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Local knowledge regarding ecosystem services and disservices from invasive alien plants in the arid Kalahari, South Africa

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ABSTRACT

Across the globe, many invasive alien plants were purposefully introduced because of their usefulness. These plants continue to provide multiple goods and services, such as fodder, fuelwood, medicines, fruits, shade and aesthetic appeal. However, as they invade negative impacts arise. This often leads to conflicts of interests and trade-offs between the benefits and costs of these species and, ultimately, the environment and local livelihoods. Traditionally, invasive plant species research in dryland systems has tended to focus on the impacts of these species on large-scale natural systems, primarily rangelands and river courses. Limited work has been undertaken regarding the role of these species in providing services and disservices within homesteads and settlements in these harsh environments. Such knowledge is important with regards to management. The primary aim of this study was therefore to assess the assimilation of invasive plant species into the lives of households in several small farming settlements in the arid Kalahari region of the Northern Cape, South Africa. Specific objectives were to: 1) assess the diversity, prevalence and size structure of invasive plants in resident's homesteads; 2) identify sources, local practices, knowledge and beliefs related to the invasive plants present as well as local management practices; and 3) understand residents' perceptions of the ecosystem services and disservices these species deliver. To do this, we used household and ‘drive-past’ surveys, in-depth interviews and measurement of plants in homesteads. From the ‘drive-past’ survey, we identified 12 officially listed and one proposed invasive plant species in the settlements, 10 of which were covered in the household survey. Eight native tree species were also present, but these were at much lower frequency and density than introduced species. Thirteen different goods and services from the invasive plants were recognised with the most common being shade, aesthetics and fuelwood. Some species, such as *Morus alba* and *Opuntia ficus-indica*, were important for fruit, while eight species were mentioned as being used for fodder. Respondents also mentioned that *O. ficus-indica*, *Prosopis* spp., *Leucaena leucocephala* and *Melia azedarach* imposed costs. These disservices included reductions in water supply, damage to buildings and human health impacts. Some of these species were also perceived to be spreading beyond homesteads in some settlements and invading rangeland. Less than a quarter of households had no invasive plants in their yards, and these were mainly new dwellings in the growing informal areas around the settlements. Invasive plants were obtained from variety of sources suggesting various pathways of introduction. We conclude by discussing some options for management focusing on *Prosopis*, as the invasive plant perceived to most rapidly expanding and generating the most disservices. We also highlight what further research is needed with regard to filling research gaps on invasive plant species within social-ecological systems in arid areas.

1. Introduction

Driven by greater acknowledgement of the complexity, historical dimensions and dynamics of human-environment relations, we are seeing the emergence of a more nuanced interpretation of the conflicting roles of introduced (non-native, exotic or alien) invasive

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plant species in both threatening and supporting ecosystem services and human well-being (Shackleton et al., 2007; Pfeiffer and Voeks, 2008; Vas et al., 2017). Indeed, it is now widely argued that, in order to understand plant invasions and before implementing control programmes, it is necessary to appreciate the negative and positive impacts of these plants on people and the economy, as well as their role in both providing and undermining ecosystem services at different scales (Bardsley and Edward-Jones, 2007; Pejchar and Mooney, 2009; Kull et al., 2011; van der Wal et al., 2015). As Simberloff et al. (2013) assert: "The full range of ecological, economic and sociological consequences should be considered when an invasion impact is evaluated".

Globally, it is well documented that invasive plants pose a significant threat to biodiversity and the delivery of ecosystem services, with serious consequences for local economies and ecosystems (Pejchar and Mooney, 2009; Simberloff et al., 2013). In South Africa, invasive plants, especially trees, have been shown to negatively impact grazing potential, affect nutrient cycles, alter plant community structures, modify fire regimes and reduce water supply (Richardson and van Wilgen, 2004). Consequently, South Africa's flagship invasive plant management programme, Working for Water (WfW), has already spent R 3.2 billion in the last 15 years to control numerous invasive plants across the country, especially where these impact water supply (van Wilgen et al., 2012). However, such considerations of the impacts of invasive plants are primarily focused at a regional, landscape or catchment scale and on biodiversity or ecosystem effects. Less attention has been paid to the local scale (homesteads and settlements) and to the benefits (ecosystem services) and drawbacks (disservices) of these species for livelihoods, especially amongst low income, natural resource dependent communities (Shackleton et al., 2007; Dos Santos et al., 2014).

Consequently, how local people relate to and benefit from invasive plants is becoming an important part of place-based invasive plant research. Recent studies have shown that people's views are shaped by the negative and positive attributes of the invasive plant species (such as its usefulness), the local social-economic and ecological context, and a set of other more individual factors (Shackleton et al., 2007; Kull et al., 2011). Specifically, these contexts and factors might include perceived levels of invasion and nuisance; whether the plants are 'wild' or domesticated; primary livelihood activities and other socio-economic factors such as poverty, land tenure and environmental policy; climate, natural vegetation and other biophysical factors; the goods and services obtained from the plants; the costs of management; and lastly personal values, local knowledge, risk perceptions and familiarity with the species (Shackleton et al., 2007; Mwangi and Swallow, 2008; Pfeiffer and Voeks, 2008; Kull et al., 2011; Dos Santos et al., 2014; Estévez et al., 2015; Shackleton et al., 2015).

Recognising this, Shackleton et al. (2007) developed a framework to aid in understanding local uses and perceptions of invasive plant species in rural areas that incorporates costs, benefits, abundance of the species, and the vulnerability levels of local communities. Initially, useful invasive plant species may be seen to have high benefits, but as invasion densities increase costs are likely to rise, potentially impacting other aspects of livelihoods and the supply of ecosystem services. This could potentially increase vulnerability. Various other authors have similarly argued for the need to explore the factors that drive local perceptions and awareness of the services and disservices of invasive plants, especially where there is high dependence on these species and conflicting values and perspectives (Eiswerth et al., 2011; van der Wal et al., 2015). Furthermore, the value of local ecological knowledge on invasive plant species and their management has generally been poorly acknowledged (Jevon and Shackleton, 2015). Since natural resource dependent people have lived with many non-native and invasive plants over decades, they have an intimate knowledge of their dynamics, life cycles and how they negatively impact on or support what matters in local livelihoods (Dos Santos et al., 2014). In particular, invasive plants can have significant positive benefits in harsh, tropical arid and semi-arid environments, like the Kalahari, where native species are naturally of low density and diversity. There are examples of the important role of invasive plant species in the livelihoods of low income communities from the drylands of Mexico (Blanckaert et al., 2007), Brazil (Dos Santos et al., 2014), South Africa (Shackleton et al., 2011, 2015), Madagascar (Kaufmann, 2004), Kenya (Mwangi and Swallow, 2008) and Ethiopia (Kull et al., 2011; Argaw, 2015). In such environments, invasive plant species provide a variety of direct benefits or provisioning services such as fuelwood, timber, fruit, forage and medicine, as well as non-consumptive benefits or regulating and cultural services such as shade, dust control, sand stabilisation, heat amelioration and aesthetic beauty (Mwangi and Swallow, 2008; Dickie et al., 2014). Indeed, many plant species were purposefully introduced into their non-native environments because of their usefulness or beauty (Mack, 2003). Approximately 20 of the 50 most prominent invasive plants in South Africa were introduced deliberately due to their beneficial nature and desired attributes (Macdonald et al., 1986). Therefore, it is not surprising that some species provide benefits to local communities and the economy, especially in arid areas.

A recent cost benefit study undertaken for *Prosopis* in the arid north-west of South Africa has shown that at current densities the benefits this tree provides through fuelwood, medicine and fodder provision marginally outweigh its costs of water uptake and grazing impacts, but invasions will likely become a net cost in the near future as densities increase (Wise et al., 2012). Benefits from the sale of fruits from the cactus *Opuntia ficus-indica* in the semi-arid thicket region of the Eastern Cape provides a cash injection for local traders, accounting for 9.2% of total household yearly income (Shackleton et al., 2011). Shackleton et al. (2007) found that respondents in two villages in the Eastern Cape would have preferred a greater abundance of *O. ficus-indica* in their local environment due to the benefits these plants provide. Similar results are also observable elsewhere. A study in the dry regions of Malawi showed that 44% of households rely on *Prosopis juliflora* for cash income (Chikuni et al., 2004). In the arid and semi-arid lands of Kenya, *P. juliflora* has both positive and negative impacts, with the latter beginning to outweigh the numerous benefits (charcoal, fodder, building material, fencing, cash from sales) this plant brings (Mwangi and Swallow, 2008; Maundu et al., 2009). In India, *Prosopis* provides up to 70% of household fuelwood needs in dry regions (Pasiecznik et al., 2001), while in Ethiopia this same genus provides a host of benefits, although the drawbacks of higher densities of this tree are becoming evident (Tessema, 2012; Argaw, 2015). *Acacia saligna* is an important agroforestry species in the dry Tigray region of Ethiopia where it helps people survive droughts and provides fodder, soil fertility and wood (Kull et al., 2011). In the dry southwest of Madagascar several species of *Opuntia* are of critical importance for pastoralists as stock feed (as well as other uses), especially since herders have become more sedentary (Kaufmann, 2004). In fact herdsmen manage and cultivate these plants, especially *O. monocantha*, in living fences for fodder and as a source of water for their livestock. Similarly, in Tigray, Ethiopia, both the spiny and spineless varieties of *O. ficus-indica* are a critical source of fodder for livestock, as well as being used for live fencing, windbreaks, erosion control, bee forage and fruit (Musimba and Bariagabre, 2003).

However, while invasive plant species such as *Opuntia* spp., *Prosopis* spp. and *Acacia* spp. provide benefits to local people, they also induce costs both locally and at societal level as highlighted

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above (Shackleton et al., 2007, 2011, 2015). For example, in Ethiopia, Kenya, South Africa and many other regions local communities are complaining of the detrimental impacts of *Prosopis* on livestock health, access to grazing, stability of water resources, and on the loss of native species (Mwangi and Swallow, 2008; Tessema, 2012; Shackleton et al., 2015). In Kenya, the negative impacts arising from this genus are forcing local people to rely more on this tree, resulting in a false sense of its value (Maundu et al., 2009). Such opposing values has led to conflicts of interest surrounding many invasive plants (Dickie et al., 2014; van Wilgen and Richardson, 2014), with the need to address trade-offs between biodiversity conservation/ecosystem management and local livelihoods often posing a considerable challenge.

Since invasive plants have both positive and negative outcomes for livelihoods, the employment of an ecosystem service framing has been suggested as a useful approach to researching species that may have conflicting interests and values (Dickie et al., 2014; Vas et al., 2017). In this paper, we view ecosystem services from invasive plants as processes and goods that contribute to the quality of life, income and health of local people. Based on the Millennium Ecosystem typology (Hassan et al., 2005), these include provisioning (such as fuelwood and medicines), regulating (such as shade) and cultural services (cultural uses, beauty) that jointly provide a host of tangible and intangible ecological, social and economic benefits to people. On the other hand, ecosystem disservices from such plants can be thought of as costs that negatively affect well-being, erode other ecosystem services, decrease productivity or increase productivity costs, or take the form of various social nuisances (Shackleton et al., 2016). Examples include water uptake, allergies and out-competition of local species. The services/disservices concept provides a way to consider the impacts of invasive plants on natural ecosystems and the services they deliver and the consequences for human welfare, but also recognises their roles in delivering a range of direct services to households (Dickie et al., 2014), some of which may not be provided by natural vegetation in arid regions.

Consequently, given the need for more local level studies that provide an improved understanding of what drives local perceptions of invasive plants, this paper aims to assess the assimilation of invasive tree and cactus species (hereafter referred to collectively as invasive plant species) into the lives of households in several small farming settlements in the arid Kalahari region of the Northern Cape, South Africa. Specifically we set out to: 1) assess the diversity, prevalence and size structure of declared invasive plants in residents' homesteads; 2) identify sources, local practices, knowledge and beliefs related to the invasive plants present as well as the effectiveness of local management practices; and 3) identify perceptions of the ecosystem services and disservices these species deliver to residents. Lastly, through analysis of the positive and negative effects of invasive plants on multiple aspects of local livelihoods and the possible trade-offs that arise, we identify those species that might emerge as contentious and in need of carefully considered management.

2. Study area

The research was conducted in the Mier Municipality in the Northern Cape Province of South Africa (26°.29′93.5″; 20°.28′32.2″), where we sampled five small settlements, some with less than 50 households and the largest with approximately 200 households (Fig. 1). The settlements included Mier (we pooled Klein and Groot Mier as they are a few kilometers apart and share a single trading store), Welkom, Rietfontein and Askham (Fig. 1). This area of the Northern Cape falls into the Kalahari region and is classified as arid/semi-desert (Mucina and Rutherford, 2006). It is typified by hot (but also extreme cold in winter) and dry conditions, with temperatures that range from 0 °C in winter to 45 °C in summer (Low and Rebelo, 1996). There is some evidence that temperatures are increasing under climate change, especially in the northern region, and these are expected to increase by 2–3 °C by 2050 (Oosthuizen and John, 2004; Midgley et al., 2005). Rainfall is erratic, but predominantly falls between November and April. Annual rainfall is approximately 200 mm, although highly variable from year to year, and this is accompanied by high evapotranspiration (Mukheibir and Sparks, 2005). The region is situated on a plateau 900 m above sea level and is typically flat and undulating, with sand dunes occurring more frequently in the south-west part of the region. The scarcity of surface water and poor soil in this sandy area are limiting factors for vegetation growth (Cole and Brown, 1976), which creates constraints on livelihoods. However, despite its aridity, the region has a variety of flora and fauna, some of which provide important products used for local household needs (such as fuelwood, traditional medicines, food, fodder, etc.), cash income generation (craft), and other aesthetic and cultural uses (Thondhlana et al., 2011a). The Kalahari vegetation is typified by an assortment of karroid bushveld, thornveld and shrubby grasslands that are occupied by small trees, tall and low shrubs, herbs, succulent herbs and grasses (Mucina and Rutherford, 2006). However, a relatively orderly progression of increasing woody plant cover and height occurs from the southern to the northern parts of the region. The most prominent native tree species include *Boscia albitrunca*, *Vachellia erioloba* (which is a protected species and live trees cannot be harvested), *Vachellia haematoxylon* and *Vachellia karroo*. All of these species provide fuelwood, and are important for shade. Alien invasive plant species, the focus of this study, are also common in the landscape in both settlements and in surrounding lands, and were primarily introduced to support livestock production, as ornamental plants and for shade (Shackleton et al., 2015).

The region is home to southern Africa's only indigenous hunter-gatherer people, the ǂKhomani San (or Bushmen), as well as a racially-mixed 'coloured' community known as the Mier. Most of

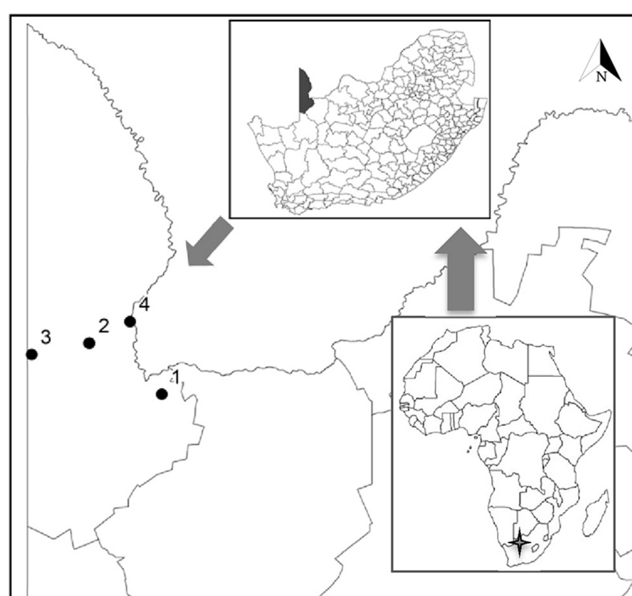

Fig. 1. Study site with the four villages (1 - Askham), (2 - Groot and Klein Mier), (3 - Rietfontein) and (4 - Welkom) in the Mier municipality (black municipality in the middle figure) in the Kalahari region of the arid Northern Cape Province of South Africa (star on the right-hand map).

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the San and Mier households live in resettlement farms and small settlements across the municipality, which are interspersed amongst commercial farms. The majority of residents in the small settlements sampled in this study identify themselves as Mier. These communities rely on land-based livelihood activities especially farming with cattle, sheep and goats and wild resource gathering, among other livelihood sources such as wages (mainly from temporary on and off-farm jobs), government welfare grants, craft making, and low paying government service projects (Thondhlana et al., 2011a). They are characterised by high levels of poverty a continuing result of the colonial and Apartheid eras whereby non-white communities were systematically marginalised (Treiman, 2007; Thondhlana et al., 2011b).

3. Methods

We used several complementary biophysical and social methods including an inventory of species using a 'drive-past' survey, a household survey, in-depth interviews and measurements of plants in homesteads. This enabled us to obtain information related to the prevalence of declared invasive plants, their benefits and costs, and local perceptions and practices surrounding them.

To determine the diversity and prevalence of declared invasive plants and native tree species within settlements, we conducted a 'drive-past' assessment of their presence in homesteads yards. Both native and invasive species were identified using keys in tree identification books (e.g. Henderson, 2001) and confirmed at the Scholand Herbarium in Grahamstown and Compton Herbarium in Cape Town. Declared invasive plant species were categorised according to the National Environmental Management: Biodiversity Act (NEM:BA) regulations (No. 10 of 2014) and the Conservation of Agricultural Resources Act (CARA) regulations (No. 43 of 1983). In these lists of declared invasive species in South Africa, each species is allocated a number from 1 to 3. These numbers indicate different management requirements based on the impact of the species (see Appendix 1 – for detailed species listings). Category 1 species require removal/control, Category 2 species need a permit and spread must be managed, while Category 3 species do not need a permit but spread must be managed. For this study, the nomenclature *Prosopis* spp. is used as there are multiple species of this genus in the area that have hybridised making species identification exceedingly difficult (Shackleton et al., 2015). The survey covered the entire settlement except in Rietfontein and Askham, where 'wealthy' areas that were not represented in the other settlements were excluded. A total of 85 homesteads in the Mier settlements (46 Klein Mier; 39 Groot Mier), 103 in Welkom, 150 in Rietfontein; and 164 homesteads in Askham were assessed in the 'drive-past' survey. This amounted to a total of 502 homesteads.

For data on local knowledge and the services (benefits) and disservices (costs) of the identified invasive plants, we conducted semi-structured interviews with 180 respondents across the five settlements. For this part of the study, *Atriplex nummularia*, *Nerium oleander*, and *Gryptostegia grandiflora* were excluded as they were not encountered in the randomised household sample (Appendix 1). Thus, the remaining 10 species formed the focus of the interviews and plant measurements (Appendix 1; Table 2). Streets within each settlement were randomly selected and residents of all available homesteads with declared invasive plants on that street were interviewed. The sample was distributed as follows: 31 respondents in Groot and Klein Mier (20 Klein Mier; 11 Groot Mier; ±36.5% of the population), 35 in Welkom (±34% of the population), 51 in Rietfontein (±25.5% of the population), and 63 in Askham (±38% of the population). The head of each household, often along with other household members, was interviewed as these individuals are most likely to have planted and/or monitored the growth of each invasive plant in their homestead, and have the best understanding of trends and changes over time. We also targeted elders as they are likely to have more insights regarding the uses, disadvantages, and practices regarding each species. The questionnaire contained sections that assessed perceptions, attitudes, practices regarding the collective uses and disadvantages of the invasive plants, local ecological knowledge on their the introduction and spread and information on management practices. The questionnaire surveys comprised of both closed ended and open ended questions with more of the latter. For example, closed ended questions related to whether respondents knew if the species was exotic and if it was spreading or not (tick: yes, no, unsure); whereas identification of and knowledge on the benefits and costs of the species was obtained through free listing and additional open ended questions (i.e. where and when did you get the species). The benefits and costs were later categorised into the different ecosystem services categories as defined in the MA (2005). During the interview process, in-depth conversations were also held with respondents who had made interesting observations that were worth following-up for more detail. In order to address the last objective regarding contentious species, the information obtained on the relative costs and benefits of each species was used to subjectively position these on the plot (matrix) adapted from Shackleton et al. (2007) and van Wilgen and Richardson (2014). This plot characterises species according to their costs (i.e. disservices) and benefits (i.e. services) along two axes of low to high benefits and low to high costs.

Additionally, at each homestead we measured the diameter of all invasive trees at 30 cm above the ground. This was chosen in preference to breast height as some of the species are scrubby and branch below breast height (this has been similarly been done in other studies in the region, e.g. Shackleton et al. (2015)). Plants with a diameter of <1 cm were regarded as seedlings and simply counted. Size-class distributions were then constructed for each species using intervals of 4 cm. For the cactus, *O. ficus-indica*, we recorded the height and number of cladodes per plant, and used height to plot size-classes. These size-class distributions provided an indication of the population structure of each invasive plant species; i.e. whether they were new arrivals, recruiting and expanding, or stable. This information was triangulated with residents' own perspectives on their spread. Randomly selected cladodes were also removed and weighed amounting to 140 in total to determine fodder value. Overall we measured 894 trees and *O. ficus-indica* plants.

4. Results

4.1. Characteristics of the study population

The households that participated in this study are typical of those found in rural areas of South Africa, with most residing in high levels of poverty (Table 1). From the profile of respondents (41.2% male and 58.8% female) and their households (Table 1) it can be seen that more than 80% of households received state grants and/or pensions, with an mean (±SD) of 1.1 ± 1.4 persons per household receiving a child and/or other grant, and 0.8 ± 0.8 persons receiving a monthly old age pension. Mean (±SD) household size was 5 ± 2.4 persons, with only 0.8 ± 0.9 wage earners per household. The most common formal job type was that of farm workers on private farms or government service projects, where these workers generally received the minimum wage payment of around R 14 per hour. Assets such as vehicles were uncommon, but most households owned a television. Education levels were low with a mean of 5.5 years of schooling for the respondent who was generally the head of household (Table 1). All respondents had lived in the area for over 20 years (33.5 years on average), and so could be assumed to have insights into changes in the landscape and distribution of invasive plants. The number of households with livestock differed between sites, and ranged from 43.3% in Mier to 21.6% in Rietfontein (Table 1). Sheep and goats were the most common type of livestock. Numbers ranged from five up to 28 sheep per household, and between 20 and 30 goats. Cattle were less common, while horses and donkeys were kept by only a few households and used for transport.

4.2. Plant inventory and prevalence and abundance across homesteads

A total of 12 different declared invasive plant species (one shrub, one woody vine, one cactus and nine trees) and one proposed invasive tree species (*Schinus molle*) were identified across the settlements, along with eight native species, three of which are extralimital (i.e. native species that have been moved by humans into areas outside of their natural distribution range within the country) (Appendix 1, Table 2). According to uses identified in the literature, the invasive plants recorded are primarily ornamental, although *O. ficus-indica* and *Prosopis* spp. are also useful for fodder (Appendix 1). Several of the invasive plants have local names that have not been previously recorded. For example, *Prosopis* is named *suid-wes* (English: south-west) in Askham, and *soetpeel* (English: sweet pod) or just *peelboom* (English: pod tree) in the other three settlements. The name *suid-wes* is said to have originated from the (incorrect) belief that this species came from Namibia. *Leucaena leucocephala* is also called *peelboom*. Locals do not have a name for *Tecoma stans*, although they could provide common names for the other species (Appendix 1). This suggests that some invasive plants have become deeply engrained into local culture as opposed to others. The different invasive plant species identified belong to all three legislated categories, with some of the less common species being in categories 1 (must be removed) and 2 (may be grown with permits), and common species such as *Prosopis* being in category 3 (existing plants need not be removed but no new planting is permitted) (Appendix 1).

Despite the relative closeness of each settlement, there were differences in the prevalence of invasive plants in homestead yards across settlements (Table 2). Welkom had a high prevalence of *E. camaldulensis* compared to the other settlements. Furthermore, the presence of some invasive plants in homesteads was unique to particular settlements. For example, the trees *J. mimosifolia* and *T. stans*, and *C. grandiflora* were only found in Rietfontein, while *M. alba* was only present in Askham. The tree *L. leucocephala* was dominant in Rietfontein, with respondents mentioning it had been recently introduced from there to Mier. However, other species like *Prosopis*, *O. ficus-india* and *S. molle* were relatively common across all settlements. The abundance of *Prosopis* in Klein and Groot Mier was said to be an outcome of poor soil and water scarcity, with *Prosopis* being one of the few tree species that grew in the harsh conditions found in these two settlements. Askham had the highest frequency of homesteads with invasive plants, with only 12% having no invasive trees. For *O. ficus-indica* and *M. azedarach* there were frequently multiple individuals per homestead (Table 2). Homesteads without invasive plants were generally newly established informal dwellings on the borders of the settlements. Furthermore, the presence of invasive plants, especially those common across settlements, was higher than that for native species (Table 2). For the native species, the percentage of homesteads with these trees was generally below 15%, except for *A. erioloba* in Askham at 17% and *T. usneoides* in Mier at 19%. This compares with a homestead prevalence of greater than 30% for many invasive plants, and up to as much as 65% and 75% for *Prosopis* and *M. azedarach* respectively.

The size-class distributions of *S. molle*, *J. mimosifolia*, *C. cunninghamian* and *E. camaldulensis* were skewed towards adult-sized populations, whereas species such as *T. stans*, *M. azedarach*, *L. leucocephala* and *Prosopis* had size-class distributions with a high proportion of seedlings, small trees and large trees (Appendix 2). These data suggest that the former are not recruiting and are therefore not spreading. In contrast to this, *T. stans* (23.7% seedlings), *L. leucocephala* (14.3% seedlings), *Prosopis* (54.8% seedlings), and *M. azedarach* (16.9% seedlings), all show superior recruiting properties and invasive potential.

4.3. Local knowledge on the introduction and propagation of invasive plants

In general respondents had a good understating of the plants in their yards, knowing their names, when they were planted, where they arrived from and their benefits and costs. For example, in Welkom, which is the closest settlement to the Kgalagadi Transfrontier Park, the presence of particular invasive trees (e.g. *E. camaldulensis* and *S. molle*) were said to be the result of SANParks (South African National Parks) supplying households with these species approximately 15 years ago (Table 3). This was part of an initiative to encourage the removal of *Prosopis* and thus help prevent the spread of this species into the park. Respondents mentioned that they were provided with a mix of indigenous and exotic/invasive tree seedlings to replace the existing *Prosopis*. They elaborated on how the latter tended to be more resilient and survive better than the former. Nonetheless, some *Rhus* and *Combretum* species have persisted as well as *Vachellia galpinii*. Through discussion during interviews, it was possible to trace the origin and spread of the popular *M. azedarach*. According to local knowledge, it seemed that *M. azedarach* was brought to Askham approximately 35–50 years ago by people returning home from elsewhere in the country or by family members visiting from Upington, a small city about 200 km away. *M. azedarach* started to self-propagate and was then introduced to Welkom and Rietfontein through friends and family taking seedlings to these settlements as gifts. In turn,

Table 1
Characteristics of respondents and their households for each of the four village settlements assessed (mean ± sd; percent of households (hh) for last column). * "n" = the number of household surveyed in each village. "No of vehicles" is an indicator of household wealth though asset ownership.

	Age	Gender (% male)	Hh size	Wage earners	State grants	State pensions	Education (years)	Residence time	No. of Vehicles	% of hh with livestock
Askham n = 63	54 ± 16	46	6 ± 3	1 ± 1	2 ± 2	1 ± 1	4 ± 4	26 ± 20	0.3 ± 0.5	33
Mier n = 31	53 ± 14	29	4 ± 3	1 ± 1	1 ± 1	1 ± 1	7 ± 3	43 ± 19	0.5 ± 0.7	43
Rietfontein n = 51	57 ± 17	49	5 ± 2	1 ± 1	1 ± 2	1 ± 1	6 ± 5	29 ± 17	0.3 ± 0.5	21
Welkom n = 35	56 ± 14	54	5 ± 2	1 ± 1	1 ± 1	1 ± 1	5 ± 4	35 ± 19	0.4 ± 0.6	29

Table 2
Prevalence (% of homesteads) and density per homestead (mean ± sd) of invasive plants and native trees assessed through a drive-by survey in each settlement (hh = household/homestead) (* indicates shrubs and vines which were not included further in the study due to their absence from homesteads surveyed – see methods) (# indicates extralimital native species).

Tree/shrub species (NEM:BA category)	Mier (n = 85)		Welkom (n = 103)		Rietfontein (n = 150)		Askham (n = 164)	
	% hh with species	Mean no. of trees per hh	% hh with species	Mean no. of trees per hh	% hh with species	Mean no. of trees per hh	% hh with species	Mean no. of trees per hh
Invasive species								
**Atriplex nummularia* Lindl. (2)	0	0	2	2 ± 4	3	3 ± 1	1	2 ± 4
Casuarina cunninghamiana Miq. (2)	5	0	4	1 ± 1	13	2 ± 1	1	0.0
**Cryptostegia grandiflora* R. Br. (1)	0	0	0	0	11	3 ± 1	0	0
Eucalyptus camaldulensis Dehnh. (1:3)	4	1 ± 0	12	1 ± 0	1	1 ± 0	1	1 ± 0
Jacaranda mimosifolia D.Don (2)	0	0	0	0	3	1 ± 0	0	0
Leucaena leucocephala (Lam.) de Wit (2)	2	1 ± 0	0	0	25	2 ± 1	0	0
Melia azedarach L. (1)	2	1 ± 0	10	1 ± 0	20	1 ± 1	76	3 ± 3
Morus alba L. (3)	0	0	0	0	0	0	1	1 ± 0
**Nerium oleander* L. (1)	0	0	0	0	4	2 ± 2	2	1 ± 0
Opuntia ficus-indica (L.) Mill (1)	5	2 ± 1	16	6 ± 5	13	2 ± 0	33	6 ± 5
Prosopis spp. (1b: 3 in NC)	65	3 ± 4	18	2 ± 1	22	2 ± 1	13	2 ± 1
Schinus molle L. (proposed)	18	1 ± 0	21	1 ± 1	35	2 ± 1	20	1 ± 1
Tecoma stans (L.) Juss. Ex Kunth (1)	0	0	0	0	11	2 ± 1	0	0
Native species (species with # are extralimital)								
Acacia erioloba E. Mey.	4	1 ± 0	12	1 ± 1	6	1 ± 1	17	1 ± 2
#*Acacia galpinii* Burtt Davy	6	1 ± 0	14	1 ± 0	6	1 ± 0	2	1 ± 0
Boscia albitrunca (Burch.) Gilg & Gilg-Ben	2	1 ± 0	0	0	0	0	1	1 ± 0
#*Combretum erythrophyllum* (Burh.) Sond.	2	1 ± 0	5	1 ± 0	2	1 ± 0	2	1 ± 0
#*Dodonaea angustifolia* L.f. (ex)	1	1 ± 0	4	3 ± 2	13 ± 0	5 ± 5	5	6 ± 9
Searsia lancea (L.f.) F.A. Barkley	3	1 ± 0	10	1 ± 0	9	1 ± 2	9	1 ± 1
Tamarix usneoides E.Mey ex Bunge	19	2 ± 2	31	2 ± 2	0	0	0	0
Ziziphus mucronata Willd.	0	0	3	1 ± 0	0	0	0	0

M. azedarach, along with most other species, were moved by residents from Rietfontein to Klein and Groot Mier, although many did not establish (Table 3). Local knowledge, particularly from respondents that have livestock and rely heavily on grazing, indicated that *Prosopis* was introduced in the early 1960s through a government programme driven by the Department of Agriculture. Respondents mentioned that as children they remembered agricultural extension officers providing private farmers and some households in these rural settlements with trees to plant for shade in their homesteads and as a source of fodder in the grazing areas. They reported that within 10 years these plants had started spreading prolifically around settlements and the rangelands. One elderly respondent declared: *"Suid-wes (Prosopis) was not here when I was a young girl. It started spreading 40 to 50 years ago. It came in the 1960s. It is a big problem for us – a weed."* In Rietfontein the church was instrumental in introducing and distributing species such as *J. mimosifolia* and *L. leucocephala*. Respondents mentioned that the local church has a nursery from which it sells trees to raise money; it is thought that the initial individuals were brought from Upington. One respondent in Rietfontein deliberated how *L. leucocephala* was not there 20–25 years ago (prior to 1992) and now, in the last 5–10 years, has spread considerably around the settlement.

Other than importation and exchanges of seedlings from other towns in the region, we found that respondents had also obtained invasive plants through other means and this varied across species (Table 3). For example *O. ficus-indica* was commonly grown from truncheons, whereas species such as *L. leucocephala* and *Prosopis* and, to a lesser extent, *M. azedarach*, *S. molle* and *T. stans* were often self-seeded (Table 3; Appendix 2). Others were propagated from seed but this was only by a few respondents. *O. ficus-indica* was said to be difficult to grow due to high winds (which blows it over), salinity and the sandy soils.

Table 3
Sources and propagation of identified invasive plants within homesteads aggregated across the four settlements (% of respondents mentioning each source).

	C. cunningha-miana	*E. camaldulensis*	*J. mimasifolia*	*L. leucocephala*	*M. azedarach*	*M. alba*	*O. ficus-indica*	*Prosopis*	*S. molle*	*T. stans*
Self-seeded	8	0	0	66	28	0	2	95	22	39
Truncheon	25	0	0	0	0	0	99	0	3	5
Was here already	8	11	0	3	2	0	0	5.3	1.5	0
Brought from nearby towns	33	33	40	0	13	100	0	0	3	0
Gift	25	0	0	13	54	0	0	0	64	44
Given by the government	0	55	0	0	2	0	0	0	2	0
Propagated a seed	0	0	2	6	2	0	0	0	6	11
Bought from church	0	0	40	10	0	0	0	0	0	0

4.4. Ecosystem services and disservices from invasive trees

4.4.1. Services

Several different provisioning, supporting/regulating and cultural ecosystem services were identified by respondents from the various invasive plants (Table 4, Fig. 2). All the trees were important for shade (60–100% of respondents mentioned this benefit from each tree species) (Table 4). We observed that many established trees had flowerbeds, beds, benches or stools under them for resting during the hottest periods of the day. Trees thus played a crucial role in regulating the micro-climate around respondents' homes. Trees with dense canopies such as *M. azedarach and M. alba* were mentioned as particularly valuable. A large number of provisioning services were also supplied. For example, many of the larger species were used for firewood by up to 40% of respondents, especially in winter when night temperatures drop below freezing, but also in lesser quantities throughout the year for cooking. *M. azedarach* branches are trimmed every year by the majority (92%) of households. Respondents mentioned that this practice ensures canopy spread and densification and helps to remove the toxic berries before they drop so they are not consumed by children or livestock. The branches of *S. molle*, *T. ramosissima* and *Prosopis* were also used for firewood on an occasional basis by a small proportion of households (Table 4). *Prosopis* was cut by some households (25%) to control it and the wood used for burning. Fruit from *M. alba* and *O. ficus-indica* was important for dietary diversity and nutrition, with this being mentioned by all respondents who had these species in their yards. Many respondents also reported the use *O. ficus-indica* for medicinal purposes, which included the treatment of diabetes, high blood pressure, tooth ache, breast and skin cancer, muscle pains as well as cuts and bruises. *M. azedarach* and *S. molle* were used to treat flu, while *M. azedarach* was used for veterinary purposes to treat worms in goats. One respondent mentioned that *S. molle* leaves are boiled and the infusion drunk to aid in the relief of asthma, while the seeds of *S. molle* were said to treat headaches by numerous respondents. Respondents also reported using *S. molle* as a mosquito repellent, while another fed *S. molle* leaves to his goats to treat livestock disease.

Prosopis, *O. ficus-indica* and to a lesser extent *L. leucocephala* were important sources of fodder for livestock. Approximately 20% of respondents respectively mentioned that they actively cut cladodes and/or collected *Prosopis* branches and pods to feed livestock. However, most respondents with livestock remarked that their livestock consume *Prosopis* when free ranging and often raid *O. ficus-indica* from homesteads and hedges. On average, households who use *O. ficus-indica* as fodder fed about six cladodes (leaves) to their livestock every week. The average weight of a cladode is 0.49 ± 0.27 kg. This works out to approximately 12 kg of fodder per month. The average number of cladodes per plant is 68, therefore a plant can supply some 34 kg of fodder. The cladodes are cut, scraped on the ground to remove the spicules, and then cut into five or six pieces and dropped into the livestock pen. Numerous species particularly those with colourful flowers (*J. mimosifolia*, *M. azedarach* and *T. stans*) were grown primarily for aesthetical purposes as a means to beautify one's home and bring colour to the rather inhospitable landscape within which people live. This is supported by the following quote: "*Syringas are very important for making the town look nice; we like it (Syringa) because it makes the area look green and gives us shade.*" Numerous other uses and benefits mentioned included the value of the different invasive species for wind breaks, making soap and fencing materials. The species that provided the most goods and services included *O. ficus-indica*, *Prosopis, S. molle* and *M. azedarach.*

4.4.2. Disservices

Four of the 10 tree species were seen to create disservices for humans and the environment in and around homesteads (Tables 5 and 6, Figs. 2 and 3). The majority of these disservices related to one species (*Prosopis*) and in particular disservices related to economic, health and safety issues. Recognition of the negative impacts of *Prosopis* was highest in Welkom (where SANParks has been active in removing *Prosopis*) and the two Mier villages (where *Prosopis* is most abundant). Here over 75% of respondents mentioned that *Prosopis* produces disservices. This compares to 44% and 56% in Rietfontein and Askham. Although respondents know this species has negative impacts, many of them indicated reluctance to remove their trees as they argued it would take too long for replacement trees to establish or they had not been successful growing other species. In Rietfontein, 5.3% respondents mentioned problems associated with *L. leucocephala* saying it spreads too fast and they have to weed their yards (Table 6). One respondent mentioned "*this species is going to become a problem in the area as it grows near water sources and goats eat the pods so it will spread fast.*" He believed it could become similar to the *Prosopis* invasion with time. This sentiment was mirrored by several respondents who highlighted how this plant wasn't around 10 years ago and yet it is already starting to spread along the edges of the settlement (referred to as *veld*). A retired school teacher mentioned that when *Prosopis* flowers many of the children at the school struggle with asthma and hay-fever. *M. azedarach* flowers similarly are also said to induce asthma. The most common disservice mentioned was excessive uptake of water by *Prosopis* (Table 5). The tendency of this plant to damage buildings, through the roots seeking water, was also mentioned. Although not necessarily a major disservice, many people disliked that fact that *M. azedarach*, a deciduous tree, lost its leaves in autumn and therefore dirtied their yards. This has led to the trimming off the branches in autumn/winter to prevent this along with the other reasons for cutting explained above. Although

Table 4
Ecosystem goods and services (benefits) from identified invasive plants mentioned by 5% or more of respondents and aggregated across the four settlements (% of respondents mentioning each service). * (the brackets report the ecosystem service category as defined in the MA (2005) including regulating services (reg), provisioning service (prov) and cultural services (cult)).

	C. cunningha-miana	*E. camaldulensis*	*J. mimasifolia*	*L. leucoce-phala*	*M. azedarach*	*M. alba*	*O. ficus indica*	*Prosopis*	*S. molle*	*T. stans*
Shade (reg & cult)	9	100	60	98	100	100	0	77	82	78
Fuelwood (prov)	0	7	0	0	41	0	0	25	10	0
Food products (prov)	0	0	0	0	0	100	100	15	0	0
Medicinal (prov)	0	0	0	0	1	0	23	0	11	0
Fodder (prov)	0	0	0	6	4	0	20	21	1	11
Hedge (reg & cult)	0	0	0	0	0	0	29	0	0	0
Wind break (reg)	9	7	0	0	2	0	1	0	1	0
Beautification (cult)	0	0	80	0	7	0	0	0	2	6
Insect repellent (prov)	0	0	0	0	0	0	0	0	23	0
Nothing	0	0	0	2	0	0	0	22	0	0

Fig. 2. A photo panel of ecosystem disservices (row 1) and services (row 2) from invasive plants in the study settlements: (1A) *Prosopis* encroaching fallow land and road verges in Reitfontein settlement; (1B) *Prosopis* flowers emitting pollen that causes allergies in humans and animals in the area; (1C) thorns that cause injuries to people and livestock as well as causing tyre punctures; (1D) *Prosopis* invasion within a rangeland on the border of Mier; (2A) *M. azedarach* acting as a shade and beatification tree in Askham – the trees have recently been pruned to prevent fruits/berries (poisonous) establishing and to encourage a more dense canopy in summer months; (2B) *Opunita* acting as a live fence and being used for fodder (bottom right corner) and *S. molle* in the background an important shade and medicinal tree; (2C) a boy collecting *Prosopis* pods from a garden tree to be used as fodder; (2D) *C. cunninghamiana* planted around a homestead for shade, beautification and a wind break. Photographs: R.T.S.

Table 5
Ecosystem disservices (negative impacts or costs) mentioned by 5% or more of respondents from four species identified as problematic and aggregated across the four settlements (% of respondents mentioning each disservice). (* brackets highlight the different disservices categories according to Shackleton et al. (2016) – including economic (eco.), health and safety (h&s) and cultural (cult)).

	L. leucocephala	*M. azedarach*	*O. ficus-indica*	*Prosopis*
Water uptake (eco & h&S)	0	0	1	97
Outcompetes other species (eco & cult)	0	0	1	5
Damages infrastructure (eco)	0	0	0	24
Spreads too rapidly (eco)	4	0	2	10
Influences water taste (h&s)	0	0	0	7
Produces of leaf litter (cult)	0	28	0	4
Poisonous berries (h&s)	0	7	0	0
Allergies (h&s)	0	1	0	7
Constipation (h&s)	0	0	19	0
Thorns/spicules (h&s)	0	0	30	8

Table 6
Knowledge and perceptions of spread and environmental impacts of identified invasive plants aggregated across the four settlements (% of respondents mentioning).

	C. cunningha-miana	*E. camaldul-ensis*	*J. mimosifolia*	*L. leucocephala*	*M. azedarach*	*M. alba*	*O. ficus-indica*	*Prosopis*	*S. molle*	*T. stans*
Known as exotic	42	89	100	38	21	0	6	73	27	23
Seen to causes environmental harm	0	0	0	3	0	0		65	0	0
Spreading in gardens	50	0	0	83	81	0	66	93	70	100
Spreading into veld/rangelands	0	0	0	24	2	0	0	93	5	6

the *O. ficus-indica* occurring in the area is relatively spineless, it does have small hair like spicules that cause irritation to the skin if touched, and many people dislike this: "*We had turksvey (O. ficus-indica) but took it out because we have small children and the prickles hurt them.*"

There was inconsistent knowledge regarding the nature of invasive plants and their invasiveness and this varied by species and settlement (Table 6). Interestingly, 66% of respondents in Mier and 71% in Welkom believed *M. azedarach* to be an exotic species compared to less than 18% in the other two settlements. This may be due to the fact that *M. azedarach* has been present in the latter two settlements for longer. No one in Mier and only 14% of respondents in Welkom believed *M. azedarach* is spreading, whereas in Rietfontein and Askham, where this species is widely believed to be indigenous, 63% and 88% of respondents viewed it to be expanding within settlements. However, regarding spread beyond the settlement, only a small proportion of respondents in Askham considered *M. azedarach* to be spreading into the surrounding *veld*.

Most respondents (65%) believed that *Prosopis* causes environmental harm, whereas this was fewer than 3% for other species. Some 93% of respondents perceived *Prosopis* to be spreading into surrounding rangelands as well as in settlements. In most settlements, respondents have made an effort to remove *Prosopis;* however, it is said to regrow within a year or two from dormant seeds or from stumps where herbicide was not applied properly – "*Working for Water told us it is a bad tree, it takes water, and they*

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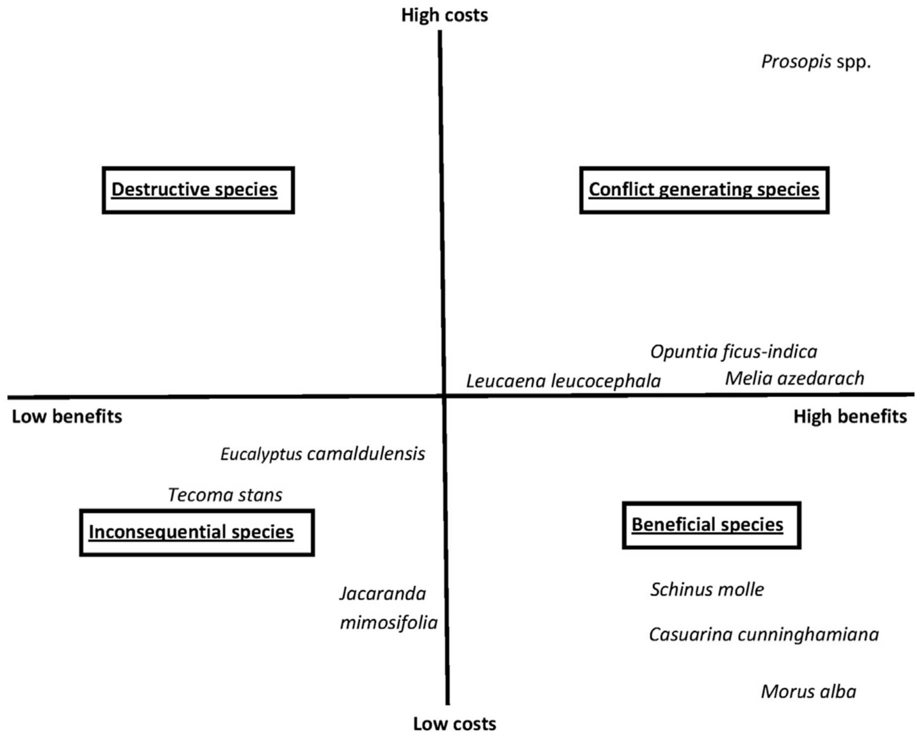

Fig. 3. Invasive plants found in the four settlements classified according to the supply of ecosystem services (benefits) and disservices (costs) (adapted from Shackleton et al. (2007) and van Wilgen and Richardson (2014)).

tried to remove it but they did not apply herbicide correctly so now they have just grown back." Another quote describes how "*when you cut the Prosopis trees, the seedlings just replace them.*" In terms of *L. leucocephala* no one in the Mier villages thought it was spreading, but 96% of people in Rietfontein believed this was the case, as mentioned above. A very small percentage of respondents viewed *S. molle*, *T. stans* and *M. azedarach* to have started emerging in areas between homesteads.

Plotting the species in relation to their services and disservices (costs and benefits) (as in Tables 4–6), we can see that the identified invasive plants fit into three of the four quadrants, with those of most concern being the top right block which represents species for which there are conflicts between the supply of services and disservices (Fig. 3). In terms of trade-offs, management and control, those that are likely to be most contentious include *O. ficus-indica L. leucocephala, M. azedarach* and *Prosopis* as they provide both services and disservices to local livelihoods and/or are spreading through self-seeding.

5. Discussion

As is the case in many other arid areas, exotic, invasive plant species have been deliberately incorporated into the landscape by some three quarters of residents of small settlements in the arid Kalahari for multiple purposes. This links primarily to the low levels of some critical ecosystem services such as shade and fodder (e.g. Kaufmann, 2004; Kull et al., 2011; Tessema, 2012; Argaw, 2015) and to the low abundance of native species. Residents' understanding and local knowledge of the invasive plant species suggests that these are well assimilated into their way of life and culture, with some species being given unique local names. Further supporting this is the fact that several species were not differentiated by residents from local biodiversity. Such a situation is not unusual and other researchers have found that local residents often do not distinguish 'adopted' invasive species from the indigenous vegetation in their localities (Shackleton et al., 2007; Pfeiffer and Voeks, 2008; Kull et al., 2011). That said, the situation differs somewhat for *Prosopis* due to concerns related to its rapid spread and its negative impacts, as well as to the wide publicity given to this plant and the active control programmes through WfW and SANParks in the region. Kull et al. (2011) mention how such external or political influence plays a key role in shaping local perceptions of invasive species, as do Shackleton and Shackleton (2016) in a survey of urban residents' knowledge of invasive tree species in Grahamstown in the Eastern Cape. *Prosopis* which occurs across all the settlements, while initially appreciated, was now regarded by many as a problematic plant. Similar accounts of how perceptions change as *Prosopis* invades have been recorded in other studies (e.g. Maundu et al., 2009). There was also some discussion of *L. leucocephala* in a similar light; however, this species is unlikely to ever become as aggressive an invader in this arid landscape. This shift in perceptions is in accordance with the conceptual model of Shackleton et al. (2007) which suggests that, for useful and highly competitive species such as *Prosopis*, the costs to livelihoods or increase in vulnerability as the tree spreads may begin to outweigh the benefits and therefore how people perceive and relate to the species.

As observed by other authors (e.g. Kull et al., 2011; Shackleton and Shackleton, 2016), the varied presence and abundance of invasive plants across settlements was influenced by several intersecting biophysical and human-related factors such as sources of seedlings (pathways and vectors of spread), people's preferences, environmental conditions, water availability and the inability to grow alternatives. For example, species unique to Rietfontein were introduced through the church, while SANParks introduced several species to Welkom. In Mier, residents were forced to weigh-up the trade-offs between the services and disservices from *Prosopis*; while recognising its disadvantages, they argued that nothing else would grow due to poor soils and water supply and so they kept it

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to provide essential shade. In Askham and Reitfontein, the predominance of a diversity of invasive trees across homesteads is likely a consequence of these settlements' improved water access. In turn, they became the node for spread into the other settlements through exchanges. Biophysical conditions and species traits can thus influence the abundance of invasive trees in homesteads simultaneously with other factors such as access to seedlings or self-establishment (Baker, 1974).

In addition to resident's knowledge on the local names and history of the invasive plants, all were able to highlight multiple benefits and uses of these species, as well as the factors that can make them problematic. Some of the services and disservices mentioned, such as shade and leaf litter respectively, are generic to most trees, while others are specific to the particular invasive species. Some of the disservices, such as the rapid spread and regeneration of some species and the difficulty eliminating them, could be seen as attributes of invasive species in general (Shackleton et al., 2007). The only species reported as having no benefits by some 20% of respondents was *Prosopis*. One of the most valued benefits, as one might expect in such arid environments, is the regulating service of shade for humans and livestock. Shade is critical as summer temperatures are extremely high and housing, especially amongst the poor residents who were the target of this study, is poorly insulated. Moreover, indigenous trees in the area are slow growing and do not produce as effective shade canopies (Seymour and Milton, 2003). Given the predicted increases in temperature for this region of South Africa of up to 4° C under climate change (Midgley et al., 2005; Mukheibir and Sparks, 2005) the need for the ameliorating effects of trees is likely to increase. Another popular service is the cultural service of beautification (Shackleton and Shackleton, 2016). Our observations, especially in Rietfontein and Askham, suggest a sense of pride amongst homestead owners in improving their yards, with many planting trees, succulents and using rocks and old painted tyres as decorations, in what would otherwise be a very dry, dusty place as it is not possible to grow grass or typical garden flowering plants.

Following these indirect services, the next most mentioned services were the provisioning services of fuelwood, food and fodder. There are few other options for fuelwood in the region, particularly given that one of the larger indigenous trees, *Vachellia erialoba* (camel thorn), is protected. In many other arid regions *Prosopis* is a key, if not the only, source of energy for households (Pasiecznik et al., 2001; Mwangi and Swallow, 2008). Due to the arid nature of the area and the fact that the settlements are so isolated, fresh fruit and vegetables which have to be brought in are not common and are expensive, therefore fruit/edible pod bearing species (e.g. *O. ficus-indica*, *M. alba* and *Prosopis*) are an important source of nutrition (Beinhart and Wotshela, 2011). Sometimes the fruit is also given away, exchanged or sold or converted into juice, beer or jams. Three of the identified invasive species (*O. ficus-indica*, *Prosopis* spp., and *L. leucocephala*) were introduced specifically as a source of fodder to support increased livestock production. This service is particularly important for livestock owners, however it needs to be taken into consideration that livestock owning households are in the minority (from about a quarter to a maximum of 43% of households in Mier), and so this can affect perspectives on the services and disservices from these species. While *Prosopis* pods and *Opuntia* cladodes and fruits tend to be eaten by livestock (mainly goats) as they forage, our results also showed that about a fifth of residents harvest these sources of fodder from their own and neighbouring homesteads to feed to their animals. The pods of *Prosopis* spp. and *L. leucocephala* are highly nutritious (*Prosopis* is also used for human consumption, especially by children) and low in tannins (Devi et al., 2013), while *Opuntia* spp. provide a source of both food and water for livestock (Kaufmann, 2004). One respondent mentioned how *Prosopis* pods are "*better than lucerne or pellets*", while others emphasised the importance of these sources of fodder during dry periods or drought years – especially *Opuntia*. For these reasons, these species have also been introduced to other arid areas and are often heavily relied upon by local people (Kaufmann, 2004; Tessema, 2012). It is these important uses of these plants as well as their tendency to spread and become problematic that makes them so called 'conflict of interest' invasive plants, requiring special attention and substantive stakeholder engagement in terms of management. Conflict, drawing on Dickie et al. (2014), emerges when there is a "failure to account for, assess, and balance trade-offs" amongst different services and disservices or where there is "failure to agree on the relative value of a particular service." Regarding the latter, some disagreement amongst livestock owners and those who do not keep livestock regarding the value of *Prosopis* was evident.

Regarding disservices, only four species were mentioned as being harmful, problematic or a nuisance in some way. The most mentioned disservice was water uptake by *Prosopis*. *Prosopis* also had the greatest diversity of disservices, including damage to infrastructure, killing other plants, affecting water taste, thorny branches that can damage hands and feet and livestock hooves, causing allergies, spreading too fast, taking up space and outcompeting other species. Some of these impacts have also been highlighted in other studies (e.g. Mwangi and Swallow, 2008). Other than some overlap with some of the above disservices, only two other disservices were mentioned for other species; in the case of *M. azedarach* this was the production of leaf litter and poisonous berries, and for *O. ficus-indica* some 20% of respondents mentioned the gastro-intestinal problems associated with the overconsumption of the plant's fruit and thorns causing irritation (a common finding – see Shackleton et al., 2007). The results thus suggest that, other than for *Prosopis*, for all other species there are more perceived benefits or services than disservices at this stage, although there is some concern about the rapid spread of *L. leucocephala.* However, it is unlikely to become a problematic invader in this region, although it could pose a substantial problem in the wetter parts of South Africa.

Considering the implications of the results for invasive species management in the region, the findings suggest that attention needs to be given to the four species in the top right hand block of Fig. 3, with a focus on *Prosopis* due to its substantial spread into rangelands and its associated disservices. *M. azedarach*, on the other hand, while spreading within settlements, is not yet seen as too problematic. Given that it is a category 1 tree, it does need to be monitored and contained and substitutes found. The local practice of trimming *M. azedarach* to enhance shade in the summer and to prevent growth of the poisonous berries may help prevent spread. Moreover, the arid nature of the area is likely to prevent spread of most of the species that can only survive with additional water provided in settlements. The same applies to *O. ficus-indica* and other lower value category 1 species. The regulations for these species have particular consequences for all newly established homesteads or those who wish to increase the numbers of trees they have. Addressing this may require research and experimentation with indigenous substitutes such as suitably adapted *Vachellia* spp. and *Sersia* spp., while at the same time ensuring that a source of water to support the growth of these trees is provided, especially in the Mier settlements. Drawing on the study results, some of the existing sources of seedlings such as churches and exchanges between residents, through supporting local nurseries, could be used to help promote the use of alternative indigenous species.

For *Prosopis*, residents specifically mentioned that their own interventions, such as the removal of self-seeded individuals or cutting for firewood, were not making any significant impact. According to the invasive species list for this region of South Africa this species is a category 3 in the Northern Cape (Appendix 1). This means existing plants may be retained, but new individuals may not be planted. However, this is problematic for *Prosopis* which is regenerating on its own. While some people would like to retain large trees, they did complain about the abundance and persistence of self-recruited seedlings. The conflict of interest status of *Prosopis* and the different perceptions of its value and usefulness means the both the benefits and costs of this species for different types of households needs to be taken into consideration for management. One respondent described how "*many people like these trees as they are the only ones that grow and provide shade and fodde*r", and while she doesn't want it to happen, she does think, given the problems associated with this species, her *Prosopis* trees should be removed. Particularly livestock owners commented on the usefulness of this species, but at the same time recognise its encroachment into rangeland. Shackleton et al. (2015) argue that since: 1) the costs of *Prosopis* are beginning to outweigh the benefits (Wise et al., 2012); 2) multiple stakeholders, including residents of poor communities, are now recognising this species as problematic; and 3) most control measures to date have not be widely effective, there is a need to consider further biological control (Shackleton et al., 2017). Introducing new, more effective, biological control, however, requires caution and careful research. In Madagascar, the decline in *Opuntia moncantha* after the introduction of a biological control agent in the early 1900s had severe consequences for the well-being of people in the dry south of the island, questioning the wisdom of this control decision and resulting in a reintroduction of *O. moncantha* into the landscape to combat famine and forest destruction (Kaufmann, 2004). Other management suggestions for *Prosopis* include an increase in efficiency of the WfW manual clearing programme (as detected by residents), and changing the status of this species to category 1 as in other provinces (Shackleton et al., 2016). The latter would, however, mean that for places like Mier where there has been limited success with other species, hardy substitute species would need to be found. Another approach to managing *Prosopis*, and which is most popular in developing countries, is to apply control through utilisation (Shackleton et al., 2017). However, this is often not adequate to prevent further spread or increases in the density of stands of this tree (Geesing et al., 2004; Shackleton et al., 2017). Other commentators have argued for the need to boost utilisation levels through consideration of new, and more sophisticated, uses for this plant such as for honey production, biopesticides, antiseptic and antifungal products, flour for animal feed, organic medicines (such as 'manna' in South Africa which is said to stabilise blood sugar levels) or bioenergy (Shackleton et al., 2015). However, this could be counter-productive and it is often not feasible in many of the remote locations where this species is found (Shackleton et al., 2017).

6. Conclusion

This study has shown that plant species from other arid regions of the world have been brought into the Northern Cape, Kalahari region for different purposes, usually to help combat existing ecosystem constraints. Fodder species were introduced mainly by government agencies, while shade and aesthetic species have been introduced by residents themselves for planting around their homesteads. Most of these species deliver important regulating and provisioning services, with *Prosopis* being the only tree mentioned as having numerous disservices, whilst simultaneously producing benefits. Management and control programmes for *Prosopis* and several other species thus need to recognise their contentious status and the role of these trees in different spaces such as in yards and settlements (urban environments) versus the rangelands. The study has highlighted the importance and usefulness of considering an approach that recognises the services and disservices of invasive trees across scales and actors, with specific attention to different local contexts (Pejchar and Mooney, 2009; Shackleton et al., 2011), as well as the need for multiple voices in any management decisions (Dickie et al., 2014). Trade-offs will be inevitable so it is important that these are fully considered through appropriate research and dialogue with the different actors or stakeholders involved (Bardsley and Edward-Jones, 2007; Dickie et al., 2014; Novoa et al., 2016). Ultimately a diversity of control methods will likely be needed for the invasive plants in this region, and *Prosopis* in particular, especially if a scalar perspective is employed (Geesing et al., 2004; Bardsley and Edward-Jones, 2007; Shackleton et al., 2017). The study also suggests that an important aspect of management, particularly in arid areas, is to seek and promote the planting of alternative indigenous or non-invasive shade producing species. Finding replacement species is even more essential in the context of climate change and the much higher temperatures and frequent heat waves expected in the Kalahari region (Midgley et al., 2005) and other arid areas. Climate change introduces many uncertainties in terms of impacts on indigenous and invasive tree species, but one aspect that is clear is that shade will become an increasingly valued service in small farming settlements, such as those in this study.

Going forward there are four key considerations which need further attention within invasive plant research in arid areas. One, more work at the interface between climate change, invasive species, livelihoods and management policy is required (Bardsley and Edward-Jones, 2007). Two, in South Africa invasive species are listed under NEM:BA and CARA on a regional/provincial basis that consists of 'artificial' borders. Commonly these provincial areas incorporate several biomes (for example the Northern Cape consists of four biomes). Species such as *M. azedarach* will never become invasive in arid regions, but are listed in these areas as Category 1 as they fall into a small part of one large province. Therefore, the future listing of invasive plant species in South Africa and elsewhere might need to be reconsidered to represent more accurately the areas for potential invasion on a biome or biophysical basis. The regulations are slowly evolving to consider this. Three, methods and studies to better understand the disservices/costs versus the services/benefits of conflict of interest invasive species are lacking (Wise et al., 2012; Shackleton et al., 2015), and further techniques need to be developed to assess these trade-offs. Lastly, a key gap in knowledge which needs to be filled in the future is how to best engage stakeholders to develop management strategies for conflict of interest species like *Prosopis* (Novoa et al., 2016).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2017.07.001.

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References

Argaw, T., 2015. Impacts of utilizing invasive *Prosopis juliflora* (SWARTZ) DC. on the rural household economy at Gewane District, Afar regional state, North-Eastern Ethiopia. J. Econ. Sustain. Dev. 6, 81–97.

Baker, H., 1974. The evolution of weeds. Annu. Rev. Ecol. Syst. 5, 1–14.

Bardsley, D., Edward-Jones, G., 2007. Invasive species policy and climate change: social perceptions of environmental change in the Mediterranean. Environ. Sci. Policy 10, 230–242.

Beinhart, W., Wotshela, L., 2011. Prickly Pear: The Social History of a Plant in the Eastern Cape. Wits University Press, Johannesburg.

Blanckaert, I., Vancraeynest, K., Swennen, R.L., Espinosa–García, F.J., Piñero, D., Lira–Saade, R., 2007. Non–crop resources and the role of indigenous knowledge in semi–arid production of Mexico. Agr. Ecosyst. Environ. 119, 39–48.

Chikuni, M.F., Dudley, C.O., Sambo, E.Y., 2004. *Prosopis glandulosa* Torrey (Leguminosae-Mimosoidae) at Swang'oma, Lake Chilwa plain: a blessing in disguise. Malawi J. Sci. Technol. 7, 10–16.

Cole, M.M., Brown, R.C., 1976. The vegetation of the Ghazi area of western Botswana. J. Biogeogr. 3, 169–196.

Devi, M.V.N., Ariharan, V.N., Prasas, N.P., 2013. Nutritive value and potential uses of *Leucaena leucocephala* as biofuel – a mini review. Res. J. Pharmaceut. Biol. Chem. Sci. 4, 515–521.

Dickie, I.A., Bennett, B.M., Burrows, L.E., Nuñez, M.A., Peltzer, D.A., Porté, A., Richardson, D.M., Rejmánek, M.M., Rundel, P.W., van Wilgen, B.W., 2014. Conflicting values: ecosystem services and invasive tree management. Biol. Invasions 16, 705–719.

Dos Santos, L.L., do Nascimento, A.L.B., Vieira, F.J., da Silva, V.A., Voeks, R., Albuquerque, U.P., 2014. The cultural value of invasive species: a case study from semi–arid, north-eastern Brazil. Econ. Bot. 68, 283–300.

Eiswerth, M.E., Yen, S.T., van Kooten, G.C., 2011. Factors determining awareness and knowledge of aquatic invasive species. Ecol. Econ. 70, 1672–1679.

Estévez, R.A., Anderson, C.B., Pizarro, J.C., Burgman, M.A., 2015. Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. Conserv. Biol. 29, 19–30.

Geesing, D., Al-Khawlani, M., Abba, M.L., 2004. Management of introduced *Prosopis* species: can economic exploitation control invasive species. Unasylva 217, 36–44.

Hassan, R., Sholes, R., Ash, N. (Eds.), 2005. Ecosystem Services and Human Well-being: Current State and Trends. Findings of the Condition and Trends Working Group. Island Press, Washington DC.

Henderson, L., 2001. Alien Weeds and Invasive Plants. A Complete Guide to Declared Weeds and Invaders in South Africa. Agricultural Research Commission, South Africa.

Jevon, T., Shackleton, C.M., 2015. Integrating local knowledge and forest surveys to assess *Lantana camara* on indigenous species recruitment in Mazeppa Bay, South Africa. Hum. Ecol. 43, 247–254.

Kaufmann, J., 2004. Prickly pear cactus and pastoralism in southwest Madagascar. Ethnology 43, 245–361.

Kull, C.A., Shackleton, C.M., Cunningham, P.J., Ducatillon, C., Dufour-Dror, J., Esler, K.J., Friday, J.B., Gouveia, A.C., Griffin, A.R., Marchantem, E., Midgley, S.J., Pauchard, A., Rangan, H., Richardson, D.M., Rinaudo, T., Tassin, J., Urgenson, L.S., von Maltitz, G.P., Zenni, R.D., Zylstra, M.J., 2011. Adoption, use and perception of Australian acacias around the world. Divers. Distrib. 17, 822–836.

Low, A.B., Rebelo, A.G. (Eds.), 1996. Vegetation of South Africa, Lesotho and Swaziland: a Companion to the Vegetation Map of South Africa, Lesotho and Swaziland. Department of Environmental Affairs and Tourism, Pretoria.

MA (Millennium Ecosystem Assessment), 2005. Ecosystem and Human Well-being: Synthesis. Island Press, Washington DC.

Macdonald, I.A.W., Kruger, F.J., Ferrar, A.A., 1986. The Ecology and Management of Biological Invasions in Southern Africa. Oxford University Press, Cape Town.

Mack, R.N., 2003. Global plant dispersal, naturalization, and invasion: pathways, modes and circumstances. In: Ruiz, G.M., Carlton, J.T. (Eds.), Invasive Species: Vectors and Management Strategies. Island Press, Washington DC.

Maundu, P., Kibet, S., Morimoto, Y., Imbumi, M., Adeka, R., 2009. Impact of *Prosopis juliflora* on Kenya's semi-arid and arid ecosystems and local livelihoods. Biodiversity 10, 33–50.

Midgley, G.F., Chapman, R.A., Hewitson, B., Johnston, P., De Wit, M., Ziervogel, G., Mukheibir, P., Van Niekerk, L., Tadross, M., Van Wilgen, B.W., Kgope, B., Morant, P., Theron, A., Scholes, R.J., Forsyth, G.G., 2005. A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-economic Effects of Climate Change in the Western Cape. Report to the Western Cape Government, Cape Town, South Africa. Report No. ENV-S-C 2005-073. Stellenbosch, CSIR.

Mucina, I., Rutherford, M.C., 2006. The Vegetation of South Africa, Lesotho and Swaziland Pretoria: Strelitzia. South African National Biodiversity Institute.

Mukheibir, P., Sparks, D., 2005. Climate Variability, Climate Change and Water Resource Strategies for Small Municipalities: Water Resource Management Strategies in Response to Climate Change in South Africa, Drawing on the Analysis of Coping Strategies Adopted by Vulnerable Communities in the Northern Cape Province of South Africa in Times of Climate Variability. Report to the Water Research Commission (WRC), Project: K5/1500. WRC, Pretoria.

Musimba, N.K.R., Bariagabre, S.A., 2003. Cactus (*Opuntia ficus-indica*) growing as an alternative livelihood in the traditional Tigrian community of Wukro Wereda of arid Eastern Tigray region of Ethiopia. Rangelands in the New Millennium. In: Proceedings of the 7th International Rangeland Conference, 26 July–1 August, Durban, South Africa.

Mwangi, E., Swallow, B., 2008. *Prosopis juliflora* invasion and rural livelihoods in the Lake Baringo area of Kenya. Conservat. Soc. 6, 130–140.

Novoa, A., Kaplan, H., Wilson, J.R.U., Richardson, D.M., 2016. Resolving a prickly situation: involving stakeholders in invasive cactus management in South Africa. Environ. Manag. 57, 998–1008.

Oosthuizen, R., John, J., 2004. Northern Cape: State of the Environment Report. Atmosphere and climate specialist report. Prepared for Department of Tourism, Environment and Conservation, Kimberly, South Africa.

Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K., Maldonado, L.J., 2001. The *Prosopis juliflora-Prosopis pallida* Complex: a Monograph. HDRA, Coventry, UK.

Pejchar, L., Mooney, H., 2009. Invasive species, ecosystem services and human well-being. Trends Ecol. Evol. 24, 497–504.

Pfeiffer, J.M., Voeks, R.A., 2008. Biological invasions and biocultural diversity: linking ecological and cultural systems. Environ. Conserv. 35, 281–293.

Richardson, D.M., van Wilgen, B., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? South Afr. J. Sci. 100, 45–52.

Seymour, C., Milton, S., 2003. A Collation and Overview of Research Information on *Acacia erioloba* (Camel Thorn) and Identification of Relevant Research Gaps to Inform Protection of the Species. Department of Water Affairs and Forestry Contract No. 2003/089, Pretoria.

Shackleton, C.M., McGarry, D., Fourie, S., Gambiza, J., Shackleton, S.E., Fabricius, C., 2007. Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa. Hum. Ecol. 35, 113–127.

Shackleton, C.M., Ruwanza, S., Sinasson Sanni, G.K., Bennett, S., De Lacy, P., Modipa, R., Mtati, N., Sachikonye, M., Thondhlana, G., 2016. Unpacking Pandora's Box: understanding and categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems 19, 587–600.

Shackleton, C.M., Shackleton, R.T., 2016. Knowledge, perceptions and willingness to control designated invasive tree species in urban household gardens in South Africa. Biol. Invasions. http://dx.doi.org/10.1007/s10530-016-1104-7.

Shackleton, R.T., Richardson, D.M., Le Maitre, D.C., 2015. Use of non-timber forest products from invasive alien *Prosopis* species (mesquite) and native trees in South Africa: implications for management. For. Ecosyst. 2, 16. http://dx.doi.org/10.1186/s40663-015-0040-9.

Shackleton, R.T., Le Maitre, D.C., van Wilgen, B.W., Richardson, D.M., 2017. Towards a national strategy to optimise the management of a widespread invasive tree (*Prosopis* species; mesquite) in South Africa. Ecosyst. Serv. http://dx.doi.org/10.1016/j.ecoser.2016.11.022.

Shackleton, S.E., Kirby, D., Gambiza, J., 2011. Invasive plants - friends or foes? Contribution of prickly pear (*Opuntia ficus-indica*) to livelihoods in Makana Municipality, Eastern Cape, South Africa. Dev. South. Afr. 28, 177–193.

Simberloff, D., Martin, J.L., Genovesi, P., Maris, V., Wardle, D.A., Aronson, J., Courchamp, F., Galil, B., Garcia-Berthou, E., Pascal, M., Pyšek, P., Sousa, R., Tabacchi, E., Vila, M., 2013. Impacts of biological invasions: what's what and the way forward. Trends Ecol. Evol. 28, 58–66.

Tessema, Y.A., 2012. Ecological and economic dimensions of the paradoxical invasive species-*Prosopis juliflora* and policy challenges in Ethiopia. J. Econ. Sustain. Dev. 3, 62–70.

Thondhlana, G., Shackleton, S., Muchapondwa, E., 2011a. Kgalagadi Transfrontier Park and its land claimants: a pre- and post-land claim conservation and development history. Environ. Res. Lett. 6, 1–12.

Thondhlana, G., Vedeld, P., Shackleton, S.E., 2011b. Natural resource use, income and dependence amongst San and Mier communities bordering the Kgalagadi Transfrontier Park, southern Kalahari, South Africa. Int. J. Sustain. Dev. World Ecol. 19, 460–470.

Treiman, D., 2007. The legacy of apartheid: racial inequalities in the new South Africa. In: Heath, F.S., Cheung, S.Y. (Eds.), Unequal Chances: Ethnic Minorities in Western Labour Markets. Oxford University Press, Oxford, pp. 1–48.

van der Wal, R., Fischer, A., Selge, S., Larson, B.M., 2015. Neither the public nor experts judge species primarily on their origins. Environ. Conserv. 42, 349–355.

van Wilgen, B.W., Forsyth, G.G., Le Maitre, D.C., Wannenburgh, A., Kotze, J.D.F., van den Berg, E., Henderson, L., 2012. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. Biol. Conserv. 148, 28–38.

van Wilgen, B.W., Richardson, D.M., 2014. Challenges and trade-offs in the management of invasive alien trees. Biol. Invasions 16, 721–734.

Vas, A.S., Kuffer, C., Kull, C.A., Richardson, D.M., Vicente, J.R., Kühn, I., Schröter, M., Hauck, J., Bonn, A., Honrado, J.P., 2017. Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst. Serv. 23, 94–107.

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. J. Arid Environ. 84, 80–90.

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