Invasive Alien Plant Species in South Africa: Impacts and Management Options

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Introduction and Justification

Invasive Alien Plant (IAP) species (commonly referred to as weeds) have emerged as a persistent problem in South Africa. They have dramatic impacts on the natural environment and concomitant implications for human welfare, livelihoods, and quality of life. Biological invasion is a natural process; however, human intervention has accelerated the rate of spread and naturalisation of many species across a multitude of foreign landscapes (Ewel *et al.* 1999:620), which has significantly increased during the last two centuries. Several studies have recognised humans and/or human activities as the driving force behind the introduction, and spread of alien species across ecosystems, with a direct correlation between the intensity of human activities and the intensity of IAP species invasion (Frenot *et al.* 2001:34). Humans are consequently both purposely and inadvertently vectors for the spread of IAP species across South Africa, and across the planet.

This article examines the problem of IAP species in South Africa and the related impacts on biological diversity, ecosystems, and human populations. It critically evaluates how human activities and choices have exacerbated the proliferation of IAP species in specific contexts. Finally, approaches to effectively address the problem of IAP species are forwarded. These include environmental education programmes, environmental legislation/policy interventions, and the use of remote sensing and GIS technologies, which present a coherent set of tools for the identification, characterisation, mapping, and modelling of species' spread and prediction of areas of potential future invasion. The use of these technologies show promise in assisting land resource managers and natural scientists in better planning and decision-making.

Most academic publications that deal with invasive alien plant species adopt a highly scientific and technical approach, focusing primarily on the biological and eradication aspects. Undeniably, the problem of invasive species is a multifaceted and global issue, affecting both natural and socio-economic environments, and often steeped in cultural and traditional value systems. The impetus for this publication (in a non-scientific journal) is accordingly to provide clear insight into IAP species and alien invasion, and to make individuals, who may be largely unaware of the issue and concomitant risks, to take cognisance of the presented risk and threats and adopt a positive attitude to, and be more involved in, the management (identification, eradication, control, and prevention) of IAP species in South Africa. Invasion by non-indigenous plant species is a real and present threat, a global issue both directly and indirectly affecting current and future human existence. This article contributes to a more comprehensive understanding of invasive alien plants by examining some of the social and management dimensions.

The impacts, risks, and subsequent management approaches articulated in this article have been formulated from an extensive review of the available literature on the subject, with the most relevant issues and approaches being presented. The author highlights the most significant threats presented by invasive aliens on the natural and human environments, and further draws attention to human intervention and technology in the overall management of the risk.

IAP Species in Context: Examination of Impacts and Related Implications

'Alien species are non-native or exotic organisms that occur outside their natural adapted ranges and dispersal potential' (Raghubanshi *et al.* 2005:539). The World Conservation Union (IUCN) defines alien invasive species as organisms that become established in native ecosystems or habitats, proliferate, alter, and threaten native biodiversity (IUCN 2000:5).

Invasion by alien species is a global phenomenon, with threatening negative impacts to the indigenous biological diversity and ecosystems (Vitousek 1990:8) as well as related negative impacts on human health and well-being (Bridges 1994:392). Invasion by plant species describe the proliferation and persistence of a species to the point that it has significant negative effects in the new (invaded) range (Mack 1996:107). Research is thus a key instrument in understanding and managing alien species and invasiveness (Pino *et al.* 2005:339), motivated not only by the need to mitigate the negative impacts of invasive species, but also to gain an understanding of the process of invasion underpinning fundamentals in ecological theory (Shea & Chesson 2002:170).

'Disturbance is a natural and oftentimes integral occurrence in most ecosystems' (Pritekel *et al.* 2005:1). Invasibility by an invasive alien plant species represents a unique form of disturbance (Pritekel *et al.* 2005:2). Invasibility may be attributed to factors such as the invaded area's climate, the environment's disturbance regime, and the competitiveness of the native species; the actual invasion being influenced by the number of invading species, their biology, and the propensity of the invaded environment to be invaded (Lonsdale 1999:1523).

The spread of invasive alien plant species presents a real threat to global biodiversity and ecosystem functioning (Mooney & Cleland, 2001:5446) and is probably second only to that of outright habitat destruction (Ragubanshi *et al.* 2005:539). The threat is likely to escalate given continued human-induced disturbances (Ewel *et al.* 199:622), with humans not taking cognisance of, and finding mitigatory measures to, their negative consequences.

Many hypotheses have tried to explain the variability in invasiveness between different plant communities, however there is currently no general theory to explain community invasibility (Lonsdale 1999:1534). Davis et al. (2000:528) theorise that invasibility is a result of fluctuations in resource availability, while Thompson et al. (2001:1057) recognise that invasibility is a product of an increase in availability of resources, either through increase or reduction of resources. Studies by Thiébaut (2005) on *Elodea species*, suggest that invasion corresponds primarily to increased resource availability.

Invasiveness of a species involves complex interactions with the invaded environment (Kolar & Lodge 2001:199). Several characteristics of invading species, for example, allelopathy, fire tolerance, competitive ability, vegetative reproduction, and fitness homeostasis and phenotypic plasticity (Sharma *et al.* 2005: 159-161), have been identified as predictors of invasibility. Invasive species often modify their environments thereby making it more hospitable (Cuddington & Hastings 2004:335), and thus may be classified as 'invasive engineers' (Jones *et al.* 1997:1947).

IAP Species: Impact on the Natural Resource Base

'Commercial forestry based on alien trees is a well established feature of the South African landscape and economy' (Le Maitre *et al.* 2002:144), with species of pines and eucalypts, covering approximately 1.5 million ha. Benefits of these alien plantations include economic development, employment, and foreign exchange through export of forestry products (Le Maitre et al. 2002:144). Unfortunately, these plantations have been associated with considerable negative impacts, most notably, significant reductions in streamflow, and substantial impacts on biodiversity and functioning of ecosystems (Le Maitre *et al.* 2002:144). Of all the alien forest plantations, black wattle (*Acacia mearnsii*), silver wattle (*A. dealbata*), blackwood (*A. melanoxylon*), bluegum (*Eucalyptus globulus*), and cluster pine (*Pinus pinaster*) have the greatest impact on water resources (van Wilgen *et al.* 1997 cited in Enright 2000:238).

Le Maitre et al. (2000:402) report a strong correlation between commercial forest stands and alien invasive plant species invasion in South Africa. Seventy eight percent of the 2.9 million ha invaded by *Pinus* species are attributed to the forestry sector; *Eucalyptus* accounts for 2.4 million ha of invasion, of which 37% attributes to forestry; and *A. mearnsii* has invaded an area greater than 2.4 million ha, of which 10% accounts for forestry.

Alien invasive plants present a serious problem in fynbos in the Western Cape (Le Maitre et al. 1996:161), with species of *Acacia*, *Pinus*, and *Hakea* having altered the biophysical nature of these invaded systems. Le Maitre et al. (1996) highlight that fynbos invaded by pines and wattles are frequently subject to fires. Altered fire regimes are highly problematic, as fires affect the rate of spread of some species, by triggering the release and subsequent germination of seeds (Enright 2000:238).

KwaZulu-Natal is notably the fifth most invaded province by total invaded area. The Western Cape is number one with 3 727 392 ha total area invaded and Gauteng is the least total invaded area (22 254 ha total area invaded) (Le Maitre *et al.* 2000:401). In KwaZulu-Natal, alien plants (most notable *A. mearnsii* and *A. dealbata*) have invaded an area of 922 012 ha, equivalent to 9.75% of the province, with the coastal zone and midlands recognised as major problem areas (Le Maitre *et al.* 2000:402). *Solanum mauritianum* is the most condensed invader while the acacias are most widespread. *Chromolaena odorata* has invaded a total area of 326 139 ha (43 178 ha condensed) and is very widespread throughout the province, predominantly in the coastal belt, notably Zululand, but is fast spreading inland along the river valleys (Goodall & Erasmus 1996:153).

Latest reports suggest that about 10 million ha, or 8.28% of South Africa has already been invaded (Le Maitre *et al.* 2000:400) by more than 180 invading plant species accruing to a loss of approximately 6.7% of mean annual surface runoff (Le Maitre *et al.* 2002:145). MacDonald *et al.* (2003:61) further suggest that 750 000 ha of invaded land should be cleared annually if the battle against invasive plants is to be won within 20 years. This 20-year effort would, however, come at a projected cost of R5.5 billion (Le Maitre *et al.* 2002:145). Studies based on the National Working for Water Programme (WfW) initiatives reveal that the mean cost of initial clearing and follow-up of a 75–100% IAP density class is approximately R1 000 per ha, excluding the cost of herbicides (Marais *et al.* 2004:99). This equates to hundreds of millions of Rands being allocated annually for IAP management and clearing programmes. Expenditure for WfW operations alone has increased from R25 million during 1995/96 to over R400 million during 2003/04 (Marais *et al.* 2004:98).

Given their eminent threat to biodiversity and ecosystem functioning, invasive alien plant species are of great concern and of focal interest to natural scientists and natural resources managers alike. Alien invasions do not follow a set pattern, is not proportionate in its global expansion (Sanz-Elorza *et al.* 2006:115), nor is the distribution of alien plants equal in any given area (Thiébaut 2005:3386). The continued propagation and establishment of alien invasive plants across new ranges is causing homogenisation of flora (Atkinson & Cameron 1993:447), effecting changes in disturbance regimes (D'Antonio & Vitousek 1992:63), effecting changes in biogeochemical cycling (Vitousek 1994:1870), transforming soil surfaces by altering germination sites and surface micro-climates (Pritekel *et al.* 2005:2), causing severe erosion and degradation of soils (MacDonald & Richardson 1986 cited in Enright 2000:238), and is considered to be a significant driving force behind global change and species extinction (Richardson & van Wilgen 2004:45).

IAP Species: Impact on Human Welfare and Quality of Life

An interesting definition of a weed is provided by Bridges (1994:392): 'A weed is a plant growing where man (a person) wishes other plants, or no plants, to grow and which has some economic, ecological, or aesthetic implication for man (a person) and/or his (or her) activities'. The key element in this definition is the implications IAP species present for humans. The impact of IAP species on humans is two-fold. Humans are impacted upon by IAP species because they are often ignorant of the severity of the threat that these organisms pose, all too often blinded by trade and economic incentives for importing these species (Baskin 1996:732). However, IAP species may also represent economic, aesthetic, cultural, and medicinal value.

Globalisation has opened avenues for international trade and transport, creating corridors for emigration of species into non-native environments (Ewel *et al.* 1999:620). An associated problem within the shipping industry is the discharge of ballast water at ports around the world. Baskin (1996:733) makes reference to ships as 'floating biological islands'; ships present an opportune vector for species transport, and subsequent naturalisation and colonisation. Explosion in human population has seen increased movement of people around the world with concomitant increase in the spread of IAP species (Jenkins 1996 cited in Ewel *et al.* 1999:621).

Humans are bound to continue to further introduce non-indigenous species into local plant populations, for example, alien species may form the basis for maintaining productivity in agricultural ecosystems, and for horticulture (Ewel 1999:621), while other alien species, for example, *Casuarina equisetifolia* (beefwood) is utilised by the mining industry for dune stabilisation, though it is a serious invader of coastal dunes and sandy sea-shores (Henderson 2001:101). Humans continue to exploit IAP species; timber from pines, tannins from species of acacias, and aesthetic and ornamental value of *Jacaranda mimosifolia* and *Lantana camara* (Chapman & Le Maitre 2001:2). To the local communities in the rural parts of the Drakensberg region of South Africa, two IAP species, namely, *A. mearnsii* and *A. dealbata*, represent a natural resource—a primary heat source, building material, medicinal extract, and a source of income from the sale of firewood (de Neergaard 2005:217). The duality of the situation is, however, the burgeoning need to clear 'wild' wattle stands.

As noted earlier, forest plantations of alien species have been around since the late 1800s. By the late 1990s, species of *Pinus* and *Eucalyptus* occupied a region of greater than 1.5 million hectares of the South African landscape (FOA, 1998 cited in Le Maitre *et al.* 2002:144). In addition to posing detrimental effects to biodiversity through decreased water availability, serious consequences arise from greatly reduced surface runoff and streamflow (Enright 2000:239). In a water scarce country like South Africa, reduced streamflow, and water levels in dams and reservoirs, threaten the socio-economic status of these regions; rivers and dams maintain an important source of water for human consumption, irrigation for agriculture, and open water for recreation (Le Maitre *et al.* 1996:162). The forestry sector, however, contributes more than 2% to the GDP, and employs in excess of one hundred thousand people (Le Maitre *et al.* 2002:144).

Related impacts of IAP species on humans and human activities include decreased agricultural productivity with concomitant impacts on both crops and animals. This form of impact relates directly to economic impacts accrued through both loss and cost, and may be in the region of billions of Rands (Bridges 1994:394). There is also documented evidence of adverse effects to both human and animal health and well-being, for example, *Parthenium hysterophorus* is known to cause asthma and dermatitis in humans (Bromilow 2001:131) and ingestion by animals (livestock and wildlife) may have far reaching consequences with respect to reproduction, production, and general wellness (Bridges 1994:393). Bridges (1994:393) further points out that IAP species generally create an aesthetically displeasing environment, which often leads to loss in recreational potential.

Intervention and Management Strategies: Approaches to Effectively Addressing the Problem

Rejmánek (2000:497) highlights three fundamental management objectives for IAP species, namely, prevention/exclusion, early detection/rapid assessment, and control/containment/eradication, which in theory, might be very simple and straight forward to accomplish. Meeting these objectives, however, given the socio-economic and political climate of South Africa, is more a question of policy and technology (Rejmánek 2000:497). Undoubtedly, humans are responsible for the current state of invasion by IAP species across the planet; socio-economic factors being the primary impetus for most invasions coupled with less than adequate treatment (Hobbs and Humphries 1995:767). The responsibility is nonetheless ours to manage and control the current state of invasion, and prevent future threats from invasive species into new environments. The author thus critically assesses the advent of environmental education programmes, environmental legislation and/or policy initiatives, and the utilisation of remote sensing and geographic information systems (GIS) technology as approaches to efficiently and effectively manage the threat posed by IAP species in South Africa.

An Environmental Education Approach

The 1992 Rio Earth Summit brought marked change and realisation to conservation and environmental management strategies in South Africa. This was fuelled by a changing political climate (one towards a free democratic society), and shifts in thinking about conserving and sustainably utilising our natural heritage. Biodiversity consequently became entrenched in many facets of culture, politics, and economics (Wynberg 2002:233).

Volumes of research have since been carried out into the impacts of IAP species on biodiversity, ecosystem functioning, and human and animal health and well-being (as indicated earlier), and methodologies and techniques for management and control. However, Ewel *et al.* (1999:628) point out that research must be coupled with education. Increased ecological literacy will certainly lead to increased public awareness regarding alien species, their introduction, and prevention, and should create an environment for better-informed decision-making with respect to management and control campaigns. The public need to fundamentally understand the ramifications of IAP species such that these ideals can be filtered through policy and legislation (Ewel 1999:628).

One of the fundamental principles of the Working for Water programme (discussed in further detail below) is education. Specifically, the programme is aimed at educating landowners and the general public (land users) of the impacts relating to IAP species in South Africa (Working for Water 2001:6). A key element of this education strategy is to ensure that nurseries do not stock and distribute non-indigenous species, without special permits. Other avenues for education include training people as auxiliary fire-fighters, and manufacturing poles accrued from tree felling for informal housing and fencing, and manufacturing building blocks from wood chips and cement; both as part of a small-scale business development scheme.

Organisations such as the South African National Biodiversity Institute (SANBI) and the Wildlife and Environment Society of South Africa (WESSA) have adopted the principles embedded in the legislation to educate the public about the need to preserve the natural environment and in doing so, maintain the health and well-being of humans, and indigenous plants and animals. These organisations play a key role in education and conservation programmes. Awareness campaigns like ‘Stop the Spread’ highlight the need for public intervention in supporting IAP species management and control programmes. The campaign contextualises the impacts in relation to IAP species and the associated costs to society, the economy, and the environment.

An Environmental Legislative/ Policy Programme Approach

Since the early 1930s research has been initiated into the problems associated with IAP species and the management of biological invasions (Richardson & van Wilgen 2004:45). It is now clearly evident that the introduction of many woody IAP species has led to a multitude of negative impacts (Le Maitre *et al.* 2002:144). This is supported by the position that the South African government has taken in as far as IAP species are concerned. In South Africa, under the NEMBA (National Environmental Management Biodiversity Act, Act 10 of 2004) regulations, the government now requires that all organs of state must prepare IAP species monitoring, control, and eradication protocols for areas under their jurisdiction. Consequently, public and public-private initiatives have been established at both national and regional/provincial levels.

In line with the advocacy of the NEMBA, Chapter 5, IAP programmes in South Africa have adopted a strategy to prevent, contain, control, and eradicate all listed invasive alien plant species. Each approach adopted by the programme is therefore relevant to a specific stage(s) of invasion. As a consequence, many studies have focused on measuring the extent of invasion in the quest to better understand the biological and/or ecological processes of invasion. The dilemma is, however, that each of these studies either focuses on a particular species and/or a particular study area in detail (Richardson & van Wilgen 2004:48). Clearly there still exists an eminent need for multi-species, regional surveys.

On 1st June 1984, regulations were promulgated in terms of the Conservation of Agricultural Resources Act, Act 43 of 1983 (CARA). CARA provides for the protection of natural vegetation and combating of weeds and invasive species, and as amended (30 March 2001), boasts a comprehensive list of weed and invader species that is divided into three categories, namely,

- **category 1** are the worst invaders; declared weeds, for example, *Acacia longifolia*, *Hakea gibbosa* and *Harrisia martinii*;
- **category 2** are recognised as problematic species but have some commercial and/or beneficial function, for example, *Acacia dealbata*, *Eucalyptus grandis* and *Pinus halepensis*; and
- **category 3** species, for example, *Morus alba*, *Ipomoea indica* and *Ailanthus altissima*. These are generally the ornamentals but maintain the potential to invade.

CARA maintains specific directives as per the management and regulation of all three category species.

The promulgation of the National Water Act, Act 36 of 1998, reserved the condition that a portion of South Africa's available water resources be reserved for human requirements, and also be made available to maintaining natural ecosystems. Subscribing to a specific code of conduct, in line with the principles of the Water Act, the forestry sector maintains riparian zones and non-afforested areas as IAP species-free zones, and riparian zones as non-afforestation zones (FIEC, 1995 cited in Le Maitre *et al.* 2002:144). However, given the extensive nature of the forestry sector, IAP species encroachment on plantations and invasive spread from within plantation areas are unquestionable and require management intervention. As is evidenced by the past, the commercial forestry sector has been the predominant vector for IAP species invasion and spread, attributed to poor management practices and lack of awareness (Enright 2000:238). This current spate of invasion attributed to the South African forestry sector is ironic given their adoption of the principles of the United Nations Conference on the Environment and Development (UNCED) (Rio 1992), regulated by the White Paper on Sustainable Forest Development, and the National Forests Act, Act 30 of 1998 (Bethlehem 2002:1).

The national 'Working for Water' (WfW) programme, initiated in 1995 under the auspices of the Department of Water Affairs and Forestry (DWAF) and vested with the responsibility of management and control of IAP species, has since conducted many projects across the country (Richardson & van Wilgen 2004:45). A significant component of the WfW programme's impetus and success may be attributed to its ability to assist in poverty alleviation, capacity building, and job creation (Working for Water 2001:3), whilst concurrently monitoring, evaluating, and controlling IAP species spread and invasion. In 2000, the programme employed more than 20 000 people, of which 54% were women, and 26% were youth, and managed a budget of R250 million (Working for Water 2001:3). A cost-benefit analysis of the programme at sites across the country revealed that the programme was efficient, despite competition with other government-funded organisations for limited funding (Hosking and du Preez 2004:144). The long-term success of the programme does, however, rely on the premise that adequate funding be ensured for the duration of the programme, and that biological measures form an integral long-term component of the endeavour, so as to prevent reintroduction of IAP species in cleared areas (Zimmermann *et al.* 2004:38). At a provincial scale, government departments and other State agencies such as the KZN Department of Agriculture and Environmental Affairs (DAEA), Umgeni Water, Ezemvelo KZN Wildlife, as well as municipalities have adopted the common goal of addressing the socio-economic and environmental impacts associated with IAP species.

A Technology-led Approach: Remote Sensing and GIS

To effectively manage and control invasive non-indigenous plant species, and protect and preserve the local biodiversity and ecosystem functioning, managers require accurate and timely spatial information to delineate the location, spatial extent, and intensity of the invasion (Johnson 1999 cited in Lawrence *et al.* 2005:1). This spatial information, acquired through remote sensing techniques, assists managers in monitoring the efficacy of current management and control strategies, monitoring possible future invasions (risk assessment), and assists in identifying target species and areas for clearing (Underwood *et al.* 2003:150).

Remote sensing may be defined as the acquisition of data about an object(s) on the surface of the earth, without the observer being in physical contact with the object(s) itself. The simplest form of remote sensing is the human eye, in which the eye acts as the lens and the human brain the processing centre that creates an image. The first commercial earth-observing satellites became available subsequent to promulgation of the US Land Remote Sensing Act of 1992 (van der Meer *et al.* 2002: 27). Currently available remote sensing systems include air-borne, satellite/space-borne, radar (radio detection and range), and lidar (light detection and ranging); the system employed being dependent on the intended use and data requirements of the investigation.

Remote sensing has been recognised as a technique to measure and map vegetation (Lawrence & Ripple 2000:2742) and hence a tool to map invasive plant species. Given its many advantages, for example, multi-temporal coverage and cost effectiveness (Kokaly *et al.* 2003:437) as well as being able to provide a synoptic view of the earth's surface, it is favoured as the tool of choice in natural resource and land use management, largely replacing traditional field surveys (Kokaly *et al.* 2003:437). Remote sensing provides a practical approach to studying varying terrains, particularly inaccessible environments, provides a multitude of sensor systems at varied spatial resolutions, alleviates spatial heterogeneity because of its broad view, and attributed to the multi-date nature of digital imagery; is ideal for time series/multi-date analysis applications (Joshi *et al.* 2004:1).

The use of digital optical remote sensing for vegetation mapping has since been widely applied (Kokaly *et al.* 2003:438). Digital imagery offers automated image processing and large spatial coverage (Underwood *et al.* 2003:151), moderate spatial resolution for community-level mapping (Dewey *et al.* 1991:479), and high spectral resolution for species-specific classification and mapping (Underwood *et al.* 2003:152). Several studies have, however, exploited digital remote sensing technologies to identify and map alien invasive plants: Lawrence *et al.* (2005) utilised hyperspectral imagery to classify spotted knapweed (*Centaurea maculosa*) and leafy spurge (*Euphorbia esula*) in southwest Montana rangeland in the United States; Peters *et al.* (1992) identified infestations of broom snakeweed (*Gutierrezia sarothrae*) using advanced very high resolution radiometer (AVHRR) and normalised difference vegetation index (NDVI) data; and airborne visible/infrared imaging spectrometer (AVIRIS) data was used to study vegetation in Yellowstone National Park (Kokaly *et al.* 2003).

Mapping the type and extent of plant invasions, as well as predicting their potential impacts and/or risk to the new range, requires accurate and timely assessment and modelling of their disturbance patterns (Joshi *et al.* 2004:2). With the advent of a Geographical Information System (GIS), the technology has been applied to understanding and mapping out the relationships between the inhabitation, spread, and establishment of alien invasive species in new environments, and their spatial heterogeneity across ecosystems (Pino *et al.* 2005:340).

A GIS is computer-based system operationalising the capture, storage, retrieval, analysis, and display of spatial data. This spatial data is primarily acquired through remote sensing and photogrammetry, thus making remote sensing an integral component of a GIS (Skidmore 2002:4). Some of the key questions addressed by a GIS include location (what is at…?), condition (where is it…?), distribution (what is the distribution/pattern…?), trend (what has changed…?), and routing (which is the best way…?) (Skidmore 2002:5). Given the analytical capabilities of a GIS, it is widely and increasingly utilised as a planning, management, and decision-support tool, particularly within the environmental and conservation sciences (Skidmore 2002:5).

GIS is now utilised extensively in the field of ecological surveying and modelling presenting a coherent set of tools for the input and analysis of spatial data (Skidmore 2002:5) and for the modelling of complex habitats (Skov & Svenning 2003:584). The monitoring and mapping of the biophysical and ecological characteristics of invasive species may thus be successfully accomplished through the utility of integrated remote sensing and GIS technologies (Skidmore 2002:5).

Discussion and Conclusion

Education is an integral part of building a well-informed society, which can make better, more well-informed decisions. Environmental education around human interventions to spread, and the related impacts of IAP species to the animals, plants, and humans alike, need to be escalated and subsequently introduced at all levels of society. Although much work has already been completed at the national and provincial levels by agencies such as WfW, and the KZN branch of the DAEA, much work has yet to done at the grassroots level. Campaigns such as 'Stop the Spread' need to become more prominent and more prevalent. Certainly, funding needs to be sourced more aggressively, given the South African context where limited finances need to be distributed across a plethora of priority needs.

Although South Africa boasts and subscribes to an extensive array of international and local policy and legislation, we often lack the capacity to enforce policy due to socio-economic and/or political constraints. Millions of Rands are spent annually on management and clearing efforts, which could otherwise be more efficiently spent, should due-diligence quotas be enforced upon landowners and public land users, through strategic policy intervention. CARA previously vested landowners with the responsibility of maintaining their properties IAP species-free, but attributed to a lack of financing and public and political will, diminished policy enforcement ensued.

The effective and efficient management of invading species certainly demands an integrated, strategic, well-structured, and coherent approach if we are to one day obviate such a threat. Spatial technologies afford a suite of tools that provide for an integrated approach to biodiversity, environmental appraisals, and land and resource management.

Albeit the extensive use of remote sensing across may parts of the world, its use in the management of alien invasions in South Africa has been largely unexploited. This may be largely attributed to a general lack of knowledge and skills in the field, and predominantly the accessibility, availability, and high associated cost. The future does hold much promise though, with a multitude of new sensors being launched by many countries, and the costs associated to acquisition and processing of data being greatly reduced, and at times, available at no cost.

Since the South African strategy towards IAP species is to prevent, eradicate, contain, and control listed (SAPIA database) invasive alien plants, part of the overall strategy should address measuring and monitoring the distribution (and rate of spread), and densities of IAP species across the country. Shortcomings of the SAPIA database and the Versfeld *et al.* (1998) study necessitate reappraisals and/or new investigations. Frequent thematic maps are inherently associated with such undertakings, especially for containment and control stages of invasion, which are the core operations that most IAP species programmes are involved with in South Africa. Furthermore, future research priorities should address development of predictive understanding of rates of spread of IAP species (Richardson & van Wilgen 2004:50) given the pertinent need to stop and prevent future spread and infestation.

With the number of new emergent species on the increase, socio-economic and political clouds invariably shifting, shortfalls in funding, and imminent threats posed by IAP species, South Africa needs to adopt and impose clear and stringent directives as to the management and control, eradication, and prevention against entry into the country of these non-native species. Although biological control programmes may supplement current approaches to management and control strategies, there is much knowledge lacking with respect to weed ecology, geographic distributions, naturalisation and spread, phenology, invasiveness, and invasion history of IAP species in South Africa. Current efforts are also often thwarted by the difficulties associated with accessibility, availability and accuracy of data, as well as time and financial constraints. Given the inextricable link between humans and the natural environment, the pursuit of human endeavour will always be associated with habitat alteration, landscape fragmentation, climate change, and subsequently, the need for IAP species management.

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