Bothalia 42,2: 71– 85 (2012)

The emerging invasive alien plants of the Drakensberg Alpine Centre, southern Africa

C. Carbutt*

Keywords: biological invasions, climate change, disturbance regime, Drakensberg Alpine Centre, early detection, emerging alien plants, expert opinion, life history traits, prioritisation, selection criteria, swift management interventions

ABSTRACT

An 'early detection'-based desktop study has identified 23 taxa as 'current' emerging invasive alien plants in the Drakensberg Alpine Centre (DAC) and suggests a further 27 taxa as probable emerging invaders in the future. These 50 species are predicted to become problematic invasive plants in the DAC because they possess the necessary invasive attributes and have access to potentially suitable habitat that could result in them becoming major invaders. Most of the 'current' emerging invasive alien plant species of the DAC are of a northern-temperate affinity and belong to the families Fabaceae and Rosaceae (four taxa each), followed by Boraginaceae and Onagraceae (two taxa each). In terms of functional type (growth form), most taxa are shrubs (9), followed by herbs (8), tall trees (5), and a single climber. The need to undertake a fieldwork component is highlighted and a list of potential study sites to sample disturbed habitats is provided. A global change driver such as increased temperature is predicted to not only result in extirpation of native alpine species, but to also possibly render the environment more susceptible to alien plant invasions due to enhanced competitive ability and pre-adapted traits. A list of emerging invasive alien plants is essential to bring about swift management interventions to reduce the threat of such biological invasions.

INTRODUCTION

Increased volumes and frequency of trade, travel, and tourism have resulted in an increased spread of invasive and potentially invasive species (Simberloff 2001). The prediction is that such trends are likely to increase in the short and medium-term future in South Africa (Richardson 2001; Le Maitre *et al*. 2004). One result of increased trade, travel, and tourism is that plants will be moved by humans across geographic barriers far beyond their natural dispersal range. To date, South Africa has been invaded by many species of non-native plants, many of which are already well established and have a negative ecological and economic impact (Wells *et al*. 1986; Richardson *et al*. 1997; Van Wilgen 2004), particularly on ecosystem services (Van Wilgen *et al*. 2008, 2011). The different rates of spread observed in different areas are attributed to synergistic interactions between the basic features of the environment, features of the disturbance regime, and life history traits (Richardson 2001; Thuiller *et al*. 2006).

Mgidi *et al*. (2004) predicted that more invasive alien species are likely to reach South Africa in the immediate future. Although upon arrival, such species are still in the infancy of their invasion (either only recently introduced and/or are entering a phase of rapid population growth), they pose an even greater threat than some of the major established invaders because of the large areas they have the potential to invade and the 'unknown factor' associated with the exponential phase of their expansion (Hobbs & Humphries 1995; Nel *et al*. 2004). Emerging invaders appear to be establishing in areas already heavily invaded by major (well-established) invaders, suggesting that due to certain climatic features, patterns of human settlement, and/or land-use patterns, certain areas are more susceptible and predisposed to invasive plants in general and that major invaders are also likely to be facilitating invasions of emerging invader species (Nel *et al*. 2004). Alien plant monitoring and management programmes, historically reactive in nature, should therefore not only target well-established invaders; the 'blacklisting' of emerging invaders as an early warning system will help identify, prioritise, and appropriately manage new invasions (Mgidi *et al*. 2004) so that the predicted trend of increasing invasions is matched with an ever-increasing ability to nullify the emerging threat (Nel *et al*. 2004; Olckers 2004). The overall objective should therefore be to proactively curb the threat of invasive alien plant species by stopping the invasion in its tracks, which will afford significant 'savings' in terms of minimising biodiversity losses and minimising overall management costs. Although the established invasive alien plants in the DAC are reasonably well known and their threat to plant biodiversity in the region recognised (Carbutt & Edwards 2004, 2006), no study has focussed explicitly on the emerging invasive alien plants of the DAC and the likely threat that such invaders may pose in the future.

Emerging invasive alien plants of the DAC are here defined as either (i) those alien plant species recorded from the DAC in the past 25 years or less that are currently still in the early stages of invasion (i.e. less than 100 populations with less than 1 000 individuals per population) and given their specific attributes and potentially suitable habitat, could expand further to become major invaders in the future (~ 'current' emerging invasive aliens); or (ii) those alien plant species naturalised in parts of South Africa that do not occur within the confines of the DAC, but in all likelihood will in the future given either their predominantly temperate affinity and/or their current range within 70 km's of the DAC (~ 'future' emerging invasive aliens).

The aims of this study were threefold: (i) outline a basic methodology to identify the emerging invasive alien plants of the DAC; (ii) develop a preliminary list

* Scientific Services, Ezemvelo KZN Wildlife, P.O. Box 13053, Cascades 3202, South Africa. e-mail: carbuttc@kznwildlife.com.
MS. received: 2011-07-19.

using the desktop component of the methodology identified in (i) above; and (iii) discuss the likely threat posed by these emerging alien invasive plants and the possible relationship between their spread and emerging global change drivers.

METHODS

Scope of study

A desktop approach was adopted to rapidly generate a preliminary list, which is especially helpful if the scope of study encompasses a large geographical area (i.e. where field work would prove costly and time consuming and may take years to complete). The best interim measure is a list to leverage swift management action that can later be fine-tuned with field work.

The geographical scope of the desktop study is the DAC, a temperate region with summer rainfall. Mean annual rainfall varies from ± 640 mm on the more leeward Lesotho side to over 2 000 mm on the main escarpment (Tyson *et al.* 1976; Van Wyk & Smith 2001). The mean temperature of the warmest month is less than 22°C, whilst winter temperatures drop to well below freezing with snow and frost commonplace. Soils of the DAC above 3 000 m therefore have frigid or cryic temperature regimes with mean annual temperatures ranging from 0°C to 8°C (Schmitz & Rooyani 1987). The varied climate is partly responsible for the 11 vegetation types (five grassland types, five shrubland types, and one forest type) occurring in the DAC (see Mucina & Rutherford 2006).

The initial proposed field work component focuses on the South African portion of the DAC although future studies should include representative areas of Lesotho. It is important to note that the term 'DAC' is based on climatological and not floristic grounds (Van Wyk & Smith 2001). The delineated area from 1 800 m a.s.l. to the highest point at 3 482 m a.s.l., encompasses three topo-ecological zones, namely montane (± 1 300 m to ± 1 900 m), sub-alpine (> 1 900 m to ± 2 800 m) and alpine (> 2 800 m to 3 482 m) zones. The DAC is therefore predominantly sub-alpine and alpine in nature, with only the upper limit of the montane zone falling marginally within the DAC. Therefore many of the emerging invasive alien plants being discovered in the montane foothills of the DAC are here listed as 'future' emerging aliens as they currently do not technically occur within the DAC, but in all likelihood will do so in the future once they breach the DAC's climatic envelope.

All sites proposed for the first phase of fieldwork are dispersed along the length of the Free State, KwaZulu-Natal and Eastern Cape Drakensberg (Figure 1; Table 1). These sites are well representative of the eastern DAC, and take into account a range of disturbance regimes and environmental heterogeneity related to altitude (lowest limit to higher altitudes); rainfall (low- to high-altitude gradients as well as north-to-south latitudinal and aspects gradients); temperature (low- to high-altitude gradients as well as north-to-south latitudinal and aspects gradients; see Figure 1) and many of the 11 vegetation types occurring within the DAC.

This study only concerns itself with alien plants introduced from areas outside the borders of South Africa (even though certain species native to South Africa, yet

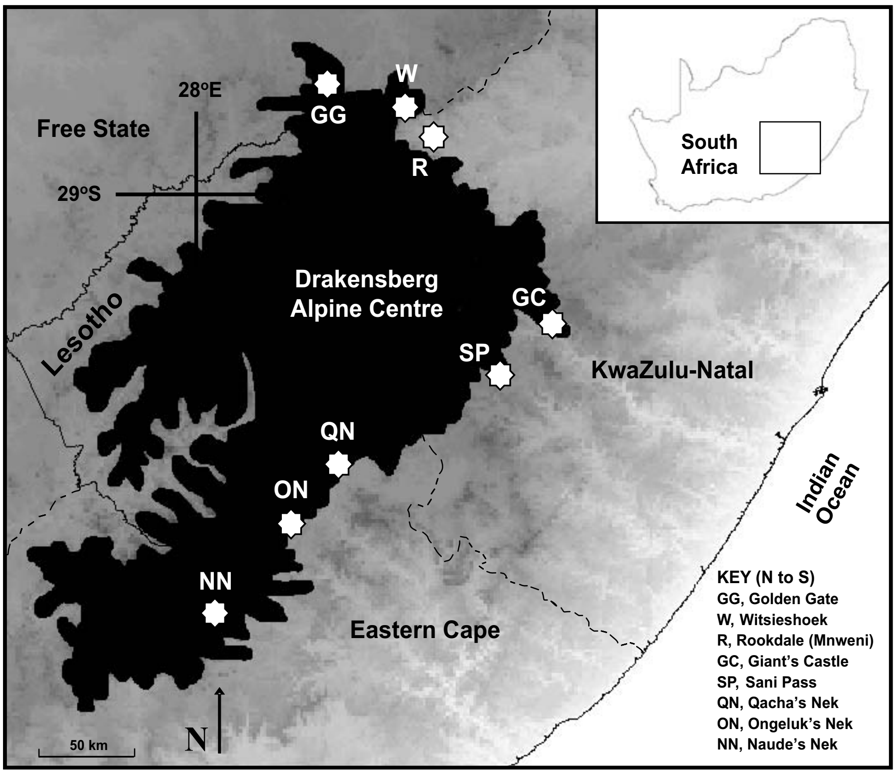

FIGURE 1.—Study sites in the eastern DAC proposed for sampling potential emerging invasive plants in disturbed habitats. This figure should also be interpreted in conjunction with Table 1.

TABLE 1.—Examples of physically disturbed sites which may facilitate the invasion of certain alien plant species in the DAC. Many such physically disturbed sites are also sites of nutrient enrichment (e.g. cattle kraals, heavily grazed or overstocked sites, and rural settlements without on-site or waterborne sanitation).

Sites of disturbance		Explanation	Example(s)	Proposed study site
General	Specific			
1. Paths.	1a. Foot paths.	Paths to homesteads or trading centres.	Qwa Qwa section of Golden Gate HNP.	Golden Gate HNP.
	1b. Tourist trails.	Paths for hiking (recreational).	Main Caves walk, Giant's Castle.	Giant's Castle.
2. Road and rail networks.	2a. Mountain passes.	Trans border access to trading centres.	Sani Pass, Ramatseliso's Gate Pass.	Sani Pass.
	2b. Local service roads.	Roads used by tourists or locals.	Winterton to Cathedral Peak, Barkly Pass, Naudes' Nek Pass, Basutho Gate Pass.	Basuto Gate Pass (Witsieshoek), Naude's Nek.
3. Settlements (habitation).	3a. Rural centres (& cattle kraals).	Disturbance, soil compaction, nutrient enrichment.	Qacha's Nek, Phuthaditjhaba, Rookdale.	Qacha's Nek, Rookdale (Mnweni lowlands, near Bergville).
	3b. Urban centres.			
4. Plantations.	Gum, wattle, pine & poplar.	Immediate sources of alien plants; and potential sites for others.	Boston, Impendhle, Maclear, and Underberg areas.	Sani Pass area.
5. Lands.	5a. Arable lands.	Easily invaded by agrestal & ruderal weeds.	Naude's Nek, Qwa Qwa.	Naude's Nek.
	5b. Pastoral lands.			
	5c. Wastelands.			
	5d. Transformed.			
6. Poorly managed rangelands.	6a. Sub-optimal grazing.	Often leading to erosion dongas.	Eastern Cape Drakensberg, Mnweni, Sani Top.	Lower Mnweni area.
	6b. Sub-optimal burning.			
7. Harvested sites.	Over-collected (exploited).	Harvesting of plants for fuel, medicines, gardens & thatching.	Ongeluk's Nek, Qacha's Nek.	Ongeluk's Nek, Qacha's Nek.
8. Naturally disturbed sites.	8a. Landslides.	Slope instability & disturbance.	Sani Pass.	Sani Pass.
	8b. Rock falls.			
	8c. Terracettes.			
	8d. River beds (flooding).			

naturally absent from the DAC, may be viewed as 'alien' if introduced into the DAC). A classic example is the 'Ermelo' ecotype of *Eragrostis curvula* (Poaceae) from the Highveld. Furthermore, certain native species may even become 'weedy' within their native range. Again such species were excluded [e.g. *Artemisia afra*, *Chrysocoma ciliata*, and *Stoebe vulgaris* (all of the Asteraceae family)]. The study also focuses predominantly on terrestrial invasive plants, the only exceptions being the aquatic herbs *Glyceria maxima* (Poaceae) and *Nasturtium officinale* (Brassicaceae). Plant nomenclature follows Germishuizen & Meyer (2003).

The floristic and threats analysis was based only on the 'current' emerging invasive alien species identified in this study.

Two-tiered 'top-down' and 'bottom-up' approach: introduction

Many alien plant programmes lack objective protocols for prioritising invasive species and areas based on likely future dimensions of spread (Rouget *et al*. 2004) and reliable methods of predicting invasion potential are hard to come by (Nel *et al*. 2004). Criteria using the impact scores of Parker *et al*. (1999) are problematic because they are essentially qualitative, lacking information relating to abundance and rates of spread (Le Maitre *et al*. 2004). Emerging invaders are also not necessarily those most obvious. For example, species that have the greatest available habitat and potential to increase in distribution are sometimes not identified by experts as important invaders (Robertson *et al*. 2004). Many are initially innocuous and restricted within their introduced range (Simberloff 2001). This may be because the dynamics of range expansion and population growth of an invasive alien plant typically include a time lag between its arrival in a new habitat and the start of widespread invasion (Simberloff 2001). Richardson (2001) cited many examples of invaders not showing invasive tendencies for as long as ± 50 to 150 years after introduction.

'*Top-down*' *approach*

To avoid 'reinventing the wheel', this study drew in part from the broad-based desktop review of South Africa's emerging invaders from natural and semi-natural habitats (Mgidi *et al*. 2004, 2007; Nel *et al*. 2004). After a screening process, confidence was placed in a final subset of 28 invaders (out of a possible total of 454) because they had been scrutinised a number of times by a number of authors. During this process, Nel *et al*. (2004) applied the expert scoring of four criteria strongly associated with factors that predict the potential invasiveness of plant species ('impact', 'weediness', 'bio-control status' and 'weedy relatives') to 454 emerging alien invaders listed in the Southern African Plant Invaders Atlas (SAPIA) database (Henderson 1998, 2007). In so doing the 454 emerging alien invaders were reduced to 115, and by further filtering were reduced to 84 according to estimates of their potential habitat ('habitat that can potentially be invaded') and current propagule pool size (Nel *et al*. 2004). Further filtering by Mgidi *et al*. (2004, 2007) then reduced the number to 28 during an exercise identifying the areas in South Africa with the greatest likelihood of being invaded. The 28 species were also used by Le Maitre *et al*. (2004) to assess their potential impacts on the biodiversity, water resources and productivity of natural rangelands (bushveld, grasslands, and shrublands) in South Africa.

The list of 28 species was then scrutinised further for the DAC context only. The final sub-set amounted to 23 taxa based on expert opinion by the author [personal field observations, published literature, and specimens lodged in the Natal University Herbarium (NU) of the University of KwaZulu-Natal], and distribution records from Henderson (2001) and the SAPIA database (Henderson 2007). Many of the 23 taxa recognised as 'current' emerging alien species in the DAC are regarded as major invaders in other parts of South Africa and therefore were not part of Mgidi *et al*. (2004) and Nel *et al*. (2004), as these studies focussed solely on emerging invasive alien plants.

Although not the primary focus of this study, a further 27 taxa have been tentatively listed as 'future' emerging invasive alien plants in the DAC. These species were selected on the premise that the next invaders to occupy the DAC in any meaningful way are most likely those of a temperate affinity and are currently located within 70 kms of the DAC's lower altitudinal boundary and therefore stand the greatest chance of breaching the DAC's climatic envelope, or are so poorly known from few localities that their 'emerging' status in South Africa is yet to be investigated in any detail. These 27 'future' emerging taxa should form the basis of future studies lest they become forgotten and their future potential ecological threat overlooked.

'Bottom-up' approach

Land cover monitoring studies have shown that large tracts of South Africa's natural ecosystems are already transformed (Fairbanks *et al*. 2000) and the extent and rate of land transformation will probably increase with time (Macdonald 1989; Tainton *et al*. 1989; D. Jewitt pers. comm.). This trend is in line with other regions of the world (Dale *et al*. 1994; Sala *et al*. 2000). Known for its high plant species richness and high levels of plant endemism, the DAC (~ Eastern Mountain hot-spot) is also characterised by high levels of man-induced habitat transformation and is therefore recognised as one of southern Africa's eight biodiversity 'hot-spots' (Cowling & Hilton-Taylor 1994, 1997).

Given the disturbance factor associated with the study area, the approach takes both disturbed and undisturbed habitats into account because invasive alien plants are able to dominate all stages of succession; early (~ suppression) and late (~ tolerance) successional strategies are contingent upon the specific competitive strategy employed and can shift in invaded ecosystems over time (see MacDougall & Turkington 2004). Furthermore, disturbed habitats such as mountain pass roads can extend the distribution of alien plants beyond reasonable altitudinal expectations (Kalwij *et al*. 2008). A number of sites have been proposed for the fieldwork component (Figure 1; Table 1). These sites may help to identify additional emerging invasive species undetected in the 'top-down' approach, the focus of which is natural and semi-natural environments.

More specifically, the 'bottom-up' approach should therefore, based on the premise that disturbance is often a critical prerequisite for the invasion of certain alien plants, (i) identify major disturbance nodes (sites) as well as major disturbance types in the DAC (Table 1); (ii) ensure that the suite of disturbance nodes takes all major types of disturbance, environmental heterogeneity, and land tenure of the DAC into account; (iii) document all (potentially invasive) alien plant species at each designated site; and (iv) compare the field list with the SAPIA database, keeping in mind that, if not already data-based, the field species could be an unrecognised emerging invader. Due to the marked environmental gradients that traverse the length of the DAC from north-to-south (and east-to-west), certain alien invasive plants may not be present across all sites (e.g. those of the drier, colder Eastern Cape Drakensberg vs. those of the warmer, wetter northern KwaZulu-Natal Drakensberg).

RESULTS

This study has identified 23 'current' emerging invasive alien plant taxa, represented by 15 families, which pose the most immediate threat to the DAC (Table 2). The families Fabaceae and Rosaceae contribute most of the emerging invasive alien species (four taxa each), followed by Boraginaceae and Onagraceae (two taxa each). All other representative families contribute only a single taxon each (Table 2). In terms of functional type (growth form), most taxa are shrubs (9), followed by herbs (8), tall trees (5), and a single climber (Table 2). Of the 23 'current' emerging invasive alien plants assessed, some 78% are of a northern temperate affinity, and 22% of a tropical affinity (Table 3). Interestingly, none of the assessed taxa were of a southern temperate affinity (*sensu* Henderson 2006). All tall trees and almost all shrubs are of a northern temperate origin, whereas the herbs are equally representative of northern temperate and tropical origins.

This study also highlights a further 27 species as possible 'future' emerging alien invasive plants, as the potential for more recently detected species to invade into the DAC should not be underestimated (Table 4). For example, *Rubus phoenicolasius* (wineberry), locally naturalised in the KwaZulu-Natal Midlands (Stirton 1981) may pose a severe problem in the future given the invasiveness of other *Rubus* species such as *R. cuneifolius* in mesic high-altitude grasslands (O'Connor 2005). Although *R. phoenicolasius* currently does not occur in the DAC, it is regarded as a 'future' emerging invasive alien plant given its temperate affinity and proximity to the DAC (the closest population being ± 70 km's away).

TABLE 2.—The 23 ‘current’ emerging alien plant invaders of the DAC. Taxa are arranged alphabetically.

Taxon	Family	Common name	Functional type (~ growth form)
Argemone ochroleuca subsp. *ochroleuca*	Papaveraceae	White-flowered Mexican poppy.	Herb (forb).
Cirsium vulgare	Asteraceae	Bull/spear thistle.	Herb (forb).
Cotoneaster pannosus	Rosaceae	Silver-leaf cotoneaster.	Shrub.
Cuscuta campestris	Convolvulaceae	Common/field dodder.	Climber (parasitic vine).
Cytisus scoparius	Fabaceae	Scotch broom.	Shrub / short tree.
Echium plantagineum	Boraginaceae	Patterson’s curse / purple viper’s-bugloss.	Herb (forb).
Echium vulgare	Boraginaceae	Blue echium / viper’s-bugloss.	Herb (forb).
Gleditsia triacanthos	Fabaceae	Honey locust.	Tall tree.
Hypericum pseudohenryi	Hypericaceae	St. John’s wort.	Shrub.
Juniperus virginiana	Cupressaceae	Eastern red cedar.	Tall tree.
Ligustrum lucidum	Oleaceae	Chinese wax-leaved privet / tree privet.	Tree.
Nasturtium officinale	Brassicaceae	Watercress.	Herb (forb), aquatic.
Oenothera rosea	Onagraceae	Pink evening primrose.	Herb (forb).
Oenothera tetraptera	Onagraceae	White evening primrose.	Herb (forb).
Opuntia ficus-indica	Cactaceae	Sweet prickly-pear.	Shrub / short tree.
Pyracantha angustifolia	Rosaceae	Narrow-leaved / yellow firethorn.	Shrub.
Quercus robur	Fagaceae	Common/English oak.	Tall tree.
Richardia brasiliensis	Rubiaceae	Brazil pusley / tropical Mexican clover.	Herb (forb).
Robinia pseudoacacia	Fabaceae	Black locust.	Tall tree.
Rosa multiflora	Rosaceae	Multi-flora rose.	Shrub.
Rosa rubiginosa	Rosaceae	Eglantine/sweet briar.	Shrub.
Salix fragilis var. *fragilis*	Salicaceae	Crack/brittle willow.	Tall tree.
Ulex europaeus	Fabaceae	European gorse / gorse.	Shrub.

DISCUSSION

The emerging invasive alien plants of the DAC

Conservatively speaking, at least 170 alien angiosperm species (or ± 6% of the DAC’s angiosperm flora) have invaded the DAC (Carbutt & Edwards 2004). Poaceae and Asteraceae contribute the most established invaders (Carbutt & Edwards 2004), a reflection of the general success of these two families in the DAC, and together with the legume family, Fabaceae, account for the majority of plant invaders worldwide (Richardson 2001). This study adds a further 23 ‘current’ emerging invasive alien species and recognises a further 27 taxa as potential ‘future’ invaders of the DAC. The families Fabaceae and Rosaceae that together contributed most of the emerging invasive taxa, also feature as prominent contributors of temperate-affiliated alien invasive species in southern Africa (see Henderson 2006). Of the families mentioned above, only the Fabaceae features prominently in the native angiosperm flora of the DAC (Carbutt & Edwards 2004). A possible reason for the high proportion of alien invasive species of a northern temperate affinity is the long history of cultivating garden ornamentals from Europe and to a lesser extent Asia (i.e. many gardens in the foothills of the DAC have provided the perfect temperate environment for cultivating ornamental alien plants). More broadly speaking, the pattern for southern Africa is an equal representation of taxa from both temperate and tropical origins (Henderson 2006). An interesting trend to monitor is the potential increase in ‘future’ emerging invasive alien plants of tropical affinity (as a ‘barometer’ of change), given the global change predictions regarding warming and displacement of native taxa.

The northern and eastern boundaries of the DAC are estimated to have on average more than 10 alien invaders per quarter-degree grid square, corresponding to areas with the highest levels of transformation, rainfall, and population density (Nel *et al*. 2004). Rouget *et al*. (2004) have predicted that most species of emerging invaders in the DAC will be confined to the sheltered confines of lower altitudes (montane foothills) below the escarpment, particularly in the northern KwaZulu-Natal Drakensberg (warmer and wetter?), the Eastern Cape and Free State Drakensberg (highly transformed through agriculture?), and the warmer, sheltered valleys of the Lesotho Maloti Mountains. Their absence from the alpine summit (Lesotho plateau), particularly at higher altitudes, is attributed to frequent frosts and low mean temperatures of the coldest month (Rouget *et al*. 2004). However, although ecosystem invasibility generally decreases with altitude as fewer alien plants are able to invade high altitude habitats due to the harsh climatic conditions (Keeley *et al*. 2003; Arévalo *et al*. 2005), a study by Kalwij *et al*. (2008) on the distribution of alien plants along Sani Pass has shown that mountain roads (particularly verges) are able to increase the altitudinal limit at which an alien plant is invasive due to the facilitation of a greater propagule pressure, a composite measure encompassing *inter alia* the effects of anthropogenically-induced soil disturbance, increased water runoff, and vehicular traffic (by introducing and spreading propagules). The outcome is the alien species’ ability to overcome invasion limiting barriers and hence spread

TABLE 3.—Threats posed by the 23 'current' emerging invasive alien plants of the DAC. Distribution data were derived from Henderson (2001) and supplemented by herbarium records and personal field observations. Additional sources of information, where relevant, are cited under each taxon.

Taxon (and additional references)	**Native range**	**Biogeographical affinity (per Henderson 2006)**	**Known range in DAC**	**Potential range in DAC**	**Threat to DAC (consequences of invasion, including target habitat / predicted niche equivalent and invasive/competitive attributes)**
Argemone ochroleuca subsp. *ochroleuca*	Texas (USA) southwards to Mexico.	Tropical.	Invading into DAC from the west and southwest (drier Lesotho lowlands and Eastern Cape).	Probably the western (drier) half of DAC most vulnerable, but may spread eastwards towards the mesic escarpment during episodes of aridification. Disturbed watercourses most susceptible to invasions.	Primarily a weed of waste places (ruderal) and cultivated lands (agrestal), therefore only able to invade and persist in severely and recently disturbed areas. Probably unable to invade into pristine natural vegetation (except perhaps along watercourses subject to episodes of flooding, where it is highly competitive). Produces a large number of seeds that are able to remain dormant during unfavourable conditions for many years.
Cirsium vulgare Hilliard (1977); Streeter (1998).	Europe (including the Mediterranean) and western Asia.	Northern temperate.	Most common along the montane foothills of the KwaZulu-Natal Drakensberg; appears to be scarce in Lesotho (?). NU herbarium localities: Bulwer (1974), Giant's Castle (1966), Katberg (1951), Underberg (1968).	Moist montane sites that have been disturbed and degraded seem most susceptible. Likely to spread across DAC in the absence of episodes of severe aridification.	Primarily a weed of disturbed areas, very competitive in moist, degraded grassland. Probably unable to invade into pristine natural vegetation. Strong competitor in cool, moist, high-altitude conditions. Produces many seeds that remain viable for long periods of time. Seeds (pappus) well adapted for wind dispersal. Its spread is favoured by trampling and soil disturbance. Degrades condition of rangelands.
Cotoneaster pannosus Starr *et al*. (2003).	Sichuan and Yunnan provinces, SW China.	Northern temperate.	Montane region of the central KwaZulu-Natal Drakensberg, eastern Free State, and western Lesotho. A few scattered localities in the Eastern Cape Drakensberg.	Most of DAC is at risk.	Known to invade grassland, forest margins, shrublands, kloofs, riverbanks, rocky outcrops, and roadsides. Has large, aggressive root systems and is known to shade out and smother sun-loving native plants. Dispersed by fruit-eating birds and is able to invade into both disturbed and pristine plant communities. Quick growing; known to quickly dominate a scrub or grassland area. Highly adaptable, can grow in moist or dry soils, and even in thin rocky soils underlying native grasslands. Forest edge and shrubland habitats are most at risk.
Cuscuta campestris Streeter (1998).	North America (Canada, USA) southwards to Mexico and possibly Bahamas, Cuba, and Jamaica.	Northern temperate.	Central KwaZulu-Natal Drakensberg and Lesotho Highlands.	Great potential to spread in DAC, particularly areas with a history of cropping. Appears to be encroaching from the west. Mesic foothills in the Eastern Cape and KwaZulu-Natal Drakensberg seem at greatest risk. Prefers damp soil in full sun.	Smothering parasite on a wide range of host plants; forms dense patches up to 6 m across. Climbs over vegetation. A prolific producer of seeds that are able to remain dormant during unfavourable conditions for long periods; seeds spread by animals and water. Can also spread by stem fragments. Known to invade a wide range of habitats. Disturbed croplands and moist sites are most at risk.
Cytisus scoparius Streeter (1998).	Central and southern Europe and the British Isles (except for Orkney and Shetland Islands).	Northern temperate.	Montane foothills of the KwaZulu-Natal Drakensberg. NU herbarium localities: Highmoor (1959, 1961, 1976), road to Underberg (1961), Van Reenen's Pass (1971).	Has the potential to spread into cool, high-lying areas such as the Eastern Cape Drakensberg.	Invades scrubland, native grassland, forest margins, riverbeds and other waterways. Spread by water and animals and grows rapidly and aggressively into very dense stands. Known to convert open systems into a dense shrubland. Shows signs of drought resistance. Can reproduce vegetatively or by seed. Resprouts after cutting. Can tolerate low soil temperatures. Its invasive success is attributed to its wide tolerance of soil conditions, its ability to fix nitrogen, and its abundant production of hard-coated and long-lasting (up to 80 years) viable seeds.

TABLE 3.—Threats posed by the 23 ‘current’ emerging invasive alien plants of the DAC. Distribution data were derived from Henderson (2001) and supplemented by herbarium records and personal field observations. Additional sources of information, where relevant, are cited under each taxon (continue).

Echium plantagineum Retief & Van Wyk (1998).	Western Europe, including south-western Britain (very rare) and the Mediterranean region.	Northern temperate.	Montane foothills of the Eastern Cape, Free State and KwaZulu-Natal Drakensberg, and Lesotho.	Has the potential to spread throughout the mesic portions of the DAC.	Invades undergrazed or overgrazed rangelands (degrades grasslands); also recorded from rocky slopes in grassland. Persists through a deep taproot and produces ± 5 000 seeds per plant; seeds are dispersed by water and animals and can remain dormant for up to seven years. Can tolerate a wide range of temperatures and can survive periods without rain. Able to germinate at any time of the year, provided conditions are optimal.
Echium vulgare Retief & Van Wyk (1998).	Europe. Distributed throughout the British Isles.	Northern temperate.	Eastern Free State, Lesotho, and Eastern Cape and KwaZulu-Natal Drakensberg.	Has the potential to spread throughout the mesic portions of the DAC.	Primarily a weed of degraded areas, therefore only able to invade and persist in severely and recently disturbed areas. Probably unable to invade into pristine natural vegetation. High threat potential as it has a tendency to invade degraded montane grassland, thereby placing large areas of the DAC at risk.
Gleditsia triacanthos Gilman & Watson (1993a).	North America (mid-western, eastern and east-central USA).	Northern temperate.	Northern and southern KwaZulu-Natal Drakensberg, Eastern Cape Drakensberg, eastern Free State and border of Lesotho on the Free State side.	Highly adaptable; has the potential to spread to almost all parts of the DAC with the exception of forested areas. Favours small stream valleys.	Known to invade grassland and riverbanks. Very adaptable to many adverse conditions (especially heat, drought, poor soils, soils of various pH, soil compaction, and flooding). Seed is viable for many years due to a thick, impermeable seed coat and can germinate under a wide range of conditions. It is a fast-growing member of early and mid-successional stands. Hardy and tolerates both xeric and hydric conditions. Dry *Protea* savanna and *Widdringtonia* fynbos on dry, sunny, low nitrogen sites, and north-facing grasslands burnt too infrequently are most at risk.
Hypericum pseudohenryi	China	Northern temperate.	Possibly only in the montane foothills of the KwaZulu-Natal Drakensberg. Problematic in the Giant’s Castle Game Reserve and Monk’s Cowl Forest Station.	Possibly also the wetter parts of the Eastern Cape Drakensberg and Lesotho catchments.	High threat due to its affinity for cooler climates and mid- to high elevations. Also its long-flowering potential and ability to self-fertilise are further threats. Poses the greatest threat to native mid- to high-elevation shrublands, stream scrub and forest margins where plants can readily germinate and form large, dense stands. Capable of altering and displacing native plant communities in areas where they invade by forming monotypic thickets. Will probably degrade stream catchment quality and diminish runoff. May outcompete plants from stream catchments and shade out hillside plants accustomed to full sun. Hardy to about -5°C but plants can resprout from the base if they are damaged by cold.
Juniperus virginiana Gilman & Watson (1993b).	Widespread in north-eastern North America, from south-eastern Canada to the Gulf of Mexico, east of the Great Plains.	Northern temperate.	Eastern Free State, Western Lesotho, and the Eastern Cape Drakensberg.	Most of the DAC is at risk, particularly degraded, open and eroded areas, and those areas being burnt too infrequently.	High threat in overgrazed, fire-excluded rangelands, particularly those of western Lesotho, eastern Free State and the drier parts of the Eastern Cape Drakensberg. However, its ability to tolerate more mesic conditions also places equivalent areas in the KwaZulu-Natal Drakensberg at risk. Known to invade grassland, riverbanks, and rocky outcrops. Frequent pioneer and invader of old fields and other open, often eroded areas. Most competitive in dry, exposed sites, and in disturbed areas. Does not establish well in more competitive, denser vegetation cover that occurs later in succession. Known to invade into rangelands in the absence of fire. Can tolerate extremely xeric (to mesic) conditions. Tolerates a wide range of soil types and soil depths. Resistant to air pollution and is frost hardy.

TABLE 3.—Threats posed by the 23 'current' emerging invasive alien plants of the DAC. Distribution data were derived from Henderson (2001) and supplemented by herbarium records and personal field observations. Additional sources of information, where relevant, are cited under each taxon (continue).

Taxon (and additional references)	**Native range**	**Biogeographical affinity (per Henderson 2006)**	**Known range in DAC**	**Potential range in DAC**	**Threat to DAC (consequences of invasion, including target habitat / predicted niche equivalent and invasive/competitive attributes)**
Ligustrum lucidum	Eastern Asia (China and Korea).	Northern temperate.	Western Lesotho and the eastern Free State.	Watercourses and forests across the mesic parts of the DAC are most at risk.	High threat. Fast growing evergreen tree that has the potential to replace mid-canopy trees in forests and can completely dominate an area of forest. Seeds are distributed by frugiferous birds. Prolific producer of seed. Also spreads by means of root suckers. Can tolerate dry and wet conditions.
Nasturtium officinale Streeter (1998).	Europe (abundant throughout Britain but rare in central and northern Scotland).	Northern temperate.	Confined mostly to the Lesotho highlands.	May spread more widely throughout Lesotho (provided streams remain pristine) and into the fast-flowing clear streams of the Eastern Cape and KwaZulu-Natal Drakensberg (provided these areas don't experience heavy, regular frosts during winter).	Known to invade rivers, riverbanks, and wetlands. Great threat to the pristine streams of the Lesotho Highlands (because it favours cold, clear flowing water). Propagates by rooting stem fragments and seeds.
Oenothera rosea Goldblatt & Raven (1997).	The New World (Central and South America).	Tropical.	Most common along the montane foothills of the KwaZulu-Natal and Eastern Cape Drakensberg.	Most of the DAC is at risk, particularly degraded and disturbed areas.	Invades riverbanks, moist sites, roadsides and waste places. Has a great ability to utilise suitable light conditions for germination. Autogamous (self-pollinates) and can tolerate aridity.
Oenothera tetraptera Goldblatt & Raven (1997).	The New World, from Texas in the USA to northern South America.	Tropical.	Eastern Free State, northern KwaZulu-Natal Drakensberg and northern Lesotho.	Most of the DAC is at risk, particularly degraded and disturbed areas.	Invades riverbanks, moist sites, roadsides and waste places. Has a great ability to utilise suitable light conditions for germination. Autogamous (self-pollinates).
Opuntia ficus-indica	Central Mexico.	Tropical.	Not well established in the DAC (unlike most of South Africa), but is invading into the DAC mostly from the north and west (drier Free State and Lesotho lowlands).	Encroaching into Lesotho from the west; if unchecked will continue to invade into the drier reaches of central Lesotho. Should not invade wetlands and hygrophilous grasslands.	Fast-growing, may spread quickly under conditions of aridification and poor range management. It is an aggressive invader of natural vegetation, especially dry and rocky places. Can regenerate from seed, cladode fragments (any broken fragment is capable of regeneration) and underground tubers. A recognised transformer of natural or semi-natural ecosystems, thereby altering ecosystem structure, integrity and functioning. Drought tolerance is enhanced by high water-use efficiency and a large water-holding capacity.
Pyracantha angustifolia	South-western China.	Northern temperate.	Eastern Free State, KwaZulu-Natal Drakensberg, and Eastern Cape Drakensberg.	May also spread into eastern Lesotho.	Very high threat to DAC. Favours high-altitude grassland and cool climates with moderate water availability. Forms dense thickets that exclude other plants and makes access difficult due to its thorns. Known to invade high-altitude grasslands, erosion channels, rocky ridges, and riparian areas. Known to smother and displace native species, particularly in grasslands. Prolific producer of seeds but can also resprout. Fast growing. Favours full sun or part shade (not full shade). Can tolerate a wide range of soil conditions.

TABLE 3.—Threats posed by the 23 'current' emerging invasive alien plants of the DAC. Distribution data were derived from Henderson (2001) and supplemented by herbarium records and personal field observations. Additional sources of information, where relevant, are cited under each taxon (continue).

Quercus robur Gilman & Watson (1994a).	Great Britain, Europe (including the Mediterranean) and western Asia (Asia minor).	Northern temperate.	Eastern Cape Drakensberg, southern KwaZulu-Natal Drakensberg, and eastern Free State / western Lesotho.	May also spread into the northern KwaZulu-Natal Drakensberg.	Known to invade forest margins, woodland, roadsides, and riverbanks in grassland and fynbos. Early invader of woodland. Appears to be drought-tolerant. Long-lived (up to 1 000 years).
Richardia brasiliensis Hall *et al.* (2005).	Central and South America (Colombia, Ecuador, Brazil, Peru and Bolivia).	Tropical.	Montane foothills of the KwaZulu-Natal Drakensberg (up to ± 2 000 m).	Has the potential to spread throughout the DAC.	High threat to DAC. Tolerates a range of environmental conditions. Regarded as subdominant under communal grazing in Highland Sourveld grasslands in the southern KwaZulu-Natal Drakensberg (O'Connor 2005). Highly invasive; spreads rapidly. Nature of invasiveness unknown. Blooms in any month that lacks frost. Is drought tolerant; able to retain moisture in fleshy stems ('semi-succulent'). Very hardy. Prolific seeder. Produces a deep taproot.
Robinia pseudoacacia Gilman & Watson (1994b).	North America (central and south-eastern USA).	Northern temperate.	Eastern Free State, southern KwaZulu-Natal Drakensberg and Eastern Cape Drakensberg.	Has the potential to invade into the drier parts of Lesotho, particularly disturbed areas characterised by inappropriate management practices.	High threat to DAC. Is an early successional species, able to establish and grow quickly. Has a highly invasive root system (vigorous root suckering). Tolerates poor soils and other adverse conditions. Known to invade riverbanks, dongas, roadsides, agricultural areas, disturbed areas, upland natural forest edges, degraded woodland, as well as rangelands and grasslands. Once established, it expands readily into areas where, through shading, it outcompetes sun-loving plants. Fast-growing. Requires little water once established. Drought tolerant.
Rosa multiflora	Eastern Asia (China, Japan and Korea).	Northern temperate.	Upper montane region of the KwaZulu-Natal Drakensberg.	Mesic escarpment most at risk.	Forms impenetrable thickets in grassland, scrub, and forest edge. It restricts the movement of wildlife and displaces native vegetation.
Rosa rubiginosa Streeter (1998).	Europe (including the Mediterranean and Britain).	Northern temperate.	Southern KwaZulu-Natal Drakensberg, eastern Free State, Eastern Cape Drakensberg and the central and western portion of Lesotho. NU herbarium locality: Pitlochrie, Barkly East district (1981).	Most of the DAC is suitable habitat.	High threat to DAC. It is an early successional species capable of rapidly invading open areas. Its rapid growth rate, rapid seed production, efficient seed dispersal aided by animals, and its potential to form a dense shrubland (and hence alter vegetation physiognomy) all contribute to its high threat status. Known to invade high-altitude grassland (especially moist valleys), watercourses, rocky outcrops, roadsides, and overgrazed land around human habitation (including wasteland). Capable of invading into dryland environments. In its invasive range, is known to facilitate the re-establishment of native woody species in disturbed forests by reducing grazing herbivory on native seedlings growing beneath the thorny shrubs. Suckering occurs freely from the crown; bushes therefore often exceed 1 m in diameter. Prevalent in high and low rainfall areas. Spreads through seed dispersal; birds eat the red fruits (hips). Seeds are also spread by run-off from waterways. Plants may also regenerate from root and crown fragments left after disturbance.

TABLE 3.—Threats posed by the 23 'current' emerging invasive alien plants of the DAC. Distribution data were derived from Henderson (2001) and supplemented by herbarium records and personal field observations. Additional sources of information, where relevant, are cited under each taxon (continue).

Taxon (and additional references)	Native range	Biogeographical affinity (per Henderson 2006)	Known range in DAC	Potential range in DAC	Threat to DAC (consequences of invasion, including target habitat / predicted niche equivalent and invasive/competitive attributes)
Salix fragilis var. *fragilis* Cremer (1999).	Western Europe and western Asia.	Northern temperate.	Widespread in the montane foothills of the Eastern Cape Drakensberg, northern and southern KwaZulu-Natal Drakensberg and eastern Free State. Also in Lesotho. NU herbarium locality: Garden Castle / Drakensberg Gardens (1980).	Already widespread in the DAC; now also spreading throughout the watercourses of Lesotho.	High threat to the riparian vegetation in water catchments of the DAC. Dense infestations, if unmitigated, will result in reduced stream flow (and therefore reduced water availability), as well as altering biomass and biodiversity along watercourses. May also threaten wetland environments. Known to invade watercourses, especially riverbanks and mid-stream gravel bars. Shading effects may also be detrimental. Will outcompete and therefore displace terrestrial, semi-aquatic, and aquatic native vegetation. Known to spread its roots into the bed of a watercourse, slowing the flow of water and reducing aeration. It forms thickets which divert water outside the main watercourse or channel, causing flooding and erosion where the stream banks are vulnerable. Its leaves create a flush of organic matter when they drop in autumn, reducing water quality and available oxygen, and directly threatening aquatic plants and animals. This, together with the vast volume of water it uses, impacts negatively on stream health. Characterised by brittle branches which are easily broken (with a 'crack'), providing material for vegetative spread (e.g. can spread prolifically from broken twigs taking root downstream). Can also reproduce prolifically from viable wind-borne seed.
Ulex europaeus Streeter (1998).	Central and western Europe, including the British Isles.	Northern temperate.	Central and southern KwaZulu-Natal Drakensberg and its foothills. NU herbarium localities: Giant's Castle (1965), Highmoor (1957, 1961), and Underberg (1974).	High potential for range expansion, throughout DAC, especially in the DAC's mesic habitats.	High threat to DAC. Its dense growth form results in impenetrable monotypic thickets that rapidly smother and outcompete native vegetation. Invades infertile and disturbed areas, but can also invade undisturbed open areas. Its ability to reach reproductive maturity in two years or less, its production of seeds annually that can remain viable for many years, its quickly spreading vegetative structures that resprout readily following cutting, grazing, or burning, all contribute to its invasiveness. While gorse prefers a cool, moist habitat, this plant has characteristics that allow it to occupy areas of drought or sites that are sunny, exposed, and dry. The characteristics include: spiny leaves covered with thick cuticles; grooved hairy stems; large roots on young plants that allow high water uptake and help anchor plants in exposed, windy sites. Its ability to: (i) fix nitrogen; (ii) acidify and (at least temporarily) impoverish soils by taking up bases; (iii) survive on a variety of soil types; (iv) produce copious amounts of heat-tolerant seeds with long-term viability; and (v) regenerate rapidly from seeds and stumps after disturbances such as brush clearing or fires are all qualities that make it even more problematic. Known to invade grassland, shrubland, vleis, and valleys, mostly in moist mountainous regions. Colonises nitrogen-poor soils, which allows it to outcompete native plants. Can spread quickly by seed or by vegetative growth from stumps after mechanical injury caused by brush clearing or fire.

to elevations either higher than expected or previously recorded (Kalwij *et al*. 2008).

Which approach is least fallible?

Previous studies have shown that the prioritisation of invasive species using a ranking system of criteria is subjective and fallible (see Nel *et al*. 2004; Rouget *et al*. 2004) because there are no objective criteria determining when a score is sufficient to qualify a species for high-priority management action (Nel *et al*. 2004). Comparisons are also difficult between species that occupy a wide range of different habitats with varying levels of disturbance and impact. Robertson *et al*. (2003) reported difficulty in ranking priority species requiring management action at a local scale, compared to more widespread species (perhaps also less abundant across their range) requiring intervention over large areas. Rankings given to species should therefore be viewed as approximate, rather than absolute (Thorp & Lynch 2000). For many of these reasons, the two-tiered methodology using both well-scrutinised scoring systems for invaders of natural and semi-natural ecosystems and a proposed fieldwork component to determine the emerging invaders of disturbed habitats has been proposed.

An alternative approach is a predictive one that makes use of Climate Envelope Models (CEMs). This approach, however, is also potentially fallible as predicting the spread of invasive plants is not a perfect science because predictions are often subject to numerous uncertainties (Schneider & Root 2001). A major flaw in using CEMs is that the role of climate in controlling distributions is not the same for all species, and other factors such as disturbance regime and biotic interactions may sometimes override climatic factors (Richardson & Bond 1991; Hulme 2003; Le Maitre *et al*. 2004; Rouget *et al*. 2004), particularly when recent introductions are not in equilibrium with their environment because their geographic ranges may still be expanding from 'refugia' into larger ranges (Rouget *et al*. 2004). Furthermore, CEMs assume that the current distribution of species provides a good indication of their potential range and the process of averaging climate suitability values assumes that the mean values represent the location where the species occurs. This assumption is likely to be flawed in areas of complex topography (Rouget *et al*. 2004). CEMs therefore appear to give the best correlations with invasive plant species distributions only at a national scale (see Rouget & Richardson 2003; Rouget *et al*. 2004). Even more disconcerting is the lack of congruency between species selected by expert ratings and those determined by CEMs (Nel *et al*. 2004).

Despite the drawbacks of each method, the need to attempt a list is of paramount importance and the value of the proactive approach in identifying emerging invasive alien plants cannot be overstated even if there are no generally accepted ways of quantifying when an area is 'invaded' or when a species is 'invasive' (Richardson 2001), and despite the blurry line dividing the emerg-

TABLE 4.—The 27 'future' emerging alien plant invaders of the DAC. Taxa are arranged alphabetically.

Taxon	Family	Common name	Functional type (~ growth form)
Acacia elata	Fabaceae	Peppertree wattle.	Tall tree.
Achillea millefolium	Asteraceae	Common yarrow/milfoil.	Herb (forb).
Anredera cordifolia	Basellaceae	Bridal wreath / Madeira vine.	Climber.
Arundo donax	Poaceae	Giant reed.	Grass/reed (graminoid).
Campuloclinium macrocephalum	Asteraceae	Pompom weed.	Herb (forb).
Coreopsis lanceolata	Asteraceae	Lance-leaved tickseed.	Herb (forb).
Cortaderia selloana	Poaceae	Pampas grass.	Tall grass (graminoid).
Eucalyptus camaldulensis	Myrtaceae	Red river-gum.	Tall tree.
Glyceria maxima	Poaceae	Reed sweet grass / reed manna grass.	Herb (graminoid), aquatic.
Lythrum hyssopifolia	Lythraceae	Hyssop loosestrife/grass-poly.	Herb (forb).
Nasella tenuissima	Poaceae	White tussock.	Grass/reed (graminoid).
Nasella trichotoma	Poaceae	Nasella tussock.	Grass/reed (graminoid).
Oenothera stricta	Onagraceae	Sweet sundrop.	Herb (forb).
Phytolacca octandra	Phytolaccaceae	Inkberry.	Shrub.
Pinus halepensis	Pinaceae	Aleppo pine.	Tree.
Pinus radiata	Pinaceae	Radiata pine.	Tree.
Pinus taeda	Pinaceae	Loblolly pine.	Tall tree.
Populus alba	Salicaceae	White poplar.	Tree.
Populus deltoides	Salicaceae	Match poplar / cottonwood.	Tall tree.
Populus nigra var. *italica*	Salicaceae	Lombardy poplar.	Tall tree.
Pyracantha crenulata	Rosaceae	Himalayan firethorn.	Shrub.
Richardia stellaris	Rubiaceae	Field madder.	Herb (forb).
Rosa canina	Rosaceae	Dog rose.	Shrub.
Rubus phoenicolasius	Rosaceae	Wineberry.	Shrublet/shrub.
Solanum pseudocapsicum	Solanaceae	Jerusalem cherry / winter cherry.	Shrublet/shrub.
Xanthium spinosum	Asteraceae	Spiny cocklebur.	Herb (forb) / shrublet.
Xanthium strumarium	Asteraceae	Large cocklebur.	Herb (forb) / shrublet.

ing and major invaders. Such a list is useful in (i) helping to select species for modelling their rates of spread; (ii) knowing what species to target and where to focus management action in the future; and (iii) facilitating better trouble-shooting methods for managing biological invasions (Nel *et al*. 2004). The benefits may even be accrued to the management (control) process itself, as South African researchers have shown that bio-control is most effective (Olckers & Hill 1999) and control measures most cost-effective (Hobbs & Humphries 1995; Olckers 2004) during the early stages of invasion.

Role of disturbance

Disturbance, be it naturally occurring or human-induced, is a fundamental driver of plant invasions (Richardson 2001; Simberloff 2001) because it promotes characteristic patterns of environmental heterogeneity and regulates ecosystem processes, population dynamics, species interactions, and species diversity by freeing up limiting resources (Davis & Moritz 2001). Its effect is thought to be so critical that some authors (e.g. Elton 1958) have maintained a view that undisturbed native communities are not susceptible to invasions by introduced species. Irrespective of other factors that facilitate or limit invasions, the susceptibility of communities to invasion by alien plants increases with increasing disturbance up to a threshold after which the disturbance then acts as a barrier—intermediate levels of disturbance are therefore most optimal for invasiveness (Richardson 2001; Woodward 2001). Invasibility resulting from disturbance is also attributed to reduced competition from resident plants through the reduction in standing ground cover (Richardson 2001; Woodward 2001).

The role of disturbance in facilitating the expansion of emerging invasive alien plants has therefore been recognised and incorporated into the proposed methodology of this study. Early successional invaders are confined mostly to post-disturbance environments and are effective at acquiring resources in an environment of high resource availability and relatively low competition (due to traits such as fast growth), and are therefore inherently better at suppressing other species in areas of disturbance (~ suppression-based competition; see MacDougall & Turkington 2004). Fortunately, the fast-growing invasives that dominate post-disturbance environments do not appear to be highly problematic in the long term because they compete poorly in late-successional assemblages. Rather, in the absence of disturbance (i.e. where resources are more limiting in natural or semi-natural environments), the alien flora is able to tolerate reduced resource levels under conditions of intense competition, thus allowing them to dominate in the latter stages of succession. This strategy is termed tolerance-based competition (MacDougall & Turkington 2004).

Opportunities for the spread of invasive plants under climate change

Climate change is predicted to be one of the greatest drivers of ecological change in the coming century (Lawler *et al.* 2009). The DAC is an excellent laboratory for the monitoring of climate change because mountainous regions are highly sensitive to environmental change (e.g. Hill 1996; Midgley *et al*. 2001), especially a change in temperature. For example, a major effect of warming is the tendency of species to track shifting climate and suitable habitat through dispersal and migration in order to remain within their optimal growth environment as present-day plant distributions are determined by their ecological compatibility with present-day climate. When climatic conditions change, plants with a specific set of adaptive characteristics may no longer be suited to the new conditions (Deacon *et al*. 1992; Stock *et al*. 1997). Consequently, species are predicted to move poleward in latitude and upward in elevation (Dunne & Harte 2001). A 3°C change in temperature is equivalent to a move of 250 km of latitude or 500 m of elevation. Alpine species will tend to migrate upslope when cooler, higher elevations begin to warm up (Grabherr *et al*. 1995; Dunne & Harte 2001; Körner 2001). Species already limited to mountaintops (i.e. already at their critical physiological threshold) will be at serious risk of local extinction due to the lack of potentially suitable habitat to migrate to (Dunne & Harte 2001) and because climates are changing more rapidly than species can adapt (Schneider & Root 2001). A further influence of global warming on alpine plant diversity is the lateral migration of species (~ 'niche filling' or 'horizontal reallocation'), with new niches being filled by species and other niches being abandoned (Gottfried *et al*. 1998; Körner 2001). Ultimately, species that are similarly affected will occupy similar habitats (Van Zinderen Bakker & Coetzee 1988; Hill 1996; Midgley *et al*. 2001).

Global climate change may not only result in the direct loss of local native species through climatic incompatibility; native plant communities will also become increasingly susceptible to invasions by alien plants. The impact of alien invasive plants, besides habitat degradation, is the extinction of native species through the effects of competition, parasitism, disease, and hybridisation (Baur & Schmidlin 2007). These invasive plants either (i) arrive pre-adapted because the 'new' local climatic conditions are similar to what they experience in their native ranges elsewhere in the world (Macdonald 1992; Dukes & Mooney 1999), or (ii) because of some form of change, their competitive ability increases in their invasive environment. Studies on plant-climate relationships therefore need to consider both the current selection pressures as well as future ones, as currently non-adaptive traits may pre-adapt taxa to future environmental conditions (Stock *et al*. 1997). A future selection pressure in the DAC is warmer temperature, which may be significant given that the climatic boundaries in the DAC are well defined and may determine the basic distribution limits for plants (Carbutt 2004). The warmer temperatures associated with global climate change may accelerate organic matter decomposition and nitrogen mineralisation, thereby creating a nitrogen environment unsuited to taxa that have evolved in such nitrogen-limited environments where soil inorganic nitrogen availability is heavily constrained by cooler temperatures (Carbutt 2004; Carbutt & Edwards 2008; Contosta *et al*. 2011). Plant communities thriving in the DAC's (currently temperature-mediated) nitrogen-limited soils may be extirpated by future episodes of significant warming because of their inability to cope with nitrogen concentrations far beyond their natural tolerance range. Such communities may therefore be replaced by common nitrophilous ruderal plants (many of which will be invasive alien plants) that are neither conservation-worthy nor native to the DAC.

Management action

Control of invasive alien species is a key operational management function and demands significant financial resources. In the uKhahlamba Drakensberg Park World Heritage Site (UDP WHS), which accounts for a significant area of the KwaZulu-Natal Drakensberg portion of the DAC, some R2 million is spent annually to clear invasive plants. A concern is that no operational funds are allocated to combat invasive alien plants in the UDP WHS; rather all funding is derived from State poverty relief programmes such as 'Landcare', 'Working for Water', 'Working on Fire', and 'Working for Wetlands', placing the Park at high risk should this funding be terminated for whatever reason (Ezemvelo KZN Wildlife 2005).

The 'art and science' of early detection is a pointless exercise unless it is followed up with control and mitigation by the relevant conservation authorities, and the failure to detect and eliminate emerging aliens will add to the financial burden of invasive alien plant control. Whilst it is acknowledged that areas of high biodiversity value will be under constant threat by invasive alien species and therefore the appropriate management action to mitigate this threat is an ongoing need (Richardson *et al.* 2005; Thuiller *et al.* 2008), the smart approach of early detection of new invasions is essential to assist management in the ongoing battle of alien plant threat mitigation. Failure to address emerging invasive alien plants in the short term may double the costs of alien plant control in the long term. The urgent need to act immediately and invest a relatively small amount to control emerging populations before they spread into all available habitats makes good business sense. The benefits of managing emerging alien plants should be calculated to include the stimulation of further job creation in rural communities, improved delivery of ecosystem goods and services, and the safeguarding of native biodiversity and ecological integrity.

CONCLUSION

South Africa has to its credit a long history of alien plant control and research (Macdonald *et al.* 1986; Van Wilgen *et al.* 2011). For example, the Working for Water (WfW) Programme of the Department of Water and Environmental Affairs (DWEA), initiated in 1995, has been widely lauded both locally (Van Wilgen *et al.* 1996; Hobbs 2004; Van Wilgen 2004) and internationally (Mark & Dickinson 2008) for its progressive and proactive approach in eradicating alien plants. Other significant allies in the war against invasive alien plants are the Weeds Research Programme of the Agricultural Research Council's (ARC) Plant Protection Research Institute (PPRI) (which includes the SAPIA database), and the WfW-funded Invasive Alien Plants Early Detection and Rapid Response (EDRR) Programme of the South African National Biodiversity Institute (SANBI).

The critical need for alien plant control and research in the DAC (relating to both major and emerging invaders) is crucial to maintaining the functional ecological integrity of the DAC. Like in many other alpine and subalpine environments, the DAC is a mountainous catchment area which supplies drinking and irrigation water, as well as hydroelectric power. All system functions (including water quality) is inevitably dependent upon a healthy and intact cover of vegetation and a species-rich flora, often likened to an 'insurance policy' in that a species-rich environment has a greater chance of weathering the barrage of human threats and natural environmental changes because there are more likely to be individuals among the many that can withstand a specific threat (see Körner 2001). For example, a species-rich environment has a greater chance of combating invasive plants because the likelihood of an invader encountering a close competitor is higher than if just a handful of native plant species were present (Richardson 2001). Every conceivable effort should ensure that the levels of established (major) invasive alien plants in the DAC are contained to an acceptable minimum and any emerging alien invasive plants are rapidly identified through early detection and eradicated before infestation levels impact negatively on the ecological integrity of the DAC.

FUTURE STUDIES

This desktop-based analysis should be expanded to include the proposed fieldwork component (to both verify and potentially widen the net of possible emerging candidates) and the scope of the assessment enlarged to include representative areas of Lesotho. The value of a proactive approach, both in terms of identifying the invasive alien species and the application of swift counter measures to eliminate emergent populations before they become well established, cannot be overstated.

ACKNOWLEDGEMENTS

The author wishes to thank I. Rushworth, S. McKean and V. Mngomezulu of Ezemvelo KZN Wildlife and Dr. R. Lechmere-Oertel, previously of the Maloti Drakensberg Transfrontier Project, for guidance and sourcing selected literature. Helpful comments and improvements from three reviewers are gratefully acknowledged.

REFERENCES

ARÉVALO, J.R., DELGADO, J.D., OTTO, R., NARANJO, A., SALAS, M. & FERNÁNDEZ-PALACIOS, J.M. 2005. Distribution of alien vs. native plant species in roadside communities along an altitudinal gradient in Tenerife and Gran Canaria (Canary Islands). *Perspectives in Plant Ecology, Evolution and Systematics* 7: 185–202.

BAUR, B. & SCHMIDLIN, S. 2007. Effects of invasive non-native species on the native biodiversity in the River Rhine. In W. Nentwig, *Biological Invasions*: 257–273. Springer-Verlag, Berlin.

CARBUTT, C. 2004. *Cape elements on high-altitude corridors and edaphic islands*. Ph.D. thesis, University of KwaZulu-Natal, Pietermaritzburg.

CARBUTT, C. & EDWARDS, T.J. 2004. The flora of the Drakensberg Alpine Centre. *Edinburgh Journal of Botany* 60: 581–607.

CARBUTT, C. & EDWARDS, T.J. 2006. The endemic and near-endemic angiosperms of the Drakensberg Alpine Centre. *South African Journal of Botany* 72: 105–132.

CARBUTT, C. & EDWARDS, T.J. 2008. *Possible effect of global warming on ecosystem function in the uKhahlamba Drakensberg Park, South Africa: particularly its influence on plant communities through nutrient enrichment*. Proceedings of the launching workshop of a "Global Change Research Network in African Mountains", Kampala (Uganda). 23–25 July 2007. Mountain Research Initiative (MRI) and the Centre for Development and Environment (CDE), University of Bern, Switzerland.

CONTOSTA, A.R., FREY, S.D. & COOPER, A.B. 2011. Seasonal dynamics of soil respiration and N mineralisation in chronically warmed and fertilised soils. *Ecosphere* 2:1–21.

COWLING, R.M. & HILTON-TAYLOR, C. 1994. Patterns of plant diversity and endemism in southern Africa: an overview. In B.J. Huntley, *Botanical diversity in southern Africa:* 31–52. National Botanical Institute, Pretoria.

COWLING, R.M. & HILTON-TAYLOR, C. 1997. Phytogeography, flora and endemism. In R.M. Cowling, D.M. Richardson & S.M. Pierce, *Vegetation of Southern Africa*: 43–61. Cambridge University Press, Cambridge.

CREMER, K. 1999. *Willow management for Australian rivers* (Natural Resource Management Special Issue). Australian Association of Natural Resource Management, Canberra. pp. 2–22.

DALE, V.H., PEARSON, S.M., OFFERMAN, H.L. & O'NEILL, R.V. 1994. Relating patterns of land-use change to faunal biodiversity in central Amazon. *Conservation Biology* 8: 1027–1036.

DAVIS, F.W. & MORITZ, M. 2001. Mechanisms of disturbance. In S.A. Levin, *Encyclopedia of Biodiversity (Volume 2)*: 153–160. Academic Press, San Diego.

DEACON, H.J., JURY, M.R. & ELLIS, F. 1992. Selective regime and time. In R.M. Cowling, *The Ecology of Fynbos: Nutrients, Fire and Diversity*: 6–22. Oxford University Press, Cape Town.

DUKES, J.S. & MOONEY, H.A. 1999. Does global change increase the success of biological invaders? *Trends in Ecology and Evolution* 14: 135–139.

DUNNE, J.A. & HARTE, J. 2001. Greenhouse effect. In S. Levin, *Encyclopedia of Biodiversity (Volume 3)*: 277–293. Academic Press, San Diego.

ELTON, C.S. 1958. *The ecology of invasions by animals and plants*. Methuen, London.

EZEMVELO KZN WILDLIFE. 2005. *Integrated Management Plan (2006–2011): uKhahlamba Drakensberg Park World Heritage Site, South Africa*. Ezemvelo KZN Wildlife, Pietermaritzburg.

FAIRBANKS, D.H.K., THOMPSON, M.W., VINK, D.E., NEWBY, T.S., VAN DEN BERG, H.M. & EVERARD, D.A. 2000. The South African land-cover characteristics database: a synopsis of the landscape. *South African Journal of Science* 96: 69–82.

GERMISHUIZEN, G. & MEYER, N.L. 2003. Plants of southern Africa: an annotated checklist. *Strelitzia* 14:1–1231.

GILMAN, E.F. & WATSON, D.G. 1993a. *Gleditsia triacanthos* var. *inermis* (thornless honeylocust). US Forest Service, Department of Agriculture. Fact sheet no. ST-279. 4p.

GILMAN, E.F. & WATSON, D.G. 1993b. *Juniperus virginiana* (eastern redcedar). USDA Forest Service Fact Sheet ST-327. 4p.

GILMAN, E.F. & WATSON, D.G. 1994a. *Quercus robur* (English oak). US Forest Service, Department of Agriculture. Fact sheet no. ST-558. 4p.

GILMAN, E. F. & WATSON, D. G. 1994b. *Robinia pseudoacacia* 'Frisia' black locust. US Forest Service, Department of Agriculture. Fact sheet no. ST-571. 4p.

GOLDBLATT, P. & RAVEN, P.H. 1997. FSA contributions 9: Onagraceae. *Bothalia* 27: 149–165.

GOTTFRIED, M., PAULI, H. & GRABHERR, G. 1998. Prediction of vegetation patterns at the limits of plant life: a new view of the alpine-nival ecotone. *Arctic and Alpine Research* 30: 207–221.

GRABHERR, G., GOTTFRIED, M., GRUBER, A. & PAULI, H. 1995. Patterns and current changes in alpine plant diversity. In F.S. Chapin & Ch. Körner, *Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences*: 167–181. Springer, Heidelberg.

HALL, D.W., VANDIVER, V.V. & FERRELL, J.A. 2005. Brazil pusley, *Richardia brasiliensis* (Moq.). Institute of Food and Agricultural Sciences, University of Florida, Gainesville FL 32611.

HENDERSON, L. 1998. Southern African Plant Invaders Atlas (SAPIA). *Applied Plant Science* 12: 31, 32.

HENDERSON, L. 2001. *Alien weeds and invasive plants: a complete guide to declared weeds and invaders in South Africa*. Plant Protection Research Institute Handbook No. 12. Agricultural Research Council, Pretoria.

HENDERSON, L. 2006. Comparisons of invasive plants in southern Africa originating from southern temperate, northern temperate and tropical regions. *Bothalia* 36: 201–222.

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

HILL, T.R. 1996. Description, classification and ordination of the dominant vegetation communities, Cathedral Peak, KwaZulu-Natal Drakensberg. *South African Journal of Botany* 62: 263–269.

HILLIARD, O.M. 1977. *Compositae in Natal*. University of Natal Press, Pietermaritzburg. 659 pp.

HILLIARD, O.M. & BURTT, B.L. 1987. *The Botany of the Southern Natal Drakensberg*. National Botanic Gardens, Cape Town.

HOBBS, R.J. 2004. The Working for Water Programme in South Africa: the science behind the success. *Diversity and Distributions* 10: 501–503.

HOBBS, R.J. & HUMPHRIES, S.E. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9: 761–770.

HULME, P.E. 2003. Winning the science battles but loosing the conservation war? *Oryx* 37: 178–193.

KALWIJ, J.M., ROBERTSON, M.P. & VAN RENSBURG, B.J. 2008. Human activity facilitates altitudinal expansion of exotic plants along a road in montane grassland, South Africa. *Applied Vegetation Science* 11: 491–498.

KEELEY, J.E., LUBIN, D. & FOTHERINGHAM, C.J. 2003. Fire and grazing impacts on plant diversity and alien plant invasions in the southern Sierra Nevada. *Ecological Applications* 13: 1355–1374.

KÖRNER, Ch. 2001. Alpine ecosystems. In S.A. Levin, *Encyclopedia of Biodiversity (Volume 1)*: 133–144. Academic Press, San Diego.

LAWLER, J.J., SHAFER, S.L., WHITE, D., KAREIVA, P., MAURER, E.P., BLAUSTEIN, A.R. & BARTLEIN, P.J. 2009. Projected climate-induced faunal change in the Western Hemisphere. *Ecology* 90: 588–597.

LE MAITRE, D.C., MGIDI, T.N., SCHONEGEVEL, L., NEL, J.L., ROUGET, M., RICHARDSON, D.M. & MIDGLEY, C. 2004. Plant invasions in South Africa, Lesotho and Swaziland: assessing the potential impacts of major and emerging plant invaders. In *An assessment of invasion potential of invasive alien plant species in South Africa*. CSIR Environmentek Report No. ENV-S-C2004-108. pp. 76–96.

MACDONALD, I.A.W. 1989. Man's role in changing the face of southern Africa. In B.J. Huntley, *Biotic diversity in southern Africa. Concepts and Conservation*: 51–77. Oxford University Press, Cape Town.

MACDONALD, I.A.W. 1992. Global change and alien invasions: implications for biodiversity and protected area management. In O.T. Solbrig, H.M. Van Emden & P.G.W.J. Van Oordt, *Biodiversity and Global Change*: 197–207. International Union of Biological Sciences, Paris.

MACDONALD, I.A.W., KRUGER, F.J. & FERRAR, A.A. 1986. *The ecology and management of biological invasions in southern Africa*. Oxford University Press, Cape Town.

MACDOUGALL, A.S. & TURKINGTON, R. 2004. Relative importance of suppression-based and tolerance-based competition in an invaded oak savanna. *Journal of Ecology* 92: 422–434.

MARK, A.F. & DICKINSON, J.M. 2008. Maximising water yield with indigenous non-forest vegetation: a New Zealand perspective. *Frontiers in Ecology and the Environment* 6: 25–34.

MGIDI, T.N., LE MAITRE, D.C., SCHONEGEVEL, L., NEL, J.L., ROUGET, M. & RICHARDSON, D.M. 2004. Alien plant invasions—incorporating emerging invaders in regional prioritisation: a pragmatic approach for South Africa. In *An assessment of invasion potential of invasive alien plant species in South Africa*. CSIR Environmentek Report No. ENV-S-C 2004-108. pp. 56–75.

MGIDI, T.N., LE MAITRE, D.C., SCHONEGEVEL, L., NEL, J.L., ROUGET, M. & RICHARDSON, D.M. 2007. Alien plant invasions—incorporating emerging invaders in regional prioritization: a pragmatic approach for southern Africa. *Journal of Environmental Management* 84: 173–187.

MIDGLEY, G.F., HANNAH, L., ROBERTS, R., MACDONALD, D.J. & ALLSOPP, J. 2001. Have Pleistocene climatic cycles influenced species richness patterns in the greater Cape Mediterranean Region? *Journal of Mediterranean Ecology* 2: 137–144.

MUCINA, L. & RUTHERFORD, M.C. 2006. *The vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. SANBI, Pretoria.

NEL, J.L., RICHARDSON, D.M., ROUGET, M., MGIDI, T., MDZEKE, N., LE MAITRE, D.C., VAN WILGEN, B.W., SCHONEGEVEL, L., HENDERSON, L. & NESER, S. 2004. A proposed classification of invasive plant species in South Africa: towards prioritising species and areas for management action. *South African Journal of Science* 100: 53–64.

O'CONNOR, T.G. 2005. Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the southern Drakensberg, South Africa. *Journal of Applied Ecology* 42: 975–988.

OLCKERS, T. 2004. Targeting 'emerging weeds' for biological control in South Africa: the benefits of halting the spread of alien plants at an early stage of their invasion. *South African Journal of Science* 100: 64–68.

OLCKERS, T. & HILL, M.P. 1999. Biological control of weeds in South Africa (1990–1998). *African Entomology Memoir No. 1*.

PARKER, I.M., SIMBERLOFF, D., LONSDALE, W.M., GOODELL, K., WONHAM, M., KAREIVA, P.M., WILLIAMSON, M., VON HOLLE, B., MOYLE, P.B., BYERS, J.E. & GOLDWASSER, L. 1999. Impact: towards a framework for understanding the ecological effects of invaders. *Biological Invasions* 1: 3–19.

RETIEF, E. & VAN WYK, A.E. 1998. The genus *Echium* (Boraginaceae) in southern Africa. *Bothalia* 28: 167–177.

RICHARDSON, D.M. 2001. Plant invasions. In S.A. Levin, *Encyclopedia of Biodiversity (Volume 4)*: 677–688. Academic Press, San Diego.

RICHARDSON, D.M. & BOND, W.J. 1991. Determinants of plant distribution: evidence from pine invasions. *American Naturalist* 137: 639–668.

RICHARDSON, D.M., MACDONALD, I.A.W., HOFFMANN, J.H. & HENDERSON, L. 1997. Alien plant invasions. In R.M. Cowling, D.M. Richardson & S.M. Pierce, *Vegetation of southern Africa*: 535–570. Cambridge University Press, Cambridge.

RICHARDSON, D.M., ROUGET, M., RALSTON, S.J., COWLING, R.M., VAN RENSBURG, B.J. & THUILLER, W. 2005. Species richness of alien plants in South Africa: environmental correlates and the relationship with indigenous plant species richness. *Ecoscience* 12: 391–402.

ROBERTSON, M.P., VILLET, M.H., FAIRBANKS, D.H.K., HENDERSON, L., HIGGINS, S.I., HOFFMANN, J.H., LE MAITRE, D.C., PALMER, A.R., RIGGS, I., SHACKLETON, C.M. & ZIMMERMANN, H.G. 2003. A proposed prioritisation system for the management of invasive alien plants in South Africa. *South African Journal of Science* 99: 37–43.

ROBERTSON, M.P., VILLET, M.H. & PALMER, A.R. 2004. A fuzzy classification technique for predicting species' distributions: an implementation using alien plants and indigenous insects. *Diversity and Distributions* 10: 461–474.

ROUGET, M. & RICHARDSON, D.M. 2003. Understanding patterns of plant invasion at different spatial scales: quantifying the roles of environment and propagule pressure. In L.E. Child, J.H. Brock, G. Brundu, K. Prach, P. Pyšek, P.M. Wade & M. Williamson, *Plant invasions: ecological threats and management solutions*: 3–15. Backhuys, Leiden.

ROUGET, M., RICHARDSON, D.M., NEL, J., LE MAITRE, D.C., EGOH, B. & MGIDI, T. 2004. Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climatic suitability. In *An assessment of invasion potential of invasive alien plant species in South Africa*. CSIR Environmentek Report No. ENV-S-C 2004-108. pp. 39–55.

SALA, O.E., CHAPIN, F.S. III, ARMESTO, J.J., BERLOW, E., BLOMFIELD, J., DIRZO, R., HUBER-SANWALD, E., HUENNEKE, L.F., JACKSON, R.B., KINZIG, A., LEEMANS, R., LODGE, D.M., MOONEY, H.A., OESTERHELD, M., POFF, N.L., SYKES, M.T., WALKER, B.H., WALKER, M. & WALL, D.H. 2000. Global biodiversity scenarios for the year 2100. *Science* 287: 1770–1774.

SCHMITZ, G. & ROOYANI, F. 1987. *Lesotho: geology, geomorphology, soils*. National University of Lesotho, Roma.

SCHNEIDER, S.H. & ROOT, T.L. 2001. Synergism of climate change and ecology. In S.A. Levin, *Encyclopedia of Biodiversity (Volume 1)*: 709–726. Academic Press, San Diego.

SIMBERLOFF, D. 2001. Effects and distribution of introduced species. In S.A. Levin, *Encyclopedia of Biodiversity (Volume 3)*: 517–529. Academic Press, San Diego.

STARR, F., STARR, K. & LOOPE, L. 2003. *Cotoneaster pannosus*—Rosaceae. United States Geological Survey, Biological Resources Division, Haleakala Field Station, Maui, Hawaii.

STIRTON, C.H. 1981. New records of naturalised *Rubus* in southern Africa. *Bothalia* 13: 333–337.

STOCK, W.D., ALLSOPP, N., VAN DER HEYDEN, F. & WITKOWSKI, E.T.F. 1997. Plant form and function. In R.M. Cowling, D.M. Richardson & S.M. Pierce, *Vegetation of southern Africa*: 376–396. Cambridge University Press, Cambridge.

STREETER, D. 1998. *The wild flowers of the British Isles*. Midsummer Books, London.

TAINTON, N.M., ZACHARIAS, P.J.K. & HARDY, M.B. 1989. The contribution of veld diversity to the agricultural economy. In B. Huntley, *Biotic diversity in southern Africa. Concepts and Conservation*: 107–120. Oxford University Press, Cape Town.

THORP, J.R. & LYNCH, R. 2000. *The determination of weeds of national significance*. National Weeds Strategy Executive Committee, Launceston.

THUILLER, W., RICHARDSON, D.M., ROUGET, M., PROCHES, S. & WILSON, J.R.U. 2006. Interactions between environment, species traits, and human uses describe patterns of plant invasions *Ecology* 87:1755–1769.

THUILLER, W., ALBERT, C., ARAÚJO, M.B., BERRY, P.M., CABEZA, M., GUISAN, A., HICKLER, T., MIDGLEY, G.F., PATERSON, J., SCHURR, F.M., SYKES, M.T. & ZIMMERMANN, N.E. 2008. Predicting global change impacts on plant species' distributions: future challenges. *Perspectives in Plant Ecology, Evolution and Systematics* 9: 137–152.

TYSON, P.D., PRESTON-WHYTE, R.A. & SCHULZE, R.E. 1976. *The climate of the Drakensberg*. The Town and Regional Planning Commission, Pietermaritzburg.

VAN WILGEN, B.W. 2004. Scientific challenges in the field of invasive alien plant management. *South African Journal of Science* 100: 19, 20.

VAN WILGEN, B.W., COWLING, R.M. & BURGERS, C.J. 1996. Valuation of ecosystem services. A case study from South African fynbos ecosystems. *Bioscience* 46: 184–189.

VAN WILGEN, B.W., REYERS, B., LE MAITRE, D.C., RICHARDSON, D.M. & 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, B.W., DYER, C., HOFFMANN, J.H., IVEY, P., LE MAITRE, D.C., MOORE, J.L., RICHARDSON, D.M., ROUGET, M., WANNENBURGH, A. & WILSON, J.R.U. 2011. National-scale strategic approaches for managing introduced plants: insights from Australian acacias in South Africa. *Diversity and Distributions* 17: 1060–1075.

VAN WYK, A.E. & SMITH, G.F. 2001. *Regions of floristic endemism in southern Africa*. Umdaus Press, Pretoria.

VAN ZINDEREN BAKKER, E.M. & COETZEE, J.A. 1988. A review of Late Quaternary pollen studies in east, central and southern Africa. *Review of Palaeobotany and Palynology* 55: 155–174.

WELLS, M.J., POYNTON, R.J., BALSINHAS, A.A., MUSIL, K.J., JOFFE, H., VAN HOEPEN, E. & ABBOTT, S.K. 1986. The history of introduction of invasive plants to southern Africa. In I.A.W. Macdonald, F.J. Kruger & A.A. Ferrar, *The ecology and management of biological invasions in southern Africa*: 21–35. Oxford University Press, Cape Town.

WOODWARD, F.I. 2001. Effects of climate. In S.A. Levin, *Encyclopedia of Biodiversity (Volume 1)*: 727–740. Academic Press, San Diego.