A preliminary assessment of the impacts of invasive alien plants on ecosystem services in South Africa

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Summary Despite significant advances in the science of invasion ecology, surprisingly little is known about the magnitude of the impacts of invasions. The work described in this paper aims to develop spatially explicit databases of both ecosystem services and invasive alien plant infestations, and to use the two to estimate impacts on each of the services. In this paper our focus is on water resources only. We describe our approach for selecting species and areas in order to estimate current and future potential impacts on water resources. The number of invasive species considered was restricted to those with extensive current or potential distributions; 17 out of a possible 160 species in fynbos shrublands in this case. We estimate that invasive alien plants currently use 16% of the mean annual surface runoff, but that this could rise to over 50% if all available habitat is allowed to become invaded.

Keywords Fynbos shrublands, water resources.

INTRODUCTION

The science of ecology has helped us to understand the physical phenomenon of biological invasions (Drake *et al.* 1989). More recently, the field of ecological economics has developed through collaborations between ecologists and economists (Costanza 1991), and some key advances have been made in understanding the economic consequences of invasions (Pimmental 2002). Such an understanding is critical in a world where decisions on the allocation of scarce funds are often based on the ability to articulate consequences. However, despite a growing understanding of the ecology of invasions, impacts are less well understood and all too often economic assessments are based on flimsy information on impacts.

In South Africa, developing an understanding of the impacts of invasive alien plants on ecosystem services has received some attention. The contention that invasive alien trees constituted a threat to the country's water resources (Le Maitre *et al.* 1996, van Wilgen *et al*. 1996) led to the establishment of an enormous government-funded program aimed at the control of these species (the 'Working for Water' program; van Wilgen *et al*. 1998). In addition, some work has been done on the consequences of invasive alien plants for the economic potential of South Africa's fynbos (Mediterranean shrubland) biome (Turpie and Heydendrych 2000). These limited studies provide at best a patchy picture of the impacts of invasive alien plants, but they have been used to suggest that the total impacts are probably substantial (van Wilgen *et al*. 2001). The clear need for improved estimates of the impacts of invasive alien plants provided the impetus for initiating research, some of which is described in this paper. The work aims to develop spatially explicit databases of both ecosystem services and invasive alien plant infestations, and to use the two to estimate impacts on each of the services currently, and in the future. This paper provides a description of the approach to be used in assessing the impacts of invasive alien plants on the key ecosystem services of water resource regulation and provisioning (Postel and Carpenter 1997, Gleick 1999).

IMPROVING ESTIMATES OF IMPACT

Estimates of the potential impacts of invasive alien plants on water resources have been used, very successfully, to secure funding for extensive clearing programs. This has been done despite the significant gaps in understanding (Görgens and van Wilgen 2004). The estimates that have been made were based, out of necessity, on some important assumptions. These included that impacts would occur everywhere in the landscape; that related alien species had similar impacts on water resources; and that water resources could be described in terms of a single aspect – surface water runoff (as opposed to assessing surface water runoff and river channel transport separately, for example).

A number of advances will allow for better estimates to be made. In the first place, our understanding of the current and future potential distribution of invasive alien plants has improved significantly (Henderson 1998, Rouget *et al.* 2004). We have also developed a more sophisticated understanding of the effects of plant invasions on the hydrological cycle (Dzvukamanja *et al*. 2005), which will allow for better estimates of impact to be made. In addition, advances in GIS have improved the spatial modelling of impacts.

In the case of water resources, we will examine how estimates made in the light of improved understanding differ from the original estimates. The development of a database on water benefits will also be combined with databases on other ecosystem services in order to compile a more complete picture of the overall impacts of invasion. Finally, we will use the spatially explicit information to assess whether or not clearing projects are correctly located in priority areas where maximum benefits can be derived (van Wilgen *et al*. in press).

APPROACH

The study reported here focused on current and future impacts on water resources in the fynbos biome in South Africa. The determination of impacts was done in three steps. The first was to determine the location of areas where water resource impacts would be most likely, now and in the future. The second was to determine the invasive alien plant species involved. The third was to estimate the magnitude of the impact of invasive alien species on current and future water resources. Each step is outlined below.

Areas where impacts take place We differentiated between two distinct areas where impacts on water resources would manifest themselves. These were landscapes away from river courses, as well as river courses themselves. To define river courses, we used the rivers mapped on 1:500,000 maps, assuming that 10 m on either side of the river would become invaded. As the 1:500,000 maps do not depict smaller tributaries, we also increased the potential area of rivers by a factor of 10, for comparison of water use estimates with and without tributaries (a comparison of 1:500,000 maps with 1:50,000 maps revealed that the latter had almost 15 times more rivers mapped).

Important invasive alien species The most important invasive alien species were determined for the fynbos biome. Important species were defined as those that have been recorded in more than 30% of quarter-degree squares in the biome concerned (data from Henderson 1998), as well as those that have the potential to invade a significant proportion of the biome concerned in future (data from Rouget *et al*. 2004). In terms of potential to invade, we excluded those species whose potential for further spread is limited by effective biological control measures. We classified invasive alien plant species into groups with similar potential for impact on water resources in order to simplify the process of estimating impacts.

Estimating the extent of invasion We used the database of Le Maitre *et al.* (2000) as a basis for estimating the current extent of invasions. The extent of future invasions has been estimated by Rouget *et al*. (2004), using a variant of climatic envelope models to derive climatic suitability surfaces for each species. We used these data to estimate the probable extent of invasion by important alien species (see below) in remaining natural vegetation. The extent of remaining natural vegetation was in turn estimated by excluding all developed and cultivated areas from the fynbos biome.

Estimating impacts on water resources Water use in upper catchments and aquifers was estimated using the 'biomass' models of Le Maitre *et al*. (1996), as modified by Dzvukamanja *et al*. (2005). The runoff reduction in riparian channels was estimated by evaporative demand with a scaling factor (relative to the biomass of invading plants) for different growth forms (Dzvukamanja *et al*. 2005).

PRELIMINARY RESULTS

The South African Plant Invaders Atlas records 571 species, but relatively few of these are major problem species that cause severe impacts. In the fynbos biome, only 11 species (out of 160 recorded) were found to occupy more than 30% of the quarter-degree squares. A further 17 species have the potential to invade a significant proportion of the biome. Of these 28 species, only 17 would have significant impacts on the hydrological cycle (Table 1). They can be grouped into seven functional groups for the purposes of estimating the impacts of these species on water resources (Table 1).

Currently, invasive alien plants are estimated to reduce surface water runoff by 16% in the fynbos biome (Table 2), based on current distribution data given by Le Maitre *et al*. (2000). Under a scenario where the invasive species would occupy the full extent of suitable remaining habitat, estimated water use would increase to between 40 and 53% of surface water runoff (Table 2).

DISCUSSION

Our analysis shows, as was already known, that surface runoff reductions due to alien plant invasions are already substantial. However, it appears that they can still increase several-fold if available habitat becomes fully invaded, which underscores the imperative for control programs to continue. South Africa is a dry country with a mean annual rainfall of less than 500 mm and only about 9% of the rainfall ends up in the rivers (Midgley *et al.* 1994). Water resource utilisation is approaching, or has exceeded, the sustainable yield

Table 1. Important invasive alien plant species that have impacts on water resources in the fynbos biome.

Functional group	Species	Zones of impact
Australian wattles	*Acacia cyclops* G.Don, *A. mearnsii* De Wild., *A. saligna* (Labill.) H.L.Wendl., *A. baileyana* F.Muell., *A. longifolia* (Andrews) Willd. and *Paraserianthes lophantha* (Willd.) I.C.Nielsen	Upper catchments, River channels
Australian eucalypts	*Eucalyptus camaldulensis* Dehnh., *E. lehmannii* (Schauer) Benth.	River channels
Spanish reed	*Arundo donax* L.	River channels
Australian hakeas	*Hakea sericea* Schrad. & J.C.Wendl., *H. gibbosa* (Sm.) Cav., *H. drupacea* (C.F.Gaertn.) Roem. & Schult.	Upper catchments
Australian myrtle	*Leptospermum laevigatum* (Gaertn.) F.Meull.	Upper catchments
Pines	*Pinus pinaster* Aiton, *P. radiata* D.Don, *P. halepensis* Mill.	Upper catchments
Poplars	*Populus canescens* (Aiton) Sm.	River channels

Table 2. Current and future estimated reductions in surface water runoff as a result of alien plant invasions in the fynbos biome.

Scenario	Estimated surface water reduction (% of MAR)
Current extent of invasion	16
All landscapes become fully invaded, but riparian areas cleared	40
All landscapes and riparian areas as mapped on 1:500,000 maps become fully invaded	41
All landscapes and riparian areas 10 times greater than those mapped on 1:500,000 maps become fully invaded	53

once the ecological and human needs, and reserve and international obligations for shared rivers are taken into account (Ashton 2002, DWAF 2004). In most rural areas people are dependent on flow in rivers for their water. They do not have large reservoirs to buffer changes in flows and reduce their vulnerability. Flow reductions in the headwater catchments are propagated downstream with significant implications for people dependent on water from the lower reaches. Therefore, the loss of water caused by invasive species is a major issue for human well-being and security as well as the direct and indirect economic impacts and the ecological impacts.

By using GIS mapping techniques, our study has also identified areas where the impacts will be most acutely felt, and these can be used to focus control operations. Most impacts will be felt in the rugged mountain areas, where rainfall is highest. Invasion along riparian areas has less of an effect, but this can still be substantial (up to 13% additional reductions in surface runoff, Table 2). Because of the lack of detail in mapped riparian zones, the actual extent of this impact is somewhat uncertain and attention should be given to better mapping of riparian zones.

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REFERENCES

Ashton, P.J. (2002). Avoiding conflicts over Africa's water resources. *Ambio* 31, 236-42.

Costanza, R. (1991). 'Ecological economics: the science and management of sustainability'. (Columbia University Press, New York).

Drake, J., Mooney, H.A., Di Castri, F., Groves, R., Kruger, F.J., Rejmánek, M. and Williamson, M., eds (1989). 'Biological invasions: a global perspective'. (John Wiley & Sons, New York).

DWAF (2004). 'National water resource strategy'. 1st edition, September 2004. (Department of Water Affairs and Forestry, Pretoria).

Dzvukamanja, T.N., Gorgens, A.H.M. and Jonker, V. (2005). 'Streamflow reduction modelling in water resource analysis'. (Water Research Commission report no. 1221/1/05, WRC, Pretoria).

Gleick, P.H. (1999). The human right to water. *Water Policy* 1, 487-503.

Görgens, A.H.M. and van Wilgen, B.W. (2004). Invasive alien plants and water resources: an assessment of current understanding, predictive ability and research challenges. *South African Journal of Science* 100, 27-34.

Henderson L. (1998). Southern African plant invaders atlas. (SAPIA). *Applied Plant Science* 12, 31-2.

Le Maitre, D.C., van Wilgen, B.W., Chapman, R.A. and McKelly, D. (1996). Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. *Journal of Applied Ecology* 33, 161-72.

Le Maitre D.C., Versfeld D.B. and Chapman R.A. (2000). The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. *Water SA* 26, 397-408.

Midgley, D.C., Pitman, W.V. and Middleton, B.J. (1994). 'The surface water resources of South Africa 1990'. Volumes 1 to 6. Report Numbers 298/1.1/94 to 298/6.1/94. (Water Research Commission, Pretoria).

Pimmental, D. (2002). 'Biological invasions: economic and environmental costs of alien plant, animal and microbe species'. (CRC Press, Boca Raton, FL).

Postel, S. and Carpenter, S. (1997). Freshwater ecosystem services. *In* 'Nature's services: societal dependence on natural ecosystems', ed. G. Daily, pp. 195-214. (Island Press, Washington, DC).

Rouget, M., Richardson, D.M., Nel, J.L., Le Maitre, D.C., 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, 475-84.

Turpie, J.K. and Heydenrych, B.J. (2000). Economic consequences of alien infestation of the Cape Floral Kingdom's Fynbos vegetation. *In* 'The economics of biological invasions', eds C. Perrings, M. Williamson and S. Dalmazzone, pp. 152-82. (Edward Elgar, Cheltenham, UK).

van Wilgen, B.W., Cowling, R.M. and Burgers, C.J. (1996). Valuation of ecosystem services: a case study from the fynbos, South Africa. *BioScience* 46, 184-9.

van Wilgen, B.W., Le Maitre, D.C. and Cowling R.M. (1998). Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water programme. *Trends in Ecology and Evolution* 13, 378.

van Wilgen, B.W., Richardson, D.M., Le Maitre, D.C., Marais, C. and Magadlela, D. (2001). The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa. *Environment, Development and Sustainability* 3, 145-68.

van Wilgen, B.W., Nel, J.L. and Rouget, M. (in press). Invasive alien plants and South African rivers: A proposed approach to the prioritization of control operations. *Freshwater Biology*.