Orange-Senqu River Basin

Orange-Senqu River Commission Secretariat
Governments of Botswana, Lesotho, Namibia and South Africa

UNDP-GEF
Orange-Senqu Strategic Action Programme
(Atlas Project ID 71598)

Control of Alien Invasive Plants in the Orange-Senqu River Basin

Technical Report 46
Rev 1, 18 October 2013

UNDP-GEF
Orange-Senqu Strategic Action Programme

Control of Alien Invasive Plants in the Orange-Senqu River Basin

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This report has been issued and amended as follows:

Revision	Description	Date	Signed
0	Draft for review	30 Sep 2013	KS, DlM
1	Edited., for circulation	18 Oct 2013	cr, mor

Project executed by:

UNOPS

Contents

Executive summary

The Orange-Senqu River basin stretches across four southern African countries, namely the Republic of Botswana, the Kingdom of Lesotho, the Republic of Namibia, and the Republic of South Africa. It is one of the largest and most utilised river basins in southern Africa. Several transboundary issues have been identified that require further assessment. One of these is alien invasive species. This particular technical paper focuses on invasive alien plant species (IAPs) in the Orange-Senqu River basin, its current extent and the importance of finding suitable clearing methods.

This paper is divided into five sections, of which the first two introduce the basin and the transboundary issues of water resource shortage, hydrological changes, deteriorating water quality and overall land degradation - to which the spread of invasive alien plants (IAPs) is intricately linked. Section three provides a detailed account of five of the most common invasive tree species, namely wattles, *Prosopis*, eucalypts, poplars and willows. A further summary of other terrestrial and aquatic invasives is given, describing their uses, their problems and existing control efforts. The section also provides a country-by-country data summary, depicting the current extent of mapping that is possible in South Africa and Lesotho, as well as partial mapping for *Prosopis* in Namibia and South Africa. The section highlights the need for improved data, to cover existing gaps for certain basin areas, such as Botswana.

Section four iterates the urgency for clearing efforts, by summarising known information on impacts of IAPs. In absolute terms the impacts will be greatest in the eastern parts of the basin where runoff is highest and where human and developmental densities are highest too. However, the arid areas in the western part of the basin are likely to be hardest hit by the spread of IAPs, because there is such a high dependence on few available water resources. The best information on IAP impacts exists for water resources. Provisional estimates of IAP water reduction in the Vaal River system are 191 million m3/yr (2.0%) and 141 million m3/yr (3.5%) in the Orange River system, including two million m3/yr for Lesotho. A lack of clearing is estimated to increase IAP water use by 25% in an Orange tributary over the next 50 to 70 years. Clearing costs would equally increase from USD 4.1 million to USD 278 million.

Section five concludes the paper with a two-pronged approach to initiate long-term basin-wide alien invasive plant clearing for the Orange-Senqu River basin. The first prong could be a communication effort, whereby focus is placed on national-level communication initiatives with the aim of convincing decision makers that an IAP control programme for the basin is essential in all four basin States. At the same time the second prong should be more practically-driven, addressing mapping of invasions and prioritising areas of intervention as well as clearing efforts in all four countries.

Abbreviations

CSIR	*Centre for Scientific and Industrial Research*
DWAF-SA	*Department of Water Affairs (South Africa)*
ha	*hectare(s)*
IAP	*invasive alien plants*
km	*kilometres*
mm	*millimetres*
Mm^3/a	*million cubic metres per annum*
NIAPS	*National Invasive Alien Plant Survey*
ORASECOM	*Orange-Senqu River Commission*
SADC	*Southern African Development Community*
SAPIA	*Southern African Plant Invaders Atlas*
USD	*United States dollar(s)*
WfW	*Working for Water*

Glossary

Deterioration of water quality: A transboundary issue in the Orange-Senqu River basin. Deterioration of water quality refers to the contamination of water bodies as a result of human activities. Contaminants are here defined as compounds that are toxic and/or persistent and/or bioaccumulating.

Ecosystem: A community of living organisms and the environment in which they live, interacting to form a functional system.

Ecosystem degradation: A transboundary issue in the Orange-Senqu River basin. Ecosystem degradation refers to anthropogenic interventions in ecosystem resulting in deforestation, land degradation and loss of species.

Ecosystem services: The benefits people derive from their environment and their ecosystems.

Invasive alien plant species: A plant species, originating in another geographic location, that was introduced to the area by humans, and that has now established itself and is successfully growing and propagating in the landscape, often at deleterious consequence to indigenous species, local resources and human well-being.

Transboundary issue: An environmental problem originating in one country and affecting another. The transboundary impact may be damage to the natural environment and/or damage to human welfare.

Variation and reduction of hydrological flow: A transboundary issue in the Orange-Senqu River basin. Variation and reduction of hydrological flow refers to an increase or decrease in the discharge of streams and rivers as a direct or indirect consequence of human activity.

1. Introduction

The Orange-Senqu River basin is one of the largest and most utilised catchments in southern Africa. The Orange-Senqu River Commission (ORASECOM), founded in 2000, advises the governments of the four basin States on the development, use and conservation of the water resources of the Orange-Senqu River System.

On-going efforts have highlighted five transboundary concerns that require a more detailed analyses and assessment with the aim of identifying potential solutions. They are stress on available water resources (surface and groundwater), changes in the hydrological regime, deterioration of water quality and land degradation, including alien invasive species.

This particular paper focuses on invasive alien plant species (IAPs) in the Orange-Senqu River basin. It summarises the key factors that cause the spread of IAPs, discusses the drawbacks and benefits of the key IAP species present in the in-stream and riparian zones of the catchment, highlights the importance of addressing the control of IAP species at a transboundary level and ends off with a discussion on exploring clearing possibilities.

2. Background

2.1 The Orange-Senqu River basin

The Orange-Senqu River basin includes the entire land area of Lesotho, a large part of central South Africa, reaches into southern Botswana and covers the southern half of Namibia (Viles, 2007). The Orange-Senqu River basin is the third largest in southern Africa, with a total catchment area approaching one million square kilometres. Its headwaters lie in the Lesotho Highlands, where the average annual precipitation is as high as 1,800 mm per annum and evaporation rates are about 1,100 mm per annum. From here, the river stretches 2,300 km westwards across increasingly arid terrain. Tributaries such as the Fish River from Namibia, as well as the Molopo from Botswana, join the Orange in the lower reaches. The Orange-Senqu reaches the Atlantic Ocean at the South Africa/ Namibia border where average annual precipitation is less than 50 mm. Average annual potential evaporation is as high as 3,000 mm in the western stretches of the basin.

Due to the progressive reduction in rainfall across the catchment, there are also a variety of vegetation types through which the river flows. Alpine vegetation is found in the high-altitude zones of Lesotho, consisting of heather communities mixed with low woody species and alpine grasses (Mucina and Rutherford, 2006). The remaining high-lying areas are dominated by montane grassland which grades into Highveld grasslands at lower altitudes before turning into the shrublands of the Nama Karoo. Karoo vegetation typifies the middle and lower Orange River basin, including the lower reaches of the Namibian Fish River tributary. The lower Orange flows through the Richtersveld in the Succulent Karoo Biome. The Orange River tributaries in Namibia run through three semi-desert systems, namely the Succulent Karoo in the far south-west, the Nama Karoo in the upstream central and southern area, and the Southern Kalahari in the east. The Kalahari consists of deep wind-blown sand, with minimal rainfall and run-off. The Molopo and Nossob catchments in Botswana also lie in the Southern Kalahari, with arid savannah vegetation.

Much of the riparian corridor is azonal with respect to vegetation, as described by Mucina and Rutherford (2006). The riparian vegetation is continually degraded through wood collection (for cooking and building material), agriculture close to river banks, clearing for small-scale alluvial mines, and continual colonisation by IAPs. In the higher rainfall areas of the upper catchment, the most common woody invasive species are *Acacia dealbata* (silver wattle), *Acacia mearnsii* (black wattle), *Populus* sp. (grey poplar), *Eucalyptus* spp. (blue gum), *Melia azederach* (syringa) and J*acaranda mimosifolia* (jacaranda). Towards the more arid areas in the central and western parts of South Africa, southern Namibia and Botswana, the primary invasive plants are *Prosopis* and *Eucalyptus* species and a variety of shrubs and herbs.

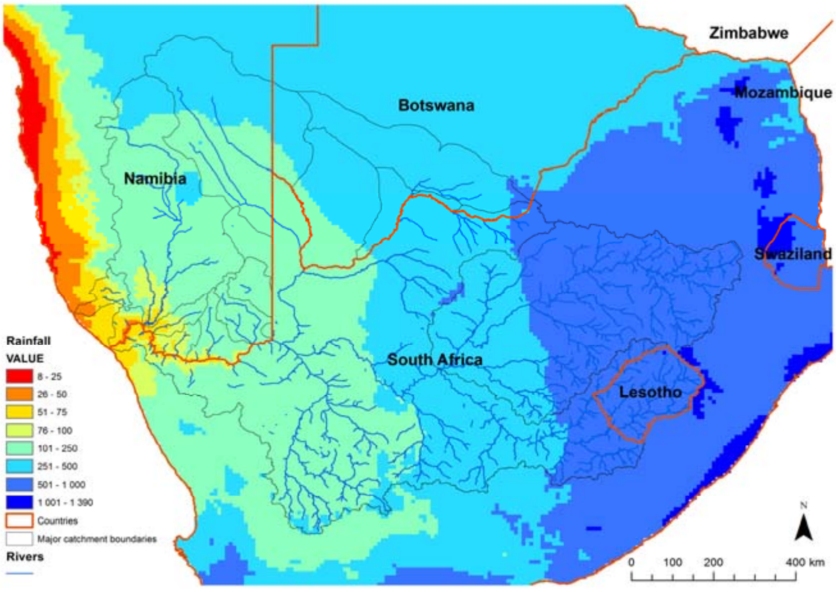

Figure 1. Map of the Orange-Senqu basin, depicting annual rainfall levels (mm). Annual rainfall from the Bioclim dataset (Hijmans et al. 2005).

2.2 Key factors affecting the spread of IAPs

The most obvious root cause for the presence of IAPs is the original introduction of the species into the area. As with most introduced tree species, this was done to derive a benefit from the species as a crop with little awareness or understanding of the potential impacts of invasions (Harding, 1987; Poynton, 2009). The invasion of IAPs is closely associated with overall ecosystem degradation (MacDougall and Turkington, 2005). The relevant factors of river and land degradation, closely associated with the spread of IAPs in the Orange-Senqu basin have been identified as: stress on available water resources, changes in hydrological regime, reduced water quality, land degradation and other anthropogenic impacts. Each of these contribute to the alteration of the natural ecological system, disturbing natural habitat and creating a niche for alien species to take hold and proliferate.

Stress on available water resources

Approximately 64% of the catchment lies within South Africa, but the country is by far the greatest proportional user of water at 95%. The Orange-Senqu is crucial in meeting the demands of South Africa's urban and industrial hubs in the Vaal tributary in the upper catchment. This includes southern Gauteng, the main gold mining areas, parts of the Highveld coal fields, several thermal power stations as well as large areas of irrigated and dryland agriculture. Towards the lower basin in the arid western part of South Africa, the main water demand is from irrigation. Approximately 60% of South Africa's water requirements covers the needs for irrigated agriculture. The whole of Lesotho falls within the basin, covering less than 5% of land area. Despite its small contribution in size and its small demand on available water, it provides over 40% of stream flow. Botswana also has low demands of primarily groundwater for rural water use along the sparsely populated Nossob and Molopo tributaries. Botswana's primary development centres are located outside of the Orange River basin and are currently not using significant amounts of the basin's surface water resources. This might well change with future development of the Lesotho Highlands Water Project. Namibia uses approximately 2% of water resources in the basin, and this proportion is essential for its commercial agriculture and mining in the southern parts of the country. Further growth in water demand is anticipated in all four countries.

At present the available water resources meet demands upstream, but future temperature increases through predicted climate change, agricultural expansion in the lower catchment (especially in Namibia), as well as provision for environmental water needs in the lower catchment all put increased stress on the basin's water resources. Improved efficiency of water use in the agriculture sector is considered essential. Another option to be investigated is the effective clearing of IAPs along the riparian zone of the Orange River system. The proliferation of IAPs is estimated to reduce river yield by as much as 13% in the upper catchment and 7.8% in the lower catchment (Le Maitre et al., 2000; Le Maitre et al., 2013). Effective clearing could reclaim these water resources for other uses.

Changes in the hydrological regime

Naturally, flow in the Orange River mouth would be approximately 11,300 Mm3 per annum, but water resource developments and use have reduced this naturalised flow to 37% (Mare, 2007). This reduction in flow as well as the storage and transfers of the basin's water resources have signify-cantly modified the seasonality of flows and reduced the occurrence of large flood events. This has altered the natural flood-disturbance pattern. The riparian zone is scoured less frequently by flood events, modifying natural plant succession dynamics (Naiman et al., 1993) and allowing particular species to establish and proliferate. These changed dynamics allow IAP species to establish themselves, as well as other plant species that have become problematic. *Phragmites australis* (common reed) occurs throughout the perennial and near-perennial systems along the edges and in shallow sections of the active channels as well as in cut-off sections (e.g. ox-bows) (Heath and Brown, 2007). The reduction in flood frequency ,regulation of moderate flood events and the smoothed flows created by irrigation transfers and dam operation in the system have allowed it to colonise areas along the Orange and Vaal (and their perennial tributaries) where it was previously removed by seasonal flooding. Aerial photographs have confirmed that the reed infestation had proliferated along the Orange from virtually none in 1976 to over 41,000 ha in 1995 (ORASECOM, 2008). Personal observations by farmers along the Orange River suggest that the increase has accelerated over the past five years (Roux pers. comm. in ORASECOM, 2008).

Deterioration of water quality

Eutrophication has been highlighted as one of the main water quality issues in the catchment (ORASECOM, 2010). Of particular concern is the Vaal tributary, where the water is often eutrophic or hypertrophic. Key reasons for river eutrophication in the case of the Orange-Senqu include insufficiently purified sewage effluent, as well as agricultural runoff. Increased nutrient levels lead to the proliferation of algae and aquatic IAPs which thrive on nutrient-enriched water (Ashton and Mitchell, 1989) as well as promoting the growth of reeds (Phragmites, Typha). Some wattle species are major invaders in the basin and are also known as active nitrogen fixers (Forrester et al., 2007). These could potentially lead to elevated nutrient levels in surrounding water resources, as was shown by a Western Cape study, where the presence of a wattle species led to increased nutrient concentrations in the immediate groundwater (Jovanovic et al., 2009).

Land degradation

Approximately 14.3 million people live in the basin and population density is greatest in the South African Vaal tributary where the urban areas of southern Gauteng, including the Vaal triangle are located (ORASECOM, 2008).

The Orange-Senqu basin has become one of the most modified and degraded in southern Africa due to extensive agricultural development in the high-rainfall grasslands, mainly dryland maize, urbanisation, industrial development and mining, and over-grazing throughout most of the dryer grasslands, arid savannah and Karoo regions. The Grassland Biome, much of which is located in this basin, is recognised as the most threatened in South Africa with substantial impacts on its biodiversity (Driver et al., 2011). Intensive irrigated agriculture and small-scale mining along the river banks has resulted in the transformation and replacement of much of the native floodplain and riparian vegetation (Nel et al., 2011; ORASECOM, 2010).

The state of the remaining native riparian vegetation is generally poor and the aquatic ecosystems have been substantially modified by changes in the river flow regimes, which have also altered the composition of the riparian vegetation, favouring the development of reed beds.

3. Key IAP species in the Orange-Senqu River basin

3.1 IAPs – known information

The information available on the occurrence and composition of alien plant invasions varies widely between the different countries in the Orange-Senqu basin, with the least information for Botswana and the most information for South Africa (MacDonald et al., 2003). This is partly because South Africa has invested in supporting the national Working for Water (WfW) programme which focuses on controlling invasions and has collated a body of information on them and their impacts. The nature, distribution and extent of invasions also varies widely between the countries, with the most extensive and dense invasions being found in the high rainfall upper catchment areas in Lesotho and South Africa. We have drawn our information on plant invasions primarily from three sources: mapping of invasions in Lesotho and South Africa and other data (Le Maitre et al., 2013), the biodiversity report for Lesotho (Lesotho, 2009), the tree atlas of Namibia (Curtis and Mannheimer, 2005) and a review of alien invasive species for Namibia (Bethune 2004), and a biodiversity report for Botswana (Botswana, 2009) and a paper on *Prosopis* (Muzila et al., 2011). We have also drawn on information compiled for a previous assessment of the state of the basin (ORASECOM, 2008). Some information has also been obtained from Macdonald et al. (1986), although this is dated.

3.2 Country-specific information

Lesotho and South Africa

We have made use of data extracted from the National Invasive Alien Plant Survey (NIAPS, Kotzé et al., 2010) by Le Maitre et al. (2013) and the Southern African Plant Invaders Atlas (SAPIA, Henderson, 2007) as well as information from the national biodiversity report for Lesotho (Lesotho, 2009). The NIAPS data is based on aerial surveys of sampling points distributed across homogeneous mapping units which were based on rainfall, soil depth and soil texture within fourth order (quaternary) catchments. Three data sets were produced: (a) one for landscape invasions which only covered the moister parts of South Africa; (b) one for landscape invasions in Lesotho; and (c) one for riparian invasions which covered the rivers shown in the 1:500,000 map series for Lesotho and South Africa (Silberbauer, 2006). The landscape invasions included both riparian and non-riparian invasions so there is some overlap. The NIAPS mapping included 28 taxa which are scramblers, shrubs and tree species and includes cactaceae; herbaceous and species not easily recognised visually were excluded. The SAPIA database includes more than 500 taxa and is based on observations, primarily from road transects, of the invasions by species and their characteristics (Henderson, 2007). Each observation is geographically referenced using a map reference and with a latitude and longitude.

A 2005 assessment (summarised in the Lesotho biodiversity report, Lesotho, 2009) found fifty-four plant species: 51 terrestrial and, three aquatic plants. Most of the terrestrial plant species were included in the NIAPS mapping, the exceptions being the herbaceous species such as *Xanthium, Striga, Salsola, Avena and Bidens*. The plants include *Carpobrotus edulis* which was introduced to South Africa. The aquatic plants include *Typha capensis* (from southern Africa), *Azolla filiculoides* and *Myriophyllum aquaticum*.

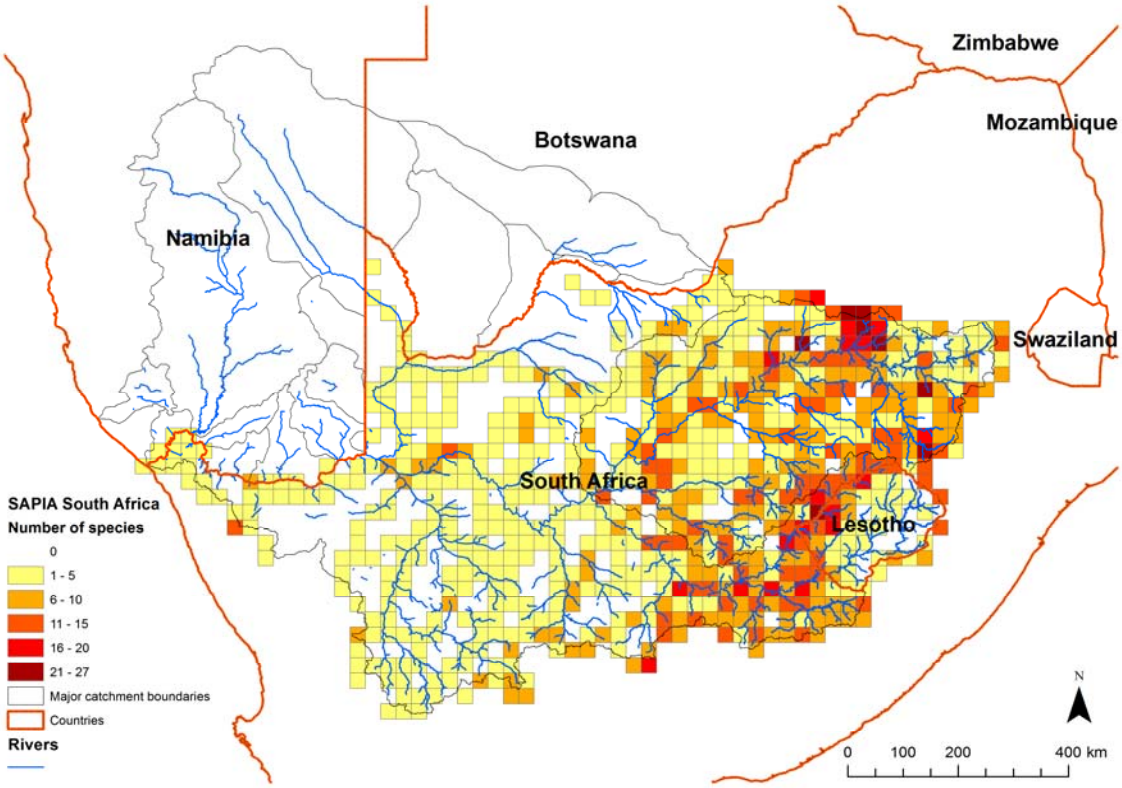

Figure 3.1. The number of plant species recorded in each 0.25 x 0.25° of arc grid-cell in the portion of the Orange-Senqu basin falling in South Africa and Lesotho. Data taken from the Southern African Invasive Plant Atlas (Henderson, 2007).

The species composition, extent and distribution of alien invasive plant species varies widely between the high rainfall grasslands of the upper Orange and Vaal River systems and the more arid middle and lower reaches. Large numbers of species are found in the moister parts of the catchment with the greatest numbers of species being found in the Witwatersrand-Vaal Triangle, the Maseru area of Lesotho, and along the Orange and Vaal River systems. In the western part of the basin there are fewer species because the dry climate prevents many species invading. The most frequently recorded taxon was *Salix babylonica* (weeping willow) with 992 records, followed by *Prosopis glandulosa* (Mesquite, 885), *Opuntia ficus-indica* (Prickly pear, 782), *Populus x canescens* (Grey poplar) and *Acacia dealbata* (Silver wattle) (Appendix A gives the top 30). Several of these species have high proportions of records where they were abundant or very abundant, notably *Populus x canescens* (32% of records), *Azolla filiculoides* (23%, Red water fern) and *Acacia dealbata* (22%). In

Lesotho and the higher-lying parts of South Africa the major invasive species are *Populus* species (poplars), *Salix* species (willows), *Rosa rubiginosa* (wild briar), *Acacia dealbata* and *A. mearnsii* (wattles), *Pinus* species (pines) and *Eucalyptus* species (eucalypts or gums).

In the more arid grasslands and the Karoo shrublands that occupy most of the basin, the main invaders are *Prosopis* species (mesquite), the succulent *Cactaceae* (e.g. *Opuntia* species), salt bushes (*Atriplex* species) and some annual herbaceous species (e.g. *Datura, Xanthium*). Willows and Poplars decrease in abundance and the dominant species in river floodplain invasions are *Eucalyptus* (gums), *Acacia mearnsii, Melia azedarach* (syringa) and *Nicotiana glauca* (wild tobacco). In the arid to lower Orange River only *Opuntia* species and other *Cactaceae* invade dryland areas while *Prosopis* species become more confined to river flood plains and alluvial flats (van den Berg, 2010). The *Cactaceae*, especially those without effective biological control (see Paterson et al., 2011) are considered a significant problem in the arid savannas and the adjacent Karoo shrublands (Le Maitre et al., 2010). *Prosopis* invasions are mainly found on the flat alluvial floodplains along perennial and ephemeral rivers and the flat alluvial plains where the stands can become dense (Van den Berg, 2010). The trees generally become denser and taller in areas where groundwater can be accessed by their very deep root systems (Harding and Bate, 1981; Le Maitre, 1999; Wise et al., 2012).

The most abundant IAPs include two aquatic invaders: *Azolla filiculoides* and *Eichhornia crassipes*, both of which prefer slow-flowing river reaches and dams. Invasions by both of these species are favoured by high nutrient levels in the water which allow them to grow and multiply rapidly (Ashton and Mitchell, 1989).

The mapping of the landscape and riparian invasions shows that there are extensive invasions in the upper-catchments of both the Orange and Vaal River catchments and particularly in the eastern parts of Lesotho (Figure 3.2). There are extensive landscape invasions in the central areas of the catchment but these were not included in Kotzé et al. (2010) landscape mapping. The riparian invasions also stand out on both the perennial and non-perennial river systems throughout both catchments. The invasions in the ephemeral to near perennial tributaries of the lower Orange River (below the Vaal River confluence) are mainly *Prosopis* but invasions on the Orange River itself and perennial reaches of the other rivers also include a wide range of species with the most important being: *Eucalyptus* species, *Acacia mearnsii*, *Populus* species, *Salix* species, *Melia azedarach* and *Arundo donax* (Henderson, 1991; Spear et al., 2011). The total invaded area in the Orange and Vaal River catchments comes to almost 5 million hectares with more than half of these invasions being found in the upper Senqu/Orange (notably in Lesotho) and Vaal River systems, particularly the upper and middle sub-catchments.

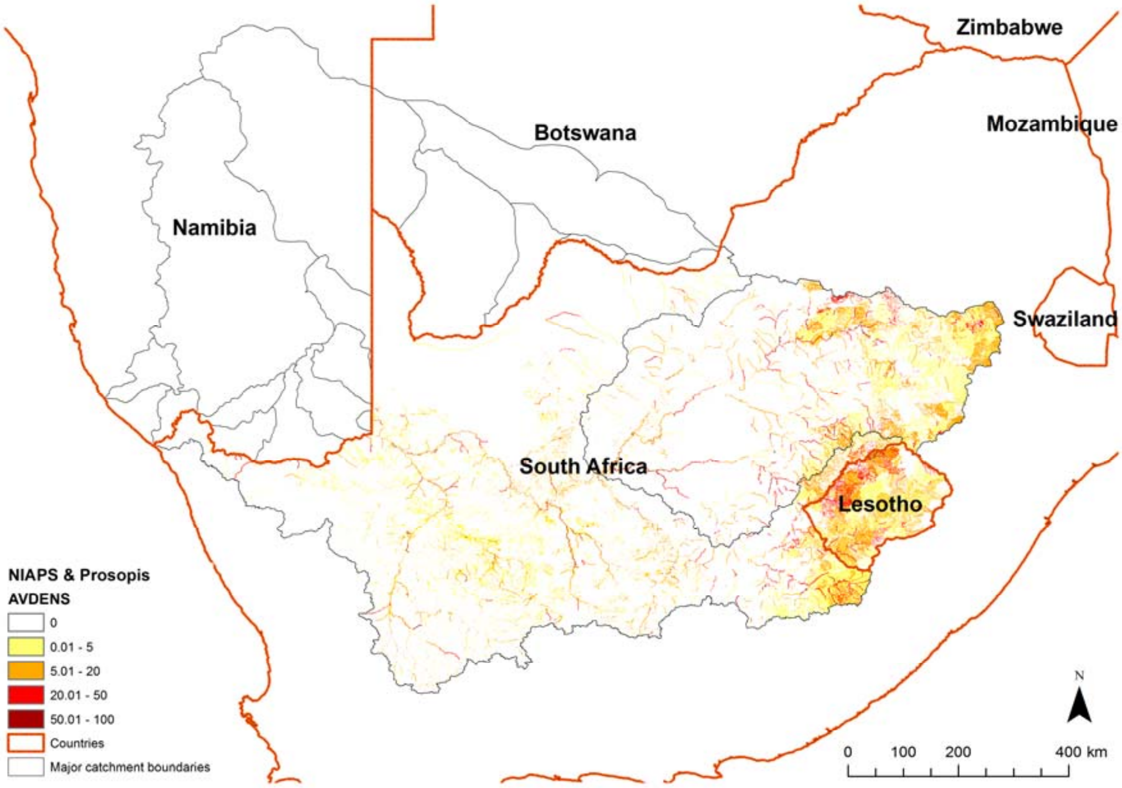

Figure 3.2. Distribution and density of invasions of alien plant species (AVDENS = mean percentage canopy cover) in South Africa and Lesotho extracted from the landscape and riparian invasions datasets of NIAPS (Kotzé et al., 2010) by Le Maitre et al. (2013). The landscape mapping only included the higher rainfall eastern parts of the Orange and Vaal River catchments in South Africa and Lesotho (on the eastern side of a north-south line through the western corner of Lesotho). Invasions of Prosopis species in the Northern Cape province of South Africa have also been included based on mapping by Van den Berg, 2010).

Prosopis invasions were separately mapped by van den Berg (2010) for the Northern Cape Province in South Africa. More than 1.32 million ha have been invaded by various *Prosopis* species and hybrids, with extensive areas of dense and closed invasions which tend to be concentrated in the bottomlands (floodplains and alluvial deposits) (Van den Berg, 2010). There are also *Prosopis* invasions in the North-West province (catchments C1, C2 and D4) and Free State which have not been mapped.

Namibia

A number of invasive alien species have been identified in Nambia including 57 terrestrial and 23 aquatic plant species (Brown and Gubb, 1986; Bethune et al., 2004). Most of the plant species are confined to the wetter central and northern parts of the country with only a few species occurring and becoming important problems in the arid southern part which includes the Fish, Auob and Nossob River systems. Although the invasions along the Orange River have only been mapped on the South African side, they are essentially the same whether on the South African or Namibian side of the floodplain. *Prosopis* species (*P. chilensis, P. glandulosa var. torreyana, P.velutina*) are considered the most important invading plants in this part of Namibia (Bethune et al., 2004). Judging by its prevalence and abundance in Namibia and South Africa (Figure 3.3), and the fact that is was introduced to both South Africa and Namibia in the late 1800s, its invasions are likely to be as extensive as they are in South Africa.

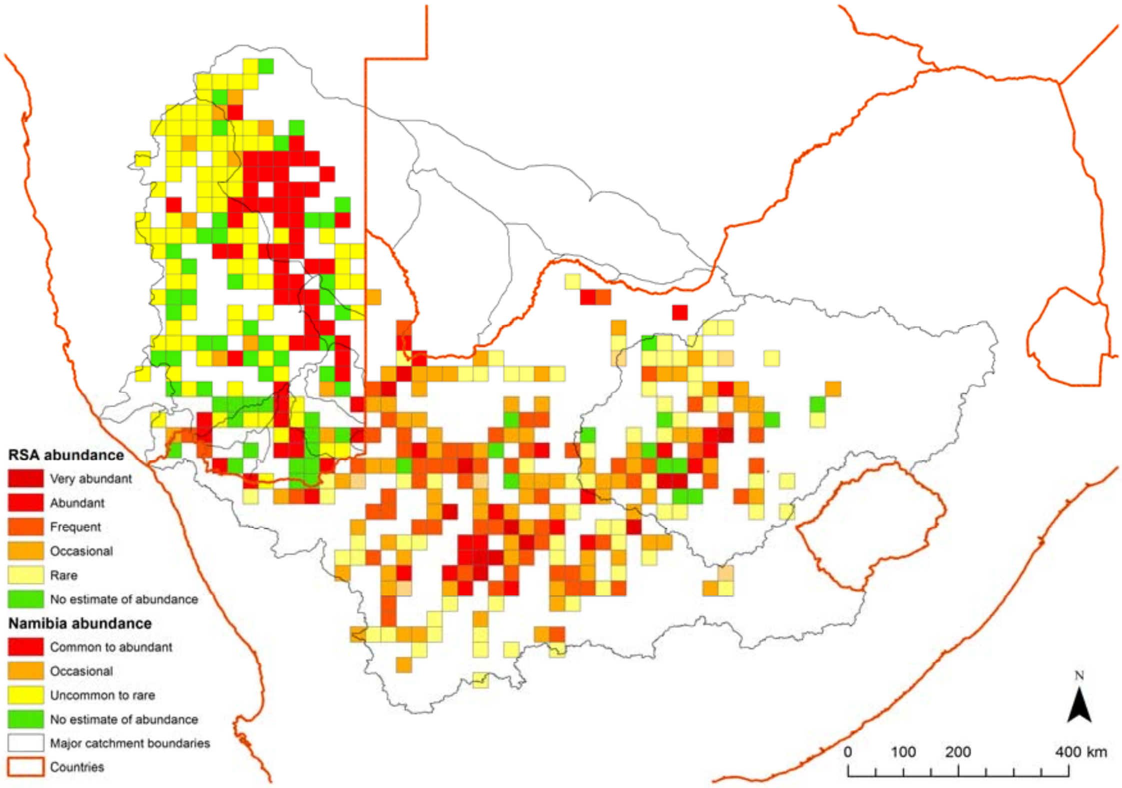

Figure 3.3. Prosopis species occurrence and abundance in 0.25 x 0.25° of arc grid-cells in South Africa and Namibia. Data taken from the SAPIA database (Henderson, 2007) and the Namibian Tree Atlas (Curtis and Mannheimer, 2005).

Other species of concern include *Argemone ochroleuca* (white-flowered Mexican poppy), *Datura stramonium* (common thorn apple) and *Nicotiana glauca*. None of the aquatic species were reported as occurring in arid southern Namibia except along the Orange River itself. Burke (2006) expressed concerns about the impacts of alien invasive species on the soon to be declared Sperrgebiet National Park. The Orange Valley shrubland and Orange woodland vegetation types were identified as being of very high conservation value, as a result of their unique biodiversity and species composition. *Prosopis* species, *Nicotiana glauca*, *Ricinus communis* and *Datura* sp. were found to be invading parts of these vegetation types, and are regarded as threats. In particular, *Prosopis* is seen as a major threat in the /Ai-/Ais-Richtersveld Transfrontier Park and the Ramsar site at the Orange mouth.

Botswana

This part of Botswana is very flat with typical Kalahari sand dune systems, very little surface water and generally deep groundwater tables, with the exception of a few pans. The only rivers are those that form the borders with South Africa and Namibia, except for the Moselebe River in the eastern part of the basin. All these rivers are ephemeral although the sources of some of them are perennial springs (e.g. Molopo and Kuruman Rivers). Some 29 alien plant species, including ten trees, have been recorded in the Kalahari savannah of southern Namibia, south-western Botswana and the adjacent areas of South Africa, most of them in association with the rivers (Brown and Gubb, 1986). *Prosopis* species (*P. glandulosa, P. pallida, P. velutina*) are a growing problem in this part of the basin (Botswana, 2009) and surveys in the Bokspits area show that it is able to form dense stands in this environment (Muzila et al., 2011). There do not seem to be records of any of the Cactaceae but *Nicotiana glauca* and *Datura* species occur on the South African and Namibian side of the rivers and would be found in Botswana as well.

3.3 Description of individual species – their problems and their uses

Wattles

A number of *Acacia* species were introduced to South Africa during the 1800s to provide timber, lathes for construction and also for their bark for tannin production (Richardson et al., 2003; Poynton, 2009). The main species found in the Orange-Senqu basin are *Acacia mearnsii* and *A. dealbata*, with the former being less frost tolerant than the latter. They were actively promoted and planted by the government forestry agencies as well as by the private sector (Poynton, 2009). They were planted throughout the highveld grasslands on farms and near rural settlements, primarily to provide firewood. They spread from there down watercourses and now are one of the main riparian invaders in the higher rainfall areas of the basin (Le Maitre et al., 2000). In Lesotho soil erosion was recognised as a major problem (which it still is) and the government Tree Planting Scheme funded the establishment of Grey poplar and Silver wattle to stabilize soil in erosion stabilization projects (FAO, 2004). From here, they invaded and spread into wetlands and along watercourses throughout the country and into South Africa. These trees also helped meet a critical need for fuelwood as Lesotho naturally had a very low tree cover with little natural forest or woodland. Although invasions have probably been limited by wood harvesting for fuel and construction, this has had little impact on their spread which is facilitated by the massive numbers of seeds this tree produces (Bromilow, 1995). The rainfall is too low for these species to grow in Namibia or Botswana. The introduction of biological control agents aimed at limiting seed production to South Africa is proving to be successful and could significantly reduce seed banks, spread rates and the aggressiveness of these species (Impson et al., 2011).

***Prosopis* species**

Prosopis species would seem to be the major invaders in the Orange-Senqu basin as a whole, given that there are extensive invasions in South Africa and similar invasions in Namibia and Botswana. Although the invasions are largely concentrated in the arid western part of the basin they are well established in the arid Kalahari savannas and their invasions extend well into the moister savannas and grasslands in South Africa (Figure 3.3). They were primarily introduced for their pods which are used for fodder but they do have several other uses including firewood and shelter for livestock (Le Maitre, 1999; Poynton, 2009; Wise et al., 2012). Despite several attempts in South Africa, and probably also in Namibia, their use for the production of barbeque wood or for charcoal for barbeques has not been successful (Wise et al., 2012). The trees rarely grow to the size where they have suitable diameter stems and branches and the cut wood is often attacked by borers. Pod yields also decline as stand density increases and in dense stands pod production can be limited to the trees on the fringe. There is potential for the generation of bioenergy but their tendency to occur in remote, generally non-electrified, areas and the concentration of dense stand in narrow strips along rivers severely limits their potential and the options for bioenergy production and commercialisation.

Their invasions appear to be somewhat limited by the arid climate in western South Africa, Namibia and Botswana and Rouget et al. (2004) concluded that they had already invaded much of their potential range in South Africa. However, what does seem to be happening (at least in South Africa) is a rapid increase in stand density and "infilling" of gaps in that range. Van den Berg (2010) reported an increase in density in the Northern Cape, South Africa, from 127,821 ha in 1974 to 1,473,953 ha in 2007, equivalent to 7.4% per annum (Wise et al., 2012). This rate will result in a doubling of the invaded area every 12 years. They are able to increase in density from open to dense stand in 10-24 years (Harding and Bate, 1981). A previous assessment (ORASECOM, 2008) argued that although *Prosopis* is a widespread problem, its invasions are facilitated by land degradation. While that may be true, one of the key reasons for its introduction, and particularly for its widespread promotion in the 1930s was that the farmers were already experiencing stresses due to land degradation (Hoffman et al., 1999; Beinart, 2003; Poynton, 2009). In fact it appears equally able to invade intact and near intact systems, particularly floodplain environments where floods naturally create disturbances and where it can have significant impacts on water resources and, thus, on human livelihoods (Wise et al., 2012). The current biological control agents are not very effective but the evidence of recent spread and the increasing problems caused by the these species are providing strong motivations for research into more effective agents (Wise et al., 2012; Zachariades et al., 2011).

***Eucalyptus* species**

Eucalyptus species are important invaders in the Orange-Senqu basin. Although they have invaded dryland environments in the higher rainfall areas of the basin, where they have spread mainly from woodlots, they are major invaders along the perennial to seasonal river systems where they often form almost continuous gallery forests. Their invasions extend right down to the lower reaches of the Orange River. More than 100 species have been introduced and around 20 have been planted commercially (Poynton, 1979). They have been widely planted in woodlots for fuelwood production and for their amenity values in areas where native trees species are rare. There are no measurements of water-use by eucalypts in these riparian situations but, based on work on their water-use in plantations, the water use of eucalypt species is mostly high (Albaugh et al., 2013).

Although the Kotzé et al. (2010) mapping did not distinguish between species the major invader is *Eucalyptus camaldulensis* (red river gum). No biological control agents are available for eucalypts.

Populus species

Populus (poplar) species, notably *P. x canescens* and *P. deltoides*, were introduced by the Dutch soon after the colonisation of South Africa in 1652 (Poynton, 2009). *Populus nigra* (Lombardy poplar) was probably introduced somewhat later. Their rapid growth, soft wood and straight trunks made them particularly suited for construction although their non-resistance to rot limited their use to dry locations (e.g. roof-beams). They were also planted for amenity value where sun was needed in winter and shade in summer. As they grew best in wet areas they were planted at springs and in stream source areas and on river banks in settlements and on most farms throughout the basin, particularly in the high-lying grassland areas of South Africa and Lesotho where their frost tolerance and fire resistance enabled them to survive. Poplars have separate male and female trees and only one sex was introduced so they only reproduce vegetatively. However, they can establish easily from truncheons (branches) so they have spread through having trees or parts of trees washed downstream in floods. They are major invaders in the colder parts of the basin (Henderson 2007) but have been less successful in warmer areas as they are subject to fungal diseases (Poynton 2009). There are no plans for biological control for these species at present.

Salix species

Salix (willow) species were introduced primarily for their amenity value in the early period of Dutch settlement and were widely planted in South Africa as well as in Lesotho (Poynton, 2009). The two major invaders are *S. babylonica* (weeping willow) and *S. mucronata* (crack willow) (Henderson, 2007). Like the poplars their invasions are largely confined to the colder, high rainfall areas in the eastern part of the basin where they have colonised rivers, occasionally forming almost continuous gallery forests. They also spread primarily vegetatively like the poplars. There are no plans for biological control for these species at present.

Other terrestrial species

As noted in the country specific descriptions (see also Appendix A), there are many alien plants that are considered major invaders in the basin including the *Cactaceae* (very important), *Arundo donax* (riparian, widespread), *Melia azedarach* (riparian), *Schinus molle* (widespread, dryland and riparian), *Nerium oleander* (widespread, riparian) and a range of grass and herbaceous species, including Datura species and *Nicotiana glauca*. *Pennisetum setaceum* is spreading rapidly, particularly in Karoo and arid savannah environments, and *Parkinsonia aculeata* (Jerusalem thorn) has the potential to invade all the areas where *Prosopis* invades.

Aquatic species

Eichhornia crassipes has been a major invader in the Vaal River system and had spread downstream beyond the Orange River confluence in recent years (Hughes pers. comm. in ORASECOM, 2008). It is known to have a high water-use (transpiration rate) and covers water bodies and slow flowing sections of rivers, becoming a physical impediment, blocking abstraction channels and irrigation equipment and altering water quality (Chamier et al., 2012; Coetzee et al., 2011a). Chemical and biological control measures have been able to reduce invasion rates but it is still a major problem and further spread is possible. *Azolla filiculoides* is very widespread in the basin in farm dams and in perennial tributaries has invaded sections of the upper and middle Orange River (Henderson, 2001; Coetzee et al., 2011a). Biological control will not eliminate this species but has significantly reduced reproduction so it rarely becomes abundant or dominant (Coetzee et al., 2011a). *Myriophyllum spicatum* (Spike water-milfoil) is known to occur in the upper Vaal River and near its confluence with the Orange River where it has become a problem in irrigation channels as well as occuring in places in the rivers themselves (Le Maitre et al., 2010; Coetzee et al., 2011b; Weyl and Coetzee, 2013). This species has the potential to become at least as big a problem as *Eichhornia* although there are prospects for effective biological control.

4. Description of the problem and justification of its transboundary importance

4.1 Impacts on ecosystem services

This section summarises information on the kinds of impacts invasive alien species have to make the case for taking action against them.

Although the impacts of these species on ecosystem services are greater, in terms of magnitude in the higher rainfall eastern parts of the basin, the relative impacts (degree of change) may be greater in the arid western parts where the yields of resources are very limited and the ecosystems are relatively fragile (Bohensky et al., 2004; Scholes and Biggs, 2004). Ecosystem services are the things that ecosystems generate which are essential for, and sustain, human livelihoods and well-being, and thus provide us with benefits (Daily, 1997; MA, 2005; Ten Brink et al., 2012). The benefits (out-comes) are derived from things that ecosystems generate (outputs) which, in turn, are the results of processes and interactions between the environment and organisms which maintain and sustain their ecosystems (Ojea et al., 2012). They can be divided into processes that sustain ecosystems and regulate fluxes (support and regulatory services), produce material goods (production services) and provide non-material but essential benefits (life-fulfilling services) (Daily, 1997; MA, 2005). Invasive alien species modify species interactions and composition and change ecosystem processes and fluxes, thus modifying ecosystem service flows (Figure 4.1) (Levine et al., 2003; Pechjar and Mooney, 2009; Ehrenfeld, 2010; Pyšek et al., 2012). These modifications generally involve decreases in some services and gains in others so the trade-offs need to be carefully and thoroughly assessed.

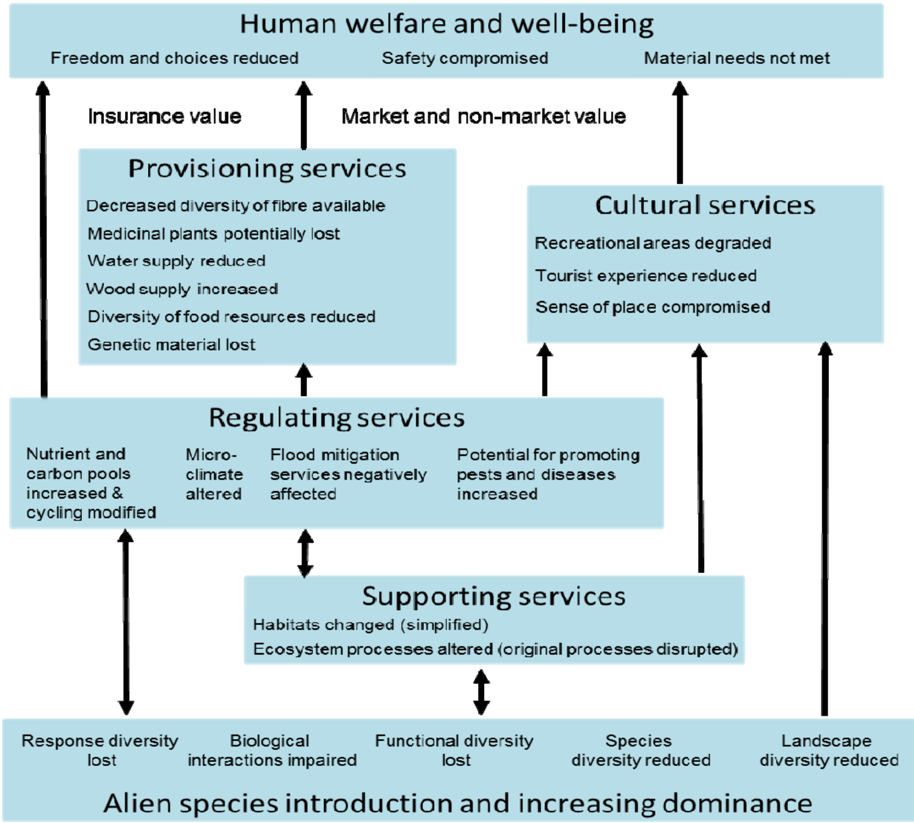

Figure 4.1. Illustration of how the impacts of invasive alien species affect biodiversity and how, in turn, those effects alter supporting, regulating, production and life fulfilling services, affecting human welfare and well-being. Adapted from Le Maitre et al. (2011).

As shown in the preceding sections, alien invasive species are widespread within the Orange-Senqu basin and the extent of the invasions and the range of species involved increases with increasing rainfall. The impacts of the species, in absolute terms, generally will also be greatest in the eastern parts of the basin where most runoff is generated, there is relatively high livestock carrying capacity and a wide variety of crops can be grown. This is also where the greatest concentration of the people are, especially in the upper and middle Vaal River system and these areas account for most of the ecosystem service demand. The relative (e.g. percentage) impacts are likely to be greatest in the arid regions in the western basin (O'Farrell et al., 2011). However, because of the intensive development of irrigation schemes in the western parts of the basin, there is a high demand for good quality water so the relative demand is very high and can only be met with water from the upper parts of the system. The major ecological impacts of the increase in alien invasive species are:

- Changes in and loss of native species biodiversity as result of interspecific competition.
- Changes in habitat structure and in ecosystem processes and functions, particularly in aquatic, wetland and riparian ecosystems where the invading species that alter sediment dynamics and sediment transport, and reduce the river and/or wetland's water quality

regulation capacity; these changes can also reduce the ability of the riparian and/or wetland vegetation to absorb and mitigate the impacts of flood events.

- Changes in vegetation water-use, generally through increased transpiration resulting in less changes in soil moisture regimes and reduced groundwater recharge and runoff and alterations in environmental flows.
- Loss of resilience in the invaded communities and their ability to recover from natural disturbances or to recover from stresses such as drought.
- In areas where alien grass species invade they can introduce fire or change its frequency and invasions by woody species can increase fuel loads increasing fire intensity and severity. Both changes can have adverse impacts on native species diversity and ecosystem functioning.

These impacts all have effects on the ecosystem services conferred on society and thus on the socio-economic benefits, particularly:

- Decreases in the amount of water that is available for human use due to reduced water flows and of the revenue and other benefits that could have been derived from that water (opportunity costs).
- The reduction in the water available to dilute pollutants, changes in water quality regulation processes, and nitrification by some species (e.g. wattles) add to the water quality problems being experienced in the system and to the costs of treating the water.
- Loss of land productivity due to suppression or replacement of natural grazing and browse and the revenue and other benefits derived from livestock and other products and benefits derived from the natural vegetation.
- In conjunction with other drivers of land degradation (e.g. over-grazing), increased loss of soils, loss of soil and catchment storage capacity and increasing the likelihood of damaging floods, sedimentation of rivers and of dams.
- Changes in the characteristics of the vegetation and landscapes which change its unique the "sense of place", which can result in the loss of unique draw cards for tourism.
- The opportunity costs incurred because of the need to invest (considerable) resources into controlling alien invasive species; the costs increase over time because invasion continue to become more extensive and more dense and have greater impacts.

The data on the composition, extent and density of the invasions summarised in the preceding section make it clear that invasive alien species are pervasive. There is much less information on their impacts as there have been few studies of the impacts in the Orange-Senqu basin. The most detailed information is on the impacts on water resources. Versfeld et al. (1998; see also Le Maitre et al., 2000) gave provisional estimates of the impacts of invasions on water resources in Lesotho in South Africa based on a reconnaissance-level survey. The overall reduction was estimated at 3,300 million m3/yr or 6.7% of the pre-development mean annual runoff. Reductions in the Vaal

River system were estimated to be 191 million m3/yr (2.0%) and 141 million m3/yr (3.5%) in the Orange River system, including two million m3/yr for Lesotho. Using more detailed modelling, Le Maitre et al. (2002) estimated that reductions in the upper Wilge River in South Africa could increase from 27 million m3/yr to 1,127 million m3/yr (25%) over the next 50 to 70 years if there was no control of invasive aliens plants, with more rapid invasion of the riparian areas. The costs of clearing would increase from 4.1 million USD to 278 million USD. A study by Cullis et al. (2007) found that there are substantial impacts on yields from dams in the Vaal and Orange system – currently 69 and 16 million m3/yr respectively. Given reasonable rates of spread they could increase to 211 and 278 million m3/yr respectively. There would be even greater reductions for run-of-river water users because their water storage systems are small (or non-existent) so they cannot offset the effects of droughts or capture high flows during floods. The most recent estimate is by Le Maitre et al. (2013) who estimated a water flow reductions of about 1,444 million m3/yr with about 64 and 193 million m3/yr in the Vaal and Orange River catchments included in the landscape mapping (see Figure 3.2). Invasions in Lesotho are estimated to account for 161 million m3/yr and thus for a disproportionate reduction in runoff.

Van Wilgen et al. (2008) assessed impacts of terrestrial invaders on three ecosystem services, water resources, grazing and biodiversity and predicted significant increases in socio-economic impacts if invasive alien plants were not successful controlled. They estimated that the reductions in the sustainable livestock carrying capacity of natural grazing in South Africa due to the current level of invasions (based on data from Versfeld et al., 1998) in the Nama Karoo and Savannah biomes was about 1% but could increase significantly to about 70% in future. *Acacia mearnsii* and *A. dealbata* were considered to have very high impacts on grazing capacity as they displace or suppress grasses and do not produce fodder; *Prosopis* impacts were not considered very high because they are offset to an extent by pod production although this declines in dense stands (Wise et al., 2012). On the other hand, *Prosopis* competes directly with *Acacia erioloba* for groundwater and suppresses, and can displace, this keystone species which provides many benefits including fodder and shelter (Robertson and Woodborne, 2002; Schachtschneider and February, 2013). It may well do the same with many other important tree species such as *Acacia karoo* and *Boschia albitrunca*. *Opuntia* species were not considered by Van Wilgen et al. (2008) but they can have significant impacts on grazing capacity as well as the effects of their thorns on livestock. *Arundo donax*, *Eucalyptus*, *Populus* and *Salix* species impacts on the riparian environments was considered very high for water resources and riparian ecosystem biodiversity and functioning. Fires in dense stand of invasive pine and eucalypt species have been found to increase sediment loss in grassland environments (Scott and van Wyk, 1990; Scott and Schulze, 1992) and *Acacia* species may have similar effects in these environments, aggravating the existing problem of soil erosion and dam sedimentation due to land degradation. In the western part of the basin in South Africa and in Namibia and Botswana it is likely that *Prosopis* species are having the greatest impacts with more than 140,000 ha already occupied by dense or closed stands and a further 260 ha of moderately dense stands in the portion of the Northern Cape in the basin alone (Table 3.4). Although Le Maitre et al. (2013) estimated that *Prosopis* species invasions reduce surface runoff by about nine million m3/yr in the Northern Cape, far less than the 150 million m3/yr estimated by Le Maitre et al. (2000), this is a semi-arid to arid region where every cubicmeter of water is valuable. It is important to realise that although arid ecosystems produce limited quantities of services so that the values appear low compared with humid systems, their scarcity makes every unit of a service far more valuable to those who depend on them (O'Farrell et al., 2011), i.e. the marginal value of units of ecosystem services is high.

Dense invasions of floating aquatic plants can alter the flow tempo in streams and rivers, disrupting the aquatic ecosystem and providing conditions for disease vectors to breed as well as blocking irrigation channels (review by Chamier et al., 2012). Dense mats can also form obstructions during floods, damaging infrastructure. Invasions by submerged aquatics, like *Myriophyllum*, block pumps and interfere with recreational activities by obstructing boats and generating bad odours. They can also provide environments which promote the development of cyanobacterial blooms which can have severe impacts on human and animal health. Reduction of light penetration alters the aquatic environment, preventing sunlight from reaching benthic areas and disrupting ecosystem processes. Some of these species, for example Water Hyacinth are very effective at taking up nutrients and heavy metals but if they are not removed then these pollutants are released when the plants die.

A number of species such as *Acacia*, *Eucalyptus*, *Prosopis* and *Populus* do provide important benefits such as firewood, shade and shelter particularly for rural communities. Blue gum trees (Eucalyptus spp.) are found along many sections of the Basin, and although invasive, are the preferred nesting tree for African Fisheagle (Anderson, 2007), thus impacting positively on this threatened raptor species. The invading trees also provide perches and nest sites for many other bird species although in many cases the effects are negative as the birds prefer the native species (Dean et al., 2002)..

4.2 Linkages with other transboundary problems

There is no doubt that invasions of natural systems (aquatic and terrestrial) are promoted by disturbances, especially those that reduce vegetation vigour and change its structure and dynamics. Land degradation through overgrazing is pervasive and facilitates alien species invasions, not least because invasive species were, and still are, introduced in an attempt to restore land productivity. Impacts on water quantity – particularly flooding, reduced flows during droughts, and lowered water tables – and on water quality through nutrient enrichment facilitate invasions by alien aquatic weeds as well as by indigenous species (such as *Phragmites*). However, there are also many examples of alien species invading near-pristine systems, with riparian systems seemingly particularly prone to invasions especially after large floods which change or cut new river channels and provide unvegetated sediment deposits for species to colonise.

Historically, the agricultural and forestry sectors played major roles by introducing species and promoting their use, usually for good reasons (Richardson et al., 2003). For example, the forestry agencies in South Africa introduced a range of tree species because South Africa was short of timber tree species particularly from the late 1800s to the 1960s. They, together with agriculture introduced and actively promoted the introduction of many tree species for fodder, fuel, tanbark, shelter and other purposes and some invasive species are still being promoted. Species were also inadvertently introduced as contaminants in seed lots and sometimes because they were mistaken for the species of interest. Beginning in the early 1900s the public demand for ornamental plants increased and led to the development of the nursery industry which, in turn, sought, and still seeks, to introduce novel species to attract buyers. The result has been an ever-growing suite of invading ornamental species with many species still at the early stages of their invasions.

Unfortunately, many of these species began, usually initially unnoticed, to invade wherever they could disperse and establish themselves. In some cases they were noticed but their spread was initially welcomed and it was not until they began to dominate habitats and landscapes that concern was raised. The story of the *Opuntia* species provides a classic example of this shift from welcoming to rejection with all shades of opinion in between (Beinart and Wotshela, 2011) and *Prosopis* species are following the same pattern (Wise et al., 2012). Although concerns were raised it often took many decades before effective action, if any was taken. Often those wishing to do something were not sure how to go about controlling invading species and what techniques to use. Often when action was taken, people failed to recognise the need for systematic planning and budgeting, particularly for follow-up, and their efforts ended in failure because their resources were inadequate. Although there are laws and regulations governing invasive species, particularly those considered weeds, the land management authorities have failed to enforce them.

The advent of a democratic South Africa in 1994, and the drive to create employment for the previously unemployed led to the establishment, among others, of the Working for Water Programme (WfW) in 1995 (Van Wilgen et al., 1998). This has improved the situation somewhat through its operations and through its funding and support of research into invasive species control, particularly biological control for plant invaders. However, a recent assessment indicates that even if it was fully effective, WfW is able to tackle too small a portion of the invaded area to do more than reduce invasion rates (Van Wilgen et al., 2012), and a new approach that is more effective in mobilising more resources and private land owners is needed (Urgenson et al., 2013), perhaps involving payments for ecosystem services (Turpie et al., 2008; Crookes et al., 2013). Although concerns have been raised about invading species in Lesotho (Lesotho, 2009), Namibia (e.g. Bethune et al., 2004) and Botswana (e.g. Botswana, 2009) it seems that none of these countries have developed strategies for IAPs or initiated any interventions at the national scale.

5. Addressing IAPs at a transboundary level

At this point in time South Africa is the most active basin member in terms of IAP control, through the Working for Water Programme (WfW). However, this national programme is spread across several sections of the South African side of the basin, and prioritisation initiatives have only recently been completed for the Free State and the Northern Cape, focussing the clearing efforts to areas where clearing has the highest impact and benefit (Le Maitre and Forsyth, 2010). Any clearing efforts in the other basin states are ad hoc and donor driven. An integrated approach to the eradication of common alien species has been recommended previously (ORASECOM, 2008) and is further explored here.

Practical experience worldwide has shown that eradication is only possible when invasions cover small, well defined areas (<1,000 ha) (Pluess et al., 2012). The IAP maps in previous sections of this paper show the vast geographic extent of plant invasions throughout the basin. The full 'eradication' of IAPs is therefore unrealistic for any of the documented species, and once off efforts are not an option. Rather, it is prudent to look at transboundary control efforts in terms of prevention, monitoring and rapid response, and long-term containment and control rather than eradication. From a geographical perspective, it is furthermore important to assume that any basin-wide control efforts need to be multi-pronged, ensuring that clearing efforts are appropriately tailored to the region and species under consideration.

Beyond the geographical extent and complexity of IAPs in the Orange-Senqu River basin, any control efforts also face a multitude of political and human capital challenges, as pointed out in previous ORASECOM reports (ORASECOM, 2008). One issue, also apparent from the content of this paper, is that the four countries differ in terms of available information on the species, their extent, density and rate of spread. Any basin-wide decision-making would require more extensive information gathering and planning in those basin states where information is currently sparse. The next issue is that the basin States may not have the same level of political commitment to dealing with IAPs. Reports in all countries express concern about IAPs to some degree, but South Africa is the only country in which the clearing of IAPs is addressed as an issue of national importance, as evidenced by the existence and continued financing of an on-going national clearing programme. It is essential that all the basin States are equally committed, so that IAP control is a matter of basin-wide cooperation. A key point here is that most of the major invasive species in the basin are species where there is a conflict of interest with one or more national departments promoting introduced species, while others are concerned about their environmental and socio-economic impacts. This is not an easy situation to resolve but the approach proposed for Acacia species in South Africa (van Wilgen et al., 2011) could provide a model to use in developing a joint strategy for invasive alien species in the basin. In arid environments invasions often have disproportionate impacts because they target specific habitats (Milton and Dean, 2010), and this needs to be taken into account as well.

Given the multiple challenges for basin-wide IAP control, a two-pronged approach could be of value. The first prong could be a communication effort, whereby focus is placed on national-level communication initiatives with the aim of convincing decision makers that an IAP control programme for the basin is essential in all four basin States. The Southern African Development Community (SADC) have recognised the need to deal more effectively with invasive alien species (SADC, 2008) and this, together with the Regional Biodiversity Action Plan, could be used as the initial starting point in this process. The four basin States also have sufficient legislation regarding the management of alien species, providing a good platform for initial discussions. It is likely that national imperatives in the various countries will complicate this process, and it needs to be anticipated that such cooperation will require the development of multi-national strategies and negotiations at the high-end political spectrum. At the same time the second prong should be more practically-driven, addressing identified gaps, quantifying the extent and impacts for IAPs at a basin scale, and collaborating more actively on biological control. This could commence with an initial basin-wide mapping exercise, covering the existing data gaps for Botswana and Namibia. The mapping could be extended to a basin-wide cost-benefit analysis, which would also include estimates of current water losses through IAP invasions, as well as future predictions for invasion scenarios, with and without clearing efforts. The results of the mapping and the assessment of the costs and benefits would provide the basis for prioritising interventions aimed at dealing with invasive alien species in the basin.

The culmination of the initiative would be a merging of the two prongs in the form of a basin IAP strategy, with spatial priority setting and targeted clearing and monitoring efforts.

A basin IAP clearing strategy should consider the following:

- Prevention – agreements on a joint policy on any new introductions of potential invasive species, with border controls in place, formalised information sharing channels and other measures.
- Early detection and rapid response to identify and deal with new invasive species in the early stages.
- Containment – limiting species spread by working inwards from the edges of their distributions.
- Control operations – mechanical/chemical and biological. Agreement is needed around a protocol for collaboration on biological control, a key component of the intervention. Any necessary agents need to be researched and introduced.

The spatial priority setting process could be based on the approach used by WfW. This programme has recognised that there are insufficient resources to deal with the entire problem – and hence their clearing operations are based on a prioritisation model which takes impacts on biodiversity and ecosystem services, species control requirements and human resources into account (Forsyth et al., 2012).

Targeted monitoring and clearing efforts require the cooperation of stakeholders, including government, land owners and the agricultural sector. To date, clearing efforts are fragmented and co-operation will become a key component to success for the control of IAPs in the basin. A potential model for effective collaboration could be based on the one that the Directorate of Natural Resource Management in the South African Department of Environment Affairs is developing. This began as a multi-departmental collaboration between national departments but now involves a much wider range of organisations.

As implementation would be operating in an environment with many uncertainties the approach should be based on adaptive management with strong monitoring and evaluation. Initially, pilot projects could be considered, focusing on areas where no current clearing efforts exist. For example, the Namibian Orange-Fish Basin Management Committee has expressed the urgency of *Prosopis* control and they have formulated a project concept, whereby they propose to explore options of clearing *Prosopis* and marketing the wood as a fuel source in towns such as Rosh Pinah and Aussenkehr, where there is a definite shortage of fuel sources. If successful, the project could become self-sufficient in the long term. So far the proposal has not been funded. Local funding is currently hampered by a lack of 'buy in' from high level staff in relevant ministries, such as the Ministry of Environment and Tourism. Obtaining outside funding currently remains the only short-term option.

Other recommendations from previous reports (ORASECOM 2008) that should be considered in any joint transboundary IAP control effort is the importance of on-going monitoring and the raising of public awareness about IAPs and their negative impacts.

In conclusion, the primary issue is not in the technical aspects of 'what to do'. That can be built on the examples of many national level strategies for invasive alien species. They all provide the type of information that we have summarised as key points above. The real crux lies in the complexities of developing a joint strategy, of getting it implemented, of sourcing the necessary resources in the face of other pressing needs, and finally - in deciding how, where and when to invest any available resources by taking action and dealing with IAPs, to get the greatest return on those investments.

References

Albaugh, J, Dye, P and King, J, 2013. Eucalyptus and water use in South Africa. *International Journal of Forestry Research* Article ID 852540, pp. 11. doi:10.1155/2013/852540.

Anderson, M.A. 2007. Personal Communication. Ornithologist for the Department of Agriculture, Land, Environment and Tourism, Northern Cape Province, South Africa. In: ORASECOM (Orange–Senqu River Commission), 2008. *Orange-Senqu Basin – Preliminary Transboundary Diagnostic Analysis*, Main Report, ORASECOM.

Ashton, PJ and Mitchell, DS, 1989. Aquatic plants: patterns and modes of invasion, attributes of invading species and assessment of control programmes. In: Drake, JA, Mooney, HA, Di Castri, F, Groves, RH, Kruger, FJ, Rejmánek, M and Williamson, M (Eds.) *Biological Invasions: A Global Perspective*, pp. 111-154, SCOPE Volume 37, John Wiley & Sons, New York.

Beinart, W, 2003. *The rise of conservation in South Africa: settlers, livestock and the environment 1770-1950.* Oxford University Press, New York.

Beinart, W and Wotshela, L, 2011. *Prickly pear: The social history of a plant in the Eastern Cape.* Wits University Press, University of the Witwatersrand, Johannesburg.

Bethune, S, Griffin, M and Joubert, D, 2004. *National Review of Invasive Alien Species – Namibia*, September 2004. Discussion Document. Final Report to SABSP. Directorate of Environmental Affairs, Windhoek.

Bohensky, E, Reyers, B, van Jaarsveld, AS and Fabricius, C, (Eds.) 2004. *Ecosystem services in the Gariep Basin: a component of the Southern African Millennium Ecosystem Assessment.* African Sun Media, Stellenbosch, South Africa.

Botswana, 2009. *Botswana Fourth National Report to the Convention of Biological Diversity*, Government of Botswana, Gaborone.

Brown, CJ and Gubb, AA, 1986. Invasive alien organisms in the Namib desert, upper Karoo and the arid and semi-arid savannas of western southern Africa. In: Macdonald, IAW, Kruger, FJ and Ferrar, AA (Eds). *The ecology and management of biological invasions in southern Africa*, Oxford University Press, Cape Town, pp. 93-103.

Burke, A, 2006. *The Sperrgebiet. Managing its biodiversity.* Enviroscience, Oranjemund and Namibia Nature Foundation, Windhoek.

Chamier, J, Schachtschneider, K, Le Maitre, DC, Ashton, PJ and Van Wilgen, BW, 2012. Impacts of invasive alien plants on water quality, with particular emphasis on South Africa. *Water SA* 38: 345-356.

Coetzee, JA, Hill, MP, Byrne, MJ and Bownes, A, 2011a. A review of the biological control programmes on *Eichhornia crassipes* (C.Mart.) Solms (Pontederiaceae), *Salvinia molesta* D.S. Mitch. (Salviniaceae), *Pistia stratiotes* L. (Araceae), *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae) and *Azolla filiculoides* Lam. (Azollaceae) in South Africa. *African Entomology* 19: 451-468.

Coetzee, JA, Bownes, A and Martin, GP, 2011b. Prospects for the biological control of submerged macrophytes in South Africa. *African Entomology* 19: 469-487.

Crookes, DJ, Blignaut, J, De Wit, MP, Esler, KJ, Le Maitre, DC, Milton, SJ, Mitchell, SA, Cloete, J, De Abreu, P, Fourie, H, Gull, K, Marx, D, Mugido, W, Ndhlovu, T, Nowell, M, Pauw, M and Rebelo, A, 2013. System dynamic modelling to assess economic viability and risk trade-offs for ecological restoration in South Africa. *Journal of Environmental Management* 120: 138-147.

Cullis, JDS, Görgens, AHM and Marais, C, 2007. A strategic study of the impact of invasive alien plants in the high rainfall catchments and riparian zones of South Africa on total surface water yield. *Water SA* 33: 35-42.

Curtis, B and Mannheimer, C, 2005. *Tree Atlas of Namibia*. National Botanical Research Institute, Windhoek.

Daily, GC (Ed.) 1997. *Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

Dean, WRJ, Anderson, MD, Milton, SJ and Anderson, TA, 2002. Avian assemblages in native *Acacia* and alien *Prosopis* drainage line woodland in the Kalahari, South Africa. *Journal of Arid Environments* 51: 1-19.

Driver A, Sink, KJ, Nel, JN, Holness, S, Van Niekerk, L, Daniels, F, Jonas, Z, Majiedt, PA, Harris, L and Maze, K, 2011. *National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems*. Synthesis Report. South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Earle, A, Malzbender, D, Turton, A, Manzungu, E, 2005. A preliminary basin profile of the Orange/Senqu River. AWIRU, University of Pretoria, South Africa.

Ehrenfeld, JG, 2010. Ecosystem consequences of biological invasions. *Annual Review of Ecology and Systematics* 41: 59–80.

FAO, 2004. *State of forests and plantations, Country Report – Lesotho*. FAO Corporate Document Repository.

Forrester, DI, Schortemeyer, M, Stock, WD, Bauhus, J, Khanna, PK, Cowie, AL, 2007. Assessing nitrogen fixation in mixed- and single-species plantations of *Eucalyptus globulus* and *Acacia mearnsii*. *Tree Physiology* 27: 1319-28.

Forsyth, GG, Le Maitre, DC, O' Farrell, P and van Wilgen, BW, 2012. The prioritisation of invasive alien plant projects using a multi-criteria decision model informed by stakeholder input and spatial data. *Journal of Environmental Management* 103: 51-57.

Harding, GB, 1987. Review – The status of *Prosopis* as a weed. *Applied Plant Science* 1(1): 43-48.

Harding, GB and Bate, GC, 1991. The occurrence of invasive *Prosopis* species in the north-western Cape, South Africa. *South African Journal of Science* 87: 188-192.

Heath, R and Brown, C, 2007. Environmental Considerations Pertaining to the Orange River. *Orange River Integrated Water Resources Management Plan*, WRP Consulting Engineers, Jeffares and Green, Sechaba Consulting, WCE Pty Ltd, Water Surveys Botswana (Pty) Ltd.

Henderson, L, 1991. Invasive alien woody plants of the northern Cape. *Bothalia* 21: 177–189.

Henderson, L, 2001. Alien weeds and invasive plants. *Plant Protection Research Institute Handbook No. 12*. Agricultural Research Council, Pretoria.

Henderson, L, 2007. Invasive, naturalised and casual alien plants in southern Africa: a summary based on the southern African Plant Invaders Atlas (SAPIA). *Bothalia* 37: 215 – 248.

Hijmans, RJ, Cameron, SE, Parra, JL, Jones, PG and Jarvis, A, 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965-1978.

Hoffman, MT, Cousins, B, Meyer, T, Petersen, A and Hendricks, H, 1999. Historical and contemporary land use and the desertification of the Karoo. In: Dean, WRJ and Milton, SJ (Eds), *The Karoo: Ecological patterns and processes*, pp. 257-273. Cambridge University Press, Cambridge UK.

Impson, FAC, Kleinjan, CA, Hoffmann, JH, Post, JA and Wood, AR, 2011. Biological control of Australian Acacia species and Paraserianthes (Willd.) Nielsen in South Africa. *African Entomology* 19: 186-207.

Jovanovic, NZ, Israel, S, Tredoux, G, Soltau, L, Le Maitre, D, Rusinga, F, Rozanov, A and Van der Merwe, N, 2009. Nitrogen dynamics in land cleared of alien vegetation (*Acacia saligna*) and impacts on groundwater at Riverlands Nature Reserve (Western Cape, South Africa). *Water SA* 35(1): 37-44.

Kotzé, I, Beukes, H, van den Berg, E and Newby, T, 2010. *National Invasive Alien Plant Survey.* Report No. GW/A/2010/21, Agricultural Research Council – Institute for Soil, Climate and Water, Pretoria.

Le Maitre, DC, 1999. *Prosopis and groundwater: a literature review and bibliography*. Report Number ENV-S-C 99077, Natural resources and the Environment, CSIR. Unpublished Report, Working for Water Programme, Department of Water Affairs and Forestry.

Le Maitre, DC, Versfeld, DB, Chapman, RA, 2000. The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. *Water SA* 26: 397-408.

Le Maitre, DC, van Wilgen, BW, Gelderblom, CM, Bailey, C, Chapman, RA and Nel, JA, 2002. Invasive alien trees and water resources in South Africa: Case studies of the costs and benefits of management. *Forest Ecology and Management* 160: 143-159.

Le Maitre, DC and Forsyth, GG, 2010. *Prioritising quaternary catchments for invasive alien plant control within the Savanna, Nama and Succulent Karoo Biomes of the Northern Cape Province.* CSIR Report No.: CSIR/NRE/ECO/ER/2010/0015/B, Natural Resources and the Environment, CSIR, Stellenbosch.

Le Maitre, DC, Gaertner, M, Marchante, E, Ens, E-J, Holmes, PM, Pauchard, AM, O'Farrell, PJ, Rogers, AM, Blanchard, R, Blignaut, J and Richardson, DM, 2011. Impacts of invasive Australian acacias: implications for management and restoration. *Diversity and Distributions* 17: 1015-1029.

Le Maitre, DC, Forsyth, GG, Dzikiti, S, Gush, MB, 2013. Estimates of the impacts of invasive alien plants on water flows in South Africa. Report No. CSIR/NRE/ECO/ER/2013/0067/B, Natural Resources and the Environment, CSIR, Stellenbosch.

Lesotho, 2009. *Lesotho Fourth National Report on Implementation of Convention on Biological Diversity.* Department of Environment, Maseru.

Levine, JM, Vilà, M, D'Antonio, CM, Dukes, JS, Grigulis, K, Lavorel, S, 2003. Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society London* 270: 775–781.

MA, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC.

Macdonald, IAW, Kruger, FJ and Ferrar, AA (Eds) 1986. *The ecology and management of biological invasions in southern Africa.* Oxford University Press, Cape Town.

Macdonald, IAW, Reaser, JK, Bright, C, Neville, LE, Howard, GW, Murphy, SJ and Preston, G (Eds.) 2003. *Invasive alien species in southern Africa: national reports & directory of resources.* Global Invasive Species Programme, Cape Town, South Africa.

MacDougall, A.S. and Turkington, R, 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* 86(1): 42-55.

Mare, H. 2007. *Review of surface hydrology in the Orange River Catchment*, ORASEKOM (Orange–Senqu River Commission) Report 002/2007.

Milton, SJ and Dean, WRJ, 2010. Plant invasions in arid areas: special problems and solutions: a South Africa perspective. *Biological Invasions* 12: 3935-3948.

Mucina, L and Rutherford, MC, 2006. *The vegetation of South Africa, Lesotho and Swaziland.* Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Muzila, M, Setshogo, MP, Moseki, B and Morapedi, R, 2011. *The African Journal of Plant Science and Biotechnology* 5(1): 75-80.

Naiman, RJ, Décamps, H and Pollock, M, 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3(2): 209-212.

Nel, JL, Driver, A, Strydom, WF, Maherry, A, Petersen, C, Hill, L, Roux, DJ, Nienaber, S, Van Deventer, H, Swartz, S and Smith-Adao, LB, 2011. *Atlas of Freshwater Ecosystem Priority Areas in South Africa.* WRC Report No. TT 500/11. Water Research Commission, Pretoria

Ojea, E, Martin-Ortega, J and Chiabini, A, 2012. Defining and classifying ecosystem services for economic valuation: the case of forest water services. *Environmental Science & Policy* 19-20: 1-15.

O'Farrell, PJ, De Lange, WJ, Le Maitre, DC, Reyers, B, Blignaut, JN, Milton, SJ, Atkinson, D, Egoh, B, Maherry, A, Colvin, C and Cowling, RM, 2011. The possibilities and pitfalls presented by a pragmatic approach to ecosystem service valuation in an arid biodiversity hotspot. *Journal of Arid Environments* 75: 612-623.

ORASECOM (Orange–Senqu River Commission), 2008. Orange-Senqu Basin – Preliminary Transboundary Diagnostic Analysis, Main Report, ORASECOM.

ORASECOM (Orange–Senqu River Commission), 2010. The state of the Orange-Senqu System. Setting the baseline water resources quality in 2010. A report on the First Joint Basin Survey (JBS-1) October and November 2010. ORASECOM.

Paterson, ID, Hoffmann, JH, Klein, H, Mathenge, CW, Neser, S and Zimmermann, HJ, 2011. Biological control of Cactaceae in South Africa. *African Entomology* 19: 230-246.

Pechjar, L and Mooney, HA, 2009. Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution* 24: 497–504.

Pluess, T, Cannon, R, Jarošík, V, Pergl, J, Pyšek and Bacher, S, 2012. When are eradication campaigns successful? A test of common assumptions. *Biological Invasions* 14: 1365-1378.

Poynton, RJ, 1979. *Tree Planting in South Africa. Vol. 2. The Eucalypts*. Department of Forestry, Pretoria.

Poynton, RJ, 2009. *Tree Planting in South Africa. Vol. 3. Other genera*. Department of Forestry, Pretoria.

Pyšek, P, Jarošík, V, Hulme, P, Pergl, J, Hejda, M, Schaffner, U and Vilà, M, 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. *Global Change Biology* 18: 1725–1737.

Richardson, DM, Cambray, JA, Chapman, RA, Dean, WRJ, Griffiths, CL, Le Maitre, DC, Newton, DJ and Winstanley, T, 2003. Vectors and Pathways of Biological Invasions in South Africa - Past, Present, and Future. In: Ruiz, GM and Carlton, JT (Eds.) *Invasive Species: Vectors and Management Strategies*, pp. 292-349, Island Press, Covelo, USA.

Robertson, I and Woodborne, S, 2002. Carbon isotopes confirm the competitive advantages of *Prosopis over Acacia erioloba. Study of environmental change using isotope techniques*. IAEA-CSP-13/P, International Atomic Energy Agency, Vienna.

Rouget, M, Richardson, DM, Nel, J, Le Maitre, DC, Egoh, B and Mgidi, T, 2004. Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climatic suitability. *Diversity and Distributions* 10: 475–484.

Schachtschneider, K and February, E, 2013. Impact of Prosopis invasion on a keystone species in the Kalahari Desert. *Plant Ecology* 214: 597-605.

SADC, 2008. *Regional Biodiversity Strategy*. Southern African Development Community, Gaborone.

Scholes, RJ, Biggs, R (Eds.) 2004. *Ecosystem services in southern Africa: a regional assessment.* Council for Scientific and Industrial Research; Pretoria, South Africa.

Scott, DF and van Wyk, DB, 1990. The effects of wildfire on soil wettability and hydrological behaviour of an afforested catchment. *Journal of Hydrology* 121: 239-256.

Scott, DF and Schulze, RE, 1992. The hydrological effects of a wildfire in a eucalypt afforested catchment. *South African Forestry Journal* 160: 67-74.

Silberbauer, MJ, 2006. *The construction of a hydrologically-correct, annotated 1:500 000 spatial dataset of the rivers of South Africa and contiguous basins.* Report No. N/000/00/REH/0701, Resource Quality Services, Department of Water Affairs, Pretoria.

Spear, D, McGeoch, MA, Foxcroft, LC and Bezuidenhout, H, 2011. Alien species in South Africa's national parks. *Koedoe* 53(1), Art. #1032, 4 pages. doi:10.4102/koedoe.v53i1.1032

Ten Brink, P, Mazza, L, Badura, T, Kettunen, M, and Withana, S, 2012. *Nature and its role in the transition to a green Economy.* Executive Summary. United Nations Environment Programme.

Turpie, JK, Marais, C and Blignaut, JN, 2008. The Working for Water Programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. *Ecological Economics* 65: 788-798.

Urgenson, LS, Prozesky, HE and Esler, KJ, 2013. Stakeholder perceptions of an ecosystem services approach to clearing invasive alien plants on private land. *Ecology and Society* 18(1): 26.

Van den Berg, EC, 2010. *Detection, Quantification and Monitoring Prosopis spp. in the Northern Cape Province of South Africa using Remote Sensing and GIS.* MSc in Environmental Science, Potchefstroom Campus, North-West University, Potchefstroom.

Van Wilgen, BW, Cowling, RM and Le Maitre, DC, 1998. Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water Programme. *Trends in Ecology and Evolution* 13: 378.

Van Wilgen, BW, Reyers, B, Le Maitre, DC, Richardson, DM and Schonegevel, L, 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. *Journal of Environmental Management* 89: 336-349.

Van Wilgen, BW, Dyer, C, Hoffmann, Ivey, P, Le Maitre, DC, Moore, JL, Richardson, DM, Rouget, M, Wannenburgh, A and Wilson, JRU, 2011. National-scale strategic approaches for managing introduced plants: insights from Australian acacias in South Africa. *Diversity and Distributions* 17: 1060-1075.

van Wilgen, BW, Forsyth, GG, Le Maitre, DC, Wannenburgh, A, Kotze, I, van den Berg, E and Henderson, L, 2012. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. *Biological Conservation* 148: 28-38.

Versfeld, DB, Le Maitre, DC, Chapman, RA, 1998. *Alien invading plants and water resources in South Africa: a preliminary assessment*. Report No. TT99/98, Water Research Commission, Pretoria.

Viles, A, 2007. *Review of groundwater resources in the Orange Catchment*, ORASECOM (Orange–Senqu River Commission) Report 004/2007.

Weyl, PSR and Coetzee, JA, 2013. The history and distribution of *Myriophyllum spicatum* L. in southern Africa. *Presentation at the International Conference on Aquatic Invasive Species*, 21-25 April, Niagara Falls, Canada. Accessed at:
http://icais.org/pdf/2013abstracts/3Wednesday/Session%20C-9/400_Weyl.pdf

Wise, RM, Van Wilgen, BW and Le Maitre, DC, 2012. Costs, benefits and management options for an invasive alien tree species: The case of mesquite in the Northern Cape, South Africa. *Journal of Arid Environments* 84: 80-90.

Zachariades, C, Hoffmann, JH and Roberts, AP, 2011. Biological control of mesquite (*Prosopis* species) (Fabaceae) in South Africa. *African Entomology* 19, 393-401.

Appendix A: Invasive alien plant list

The number of records of the top 30 alien invasive plant species in the quarter-degree grid cells in the Orange-Senqu River basin in South Africa in each abundance class. Data extracted from the Southern African Plant Invaders Atlas (Henderson 2007).

Species	***Present***	***Rare***	***Occas-ional***	***Fre-quent***	***Ab-undant***	***Very ab-undant***	***Total***
Salix babylonica L.	179	129	317	213	121	32	992
Prosopis glandulosa var. *torreyana/velutina*	44	218	272	231	84	36	885
Opuntia ficus-indica (L.) Mill.	116	300	257	104	5		782
Populus x canescens (Ait.) J.E. Sm.	160	32	102	70	143	25	532
Acacia dealbata Link	118	67	110	102	84	26	507
Eucalyptus sp.	79	138	182	55	10	1	465
Melia azedarach L.	107	175	130	41	2		455
Azolla filiculoides Lam.	157	30	23	19	81	16	419
Prunus persica (L.) Batsch	71	143	131	73	1		419
Cirsium vulgare (Savi) Ten.	75	33	88	102	28	6	332
Verbena bonariensis L.	116	7	49	70	60	7	309
Datura stramonium L.	104	18	84	66	27		298
Agave americana L.	70	109	77	22	5		283
Cosmos bipinnatus Cav.	102	5	19	77	73	7	283
Pyracantha angustifolia (Franch.) C.K. Schneid.	45	84	83	54	12		278
Rosa rubiginosa L.	35	40	70	99	25	3	272
Gleditsia triacanthos L.	53	101	82	33			269
Acacia mearnsii De Wild.	65	48	52	56	37	7	265
Opuntia robusta H.L. Wendl.	41	132	65	13	1		252
Nicotiana glauca R.C. Grah.	49	62	87	45	6	1	250
Robinia pseudoacacia L.	70	44	47	23	36	5	225
Arundo donax L.	99	43	46	24	11	1	224
Argemone ochroleuca Sweet subsp. *ochroleuca*	40	24	45	68	18	5	200
Schinus molle L.	35	74	57	13	1	1	181
Populus alba/canescens	18	31	34	47	37	3	170
Salix fragilis L.	24	14	31	38	25	6	138
Eichhornia crassipes (Mart.) Solms-Laub.	124			1	2		128
Populus nigra L. var. *italica* Muenchh.	30	19	56	22	1		128
Populus deltoides Bartr. ex Marsh.	28	38	40	19	2		127
Atriplex nummularia Lindley ssp. *nummularia*	20	41	35	19	5		121