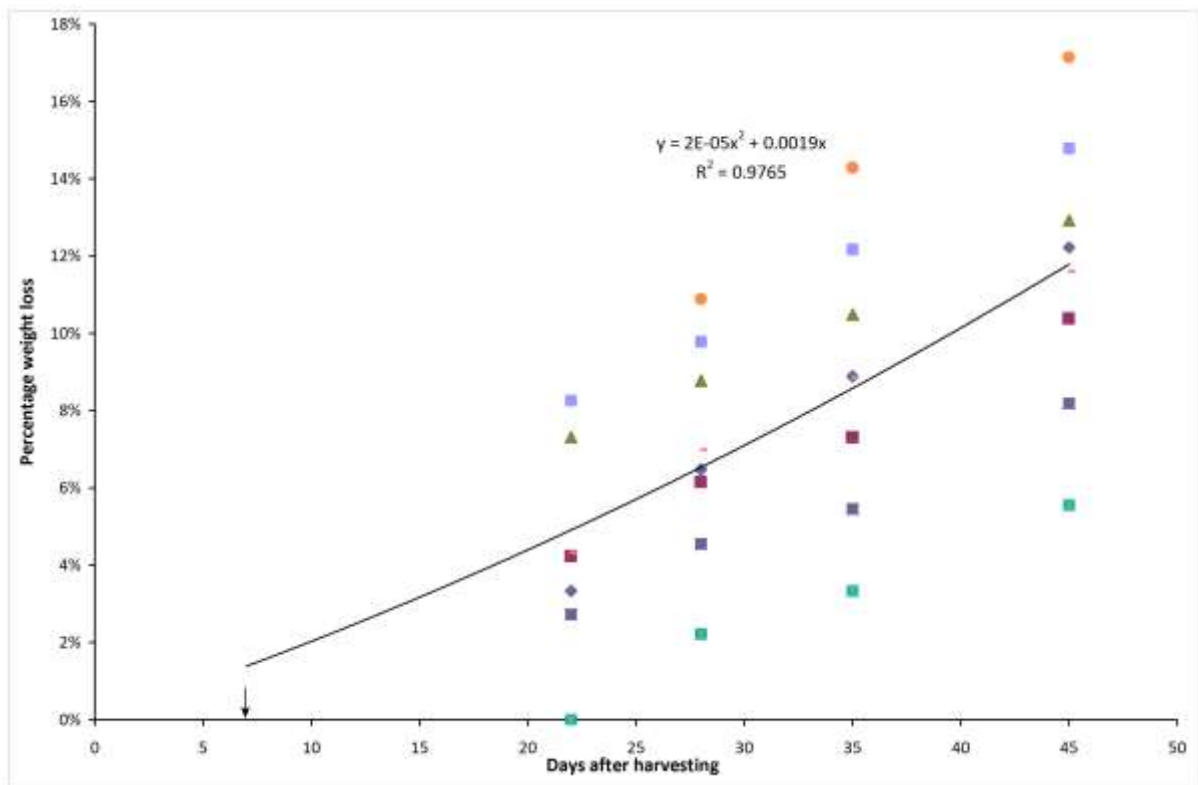


Figure 3. Wood drying rates over time for a few selected stumps. Note that the first weighing took place only seven days after harvesting (indicated by arrow), thus a loss of moisture before the first measurements as depicted on the graph can be expected.

Standing biomass

Based on the above average harvestable wood biomass per tree height class, and the areas covered by the different habitats around Gibeon (Strohbach *et al.* in prep.), and estimated total wood yield could be calculated (Table 2). Assuming that a 10 kg bag of *Prosopis* wood can be sold for N\$10.00, an amount of approximately N\$2.9 Million can be generated from cutting all the *Prosopis* in the fountain, commonage and flood plain areas (Table 2). Restrictions imposed by the Forestry Act (Act 12 of 2001) (Government of Namibia 2001) on removing trees from river banks to prevent erosion of these however means that this figure will need to be downward adjusted, as roughly half the riverbank vegetation (containing the most harvestable trees) is within the 100 m buffer zone along the river as prescribed by the Act (Strohbach *et al.* in prep.).

It needs to be remembered that the population is strongly regenerating, with smaller trees and shrubs (<3 m) dominating the stands (Figure 4). Removals of the large individuals will not successfully eradicate the population, if the smaller individuals are left standing. *Prosopis* is also able to coppice (Figures 5a-c), meaning that a post-felling treatment to the stumps needs to be made to prevent such regrowth.

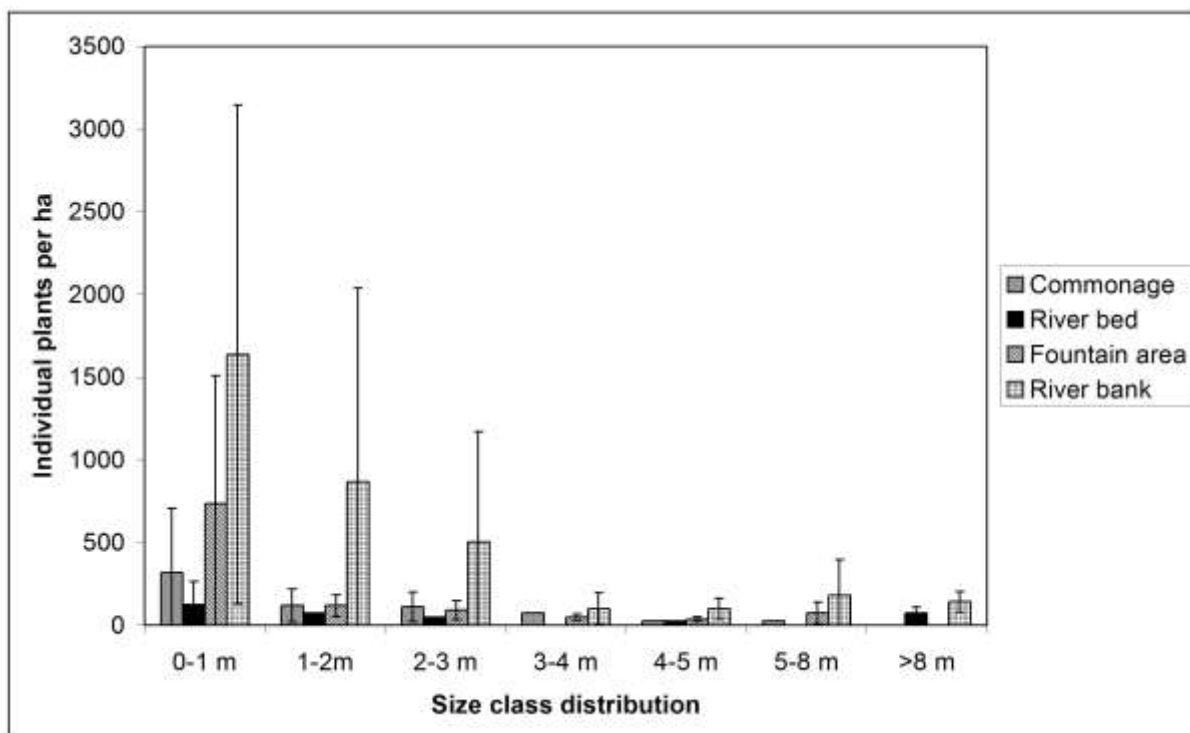


Figure 4. Height class distributions of *Prosopis* trees measured along transects in the various habitats.





Figure 5a-c. Felled *Prosopis* trees and shrubs coppice strongly from the base.

Table 2. Characteristics of the five different habitat types considered in this study, including the estimated wood yield from each habitat.

| Landscape | Area (ha) | <i>Prosopis</i> density (plants/ha) | | | | | | Estimated harvestable biomass* | Total harvestable biomass | Potential estimated gross revenue |
|-----------------------------------------------------------------|---------------|-------------------------------------|-------------------|---------------------|----------------------|----------------------|-------------------|--------------------------------|---------------------------|--------------------------------------------|
| | | 0 – 2 m (0 kg) | 2 – 3 m (5 kg) | 3 – 4 m (8.6 kg) | 4 – 5 m (14.8 kg) | 5 – 8 m (43.5 kg) | > 8 m (168 kg) | | | |
| Tree size class (average harvestable woody biomass per tree) | | | | | | | | | | (calculated at N\$10.00/10 kg bag of wood) |
| Commonage | 142.35 | 440 | 112.5 | 75 | 25 | 25 | 0 | (0.720) 0.576 | 81.94 | N\$ 81,937 |
| Floodplains | 277.03 | No data | | | | | | | | |
| Fountain vegetation | 44.30 | 856 | 92 | 50 | 37.5 | 75 | 0 | (3.776) 3.021 | 133.81 | N\$ 133,808 |
| River bank vegetation | 113.45 | 2506 | 505 | 100 | 100 | 180 | 142 | (26.507) 21.206 | 2,405.78 | N\$ 2,405,775 |
| Riverbed | 101.35 | 200 | 50 | 0 | 25 | 0 | 75 | (8.607) 6.886 | 697.90 | N\$ 697,896 |
| Grand Total | 678.47 | | | | | | | | 3,319.42 | N\$ 3,319,416 |

*The first figure (in parentheses) is the estimated wet weight; the second figure (without parentheses) has been reduced by 20% to compensate for mass loss due to drying out of the fresh cut wood.

Wood burning properties

No empirical studies were done on the burning properties of *Prosopis* wood within the framework of this study. However, from own observations, the wood burns well, and forms charcoal similar to many of the common hardwood species in Namibia (e.g. *Acacia reficiens*, which is commonly sold in supermarkets). It is better than wood of *swarthaak* (*Acacia mellifera* subsp. *dentinens*), but not as hard as camelthorn or leadwood (*Acacia erioloba* or *Combretum imberbe*). Even smaller wood pieces make a good fire for barbeque (*braai*). These observations are confirmed by Sirmah *et al.* (2008) and Oduor & Githiomi (2013). For comparison purposes, some wood density data and calorific data for related *Prosopis* species (within the *Prosopis juliflora* complex) in comparison to indigenous woody species were obtained from the literature (Table 3). These values however are highly dependent on the growing conditions of the trees (Montes *et al.* 2011).

Table 3. Comparative wood density and wood calorific values for several indigenous woody species and *Prosopis* species related to the *P. juliflora* complex.

| Species | Density (kg/m ³) | Calorific value (kJ/g) | Country | Information source |
|----------------------------|------------------------------|----------------------------------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| <i>Acacia erioloba</i> | 1059 | | Zimbabwe | Chave <i>et al.</i> (2009); Zanne <i>et al.</i> (2009) |
| <i>Acacia mellifera</i> | 703 | 19.19 | Sudan | Khider & Elsaki (2012) |
| <i>Acacia nilotica</i> | 978 800-840 966 688 | 23.40 19.57-23.68 26.63 19.71 | India | Nirmal Kumar <i>et al.</i> (2009) Goel & Behl (1996) Nirmal Kumar <i>et al.</i> (2011) Puri <i>et al.</i> (1994) |
| <i>Acacia senegal</i> | 728 | 19.31 | Sudan | Khider & Elsaki (2012) |
| <i>Combretum imberbe</i> | 1059 | | Zimbabwe | Chave <i>et al.</i> (2009); Zanne <i>et al.</i> (2009) |
| <i>Prosopis cineraria</i> | 942 867 | 21.93 26.63 | India | Nirmal Kumar <i>et al.</i> (2009) Nirmal Kumar <i>et al.</i> (2011) |
| <i>Prosopis chilensis</i> | 740 720 | | N America S America | Chave <i>et al.</i> (2009); Zanne <i>et al.</i> (2009) |
| <i>Prosopis glandulosa</i> | 705 820 | | N America Tropical Africa | Chave <i>et al.</i> (2009); Zanne <i>et al.</i> (2009) |
| <i>Prosopis juliflora</i> | 891 828 800-890 | 20.34 21.5 20.33-23.90 | Kenya India India | Oduor & Githiomi (2013) Nirmal Kumar <i>et al.</i> (2009) Goel & Behl (1996) |
| <i>Prosopis pallida</i> | 834 | 20.72 | Kenya | Oduor & Githiomi (2013) |

In the first few weeks after harvesting, the wood was slow to start burning due to still being moist. This improved after about two months. Once burning, even thicker stumps will char through completely even if removed from the fire itself. In comparison, many other hardwoods commonly available as firewood in supermarkets would remain half-burned if removed from the actual fire (pers. obs.).

Discussion and Conclusion

The infestation by *Prosopis* along the Fish River in southern Namibia poses a real threat to downstream water supply as well as the natural biodiversity of the river ecosystem (Strohbach *et al.* in prep.). A management programme to control this threat is thus essential to ensure that major investments like the Neckartal Dam will perform its function in future. Harvesting wood for sale as firewood will also provide the impoverished community at Gibeon with a valuable source of income. A number of consideration need to be taken into account, though:

Other potential uses for *Prosopis* wood

The production of charcoal was considered a less attractive economic solution in this study. Charcoal production would mean an additional investment in terms of kiln, sieves, packaging material and marketing. Charcoal is generally packaged in expensive, printed paper bags, with strict quality control. Conversely, firewood is generally packaged in cheap(er) polyethylene bags ("fodder bags") without special markings, and without extensive quality control, as long as the minimum weight and minimum size of wood are maintained. Charcoal is also generally marketed to large supermarket chains (including exporting to overseas markets), requiring intensive marketing and a constant supply of produce while the firewood market in Namibia is more informal. Considering the extreme weight loss during charring (charcoal is only about 18% of the original weight (Lea 1996), and the fact that charcoal and firewood have very similar prices per kg in local supermarkets, means that the sale of firewood will likely earn the producers more per kg wood harvested compared to charcoal.

A large amount of "fines" (branches less than 5 cm diameter) will remain. These are generally also the branches armed with spines, making them difficult to sell. One potential use will be firewood for local use; another would be production of biochar. Biochar is used for soil amelioration (Lehmann *et al.* 2011; Biederman & Harpole 2013), and has resulted in significant yield increases in dryland cropping systems in northern Namibia (Zimmermann & Amupolo 2013). Potential markets for biochar will be the irrigation schemes at Hardap, Stampriet and Naute, as well as the proposed irrigation scheme at the Neckartal Dam. The production of biochar will however probably be fairly capital-intensive; in order to purchase the necessary kilns and marketing efforts for the biochar will also be required.

The cutting of wood into sellable-sized stumps (ca 30 cm long) will produce large quantities of sawdust. This sawdust can be packaged for food processing purposes (e.g. smoking of meat). *Prosopis* (known/sold as mesquite) is highly regarded as barbeque and smoking wood in the USA (Riversideq.com 2009; Monteleone 2013; Real Texas BBQ Rub, Inc 2013). However, care needs to be taken that the packaged sawdust is clean of sand, oil (as with chain saw residues) and other contaminants. Excessive amounts of sawdust can also be composted. Sawdust compost generally produces low nitrogen/high carbon compost (Gardening Know How 2014; Polomski & Doubrava 2015; The Home Composter 2015).

Ecological considerations of *Prosopis* management

The extreme large amount of juvenile plants, which have not yet reached harvestable size, is a concern, as is the strong coppicing ability of *Prosopis*. Lack of control of this has led to worse encroachment, and thus habitat transformation, in Ethiopia, where it is also regarded as a noxious alien invasive (Berhanu & Tesfaye 2006). Likewise, seedlings emerging from the existing soil seed bank need to be controlled. The soil seed bank has been found to be viable for more than a year, with the major threat to the viability of seeds being bruchids boring into the seeds (Marone *et al.* 2000). Some of these insects were introduced to Namibia and are said to have spread widely (Smit 2005). However, no evidence of this could be found in the Gibeon area.

A simple tool which could be used for the removal of *Prosopis* saplings is the 'tree-popper' (CreaTique & Chameleon Innovation 2015; Joubert *et al.* 2014). The advantage of applying this method in removing seedlings is that they are removed with roots implying that coppicing will not be possible. The control of coppice from bigger stumps will have to be done manually, or better still, by the direct treatment of the stumps with an aboricide. No foliar or soil application of aboricides are recommended due to the fact that these spread readily through the soil and could either kill natural vegetation, or contaminate the water in the Fish River (Ogle & Warren 1954; Weber & Whitacre 1982; Futch & Singh 1999).

The removal of 'indigenous vegetation' from the banks of rivers (within 100 m from the river) is prohibited under the Forestry Act (Act 12 of 2001) (Government of Namibia 2001). As this is

however the area with the densest invasion of *Prosopis* at Gibeon (Strohbach *et al.* in prep.), the infestation needs to be removed from this habitat as well, in order to prevent re-infestation of cleared areas as well as to protect the water source in the Fish River. A gradual clearing approach, coupled with active replanting of indigenous trees, is recommended. We propose the complete removal of all saplings below 2 m height, as well as up to 50% of all individuals over 2 m height, within the first year from this buffer zone. This needs to be followed by immediate replanting of *Acacia karroo*, *A. erioloba*, *A. tortilis*, *Euclea pseudobenensis*, *Tamarix usneoides* and *Ziziphus mucronata* into the cleared spaces. Reliance on natural reseeding of these species will be futile, as *Prosopis* is known to have a strong allelopathic effect, suppressing the emergence and establishment of seedlings (Al-Humaid & Warrag 1998). As the replanted trees establish, the remaining *Prosopis* trees can be removed over a five-year period.

In conclusion, there is an opportunity for a public-private partnership project between the Directorates of Forestry, Water Environment and Hydrology as well as the local community to remove the alien invasive *Prosopis* from the Fish River Ecosystem. Initially the river bank at Gibeon can be cleared as a trial for a much larger project to clear *Prosopis* from the entire Fish River Valley.

References

- AL-HUMAIID, A.I. & WARRAG, M.O.A. 1998. Allelopathic effects of mesquite (*Prosopis juliflora*) foliage on seed germination and seedling growth of Bermudagrass (*Cynodon dactylon*). *Journal of Arid Environments* 38: 237–243.
- AUALA, H., CLOETE, C., GOTTLIEB, T., HAIMBILI, E., HEMBAPU, N., KABAJANI, M., NDJAMBA, J., SHEKUNYENGE, A., SHIPANI, H. & SHUUYA, T. 2012. An analysis of the environmental and socio-economic impacts of *Prosopis* in the Auob and Nossob Basins, Namibia. Summer Land Care Programme II, Desert Research Foundation of Namibia & Gobabeb Research & Training Centre, Windhoek & Gobabeb.
- BERHANU, A. & TESFAYE, G. 2006. The *Prosopis* dilemma, impacts on dryland biodiversity and some controlling methods. *Journal of the Drylands* 1: 158–164.
- BETHUNE, S., GRIFFIN, M. & JOUBERT, D.F. 2004. National Review of Invasive Alien Species (Consultancy to collect Information on: Invasive Alien Species in Namibia for SABSP (Southern Africa Biodiversity Support Programme). Discussion report. Directorate of Environmental Affairs, Ministry of Environment and Tourism, Windhoek, Namibia.
- BIEDERMAN, L.A. & HARPOLE, W.S. 2013. Biochar and its effects on plant productivity and nutrient cycling: a meta - analysis. *GCB Bioenergy* 5: 202–214.
- BROWN, C.J., MACDONALD, I.A.W. & BROWN, S.E. 1985. Invasive alien organisms in South West Africa/Namibia. South African National Scientific Programme Report, No. 119. Foundation for Research Development, Pretoria.
- CHAVE, J., COOMES, D., JANSEN, S., LEWIS, S.L., SWENSON, N.G. & ZANNE, A.E. 2009. Towards a worldwide wood economics spectrum. *Ecology Letters* 12: 351–366.
- CHOGE, S.K., PASIECZNIK, N.M., HARVEY, M., WRIGHT, J., AWAN, S.Z. & HARRIS, P.J.C. 2007. *Prosopis* pods as human food, with special reference to Kenya. *Water SA* 33: 419–424.
- CREATIQUE & CHAMELEON INNOVATION. 2015. Tree Popper [WWW Document]. URL <http://www.treepopper.co.za/index.php/home>
- DÜVEL, U.V. 1985. Die bosbenuttingsprojek. *Agricola* 2: 29–31.
- ESCOBAR, B., ESTÉVEZ, A.M., FUENTES, C. & VENEGAS, D. 2009. Use of algarrobo (*Prosopis chilensis* (Mol) Stuntz flour as protein and dietary fiber source in cookies and fried chips manufacture]. *Archivos Latinoamericanos de Nutricion* 59: 191–198.
- FAGG, C.W. & STEWART, J.L. 1994. The value of *Acacia* and *Prosopis* in arid and semi-arid environments. *Journal of Arid Environments* 27: 3–25.
- FELGER, R.S. & MOSER, M.B. 1971. Seri Use of Mesquite (*Prosopis glandulosa* var *torreyana*). *Kiva* 37: 53–60.

- FELKER, P., GRADOS, N., CRUZ, G. & PROKOPIUK, D. 2003. Economic assessment of production of flour from *Prosopis alba* and *P. pallida* pods for human food applications. *Journal of Arid Environments* 53: 517–528.
- FUTCH, S.H. & SINGH, M. 1999. Herbicide mobility using soil leaching columns. *Bulletin of Environmental Contamination and Toxicology* 62: 520–529.
- GARDENING KNOW HOW. 2014. Using Sawdust In Your Compost Pile [WWW Document]. Gard. Know How. URL <http://www.gardeningknowhow.com/composting/ingredients/using-sawdust-in-your-compost-pile.htm>
- GOEL, V.L. & BEHL, H.M. 1996. Fuelwood quality of promising tree species for alkaline soil sites in relation to tree age. *Biomass Bioenergy* 10: 57–61.
- GOVERNMENT OF NAMIBIA, 2001. Forestry Act, 2001.
- HENDERSON, L. 2001. Alien weeds and invasive plants. Plant Protection Research Institute Handbook, No. 12. Plant Protection Research Institute, Agricultural Research Council, Pretoria.
- JOUBERT, D., ZIMMERMANN, I., FENDLER, J., WINSCHIERS-THEOPHILUS, H., GRAZ, F.P., SMIT, N. & HOFFMAN, M.T. 2014. The development of an expert system for arid rangeland management in central Namibia with emphasis on bush thickening. *African Journal of Range & Forage Science* 31: 161–172.
- KHIDER, T.O. & ELSAKI, O.T. 2012. Heat Value of Four Hardwood Species from Sudan. *Journal of Forest Products and Industries* 1: 5–9.
- LEA, J.D. 1996. A review of literature on charcoal in Haiti. In: Felker, P., Moss, J. (Eds.), *Prosopis: Semiarid fuelwood and forage tree. Building Consensus for the Disenfranchised*. US National Academy of Sciences, Washington, D.C., pp. 2–33–2–44.
- LEHMANN, J., RILLIG, M.C., THIES, J., MASIELLO, C.A., HOCKADAY, W.C. & CROWLEY, D. 2011. Biochar effects on soil biota—a review. *Soil Biology and Biochemistry* 43: 1812–1836.
- LYON, C.K., GUMBMAN, M.R. & BECKER, R. 1988. Value of mesquite leaves as forage. *Journal of the Science of Food and Agriculture* 44: 111–117.
- MARANGONI, A.M. & ALLI, I. 1988. Composition and properties of seeds and pods of the tree legume *Prosopis juliflora* (DC). *Journal of the Science of Food and Agriculture* 44: 99–110.
- MARONE, L., HORNO, M.E. & SOLAR, R.G.D. 2000. Post-dispersal fate of seeds in the Monte desert of Argentina: patterns of germination in successive wet and dry years. *Journal of Ecology* 88: 940–949.
- MONTELEONE, M. 2013. Best Wood for Smoking Meat - A Guide to Hardwoods for Smoking [WWW Document]. Pit Boss. URL <http://pitbossbelt.com/wp/best-wood-for-smoking-meat-oak-hickory-maple-mesquite>
- MONTES, C.S., DA SILVA, D.A., GARCIA, R.A., BOLZÓN DE MUÑIZ, G.I. & WEBER, J.C. 2011. Calorific value of *Prosopis africana* and *Balanites aegyptiaca* wood: Relationships with tree growth, wood density and rainfall gradients in the West African Sahel. *Biomass Bioenergy* 35: 346–353.
- NIRMAL KUMAR, J.I., PATEL, K., KUMAR, R.N. & BHOI, R.K. 2009. An assessment of Indian fuelwood with regards to properties and environmental impact. *Asian Journal on Energy and Environment* 10: 99–107.
- NIRMAL KUMAR, J.I., PATEL, K., KUMAR, R.N. & BHOI, R.K., 2011. An evaluation of fuelwood properties of some Aravally mountain tree and shrub species of Western India. *Biomass Bioenergy* 35:411–414.
- NTESA, C., KABAJANI, M. & STROHBACH, B.J. 2014. Baseline Assessment of *Prosopis* in Gibeon, Orange-Fish River Basin. Unpublished report, Desert Research Foundation of Namibia and the United States Agency for International Development (USAID), Polytechnic of Namibia, Windhoek.
- ODUOR, N.M. & GITHIOMI, J.K. 2013. Fuel-wood energy properties of *Prosopis juliflora* and *Prosopis pallida* grown in Baringo District, Kenya. *African Journal of Agricultural Research* 8: 2476–2481.
- OGLE, R.E. & WARREN, G.F. 1954. Fate and Activity of Herbicides in Soils. *Weeds* 3: 257–273.
- PASIECZNIK, N.M., HARRIS, P.J.C. & SMITH, S.J. 2004. Identifying tropical *Prosopis* species: a field guide. HDRA Publishing, Coventry. UK.
- POLOMSKI, B. & DOUBRAVA, N. 2015. Composting [WWW Document]. Clemson Coop. Ext. URL http://www.clemson.edu/extension/hgic/plants/other/compost_mulch/hgic1600.html
- PURI, S., SINGH, S. & BHUSHAN, B. 1994. Evaluation of fuelwood quality of indigenous and exotic tree species of India's semiarid region. *Agroforestry Systems* 26: 123–130.

- REAL TEXAS BBQ RUB, INC. 2013. BBQ Wood Information Center [WWW Document]. URL <http://www.texasbbqrub.com/wood.htm>
- RIVERSIDEQ.COM. 2009. Smoking with Mesquite Texas Style [WWW Document]. URL <http://www.riversideq.com/wood/woodhome.html>
- SIRMAH, P., MUISU, F., MBURU, F., DUMARÇAY, S. & GÉRARDIN, P. 2008. Evaluation of *Prosopis juliflora* properties as an alternative to wood shortage in Kenya. *Bois et Forêts des Tropiques* 298: 25–35.
- SMIT, G.N. 1989. Quantitative description of woody plant communities: Part II. Computerized calculation procedures. *Journal of the Grassland Society of South Africa* 6: 192–194.
- SMIT, G.N. 2014. BECVOL 3: an expansion of the aboveground biomass quantification model for trees and shrubs to include the wood component. *African Journal of Range and Forage Science* 31: 179–186.
- SMIT, P. 2005. Geo-ecology and environmental change: An applied approach to manage *Prosopis*-invaded landscapes in Namibia. Ph.D. thesis, University of Namibia, Windhoek.
- STROHBACH, B.J., NTESA, C., KABAJANI, M., SHIDOLO, E.K. & D'ALTON, C.D. 2015. *Prosopis* encroachment along the Fish River at Gibeon, Namibia. I. Habitat preferences, population densities and the effect on the environment. *Dinteria*, *in press*.
- THE HOME COMPOSTER. 2015. Composting Sawdust, Wood Shavings and Bark [WWW Document]. Home Compost. URL <http://www.askorganic.co.uk/composting>
- VAN DEN BERG, E.C. 2010. Detection, quantification and monitoring *Prosopis* spp. in the Northern Cape Province of South Africa using Remote Sensing and GIS. M. in Environmental Sciences thesis, Potchefstroom Campus of the North-West University, Potchefstroom.
- WEBER, J.B. & WHITACRE, D.M. 1982. Mobility of Herbicides in Soil Columns under Saturated- and Unsaturated-Flow Conditions. *Weed Science* 30: 579–584.
- ZANNE, A.E., LOPEZ-GONZALEZ, G., COOMES, D.A., ILIC, J., JANSEN, S., LEWIS, S.L., MILLER, R.B., SWENSON, N.G., WIEMANN, M.C. & CHAVE, J. 2009. Global Wood Density Database. Data from: Towards a worldwide wood economics spectrum. [WWW Document]. DRYAD. URL <http://datadryad.org/handle/10255/dryad.235>
- ZIMMERMANN, I. & AMUPOLO, H. 2013. Conversion of encroached bush to biochar for improved soil and livestock. *Agricola* 24: 14–19.

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MENDELSON, J. & ROBERTS, C. 1997. An Environmental Profile and Atlas of Caprivi. Directorate of Environmental Affairs, Windhoek, Namibia.

SCHULZE, E. D., LANGE, O. L. & GEBAUER, G. 1991. Carbon and nitrogen isotope ratios of mistletoes growing on nitrogen and non-nitrogen fixing hosts and on CAM plants in the Namib Desert confirm partial heterotrophy. *Oecologia* 88: 457-462.

STOKING, M. A. 1994. Assessing vegetative cover and management effects. In: Lal, R. (ed.), Soil Erosion Research Methods, 2nd edition, pp. 211-232. Soil and Water Conservation Society and St. Lucie Press, Akeny / Delray Beach.

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