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

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

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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 m^2) 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 Stohbach *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.

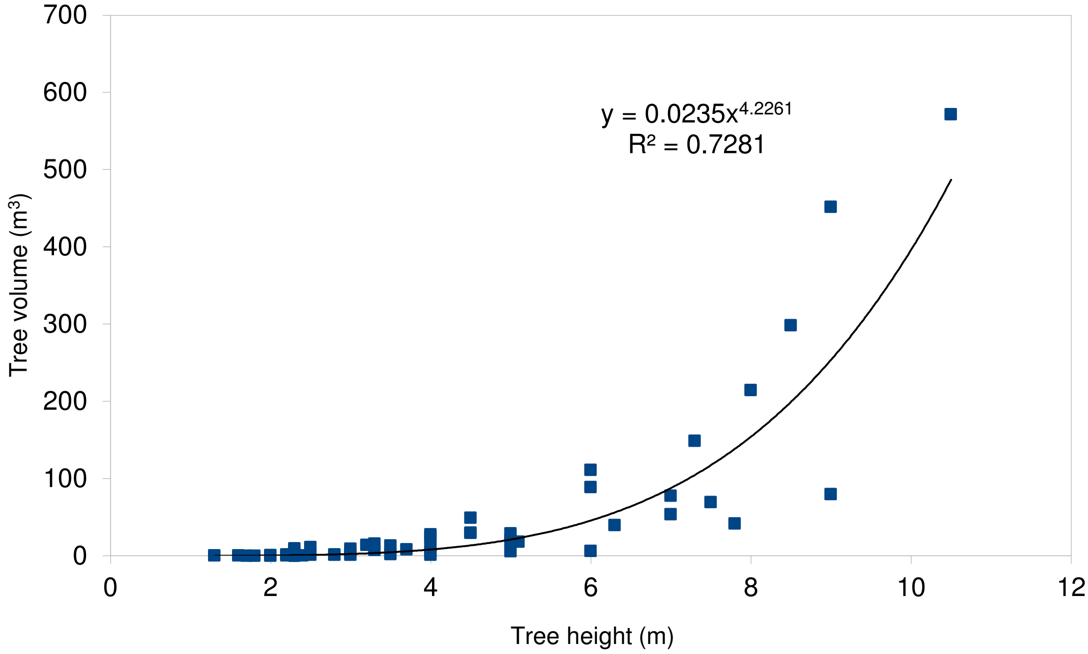

Figure 1. Relationship between *Prosopis* tree height and the tree canopy volume, as determined by the BECVOL method.

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.

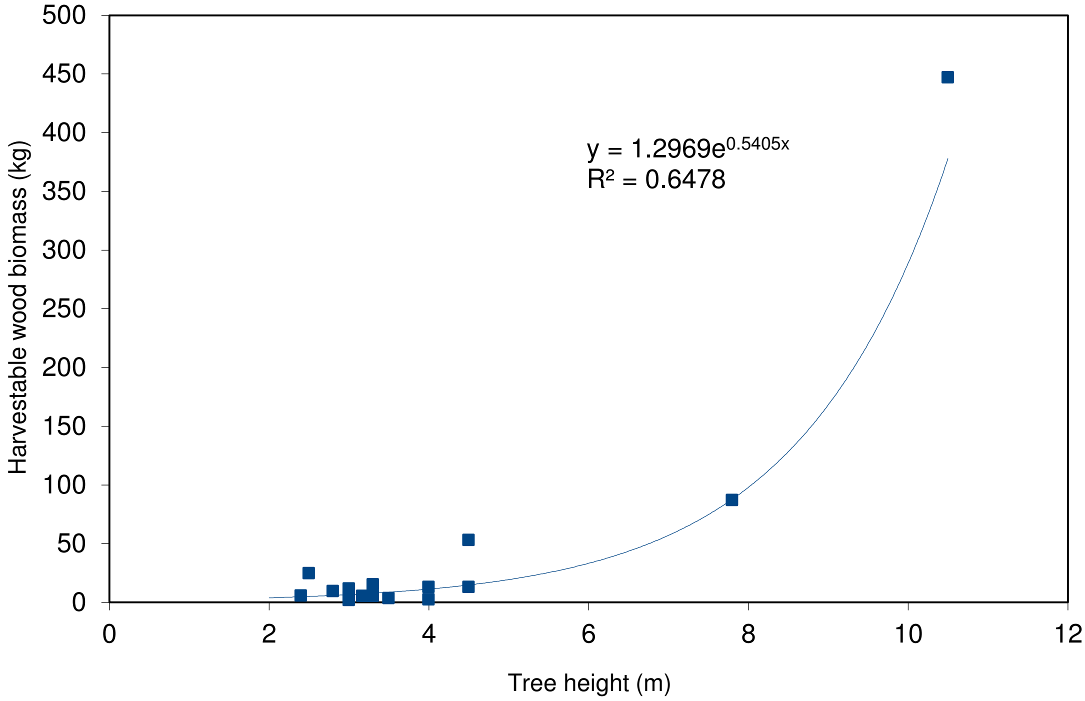

Figure 2. The relationship between harvestable wood biomass and tree height of *Prosopis* species at Gibeon.

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.

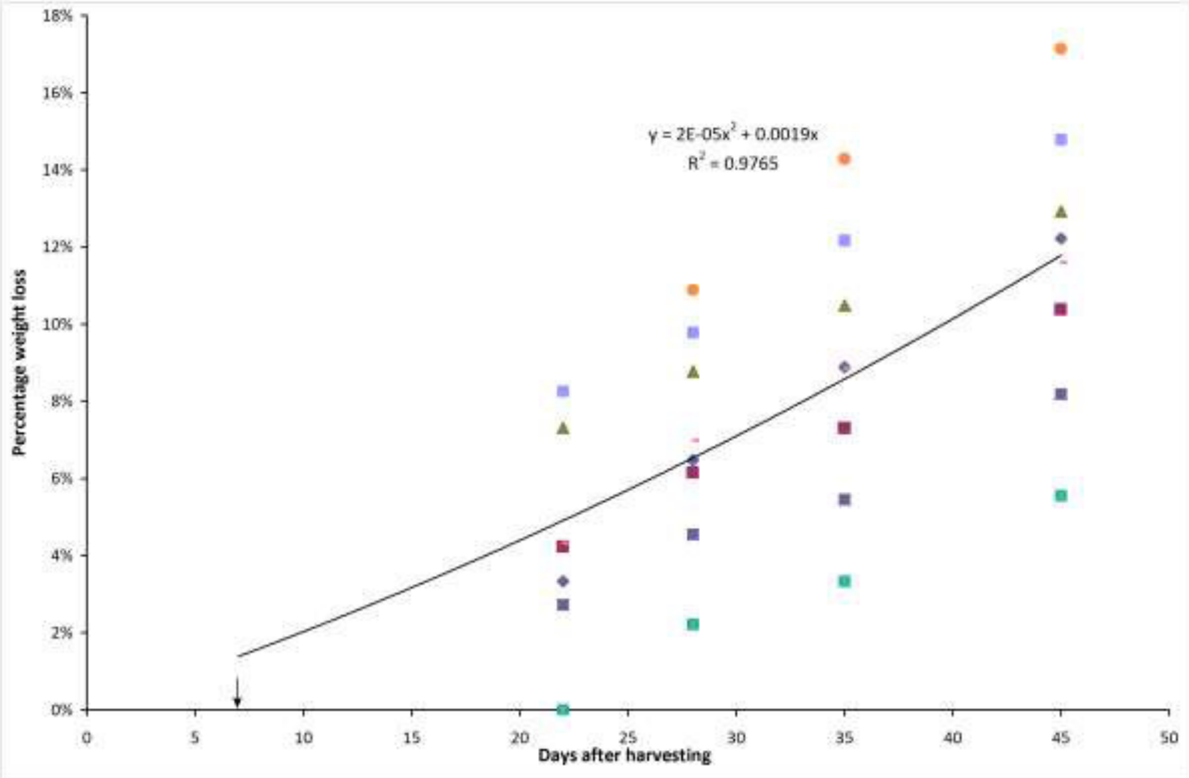

Figure 3. Wood drying rates over time for a few selected stumps. Note that the first weighing took place only seven days after harvesting (indicated by arrow), thus a loss of moisture before the first measurements as depicted on the graph can be expected.

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 successful 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.

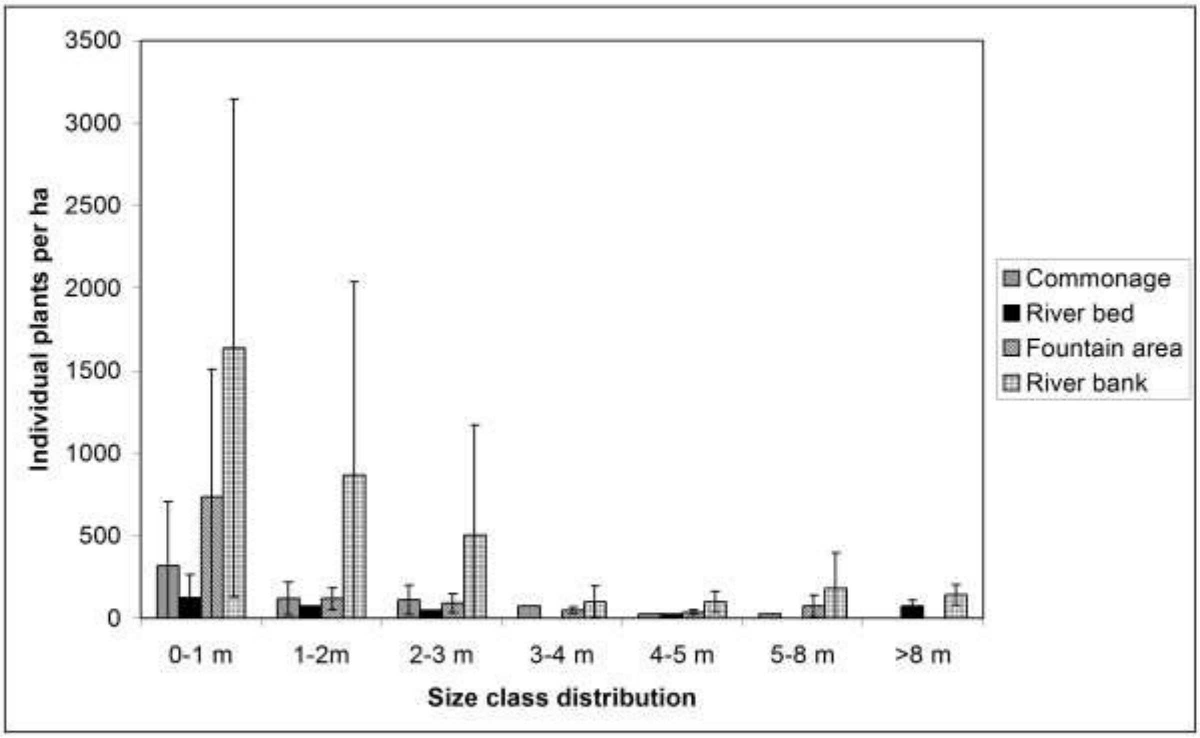

Figure 4. Height class distributions of *Prosopis* trees measured along transects in the various habitats.

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)	***Prosopis* density** (plants/ha)						**Estimated harvestable biomass***	**Total harvestable biomass**	**Potential estimated gross revenue**
Tree size class (average harvestable woody biomass per tree)		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)	tons/ha	total (tons)	(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
Acacia erioloba	1059		Zimbabwe	Chave *et al.* (2009); Zanne *et al.* (2009)
Acacia mellifera	703	19.19	Sudan	Khider & Elsaki (2012)
Acacia nilotica	978 800-840 966 688	23.40 19.57-23.68 26.63 19.71	India	Nirmal Kumar *et al.* (2009) Goel & Behl (1996) Nirmal Kumar *et al.* (2011) Puri *et al.* (1994)
Acacia senegal	728	19.31	Sudan	Khider & Elsaki (2012)
Combretum imberbe	1059		Zimbabwe	Chave *et al.* (2009); Zanne *et al.* (2009)
Prosopis cineraria	942 867	21.93 26.63	India	Nirmal Kumar *et al.* (2009) Nirmal Kumar *et al.* (2011)
Prosopis chilensis	740 720		N America S America	Chave *et al.* (2009); Zanne *et al.* (2009)
Prosopis glandulosa	705 820		N America Tropical Africa	Chave *et al.* (2009); Zanne *et al.* (2009)
Prosopis juliflora	891 828 800-890	20.34 21.5 20.33-23.90	Kenya India India	Oduor & Githiomi (2013) Nirmal Kumar *et al.* (2009) Goel & Behl (1996)
Prosopis pallida	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 lead 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 applkying 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 pseudebenus, 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 allelophatic 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.

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