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Changes in the composition and distribution of alien plants in South Africa: An update from the Southern African Plant Invaders Atlas

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Background: Data on alien species status and occurrence are essential variables for the monitoring and reporting of biological invasions. The Southern African Plant Invaders Atlas (SAPIA) Project has, over the past 23 years, atlassed alien plants growing outside of cultivation.

Objectives: To document changes in the alien plant taxa recorded in SAPIA, assess trends in invasive distributions and explore effects of management and regulations.

Method: The numbers of alien plant taxa recorded were compared between May 2006 and May 2016, and changes in the extent of invasions at a quarter-degree squares (qds) scale were compared between 2000 and 2016. The effectiveness of regulations and interventions was assessed in terms of the relative change in the extent of invasions.

Results: As of May 2016, SAPIA had records for 773 alien plant taxa, an increase of 172 since 2006. Between 2000 and 2016, the number of qds occupied by alien plants increased by ~50%, due both to ongoing sampling and to spread. Successful classical biological control programmes have reduced the rate of spread of some taxa and in a few cases have led to range contractions. However, other interventions had no detectable effect at a qds scale.

Conclusions: South Africa has a growing number of invasive alien plant species across an increasing area. More taxa should be listed under national regulations, but ultimately more needs to be done to ensure that management is strategic and effective. SAPIA is a valuable tool for monitoring alien plant status and should be developed further so that invasions can be accurately tracked over time.

Introduction

There has been an increasing emphasis on developing standard metrics to measure and report biodiversity change (Pereira et al. 2013). In particular, there has been a recent call for a standardised system to monitor biological invasions in a country using information on (1) alien species occurrence, (2) species alien status (status of a species as either alien or native) and (3) alien species impact (Latombe et al. in press), although metrics on invaded areas and dispersal pathways will also be required (McGeoch et al. 2016; Wilson et al. 2017a). In terms of countries reporting on alien species occurrence, Latombe et al. (in press) argued that there should be a modular approach such that as national observation and monitoring systems develop, they become increasingly sophisticated. Four key stages in the development of such a monitoring system were identified: from a national list of alien species, to the presence of alien species in priority sites, to estimates of the national extent and area occupied by species and finally to a network of long-term monitoring sites. South Africa is in the enviable situation of already having achieved the third of these stages through a long-running atlas project that has been recording information on the national extent of alien plants since 1994 – the Southern African Plant Invaders Atlas (SAPIA) (Henderson 1998a).

The Southern African Plant Invaders Atlas was launched in January 1994 to collate data on the distribution, abundance and habitat types of alien plants growing outside of cultivation in southern Africa (Henderson 1998a). The atlas region covers primarily South Africa, and to a much lesser extent, neighbouring countries. The SAPIA database incorporates records gathered by 670 participants since 1994, along with roadside surveys by the lead author (L.H.) since 1979 (Henderson 1989, 1991a, 1991b, 1992, 1998b, 2007; Henderson & Musil 1984; Wells, Duggan & Henderson 1980). The species lists and distribution data in the SAPIA database have provided baseline information for national projects on invasive alien plants, such as the Natural Resources Management

Note: This paper was initially delivered at the 43rd Annual Research Symposium on the Management of Biological Invasions in South Africa, Goudini Spa, Western Cape, South Africa on 18-20 May 2016.

Programmes (NRMP) of the Department of Environmental Affairs (DEA). It has also directly contributed to the listing of invasive plants under the *Alien and Invasive Species Regulations* of the *National Environmental Management: Biodiversity Act*, Act 10 of 2004 (NEM:BA A&IS Regulations) (Department of Environmental Affairs 2014a). The SAPIA database is a useful and functioning resource for the storage, management and verification of data and as such provides support to a number of applied initiatives, including biological control (Zachariades et al. 2017) and work on incursion response planning by the South African National Biodiversity Institute's Invasive Species Programme (SANBI's ISP; Wilson et al. 2013).

The first comprehensive overview of the SAPIA database was published in 2007 (Henderson 2007). This publication gave a listing of all taxa in the database up to May 2006 and comprehensive information on the geographical extent and abundance of all taxa from 1979 until the end of 2000. A total of 557 species or 601 taxa (species, infra-specific taxa and unidentified species) were listed, of which 97 were prominent invaders. The SAPIA database is not, however, the most comprehensive source of information on naturalised species in South Africa. The first compilation of naturalised plants was produced by Wells et al. (1986), and at least a further 500 naturalised species are known in South Africa from the literature and herbarium collections in South Africa (Germishuizen & Meyer 2003; POSA 2012).

The aims of this paper are to:

- provide an updated list of alien plant taxa recorded in SAPIA and their invasion status in South Africa;
- document changes in the recorded extent of alien plant taxa and assess factors that might be responsible for these changes;
- provide support for decisions on national projects dealing with legislation and the control of invasive alien plants; and
- provide recommendations for how SAPIA can be improved to support efforts to monitor and report on the status of biological invasions in the region.

Methods

The SAPIA database is regularly updated with the latest copy of the database available from the lead author (L.H.) or from SANBI. This analysis was conducted using data collated in SAPIA up until the end of May 2016 (see Online Appendix 1 for the data here). Records were limited to alien plant taxa recorded as naturalised or as escapes from cultivation in South Africa, Lesotho and Swaziland. However, in a few instances, there are taxa that are not recorded from these three countries but are recorded as naturalised in neighbouring countries – these were noted. Current species and family names are mainly according to the Plant List (2013) and US National Plant Germplasm System: GRIN Taxonomy (2016).

Species introduction status

The previous review by Henderson (2007) provided data on taxa added to SAPIA up to May 2006; here, we examined the taxa that were added until May 2016 (i.e. over the course of a decade, Appendix 1). To look for taxonomic biases, we tested to see which families had significant changes in the number of taxa recorded in SAPIA relative to other families by calculating the probability using the hypergeometric distribution in R (R Core Team 2016). We corrected for multiple comparisons using the p.adjust function using the false discovery rate test (Benjamini & Hochberg 1995).

For a taxon to be recorded in SAPIA, it must have been growing outside of cultivation, but the population need not be invasive or have naturalised (*sensu* Blackburn et al. 2011, see also Appendix 2, Table 1-A2). To assess the link between SAPIA and the Blackburn Scheme, we compared information on the distribution and number of records in SAPIA with two recent detailed field evaluations: Jacobs et al. (2017) looked at *Melaleuca* spp. and N. Magona (unpublished data) did a similar exercise for *Acacia* spp.

Species distribution status

The Southern African Plant Invaders Atlas records come from several main sources – roadside surveys conducted by the lead author (L.H.), records from academics and managers specifically tasked with monitoring particular species (e.g. SANBI's ISP) and, finally, the general public using methods described in Henderson (2007). Roadside surveys by the lead author (L.H.) were conducted per 5-min square, using five qualitative abundance ratings [(1) rare: one sighting of one or a few plants; (2) occasional: a few sightings of one or a few plants; (3) frequent: many sightings of single plants or small groups; (4) abundant: many clumps or stands; and (5) very abundant: extensive stands]. Recently, all records are assigned a point locality with a note on precision and extent at the locale. As the aim of this paper was to look for broad-scale changes, and as the aim of SAPIA is to provide an atlas rather than detailed landscape level maps, we analysed distributions in terms of occupancy of quarter-degree squares (qds). To provide a comparison with the last review (Henderson 2007), distributions for the period up to 2000 were compared to those from the period from 2000 to May 2016. To limit bias, plant taxa that were added to the database based on records collected prior to 2000 but only collated after 2000 were not used in the analyses of changes in range.

To analyse changes in species distributions, we first looked at the changes between 2000 and 2016 with respect to how widespread plants were in 2000. There was no *a priori* reason to expect the relationship to be linear or log-linear, but initial assessments using general additive models indicated that the relationship was well described by a log-linear model. However, when these data were analysed using generalised linear models with Poisson errors, the residuals were heavily skewed. This was not surprising as there were numerous taxa that were in zero qds in 2000 but in several qds in 2016, while increases in the range of widespread taxa are limited by the size of the region (and more specifically, the number of qds that have suitable climate or habitat, e.g. Wilson et al. 2007). As such, we used a linear model with negative binomial errors (function glm.nb in the MASS library, Venables & Ripley 2002). Given the relationship is actually bounded, it might be expected to overestimate possible increases in range sizes, but checks of the fit of the model indicated that it was within acceptable ranges.

We then determined which taxa showed the greatest increase in their recorded ranges by examining the residuals from the fitted model. This provided an objective ranking of taxa in terms of increases in distributions relative to each other (Appendix 3, Table 1-A3). However, these increases are influenced by the focus of the sampling, which changed over the period under investigation. Prior to 2000, herbaceous taxa were largely excluded from SAPIA [except for about 33 species; most of which were listed as declared weeds under the *Conservation of Agricultural Resources Act* (CARA)]. Between 2000 and 2016, the curator of SAPIA (the lead author, L.H.) decided to more systematically record agricultural weeds and herbaceous taxa associated with human disturbance. Using expert opinion, taxa were classified as those that were known to have been under-recorded prior to 2000 and omitted from the analysis to determine a list of taxa that have spread most over the period (as opposed to those that have simply been sampled more).

To explore the impact of survey effort on distribution changes, we also compared changes in the distribution of species that have been the focus of intense survey effort over this period. The taxa selected were part of active projects to determine eradication feasibility by the SANBI's ISP (see Table 1 in Wilson et al. 2013).

Effectiveness of interventions and regulations

The NEM:BA A&IS Lists are based on the current impact and the future threat that species pose to South Africa (see Appendix 2, Table 2-A2 for a description of the different regulatory categories). Nonetheless, one would expect a link between the regulatory categories, status and extent (Parker et al. 1999 but see Hulme 2012). We first plotted range size against the regulatory status, and then tested to see if adding regulatory status as a factor to the model would have an impact on model fit.

Similarly, to explore the impact of management on the observed changes in distribution, we compared listed taxa that have been subject to clearing operations by the DEA's NRMP between 2000 and 2012 (A. Wannenburgh, unpublished information, notes on each taxa are in Online

TABLE 1: Plants that have shown the greatest increase in range in the Southern African Plant Invaders Atlas (SAPIA) 2000–2016, and that locally reach very high local abundances.

Taxon	Common name	qds up to 2000	qds up to 2016
Cylindropuntia fulgida var. *mamillata*	Boxing-glove cactus	0	83
Campuloclinium macrocephalum	Pompom weed	14	108
Argemone ochroleuca subsp. ochroleuca	White-flowered Mexican poppy	154	516
Parthenium hysterophorus	Famine weed	15	89
Opuntia engelmannii (= *O. lindheimeri*; *O. tardospina*)	Small round-leaved prickly pear	10	65
Mirabilis jalapa	Four-o' clock	7	52
Opuntia humifusa	Creeping prickly pear	25	99
Cryptostegia grandiflora	Rubber vine	1	18
Pennisetum setaceum	Fountain grass	66	174
Cortaderia jubata	Purple pampas grass	7	36
Cirsium vulgare	Spear thistle	188	365
Prosopis glandulosa var. *torreyana*	Honey mesquite	40	112
Limonium sinuatum	Statice	10	43
Tecoma stans	Yellow bells	57	139
Sagittaria platyphylla	Slender arrowhead	0	8
Egeria densa	Dense water weed	2	16
Echium plantagineum	Patterson's curse	51	119
Glyceria maxima	Reed meadow grass	0	7
Sorghum halepense	Johnson grass OR Aleppo grass	41	99
Trichocereus spachianus (*Echinopsis spachiana* misapplied; *E. schickendantzii* misapplied)	Torch cactus	57	123
Argemone albiflora subsp. *texana*	White prickly poppy	0	6
Lilium formosanum (= *L. longiflorum* var. *formosanum*)	Formosa lily	15	43
Tithonia rotundifolia	Red sunflower	19	47
Xanthium strumarium	Large cocklebur	149	234
Eucalyptus camaldulensis	River red gum	121	195
Cereus jamacaru	Queen of the night	124	199
Cylindropuntia imbricata (= *Opuntia imbricata*)	Imbricate cactus	131	208
Ageratum houstonianum	Mexican ageratum	26	56
Dolichandra unguis-cati (= *Macfadyena unguis-cati*)	Cat's claw creeper	22	49
Ageratina adenophora	Crofton weed	11	29

This is based on ranking taxa according to the residuals of the fitted relationship between increase in range over 2000–2016 and range in 2000 (Figure 2, Appendix 5) with those taxa that are known to have been under-reported prior to 2000 excluded from the model. Only 30 taxa that are known to have reached very high local abundance are shown here. For the 50 taxa that have shown the greatest increase in recorded range (irrespective of sampling effort and local abundance), see Appendix 3. Note that these increases can still represent differences in sampling effort and identification and not actual spread. For example, *Cylindropuntia fulgida* var. *mamillata* was most probably highly under-reported before 2000, with some infestations likely to be over 30 years old (H.G. Zimmermann), and *Prosopis glandulosa* var. *torreyana* was possibly under-reported before 2000 because of difficulty in distinguishing the species and hybrids.

Appendix 1) to listed taxa that have not been subject to clearing.

The efficacy of biological control programmes has been assessed for all plants targeted using a standard system (Klein 2011; Moran, Hoffmann & Hill 2011a; Zachariades et al. 2017; see Appendix 2, Table 3-A2 for a list of the descriptions). To assess whether the success of biological control has also had an impact on alien plant distributions, we first looked to see if taxa that were under 'complete' biological control have shown less of an increase in range over the period 2000–2016 by adding this as a factor in the model. Second, to assess the impact in more depth, we looked at two plant groups that have been subjected to long-standing, highly successful and well-monitored biological control programmes – Australian acacias (Impson et al. 2011), and six invasive aquatic species that have been intensively surveyed by biological control researchers at the Agricultural Research Council (ARC) and Rhodes University over the past decade (Hill & Coetzee 2017).

Results

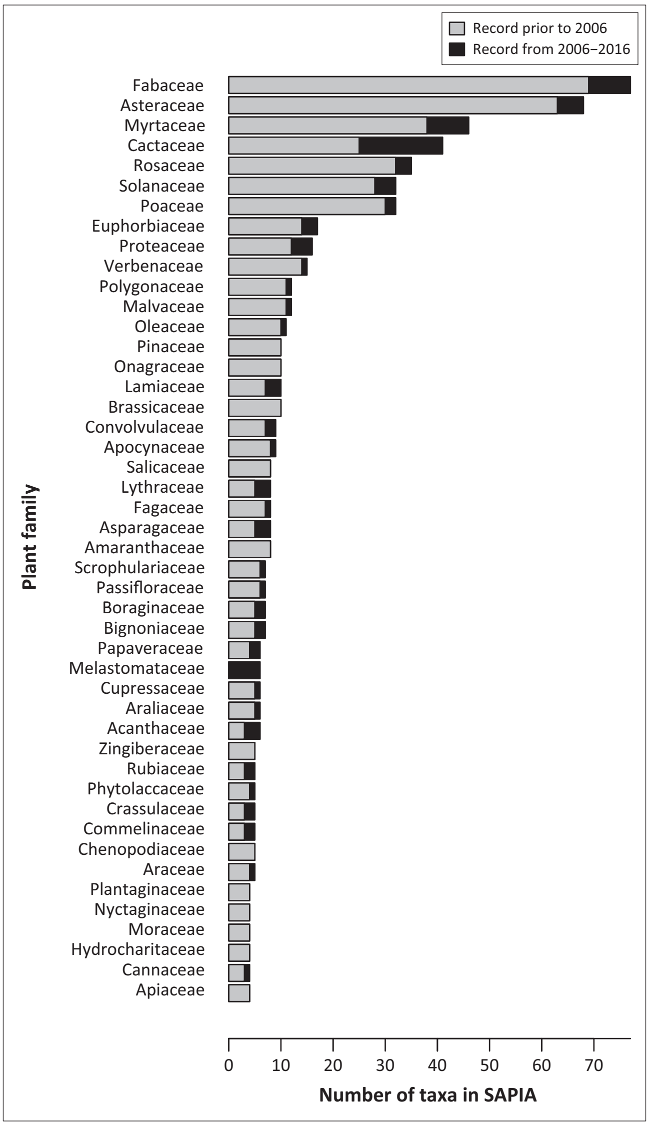
The data set extracted from SAPIA and used in this analysis is available as Online Appendix 1.

Species introduction status

There were 773 taxa (species, infra-specific taxa and combined taxa) catalogued in the SAPIA database from South Africa as of May 2016. This represents an increase in 172 taxa since May 2006 (although due to changes in nomenclature the true increase is slightly different, see discussion). Of these new taxa, 130 have no prior records in POSA (2012), Germishuizen and Meyer (2003) or Wells et al. (1986) (see Appendix 1 for a full list of new taxa); 73 of these have only been recorded in one qds, whereas 14 have been recorded in more than five qds. There were an additional nine taxa that have been recorded in SAPIA from neighbouring countries but not as yet in South Africa (see Online Appendix 1).

The families with the most new taxa recorded since 2006 were Cactaceae with 16 taxa, followed by Fabaceae and Myrtaceae with 8 taxa each; Melastomataceae and Asteraceae have 6 and 5 new taxa, respectively (Figure 1). Significantly more taxa in Berberidaceae, Cactaceae, Ericaceae, Melastomataceae and Polypodiaceae were added in this period to SAPIA when compared with other families, and relatively fewer taxa of Asteraceae and Fabaceae were added. Both Cactaceae and Melastomataceae had significantly more additions after correcting for multiple comparisons.

The introduction status of taxa as determined by dedicated and detailed field surveys shows that the extent as captured by SAPIA provides a fairly good indication of introduction status (Appendix 4). Taxa recorded in SAPIA from multiple sites are almost invariably category E under Blackburn et al.'s (2011) scheme. All taxa that were found to have naturalised populations were listed in SAPIA, and only a few taxa with



Source: Online Appendix 1

FIGURE 1: The number of alien plant taxa recorded in Southern African Plant Invaders Atlas (SAPIA) split along familial lines. Only families with at least four taxa are shown.

naturalised populations had not yet been added to SAPIA (although they would be based on these field observations). However, for taxa recorded from only a few sites, detailed field evaluations will be required to confirm the extent of naturalisation and invasion.

Species distribution status

As of May 2016, SAPIA contained 87 000 records. As there were often multiple records of a species from any qds, the number of instances of an alien plant being present in a qds was 26 554. Between 2000 and 2016, there were 9069 instances where a taxon was found in a new qds, although if under-recorded taxa are excluded, there are 7221 instances [207 taxa are under-recorded in the SAPIA database and may be better documented in POSA and Germishuizen and Meyer (2003), see Online Appendix 1 for details]. This represents approximately a 43% increase in range since 2000 (~50% if previously under-recorded taxa are included). This does not, however, reflect instances where taxa have disappeared from a qds over this period (e.g. aquatic weeds), and these figures do not include taxa that were added to SAPIA based on records prior to 2000 (as the figure at that time was not known).

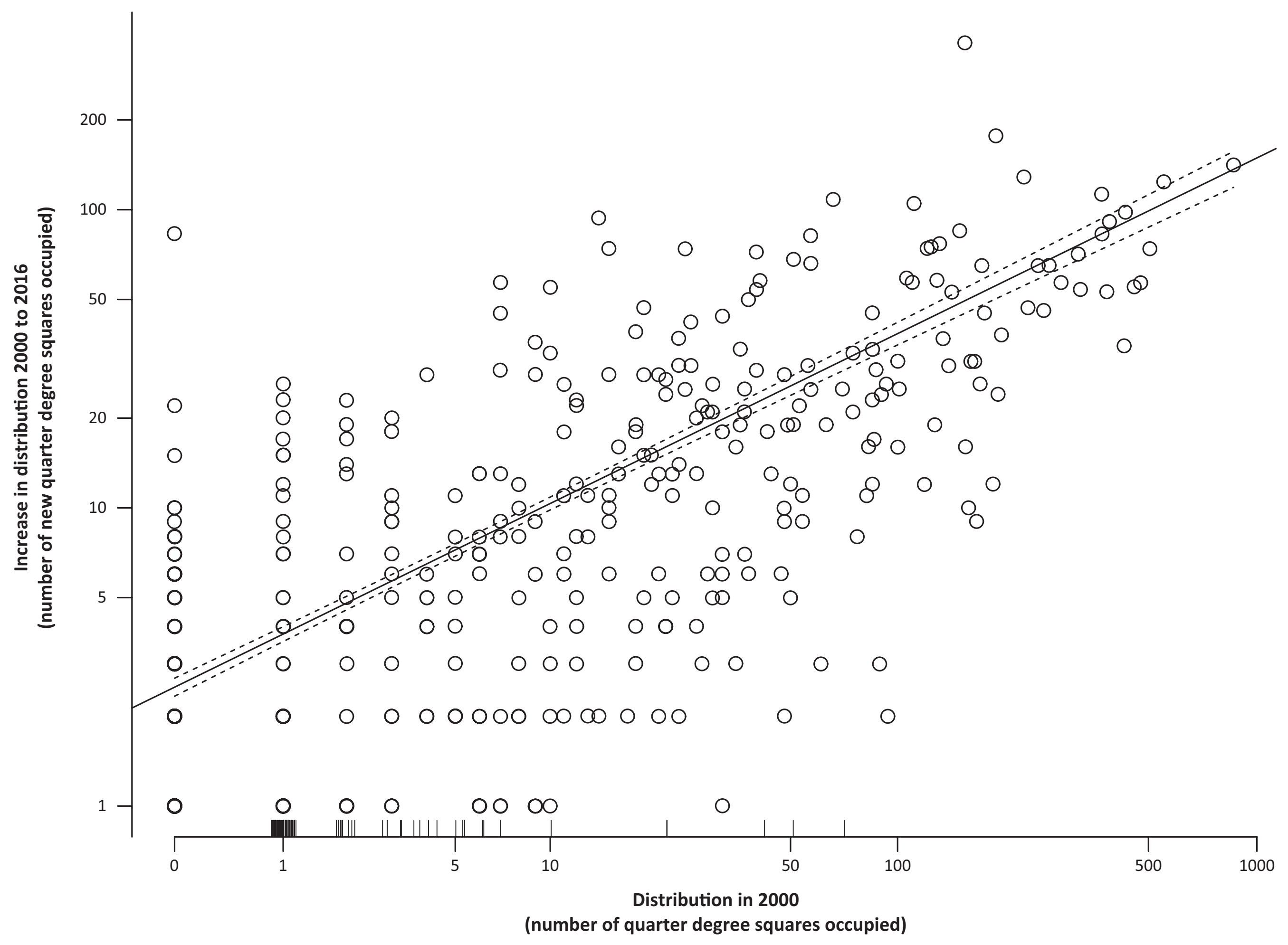
A generalised linear model with negative binomial errors provided a good fit to the data on the increase in distribution over the period 2000–2016 as a function of distribution in 2000 (Figure 2, Appendix 5). Taxa with small ranges in 2000 have seen their broad-scale distributions increase on average by up to fivefold over the intervening 16 years, while very widespread taxa have on average increased by 10%. By comparison, the annual rate of spread of alien trees at a landscape scale in South Africa is often estimated in the region of 4% – 8% when projecting costs (e.g. van Wilgen et al. 2016). It is not clear whether these differences are due to different rates of spread at different scales, or due to SAPIA still having under-sampled widespread taxa; but clearly, there is a very large amount of variation and using a single figure for spread in any model is highly questionable.

The list of taxa that have shown the greatest relative increase in range size is shown in Table 1.

The 38 taxa targeted by SANBI ISP (i.e. taxa that have been the focus of intense survey effort) showed a significantly greater increase in range than other taxa (LR = 11.8, d.f. = 1, $p < 0.01$), although the interaction effect between range size in 2000 and SANBI ISP was not significant. This result was consistent even if under-recorded taxa were excluded (LR = 30.1, d.f. = 1, $p < 0.01$; notably four SANBI ISP targets are known to be under-recorded in SAPIA prior to 2000: *Furcraea foetida*, *Harrisia balansae*, *Hydrilla verticillata* and *Paspalum quadrifarium*). While the SANBI ISP targets are clearly not a random selection of taxa, this result supports the contention that while SAPIA provides a useful baseline, more intensive surveys are required to get accurate estimates of range sizes.

Effectiveness of interventions and regulations

A total of 379 terrestrial plant taxa or 378 species are listed under the NEM:BA A&IS Regulations. All listed taxa which



Source: Online appendix 1

Each point is a taxon recorded in SAPIA, with taxa that did not increase in range shown as ticks on the x-axis. Taxa that are known to have been under-recorded prior to 2000 are not shown to minimise the impact of sampling effort on the pattern (see Appendix 5 for a plot of the full data set). The values shown are the cumulative number of qds where taxa are recorded, and so do not take into account the possibility that taxa are no longer present in those localities. The solid line is a fitted linear model assuming negative binomial errors, with the dotted lines as ±1 standard error around this line (see Appendix 5 for details). Some error (jitter) was added to the points to avoid over plotting.

FIGURE 2: The increase in recorded distribution of alien plants in Southern African Plant Invaders Atlas (SAPIA) between 2000 and 2016 as a function of their distribution in 2000.

are documented in SAPIA are noted in Online Appendix 1 (338 taxa in total). Of the 40 listed taxa which are not recorded in SAPIA, 26 are potentially invasive and have been listed as a precautionary measure, 11 are listed only for the sub-Antarctic's Prince Edward and Marion islands, and of the remaining 3, *Ammophila arenaria* is not recorded on SAPIA as SAPIA has not surveyed fore-dunes nor have any public reported the species, *Nephrolepis exaltata* is listed in the regulations due to a misidentification (it is recorded under the correct name, *Nephrolepis cordifolia,* in SAPIA) and *Orobanche ramosa* is a parasitic plant long known in the Western Cape but not recorded in SAPIA (Table 2). Around 44% of taxa recorded in SAPIA are listed, with newer additions to SAPIA less likely to have been listed (49% of taxa recorded in SAPIA prior to 2006 are regulated, whereas 18% of taxa recorded after 2006 are regulated).

There is a clear relationship between the listed category and how widespread alien plants are (LR = 178, d.f. = 4, $p < 0.001$; Figure 3). Category 1a taxa are similar in extent to non-listed taxa, category 1b taxa are much more widespread and curiously category 2 taxa (that can be grown under a permit) are the most widespread taxa. This might reflect the fact that taxa that are both useful and invasive have already been widely distributed for utilisation.

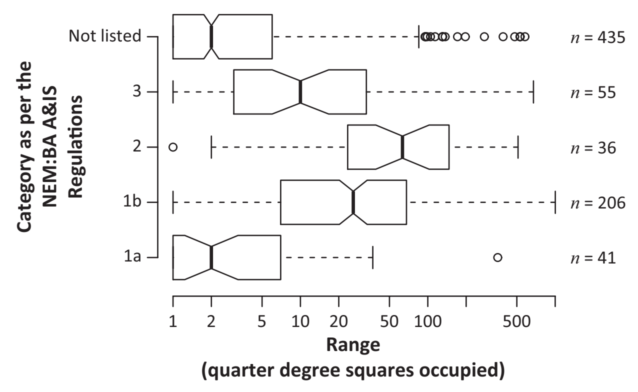
In terms of the link between regulatory status and the change in extent over the period 2000–2016, the interaction effect was

TABLE 2: Alien plant taxa that are listed under the NEM:BA A&IS Regulations, but which are not recorded in SAPIA.

Scientific name	Family	Common name	NEM:BA category	Reason for inclusion in NEM:BA
Ammophila arenaria	Poaceae	Marram grass	3	This species is clearly invasive in South Africa. However, it is not in SAPIA as coastal dune species were not recorded during the initial SAPIA surveys, and no records were received from the public
Bartlettina sordida	Asteraceae	Bartlettina	1b	Precautionary; invasive in New Zealand; invasive related genera in South Africa (*Ageratina, Campuloclinium, Chromolaena*)
Berberis thunbergii	Berberidaceae	Japanese barberry	3	Precautionary; invasive in USA
Cabomba caroliniana	Cabombaceae	Cabomba	1a	Precautionary; invasive and restricted in Australia, New Zealand, USA
Celtis occidentalis	Cannabaceae	European hackberry	3	Precautionary; invasive Australia; congeneric invasive species in South Africa
Cereus hexagonus	Cactaceae	Queen of the night	1b	Precautionary; difficult to distinguish from the invasive *C. jamacaru*
Cereus hildmannianus subsp. *uruguayanus*	Cactaceae	Queen of the night	1b	Suspected of being naturalised or interbreeding with the invasive *C. jamacaru*
Cotoneaster salicifolius	Rosaceae	Willow-leaved showberry	1b	Precautionary; restricted in Australia; congeneric invasive species in South Africa
Cotoneaster simonsii	Rosaceae	Himalayan cotoneaster	1b	Precautionary; invasive and restricted in Australia; congeneric invasive species in South Africa
Echinodorus cordifolius	Alismataceae	Creeping burhead	1b	Precautionary; potentially invasive; similar to invasive *Sagittaria* species in South Africa
Echinodorus tenellus	Alismataceae	Amazon swordplant	1b	Precautionary; potentially invasive; similar to invasive *Sagittaria* species in South Africa
Equisetum hyemale	Equisetaceae	Common scouring-rush	1a	Precautionary; invasive and restricted in Australia and New Zealand
Grevillea rosmarinifolia	Proteaceae	Rosemary grevillea	3	Precautionary; invasive in Australia
Houttuynia cordata	Saururaceae	Chameleon plant	3	Precautionary; invasive in Australia and New Zealand; restricted in New Zealand
Hypericum androsaemum	Hypericaceae	Tutsan	1b	Precautionary; invasive and restricted in Australia
Ludwigia peruviana	Onagraceae	Peruvian primrose bush	1a	Precautionary; invasive and restricted in Australia and New Zealand
Marsilea mutica	Marsileaceae	Australian water clover	1a	Precautionary; invasive and restricted in New Zealand
Nephrolepis exaltata	Nephrolepidaceae	Sword fern	1b and 3	Misidentified and invasive status unknown. Long mistaken as the invasive species in South Africa which has now been confirmed as *N. cordifolia*
Nuphar lutea	Nymphaeaceae	Yellow pond lily	1a	Precautionary; invasive and restricted in New Zealand
Nymphoides peltata	Menyanthaceae	Fringed water lily	1a	Precautionary; invasive in New Zealand and USA; restricted in New Zealand
Orobanche ramosa	Orobanchaceae	Branched broomrape	1b	Long known as a parasite on crops and native plants in the W Cape but not recorded in SAPIA. Invasive and the subject of eradication efforts in Australia and the USA
Paulownia tomentosa	Paulowniaceae	Empress tree	1a	Precautionary; invasive in Australia, New Zealand and USA; restricted in USA
Pyracantha crenatoserrata	Rosaceae	Chinese firethorn	1b	Precautionary; invasive and restricted in Australia; congeneric invasive species in South Africa
Pyracantha koidzumii	Rosaceae	Formosa firethorn	1b	Precautionary; invasive in Australia and USA; congeneric invasive species in South Africa
Rhus glabra	Anacardiaceae	Scarlet sumac	3	Precautionary; invasive in USA
Sasa ramosa	Poaceae	Dwarf yellow-striped bamboo	3	Precautionary; weed in Australia and Taiwan
Tamarix aphylla	Tamaricaceae	Desert tamarisk	1b	Precautionary; invasive in Australia and USA; restricted in Australia; congeneric invasive species in South Africa
Tamarix gallica	Tamaricaceae	French tamarisk	1b	Precautionary; invasive and restricted in USA; congeneric invasive species in South Africa
Vinca minor	Apocynaceae	Lesser periwinkle	1b	Precautionary; invasive in USA; congeneric invasive species in South Africa

Source: NEM: BA A&IS Regulations, *Alien and Invasive Species Regulations of the National Environmental Management: Biodiversity Act*, Act 10 of 2004; SAPIA, Southern African Plant Invaders Atlas

This table does not include 11 species which are listed only for South Africa's sub-Antarctic Prince Edward Islands (cf. Greve et al. 2017) as these are out of the scope of SAPIA *(Agrostis castellana, A. gigantea, A. stolonifera, Alopecurus geniculatus, Cerastium fontanum, Elytrigia repens, Festuca rubra, Luzula multiflora, Poa pratensis, Sagina procumbens* and *Stellaria media)*, although note six taxa listed for the Prince Edward Islands are also known to have naturalised in continental South Africa *(Agrostis gigantea, Cerastium fontanum, Elytrigia repens, Poa pratensis, Rumex acetosella* and *Stellaria media).*



Source: Online appendix 1

See Appendix 2b for a detailed description of the different categories, although it is worth noting that category 1a taxa are those targeted for nation-wide eradication, so should have relatively small ranges.

FIGURE 3: Different regulatory categories of alien plants in South Africa have very different range sizes.

not significant, although only just so (LR = 9.39, d.f. = 4, p = 0.0521). This is unsurprising, given the large differences in range size for the different regulatory categories (Figure 3). There was, however, a very large effect of regulatory status on observed rates of spread for those taxa which were not under-represented in SAPIA prior to 2000 (Appendix 5c). There were no significant differences between different categories of regulated taxa, but taxa in all regulated categories have spread much farther than non-listed taxa.

Approximately 126 taxa have been targeted for clearing by NRMP between 2000 and 2012. Most effort has been directed towards eight taxa, which make up 80% of the total condensed area treated. These taxa are: *Solanum mauritianum* (20%), *Acacia mearnsii* (14%), *Prosopis* spp. (14%), *Acacia dealbata* (9%), *Pinus* spp. (8%), *Cereus jamacaru* (7%), *Lantana camara* (4%) and *Eucalyptus* spp. (4%). Forty taxa make up 98% of the total condensed area treated. The remaining taxa make up 2% of the condensed area treated (Online Appendix 1). Targeting by DEA NRMP was not found to have a significant effect on the increase in broad-scale range of taxa relative to other taxa in SAPIA [e.g. when comparing a model with an interaction term between range size in 2000 and status as a major NRMP target with the base model with under-recorded taxa removed (i.e. Appendix 5b): LR = 3.69, d.f. = 2, p = 0.16].

Biological control programmes have been launched or are under investigation for 77 species, of which 13 species are rated as under complete control, 20 species under substantial control, 14 under negligible control, 1 under negligible to substantial control, 11 not determined and 18 under investigation (H. Klein, ARC-PPRI, pers. comm., July 2016) (Online Appendix 1). When the success of biological control was added to the model, the results were very complicated and not as expected. Taxa under complete control seemed to have actually spread farther relative to other taxa, whereas taxa under substantial (i.e. less control than complete) had spread less relative to other taxa. But a detailed interpretation was difficult as there was a significant interaction between range size in 2000, the level of success of the biological control and the spread observed. On closer inspection, it became clear that this was partly due to the fact that for some taxa that were under complete biological control, the agents responsible had only been released post-2000, that is, a plant taxon could have both spread rapidly and be contained by biological control in the period (*Cylindropuntia fulgida* var. *mamillata*, in particular). Therefore, we reran the analysis and compared taxa that were under complete or substantial biological control based on agents released prior to 2000 that caused considerable damage (*sensu* Klein 2011) against other taxa where there was a biological control programme in place, but if there was any success, it was later on (and so less likely to impact the pattern seen here). The result was much clearer. Alien plant taxa under successful biological control have spread much less than other alien plant taxa where biological control has been attempted (LR = 8.50, d.f. = 1, p = 0.0035). To put this in perspective, if a taxon was present in 100 qds in 2000, it would be expected to be in 127 qds by 2016 if biological control was successful, but 161 qds if biological control was not successful, that is, rates of spread were roughly halved.

Similarly, in terms of the specific biological control case-studies, Australian acacias that are under complete biological control appear to have shown much smaller increases in range than those that are not under complete control (Table 3). For the biological control of aquatic weeds, the results are even more impressive (Table 4). While there have been increases in the total number of qds that have ever been invaded, it is clear that the current range of several taxa has actually decreased over time.

Discussion

South Africa has a major alien plant invasion debt (Rouget et al. 2016). Well over a 100 new taxa have been recorded as naturalised or escapes from cultivation in the past decade and the recorded range of almost all plants has increased significantly. These observations are both cause for concern. However, it is also clear that there is a strong correlation between survey effort and both the number of naturalised plants detected and the extent of known invaders. Only for a very few taxa where explicit resources have been dedicated to their survey (e.g. Hill & Coetzee 2017; Wilson et al. 2013), can we be confident that their range is reasonably delimited at a qds scale. Thankfully, effective biological control (Zachariades et al. 2017) appears to have reduced rates of spread and have actually resulted in a contraction of the range of some taxa. Below, we discuss these and a few other results in more depth, make recommendations for improvements to the NEM:BA A&IS Regulations and conclude with how SAPIA can be improved in future.

Major increasing environmental threats

Species capable of invading and persisting in natural vegetation, and referred to as environmental weeds, pose the

TABLE 3: Biological control and changes in the distribution of invasive *Acacia* species.

Scientific name	Common name	qds up to 2000	qds up to 2016	% change	Increase relative to other taxa in SAPIA	Feeding guild of biological control agent and date of first release	Level of biological control
Acacia longifolia	Long-leaved wattle	94	96	2	-1.81	Bud galler (1982) Seed-feeder (1985)	Substantial
Acacia cyclops	Rooikrans	166	175	5	-1.28	Seed-feeder (1994) Flower galler (2001)	Substantial
Acacia saligna	Port Jackson	158	168	6	-1.2	Gall former (1987) Seed-feeder (2001)	Substantial
Acacia pycnantha	Golden wattle	35	38	8	-1.34	Bud galler (1987) Seed-feeder (2003)	Substantial
Acacia mearnsii	Black wattle	428	463	8	-0.78	Seed-feeder (1994) Flower galler (2006)	Not determined
Acacia baileyana	Bailey's wattle	86	103	20	-0.61	Seed-feeder (2006)	Negligible
Acacia melanoxylon	Australian blackwood	134	171	28	-0.19	Seed-feeder (1986)	Substantial
Acacia podalyriifolia	Pearl acacia	57	82	44	-0.09	Seed-feeder (2008)	Not determined
Acacia elata	Pepper tree wattle	35	51	46	-0.24	None	Under investigation

Source: Klein 2011; Impson et al. 2011; with the level of control as per the categories in Appendix 2c.

The increase relative to other taxa in SAPIA is based on residuals from the model with under-reported taxa removed (Appendix 5b). I've suggested a move, but if it isn't done, please still correct to 2c

qds, quarter-degree squares; SAPIA, Southern African Plant Invaders Atlas.

TABLE 4: Biological control and changes in the distribution of invasive aquatic species.

Scientific name	Common name	qds cumulative up to 2000	qds cumulative up to 2016	qds new	qds actual	% change	Level of biological control
				2001–2016	2001–2016	2001–2016	
Azolla filiculoides	Red water fern	191	215	24	65	-66	Complete
Myriophyllum aquaticum	Parrot's feather	48	58	10	29	-40	Complete
Eichhornia crassipes	Water hyacinth	87	116	29	74	-15	Substantial
Pistia stratiotes	Water lettuce	24	38	14	25	4	Complete
Salvinia molesta	Salvinia	28	50	22	41	46	Complete
Azolla cristata	Tropical red water fern	19	34	15	29	53	Under investigation

Cumulative qds up to 2000 and 2016 include historical qds where a taxon may no longer be present due to biological control; actual qds are where a taxon was confirmed to be present between 2001 and 2016. These data are based on surveys of water bodies conducted by biological control researchers at the Agricultural Research Council (ARC) and Rhodes University over the past decade (Hill & Coetzee 2017). As they revisited sites, it is possible to monitor absences (i.e. sites that were known to be occupied prior to 2000 but were not found to be occupied 2001–2016).

qds, quarter-degree squares.

greatest threat to biodiversity. While an aim of this paper was to determine which taxa have spread the most since 2000 (i.e. Table 1), this does not give the complete picture of which taxa pose the greatest threats. The analyses presented here represent a starting point, but to fully assess and prioritise control programmes, information on potential future spread, field observations as to the impacts caused and the experiences of managers on the ground must be taken into account. We draw attention to nine taxa that we believe are of particular concern (Figure 4): *Campuloclinium macrocephalum*, *Parthenium hysterophorus*, *Opuntia engelmannii*, *Cryptostegia grandiflora*, *Pennisetum setaceum*, *Tecoma stans*, *Sagittaria platyphylla*, *Gleditsia triacanthos* and *Trichocereus spachianus* (see Zachariades et al. 2017 and references therein for a discussion on biological control of some of these taxa).

The species of most concern are those where biological control is not available, and that are not being contained by traditional control methods, in particular *C. grandiflora*, *P. setaceum* and *T. spachianus*. *Gleditsia triacanthos*, although it did not feature amongst the top 30 species in Table 1 because it has not been recorded at a high local abundance, almost doubled its extent from 111 to 216 qds and has the potential to become as troublesome as *Prosopis* spp. (Zachariades, Hoffmann & Roberts 2011) Biological control has only been partially effective against the Eastern Cape form of *O. engelmannii* (H. Klein, ARC-PPRI, pers. comm., July 2016). Biological control programmes are still at an early stage against *C. macrocephalum*, *T. stans*, *P. hysterophorus* and *S. platyphylla*. National species management programmes have been developed for some of these species (e.g. see Terblanche et al. 2016 for *P. hysterophorus*), but they are still to be implemented.

By contrast, the taxon that showed the greatest spread, *C. fulgida* var. *mamillata*, is not of particular concern as biological control has been extremely effective (Klein 2012) and has led to population collapse and death at all sites where the biological control agent, a cochineal, has been established (Xivuri et al. unpublished data). Similarly, there is effective biological control against *Opuntia humifusa*, although more work needs to be done to implement it.

It is perhaps not surprising that there was no evidence of DEA NRMP activities having reduced the rates of spread of targeted taxa. DEA NRMP control programmes are not

Source: Photos by Lesley Henderson

These plants are highlight as of particular concern based on: their spread over the past decade (e.g. Table 1); the fact there is not currently effective biological control; on observations of populations in the field; and on concerns raised by land managers. From top left by row to bottom right (based on relative rates of spread from fast to slow): *Campuloclinium macrocephalum*, *Parthenium hysterophorus*, *Opuntia engelmannii*, *Cryptostegia grandiflora*, *Pennisetum setaceum*, *Tecoma stans*, *Sagittaria platyphylla, Gleditsia triacanthos* and *Trichocereus spachianus*.

FIGURE 4: Nine alien plants that have shown large increases in range and that we consider to be the most important environmental threats.

strategic (van Wilgen et al. 2012), and as far as we are aware there have been no dedicated strategic efforts to contain specific invasive plants, or to reduce the rate at which they invade particular areas (see Le Maitre, Forsyth & Wilson 2015 for an example of a proposed strategy). By contrast, there is a clear signal that biological control has reduced the rates of spread.

Biological control as a method of limiting and reducing alien plant extents

Some species that have been the subjects of successful biological control programmes have shown very little expansion in their distribution areas in terms of qds occupied, and in general, successful biological control seems to be associated with a reduction in the rate of spread. In particular, the SAPIA distribution data presented here support the theory that seed-reducing agents are capable of slowing rates of spread and curbing expansion of invasive alien plant populations (Table 3). While it could be argued that these species have shown little expansion because they have almost reached the limits of their suitable range, models of their potential range indicate that there are still large suitable areas of the country as yet uninvaded (Rouget et al. 2004; Wilson et al. 2007), and the model used here takes starting range size into account and looks at changes relative to other taxa.

SAPIA also has good evidence of range contraction of *Azolla filiculoides* following the implementation of a biological control programme (Henderson 2011). Evidence of range contraction was made possible by intensive surveys prior to and following biological control by the researchers involved in the biological control programme (Coetzee et al. 2011, McConnachie, Hill & Byrne 2004). Up to the year 2000, shortly after the commencement of biological control, *A. filiculoides* had been recorded in 191 qds (see Table 4). By 2004, biological control led to the extirpation of *A. filiculoides* from the majority of sites surveyed (Coetzee et al. 2011). From 2001 to May 2016, it was recorded in only 24 new qds. Although the cumulative total qds is 215, it was actually recorded in 65 qds since 2001 (equivalent to a 66% contraction), and in only 14 qds since 2010 (equivalent to a 92% contraction). Aquatic weeds also showing contraction are *Myriophyllum aquaticum* with a 40% reduction and *Eichhornia crassipes* with a 15% contraction. *Pistia stratiotes* showed a slight expansion with almost as many qds up to 2000 as after 2000. *Salvinia molesta* showed the most expansion of 46%. Coetzee et al. (2011) still regard the programmes against *P. stratiotes* and *S. molesta* as successful but require better implementation of the programmes, with augmentative releases and re-distribution of agents. *Azolla cristata*, which has not been part of a formal biological control programme, showed the most expansion of 53%. This data set highlights the value of repeated monitoring at the same sites over time to determine trends.

New threats

The large number of cacti amongst the newly recorded taxa is probably partly the result of increased detection and awareness created by the national cactus working group

TABLE 5: Invasive plant taxa where sterile cultivars or hybrids are exempted from NEM:BA.

Scientific name	Family	Common name	Range in qds
Acer negundo	Aceraceae	Ash-leaved maple	21
Ageratum houstonianum	Asteraceae	Mexican ageratum	56
Buddleja davidii	Scrophulariaceae	Chinese sagewood	1
Berberis thunbergii	Berberidaceae	Japanese barberry	0
Callistemon viminalis (= *Melaleuca viminalis*)	Myrtaceae	Weeping bottlebrush	12
Canna indica	Cannaceae	Indian shot	68
Catharanthus roseus	Apocynaceae	Madagascar periwinkle	88
Centranthus ruber	Caprifoliaceae	Red valerian	6
Cestrum species not specifically listed	Solanaceae	Cestrums	0
Coreopsis lanceolata	Asteraceae	Tickseed	37
Cortaderia selloana	Poaceae	Common pampas grass	36
Duranta erecta	Verbenaceae	Forget-me-not-tree	38
Gleditsia triacanthos	Fabaceae	Honey locust	216
Hedera canariensis	Araliaceae	Canary ivy	2
Hedera helix	Araliaceae	English ivy	3
Ipomoea indica	Convolvulaceae	Morning glory	34
Ipomoea purpurea	Convolvulaceae	Common morning glory	62
Ligustrum lucidum	Oleaceae	Chinese wax-leaved privet	35
Ligustrum ovalifolium	Oleaceae	Californian privet	3
Limonium sinuatum	Plumbaginaceae	Statice	43
Metrosideros excelsa	Myrtaceae	New Zealand Christmas tree	3
Morus alba	Moraceae	Common mulberry	187
Murraya paniculata (= *M. exotica*)	Rutaceae	Orange jessamine	2
Nephrolepis cordifolia (previously misidentified as *N. exaltata*)	Nephrolepidaceae	Erect sword fern	21
Nephrolepis exaltata	Nephrolepidaceae	Sword fern	?
Nerium oleander	Apocynaceae	Oleander	28
Pennisetum setaceum	Poaceae	Fountain grass	174
Pinus elliottii	Pinaceae	Slash pine	33
Pyracantha angustifolia	Rosaceae	Yellow firethorn	195
Pyracantha coccinea	Rosaceae	Red firethorn	7
Pyracantha crenatoserrata	Rosaceae	Chinese firethorn	0
Pyracantha crenulata	Rosaceae	Himalayan firethorn	46
Pyracantha koidzumii	Rosaceae	Formosa firethorn	0
Vinca major	Apocynaceae	Greater periwinkle	24
Vinca minor	Apocynaceae	Lesser periwinkle	0

Source: Department of Environmental Affairs 2014a, 2014b

Cultivars of *Lantana* species or hybrids non-indigenous to South Africa are not stated as exempt but are inferred as exempt by the listing of all seed-producing species and hybrids.

(Kaplan et al., 2017), and it is apparent from field surveys that some taxa have probably been naturalised for decades, for example, *C. fulgida* var. *mamillata* (H.G. Zimmermann, Helmuth Zimmermann & Associates, pers. comm., July 2016). However, this also represents a new wave of cactus invasions arising from horticulture rather than agriculture (Novoa et al. 2015). Many new taxa in the Proteaceae and Myrtaceae have been recorded for the Western Cape and include species of *Banksia*, *Callistemon* and *Melaleuca* used in horticulture and floriculture. By contrast, there have been few recent introductions for forestry, so it is unsurprising that there were no new records of naturalisation in Pinaceae.

We expect that different threats will emerge as the dominant pathways of dispersal into and around the country change. In particular, there is the potential for spread between neighbouring countries (Faulkner et al. 2017). Some of the taxa that are invasive in neighbouring countries might already be in cultivation or might have had opportunities to spread but the climate is not suitable; but in some cases, spread of alien plants from neighbouring countries has been indicated as the primary source of invasions in South Africa (e.g. *P. hysterophorus*). A few species in SAPIA only recorded for Zimbabwe and Mozambique which are of concern are *Hyptis suaveolens*, *Limnobium laevigatum* and *Vernonanthura phosphorica* (Online Appendix 1). This is an issue that will clearly require greater international cooperation in biosecurity (Faulkner et al. 2017).

While it is concerning that taxa which have been assessed for their eradication feasibility appear to have spread significantly faster than other taxa, much of this is likely down to survey effort. All the SANBI ISP targets are the subject of active and passive surveillance programmes, often with the production of detailed risk maps and engagement with local stakeholders (e.g. Kaplan et al. 2014). As such, the current known distributions of SANBI ISP targets are expected to be much closer to the actual distributions – such a broad-scale delimitation is a pre-requisite for a successful incursion response (Wilson et al. 2017b). While this serves to again highlight the fact that many taxa in SAPIA are likely to be under-sampled, it is, however, also likely that many SANBI ISP targets are indeed spreading. The distribution of *C. macrocephalum* (pompom weed), for example, has increased rapidly over the past decade, and its spread has probably been exacerbated by various human-mediated dispersal vectors (McConnachie et al. 2011). Therefore, the 130 newly recorded taxa (Appendix 1) should be urgently screened for taxa where nation-wide eradication might be a feasible and desirable goal (category 1a under the NEM:BA A&IS Regulations). Of course, this is not to say that other taxa should not be likewise assessed. For example, *Bartlettina sordida*, which is not recorded in SAPIA, but is listed as category 1b, should be assessed for eradication feasibility and listing as category 1a. It is known to be in cultivation, but so far, there are no records of invasion. Evidence of its invasiveness in New Zealand (Breitwieser et al. 2010–2016), and its close relationship to other notoriously invasive species of the tribe Eupatoriae in the Asteraceae, such as *Chromolaena odorata*, *C. macrocephalum* and *Ageratina adenophora*, should make it a priority species for eradication.

Recommendations for changes to the NEM:BA A&IS Regulations

In this section, we provide some recommendations for changes to the NEM:BA A&IS Regulations, specifically: (1) several taxa should be listed or delisted, (2) there needs to be a formal process for dealing with the listing of taxa below the species level (e.g. subspecies and cultivars) and (3) there should be a separation between environmental and agricultural weeds.

SAPIA was used extensively to underpin the listing of taxa under the NEM:BA A&IS Regulations (Department of Environmental Affairs 2014a, 2014b) and should be used to inform updates of the lists. The NEM:BA A&IS Regulations were the result of an extensive process over a decade. However, there are some errors (cf. Wood 2017 for a discussion on the microbial lists), and the regulations recognise that the lists will need to be dynamic as the situation changes (there has already been one update as of February 2017). Species which could be considered for listing as 1b under NEM:BA because they are environmental weeds with the potential for much more spread include: *Berberis aristata*, *Clusia rosea*, *Handroanthus chrysotrichus*, *Hypericum pseudohenryi*, *Manihot grahamii*, *Salvia coccinea*, *Thunbergia grandiflora*, *Tithonia tubaeformis*, *Verbascum thapsus* and *Verbena incompta*. Some taxa which should be considered for listing under NEM:BA, but there are potential conflicts of interest with the horticultural and other industries, include *Anigozanthos flavidus*, *Canna generalis*, *Gaura lindheimeri*, *Oenothera* spp., *Solidago* spp. and *Syzygium paniculatum*. Species which are listed as 1a, but are already widespread in the country should be reclassified as 1b [e.g. *Coreopsis lanceolata*, *F. foetida*, *Opuntia robusta* (excluding spineless cultivars) and *Tephrocactus articulatus*]. There are also, however, some taxa which are listed for which there is no solid evidence that they are in the country (e.g. SANBI ISP has been trying for several field seasons to find *Euphorbia esula* without success, and it appears that the initial report might have been a mistake). Taxa which are listed under the regulations as 1a, 1b, 2 or 3 must have a physical herbarium record to prove that they are (or at least have been) in the country, and equally for taxa to be listed as prohibited, there should be a process for determining that the taxa really are not already present.

A major issue with the regulations is the need to deal with sub-specific entities, in particular, the horticultural industry is keen to ensure that cultivars of invasive taxa that pose an acceptable invasion risk should be exempt. However, even sterile cultivars can be invasive, for example, *Opuntia aurantiaca* can spread by detached stem sections and sterile fruits, and *Vinca major* can spread by rhizomes and stolons. The exemption of sterile cultivars of *V. major* nullifies its listing and allows nurseries to sell invasive plants. Currently, 'sterile' cultivars of 34 species are exempt (see Table 5), but there is no formal process for proving sterility. There is a common perception that plant sterility only means the inability to form viable seeds, but sexual reproduction in plants is dependent upon three major factors: the formation of fertile pollen, fertile embryo sacs and viable seeds (Spies & Du Plessis 1987). There needs to be a set protocol to determine the necessary and sufficient conditions for a plant taxon to be deemed an acceptable invasion risk on the basis of sterility, given that entities of the same species are proscribed. This should be based on a few principles: sterility must be such that the risk of invasions and impacts is acceptable; given closely related taxa have been shown to be invasive, the balance of evidence is no longer the same as for regulating a species, that is, the precautionary principle should apply; there needs to be a way in which sterile individuals can be differentiated from non-sterile individuals, that is, there needs to be a mechanism for implementation; and the process needs to be transparent, consistent and agreed by all stakeholders (cf. Zengeya et al. 2017). As such, it poses a scientific and regulatory challenge that will require some investment to address fully.

NEM:BA superseded CARA, which for many years was the only legislation dealing with weeds and invasive plants in South Africa. Currently, NEM:BA includes most of the taxa which were listed under CARA and this includes species which are mainly weeds of disturbed sites and agricultural lands, for example, species of *Argemone*, *Cirsium*, *Datura* and *Xanthium*. NEM:BA's prime concern is with environmental weeds and should exclude species which show limited ability to invade and persist in natural areas or undisturbed sites. Again, there should be a clear process for defining this cut-off as it might not be clear for many species. For example, Geerts et al. (2013) argued that *Genista monspessulana* currently poses a greater risk than *Spartium junceum* to the fynbos due to its greater ability to invade natural ecosystems, but the authors were not able to provide a mechanistic explanation for the differences between these two broom species. There should ideally be separate processes for listing taxa as environmental or agricultural threats although clearly some taxa will be both.

Limitations of the Southern African Plant Invaders Atlas database and recommendations for improvement

The SAPIA database has its limitations and users of the data need to be aware of these. Ideally, atlas data should be collected from the full extent of the atlas region, with a good measure of sampling intensity, within a specific time frame. The SAPIA database incorporates data that have been collected with varying sampling effort in space and time and could possibly qualify as an *ad hoc* dataset defined by Robertson, Cumming and Erasmus (2010).

The roadside surveys conducted by the author (L.H.) form the backbone of the SAPIA database, contributing about 60 000 of the total 87 000 records. These surveys followed a standard procedure but were rapid and lacked the sampling intensity of site inspection and are biased towards the more conspicuous trees and shrubs. Data received from SANBI's ISP since 2010 are mainly confined to potential and current eradication targets (Wilson et al. 2013). Records from the public are mostly *ad hoc* at specific sites. As a consequence of all these factors, the SAPIA database cannot provide accurate, up-to-date distribution data for all taxa across South Africa. For example, some species have shown little expansion, but they could have been underestimated, for example, *Cestrum laevigatum* with only 13% increase is easily overlooked as it blends into the natural vegetation. *Nassella* species are not easily detected during roadside surveys and no records were received from the public. Better data could be obtained if there were more data collectors spread across the atlas region, with a standardised recording procedure and sampling effort.

Recording absences (both from sites where the taxon has never been recorded and particularly from sites where it is no longer present) are essential if data are to be used for long-term monitoring and to track changes. In SAPIA, absence records have only been recorded for five aquatic species (see Table 4) as part of the Rhodes Invasive Aquatic Plants Surveys (Hill & Coetzee 2017). Dubious records, however, are queried. If an observer cannot provide satisfactory evidence (e.g. a photograph) to confirm a taxon's identity, then the record is not entered into SAPIA. Where identification is highly problematic, it might be necessary to submit a herbarium specimen for correct identification, although it is not practical or desirable for all SAPIA records to be linked to herbarium specimens. Other approaches to identification, for example, through the wisdom of the crowd (Silvertown et al. 2015), might be needed. But to achieve the recommendations of Latombe et al. (in press) for monitoring and reporting on biological invasions, there should be a process in addition to SAPIA whereby several long-term monitoring sites are established at which invasion dynamics of all taxa are documented in detail.

Similarly, while SAPIA provides some indication of the introduction status of species, a separate process is required to list all alien plants in the country and to confirm their status along the introduction–naturalisation–invasion continuum as per Blackburn et al. (2011). There have been several attempts at this for cultivated plants (Glen 2002) and trees (van Wyk & Glen 2016), but to create a full inventory that is kept regularly updated will be a major task made extremely difficult because many introduced plants are known only as cultivars by the nursery industry and many plants that have been introduced might no longer be cultivated. The scope of SAPIA should remain to record taxa growing outside of cultivation, though perhaps with the addition of a field for assessing whether populations are naturalised or invasive as per the Blackburn Scheme (see Wilson et al. 2014 for a field interpretation of the scheme for alien trees).

Even comparing lists of taxa in Henderson (2007) and this publication is complicated. In Henderson (2007), 601 taxa were listed but 44 of these, which were identified only to genus level, for example, *Datura* sp., but were most likely already listed, have been excluded from the current publication. *Lemna gibba* has been excluded because it is regarded as indigenous. Recent research has shown that *Myriophyllum spicatum* in South Africa should be regarded as indigenous (Weyl et al. 2016). Some species that appear on this list for the first time were previously known from the region but were misidentified, for example, *H. balansae* as *Acanthocereus tetragonus*, *N. cordifolia* as *N. exaltata* and *F. foetida* was confused with *Agave sisalana*. Such issues will likely continue in perpetuity, but it again highlights the need for careful documentation. Although it will not completely resolve this issue, the nomenclature used in SAPIA is now linked to that of the Botanical Research And Herbarium Management System (BRAHMS) and so ultimately to internationally agreed lists.

This publication only lists species alien to South Africa. Some extra-limital indigenous species and cultivars have been recorded in the SAPIA database but have been excluded from this publication, for example, *Crocosmia* cf. *paniculata* cultivar, *Erica glandulosa*, *Euryops chrysanthemoides* and *Ipomoea cairica*. Resolving issues of nativity below the level of a country is difficult though not intractable, and protocols are needed for dealing with such taxa when they spread or are spread beyond their natural distribution range and become problematic. SAPIA also contains some data of alien plants in neighbouring countries, but the level of sampling is much lower. Efforts are underway to develop SAPIA-type atlases for other parts of Africa (Arne Witt, CABI, pers. comm., July 2016). We hope that SAPIA can provide a framework for such initiatives, or at least serve as a practical example of the value of such data to research and management.

The quality and quantity of SAPIA data could be improved by having more data collectors country-wide and a central online facility for submitting and storing data. Plans to make all SAPIA data available online at the Weeds and Invasive Plants website (Henderson 2006) failed due to a complete breakdown in the management of the Agricultural Geo-Referenced Information System (AGIS) host site. Currently, the SAPIA database is housed at SANBI on the Pretoria server. A data-sharing agreement between ARC and SANBI has paved the way for the SAPIA data to soon become accessible through SANBI's BRAHMS online website.

Finally, the future of the SAPIA database is dependent on a secure source of funding. Funding over the past 16 years has been provided by the DEA, but this was only for coordination of the SAPIA project and roadside surveys by the lead author (L.H.). Much more funding is required for improvements to data collection, which will entail the employment of more dedicated data collectors, and for an online facility for storing and submitting data.

Conclusion

This review has highlighted rapidly spreading taxa, which require urgent attention. Some are already subjects of biological control programmes but should receive increased priority with the implementation of national species management programmes, for example, *C. macrocephalum*, *P. hysterophorus*, *T. stans* and *O. engelmannii*, whereas others should be considered for biological control, for example, *C. grandiflora*, *G. triacanthos*, *P. setaceum* and *T. spachianus*.

The small expansion and even contraction of some of the most prominent invaders such as *Acacia longifolia*, *Acacia saligna*, *Acacia cyclops* and *A. filiculoides*, which have been the subjects of successful biological control programmes, reinforces the value of biological control in the management of invasive alien species. However, the expansion of some species, despite the availability of effective biological control agents, such as *C. jamacaru*, *Cylindropuntia imbricata* and *Opuntia stricta*, indicates that there needs to be better implementation of biological control in some instances (Zachariades et al. 2017).

This review has shown that there is an ever-increasing number of invasive and potentially invasive taxa to deal with in South Africa, that is, there is a substantial invasion debt (Rouget et al. 2016). From our results, it is also clear that invasive plant taxa (particularly those that are listed in the regulations) are continuing to spread at alarming rates. More taxa should be considered for listing as invasive species under the NEM:BA A&IS Regulations; some taxa, which are mainly associated with disturbance and agricultural lands, should be removed from the NEM:BA A&IS Lists; proof of sterility needs to be obtained for the cultivars of 34 species which have been exempted; but ultimately more needs to be done to ensure that management is strategic and effective.

By enabling us to highlight these trends and issues, we believe SAPIA continues to be an essential tool for the monitoring and reporting on the status of alien plants in South Africa.

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The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

L.H. initiated the manuscript, collated the data and led the writing. J.R.U.W. conducted the statistical analyses and helped with the writing.

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Appendix 1

TABLE 1-A1: Alien plant taxa recorded from South Africa and added to SAPIA since 2006 that had not previously been recorded as naturalised or as having escaped from cultivation in South Africa prior to inclusion in SAPIA.

	Scientific name	Family	Common name	Growth form	Cultivated use	qds in SAPIA	NEM:BA category	Origin and other notes
1	*Acacia adunca*	Fabaceae	Cascade wattle	Tree		1	1a	Australia
2	*Actinidia deliciosa*	Actinidiaceae	Kiwifruit	Climber	Ed	1	Not listed	Asia (China)
3	*Agathis* sp.	Araucariaceae	Kauri pine	Tree	Orn	1	Not listed	Asia, Australia, Pacific
4	*Alocasia macrorrhizos*	Araceae	Giant taro	Herb	Orn	1	Not listed	Asia, Australasia
5	*Alopecurus arundinaceus*	Poaceae	Creeping foxtail	Grass	Fod?	1	Not listed	N Africa, Europe, Asia
6	*Aloysia gratissima*	Verbenaceae	Common bee-brush	Shrub	Hon?, orn	1	Not listed	N & S America, Mexico
7	*Arachis* cf. *pintoi*	Fabaceae	Pinto peanut	Herb	Fod	1	Not listed	S America (Brazil)
8	*Aralia spinosa*	Araliaceae	Devil's walking stick	Tree	Orn	1	Not listed	N America (USA)
9	*Argemone albiflora* subsp. *texana*	Papaveraceae	White prickly poppy	Herb	Orn?	6	Not listed	N America (USA)
10	*Austrocylindropuntia cylindrica*	Cactaceae	Cane cactus	Succulent shrub	Orn	3	1a	S America (Ecuador)
11	*Banksia serrata*	Proteaceae	Saw banksia	Tree or shrub	Orn	2	Not listed	Australia
12	*Banksia speciosa*	Proteaceae	Showy banksia	Tree or shrub	Orn	1	Not listed	Australia
13	*Bauhinia forficata*	Fabaceae	Thorny orchid tree	Tree	Orn	2	Not listed	S America
14	*Berberis aristata*	Berberidaceae	Indian barberry	Shrub	Orn, ed	1	Not listed	Asia
15	*Berberis julianae*	Berberidaceae	Chinese barberry	Shrub	Orn	3	Not listed	Asia (China)
16	*Betula pendula*	Betulaceae	Silver birch	Tree	Orn	1	Not listed	N Africa, Europe, Asia
17	*Bocconia frutescens*	Papaveraceae	Plume-poppy	Shrub	Orn	1	Not listed	Mexico, C America, W Indies
18	*Breynia disticha*	Euphorbiaceae	Snowbush	Shrub	Orn	2	Not listed	Pacific Islands
19	*Brugmansia arborea*	Solanaceae	Angel's-trumpet	Shrub	Orn	1	Not listed	S America
20	*Bryophyllum fedtschenkoi*	Crassulaceae	NA	Succulent herb or shrublet	Orn	1	Not listed	Madagascar
21	*Callisia fragrans*	Commelinaceae	NA	Herb	Orn	1	Not listed	Mexico
22	*Callistemon rugulosus* (= *Melaleuca rugulosa*)	Myrtaceae	Scarlet bottlebrush	Tree or shrub	Orn	2	Not listed	Australia
23	*Calluna vulgaris*	Ericaceae	Heather	Shrub	Orn	1	Not listed	Europe, Asia
24	*Calothamnus sanguineus*	Myrtaceae	One-sided bottlebrush	Shrub	Orn	1	Not listed	Australia
25	*Canna flaccida*	Cannaceae	Golden canna	Herb	Orn	4	Not listed	N America (USA)
26	*Cantinoa mutabilis*	Lamiaceae	NA	Herb	Orn	1	Not listed	N & S America
27	*Chukrasia tabularis*	Meliaceae	Indian mahogany	Tree	Silv	1	Not listed	Asia
28	*Cistus ladanifer*	Cistaceae	Common gum cistus	Shrub	Orn	1	Not listed	Europe (W Mediterranean)
29	*Clerodendrum bungei*	Lamiaceae	Glory-flower	Shrub	Orn	4	Not listed	Asia
30	*Coprosma repens*	Rubiaceae	Mirror plant	Shrub	Orn	2	Not listed	New Zealand
31	*Cornus* cf. *florida*	Cornaceae	Flowering dogwood	Tree	Orn	1	Not listed	N America
32	*Crataegus* cf. *mexicana*	Rosaceae	Mexican hawthorn	Tree or shrub	Orn	1	Not listed	Mexico, C America
33	*Cryptostegia madagascariensis*	Apocynaceae	Purple rubber vine	Climber	Orn	2	1b	Madagascar
34	*Cuphea micropetala*	Lythraceae	Tartan bush	Shrub	Orn	1	Not listed	Mexico
35	*Cylindropuntia fulgida* var. *mamillata*	Cactaceae	Boxing-glove cactus	Succulent shrub	Orn	83	1b	USA, Mexico
36	*Cylindropuntia pallida*	Cactaceae	Pink-flowered sheathed cholla	Succulent shrub	Orn	10	1a	Mexico
37	*Cylindropuntia spinosior*	Cactaceae	Cane cholla	Succulent shrub	Orn	2	1a	USA, Mexico
38	*Diplazium esculentum*	Athyriaceae	Vegetable fern	Fern	Orn, ed	1	Not listed	Asia
39	*Dryandra formosa* (= *Banksia formosa*)	Proteaceae	Showy dryandra	Shrub	Orn	1	Not listed	Australia
40	*Echinopsis chamaecereus*	Cactaceae	Peanut cactus	Succulent herb	Orn	2	Not listed	S America (Argentina)
41	*Echinopsis huascha*	Cactaceae	Red torch cactus	Succulent shrub	Orn	1	Not listed	S America (Argentina)
42	*Echinopsis oxygona*	Cactaceae	Pink Easter-lily cactus	Succulent herb	Orn	1	Not listed	S America
43	*Echium candicans*	Boraginaceae	Pride-of-Madeira	Herb	Orn	3	Not listed	Madeira
44	*Elaeocarpus sphaericus* (= *Elaeocarpus grandis*)?	Elaeocarpaceae	Blueberry-ash	Tree	Silv	1	Not listed	Australia
45	*Enterolobium contortisiliquum*	Fabaceae	Black ear	Tree	Orn	1	Not listed	S America
46	*Epipremnum aureum*	Araceae	Devil's ivy	Climber	Orn	4	Not listed	Pacific – French Polynesia

Appendix table continued on the next page →

TABLE 1-A1: (Continued...) Alien plant taxa recorded from South Africa and added to SAPIA since 2006 that had not previously been recorded as naturalised or as having escaped from cultivation in South Africa prior to inclusion in SAPIA.

	Scientific name	Family	Common name	Growth form	Cultivated use	qds in SAPIA	NEM:BA category	Origin and other notes
47	*Eucalyptus botryoides*	Myrtaceae	Bangalay	Tree	Hon?, silv?	1	Not listed	Australia
48	*Eucalyptus melliodora*	Myrtaceae	Yellow box gum	Tree	Hon?, silv?	1	Not listed	Australia
49	*Euphorbia esula*	Euphorbiaceae	Leafy spurge	Herb	None	1	1a	N Africa, Europe, Asia. Presence has not been confirmed, suspected misidentification
50	*Euphorbia milii*	Euphorbiaceae	Christ's-thorn	Succulent shrublet	Orn	1	Not listed	Madagascar
51	*Fraxinus* sp.	Oleaceae	Green ash or velvet ash?	Tree	Orn	8	Not listed	N America (USA and Canada) and Mexico
52	*Fumaria officinalis*	Fumariaceae	Common fumitory	Herb	Med?	1	Not listed	Europe
53	*Furcraea foetida*	Asparagaceae	Mauritius hemp	Succulent shrub	Orn	18	Not listed	S America, W Indies
54	*Furcraea selloa*	Asparagaceae	Maguey	Succulent shrub	Orn	2	Not listed	Mexico, C & S America
55	*Gunnera* sp.	Gunneraceae	Giant gunnera	Herb	Orn	1	Not listed	S America?
56	*Harrisia pomanensis*	Cactaceae	Devil's-rope cactus	Succulent shrub or climber	Orn	3	1a	S America
57	*Harrisia tortuosa*	Cactaceae	Spiny snake cactus	Succulent shrub or climber	Orn	4	1b	S America
58	*Helianthus annuus* multi-headed cultivar	Asteraceae	Sunflower	Shrub	Orn	20	Not listed	N America (USA, Canada), Mexico
59	*Heliotropium europaeum*	Boraginaceae	European heliotrope	Herb	Orn	2	Not listed	N Africa, Europe, Asia
60	*Heterocentron subtriplinervium* (= *Melastoma subtriplinervium*)	Melastomataceae	Pearlflower	Shrub	Orn	1	Not listed	Mexico
61	*Hydrangea macrophylla*	Hydrangeaceae	Hydrangea	Shrub	Orn	1	Not listed	Asia (Japan)
62	*Hydrocleys nymphoides*	Limnocharitaceae	Water poppy	Aquatic herb	Orn	1	1a	C & S America, W Indies
63	*Ipomoea hederifolia*	Convolvulaceae	Ivy-leaf morning glory	Climber	Orn	3	Not listed	Americas
64	*Ixora coccinea*	Rubiaceae	Flame-of-the-woods	Shrub	Orn	2	Not listed	Asia
65	*Kalanchoe beharensis*	Crassulaceae	Elephant's ear kalanchoe	Succulent shrub	Orn	2	Not listed	Madagascar
66	*Kunzea ericoides*	Myrtaceae	Burgan, white tea-tree	Shrub or tree	Orn	1	1a	Australia, New Zealand
67	*Lagerstroemia speciosa*	Lythraceae	Queen crepe myrtle	Tree	Orn	1	Not listed	Asia
68	*Lamium galeobdolon*	Lamiaceae	Aluminium plant	Herb	Orn	1	Not listed	Europe
69	*Limonium perezii*	Plumbaginaceae	Canary sea lavender	Herb	Orn	1	Not listed	Canary Islands
70	*Liquidambar styraciflua*	Altingiaceae	Sweet gum	Tree	Orn	2	Not listed	USA, Mexico, C America
71	*Macroptilium atropurpureum*	Fabaceae	Purple-bean	Climber	Fod	2	Not listed	USA (Texas), Mexico, C & S America, W Indies
72	*Malvaviscus penduliflorus*	Malvaceae	Molinillo	Shrub	Orn	3	Not listed	Mexico
73	*Maranta leuconeura*	Marantaceae	Prayerplant	Herb	Orn	1	Not listed	S America (Brazil)
74	*Melaleuca nesophila*	Myrtaceae	Mauve honey myrtle	Shrub or tree	orn	1	Not listed	Australia
75	*Melaleuca parvistaminea*	Myrtaceae	Rough-barked honey myrtle	Shrub or tree	Orn	1	Not listed	Australia
76	*Melaleuca quinquenervia*	Myrtaceae	Broadleaf paperbark	Tree	Orn	3	1b	Australasia, Pacific
77	*Melastoma malabathricum* (= *M. candidum*)	Melastomataceae	Malabar melastome	Shrub	Orn, med	1	Not listed	Asia
78	*Mimosa albida*	Fabaceae	NA	Shrub or tree	Orn	2	Not listed	Mexico, C & S America
79	*Myoporum insulare*	Myoporaceae	Boobyalla	Shrub or tree	Orn, shelter	7	3	Australia
80	*Myoporum laetum*	Myoporaceae	New Zealand Manatoka	Shrub or tree	Orn, shelter	1	3	New Zealand
81	*Myrtillocactus geometrizans*	Cactaceae	Bilberry cactus	Succulent shrub	Orn	6	1a	Mexico, C America
82	*Nandina domestica*	Berberidaceae	Chinese-bamboo	Shrub	Orn	2	Not listed	Asia
83	*Nopalaea cochenillifera*	Cactaceae	Cochineal cactus	Succulent shrub	Orn, med	3	Not listed	Mexico
84	*Nymphoides peltata*	Menyanthaceae	Fringed water lily	Aquatic herb	Orn	1	1a	Europe, Asia
85	*Odontonema cuspidatum*	Acanthaceae	Scarlet firespike	shrub	Orn	3		Mexico
86	*Opuntia elata* var. *elata*	Cactaceae	Orange tuna	Succulent shrub	Orn	22	1b	S America
87	*Opuntia robusta* spiny form	Cactaceae	Blue-leaf cactus	Suculent shrub	Orn	9	1a	Mexico

Appendix table continued on the next page →

TABLE 1-A1: (Continued...) Alien plant taxa recorded from South Africa and added to SAPIA since 2006 that had not previously been recorded as naturalised or as having escaped from cultivation in South Africa prior to inclusion in SAPIA.

	Scientific name	Family	Common name	Growth form	Cultivated use	qds in SAPIA	NEM:BA category	Origin and other notes
88	*Peniocereus serpentinus*	Cactaceae	Serpent cactus	Succulent shrub	Orn	4	1b	Mexico
89	*Petiveria alliacea*	Phytolaccaceae	Guinea hen-weed	Herbaceous shrub	Orn, med	2	Not listed	N, C & S America
90	*Platycerium bifurcatum*	Polypodiaceae	Staghorn fern	Fern	Orn	2	Not listed	Australasia
91	*Punica granatum 'Nana'*	Lythraceae	Dwarf pomegranate cultivar	Shrub	Orn	6	Not listed	Asia
92	*Pyrostegia venusta*	Bignoniaceae	Golden shower	Climber	Orn	2	Not listed	S America (Brazil)
93	*Quercus acutissima*	Fagaceae	Bristle oak	Tree	Orn	1	Not listed	Asia
94	*Ravenala madagascariensis*	Strelitziaceae	Traveller's-palm	Tree	Orn	1	Not listed	Madagascar
95	*Reynoutria × bohemica* (= *Fallopia × bohemica*)	Polygonaceae	Bohemian knotweed	Shrub	Orn	1	Not listed	Europe
96	*Rhaphiolepis indica*	Rosaceae	Indian hawthorn	Shrub	Orn	1	Not listed	Asia
97	*Rhododendron* sp.	Ericaceae	Rhododendron	Shrub or tree	Orn	1	Not listed	Asia
98	*Roldana petasitis*	Asteraceae	Velvet groundsel	Shrub	Orn	1	Not listed	Mexico, C America
99	*Rubus ellipticus*	Rosaceae	Yellow Himalayan raspberry	Shrub	Ed	2	1a	Asia
100	*Ruellia simplex*	Acanthaceae	Mexican blue-bells	Herb	Orn	2	Not listed	Mexico
101	*Sagittaria latifolia*	Alismataceae	Common arrowhead	Aquatic herb	Orn	2	Not listed	N America (Canada, USA), Mexico, C & S America, W Indies
102	*Sagittaria platyphylla*	Alismataceae	Slender arrowhead	Aquatic herb	Orn	8	1a	N & C America
103	*Salvinia minima*	Salviniaceae	Small salvinia	Aquatic herb	Orn	2	1b	Mexico, C & S America
104	*Sansevieria trifasciata*	Asparagaceae	Mother-in-law's-tongue	Succulent herb	Orn	1	Not listed	W Africa
105	*Senna alata*	Fabaceae	Candlestick senna	Shrub	Orn, med	2	Not listed	Mexico
106	*Senna spectabilis*	Fabaceae	Scented cassia	Tree	Orn	3	Not listed	N, C & S America
107	*Silene dioica*	Caryophyllaceae	Red campion	Herb	Orn	1	Not listed	Europe
108	*Sisyrinchium angustifolium* (= *S. graminoides*)	Iridaceae	Narrow-leaf blue-eyed-grass	Herb	Orn	1	Not listed	N America (Canada & USA)
109	*Solanum laciniatum*	Solanaceae	Kangaroo-apple	Shrub	Orn	2	Not listed	New Zealand
110	*Solanum lycopersicum*	Solanaceae	Tomato	Herb	Agric	3	Not listed	C & S America
111	*Solanum lycopersicum* var. *cerasiforme*	Solanaceae	Cherry tomato	Herb	Agric	1	Not listed	C & S America
112	*Solidago altissima*	Asteraceae	Late goldenrod	Herb	Orn	3	Not listed	N America (Canada, USA, Mexico)
113	*Solidago gigantea*	Asteraceae	Early or tall goldenrod	Herb	Orn	1	Not listed	N America (USA, Canada)
114	*Spartina alterniflora*	Poaceae	Smooth cordgrass	Aquatic grass	None	1	1a	N America
115	*Stenocereus* cf. *pruinosus*	Cactaceae	Pitaya	Tree or shrub	Orn, ed	1	Not listed	Mexico
116	*Stictocardia beraviensis* (= *Ipomoea beraviensis*)	Convolvulaceae	'Hawaiian' sunset vine	Climber	Orn	1	Not listed	Tropical Africa, Madagascar
117	*Taxodium distichum*	Cupressaceae	Swamp cypress	Tree	Orn	2	Not listed	N America (USA)
118	*Tecoma* cf. *fulva* subsp. *garrocha* (= *T. garrocha*)	Bignoniaceae	Orange bells	Tree or shrub	Orn	1	Not listed	S America
119	*Telopea speciosissima*	Proteaceae	Waratah	Shrub	Orn	1	Not listed	Australia
120	*Thunbergia grandiflora*	Acanthaceae	Blue trumpetvine	Climber	Orn	6	Not listed	Asia
121	*Tibouchina elegans*	Melastomataceae	Glory bush	Shrub	Orn	1	Not listed	S America
122	*Tibouchina granulosa*	Melastomataceae	Glory bush tree	Tree or shrub	Orn	1	Not listed	S America (Brazil)
123	*Tibouchina mutabilis*	Melastomataceae	NA	Tree	Orn	1	Not listed	S America (Brazil)
124	*Tibouchina urvilleana*	Melastomataceae	Purple glory bush	Shrub	Orn	1	Not listed	S America (Brazil)
125	*Tillandsia usneoides*	Bromeliaceae	Spanish-moss	Herb or epiphyte	Orn	1	Not listed	N, C & S America, W Indies
126	*Tithonia tubaeformis*	Asteraceae	NA	Tree or shrub	Orn? or fertilizer?	1	Not listed	Mexico, C America
127	*Tradescantia pallida*	Commelinaceae	Purple heart	Succulentherb	Orn	1	Not listed	Mexico
128	*Trichocereus pachanoi* (= *Echinopsis pachanoi*)	Cactaceae	San Pedro cactus	Tree	Orn, med	1	Not listed	S America
129	*Turnera ulmifolia*	Passifloraceae	Yellow-alder	Shrub	Orn	1	Not listed	Mexico, W Indies
130	*Verbascum thapsus*	Scrophulariaceae	Velvet-dock	Herb	Orn	15	Not listed	N Africa, Europe, Asia

Source: SAPIA Database, ARC-PPRI; US National Plant Germplasm System: GRIN Taxonomy 2016

During this period, a few new taxa were recorded from outside of South Africa but not included in this table: *Hyptis suaveolens* from Mozambique; *Limnobium laevigatum*, *Magnolia champaca* and *Vernonanthura phosphorica* from Zimbabwe.

Agric, agricultural crop; Ed, edible fruit; Fod, fodder; Hon, honey; Med, medicinal; Orn, ornamental; Silv, silvicultural crop.

Appendix 2

Details of categorisation schemes used to classify alien plants.

TABLE 1-A2: Categories for species introduction status as per Blackburn et al. 2011.

Category	Definition
A	Not transported beyond limits of native range
B1	Individuals transported beyond limits of native range, and in captivity or quarantine (i.e. individuals provided with conditions suitable for them, but explicit measures of containment are in place)
B2	Individuals transported beyond limits of native range, and in cultivation (i.e. individuals provided with conditions suitable for them but explicit measures to prevent dispersal are limited at best)
B3	Individuals transported beyond limits of native range, and directly released into novel environment
C0	Individuals released into the wild (i.e. outside of captivity or cultivation) in location where introduced, but incapable of surviving for a significant period
C1	Individuals surviving in the wild (i.e. outside of captivity or cultivation) in location where introduced, no reproduction
C2	Individuals surviving in the wild in location where introduced, reproduction occurring, but population not self-sustaining
C3	Individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining
D1	Self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction
D2	Self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction
E	Fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence

TABLE 2-A2: The regulatory categories of taxa as defined under the NEM:BA A&IS Regulations. The regulations and categorised lists of invasive taxa were published in the South African Government Gazette in August 2014 (Department of Environmental Affairs 2014b). Prohibited activities applying to all listed species (except category 2 species with a permit) include importing into South Africa, growing, propagating, moving, selling or donating.

Category	Interpreted definition
1a	Immediate compulsory control. This has been interpreted that nation-wide eradication is feasible and has been set as the management goal (Wilson et al. 2013).
1b	Must be controlled as part of a species management programme. These include widespread and the most troublesome species. Landowners must comply with management programmes if these have been developed.
2	Permit required for cultivation. Outside of specified areas they are treated as 1b.
3	Must be controlled in riparian/wetland areas; not yet widely troublesome or troublesome but a phased approach is required; can be shifted to 1b after re-assessment.
Prohibited	The species is not present in the country and is not allowed to be imported.

References

Klein, H., 2011, A catalogue of the insects, mites and pathogens that have been used or rejected, or are under consideration, for the biological control of invasive alien plants in South Africa, *African Entomology* 19, 515–549.

Moran, V.C., Hoffmann, J.H. & Hill, M.P., 2011, A context for the 2011 compilation of reviews on the biological control of invasive alien plants in South Africa, *African Entomology* 19, 177–185.

TABLE 3-A2: Categories for classifying the status of biological control programmes as per Klein (2011). Biological control, using natural enemies, has become indispensable in the suppression of invasive alien plant species in South Africa and the most recent review of all the programmes is provided in Moran et al. (2011a). The degree of control for each species has been rated by estimating the degree to which the impact or importance of the target species has been reduced by the biological control agents (Klein 2011). Assessments are based on the degree of reduction in the use of alternative control methods (chemical or mechanical) since the introduction of biological control agents, and include the following categories (Klein 2011):

Category	Definition
Complete	No other control measures are needed to reduce the weed to acceptable levels, at least in areas where the agents have been established
Substantial	Other methods are needed to reduce the weed to acceptable levels, but less effort is required (e.g. less frequent herbicide application or less herbicide needed per unit area)
Negligible	In spite of damage inflicted by the agents, control of the weed remains entirely reliant on the implementation of other control measures
Not determined	Either the release of the agents has been too recent for meaningful evaluation, or the programme has not been evaluated
Under investigation	Agents are being researched and no releases have yet been made

References

Department of Environmental Affairs, 2014a, *National Environmental Management: Biodiversity Act 2004 (Act No. 10 of 2004) Alien and Invasive Species Lists*, Government Gazette of South Africa, Pretoria, pp. 3–80.

Department of Environmental Affairs, 2014b, *Government Notice R. 598, National Environmental Management: Biodiversity Act (10/2004): Alien and Invasive Species Regulations*, Government Gazette No. 37885.

Appendix 3

TABLE 1-A3: The 50 alien plants that have seen the greatest relative increase in their recorded distribution in SAPIA over the past 15 years. This is based on residuals from the model (Appendix 5) and ordered from the taxon that has seen the greatest relative increase downwards. Note that many of these species are herbaceous weeds associated with human disturbance. There was a deliberate effort by the curator of SAPIA (the lead author, L.H.) to collect such distribution data from 2000 onwards as it had previously not been collected in detail. Notably, however, these taxa are still likely to be underestimated in SAPIA and in many cases are yet to be found invading areas with low levels of human disturbance.

Scientific name	Common name	Range up to 2000	Range up to 2016	Recorded as very abundant at a site	Previously under-recorded in SAPIA (and so the observed spread is likely to be a sampling artefact)	Biological control
Cylindropuntia fulgida var. *mamillata*	Boxing-glove cactus	0	83	TRUE	FALSE	Recently has come under complete biocontrol
Erigeron sumatrensis (= *Conyza albida, C. sumatrensis*)	Tall fleabane	1	95	TRUE	TRUE	
Sesbania bispinosa var. *bispinosa*	Spiny sesbania	1	75	TRUE	TRUE	
Rapistrum rugosum	Wild mustard	0	44	TRUE	TRUE	
Salvia verbenaca	Wild sage	0	41	TRUE	TRUE	
Verbena rigida (= *V. venosa*)	Veined verbena	1	50	TRUE	TRUE	
Oenothera stricta	Sweet sundrop	0	28	TRUE	TRUE	
Medicago sativa	Lucerne	2	51	TRUE	TRUE	
Argemone ochroleuca subsp. *ochroleuca*	White-flowered Mexican poppy	154	516	TRUE	FALSE	Under investigation for biological control
Verbena bonariensis	Purple top OR tall verbena	58	267	TRUE	TRUE	
Zinnia peruviana	Redstar zinnia	4	57	TRUE	TRUE	
Erigeron bonariensis (= *Conyza bonariensis*)	Flax-leaf fleabane	4	57	TRUE	TRUE	
Opuntia elata var. *elata*	Orange tuna	0	22	TRUE	FALSE	
Campuloclinium macrocephalum	Pompom weed	14	108	TRUE	FALSE	Biological control agents released but efficacy still to be determined
Verbena incompta (= *V. bonariensis* var. *conglomerata*)	NA	0	21	TRUE	TRUE	
Helianthus annuus cultivar	Multi-headed sunflower	0	20	TRUE	FALSE	
Melilotus albus	White sweet clover	15	105	TRUE	TRUE	
Canna X generalis	Garden canna	7	64	FALSE	FALSE	
Lupinus angustifolius	Blue lupine	0	18	TRUE	TRUE	
Furcraea foetida	Mauritius hemp	0	18	TRUE	FALSE	
Tephrocactus articulatus	Pine cone cactus OR paper-spine cholla	1	27	TRUE	FALSE	
Ammi majus	Bishop's weed	1	26	TRUE	TRUE	
Parthenium hysterophorus	Famine weed	15	89	TRUE	FALSE	Biological control agents released but efficacy still to be determined
Glandularia aristigera	Fine-leaved verbena	14	85	TRUE	TRUE	
Tradescantia fluminensis	White-flowered wandering Jew OR spiderwort	0	16	TRUE	FALSE	Biological control under investigation
Salvia tiliifolia	Lindenleaf sage	0	16	TRUE	FALSE	
Vinca major	Greater periwinkle	1	24	TRUE	FALSE	
Verbascum thapsus	Common mullein OR velvet-dock	0	15	TRUE	FALSE	
Opuntia engelmannii (= *O. lindheimeri, O. tardospina*)	Small round-leaved prickly pear	10	65	TRUE	FALSE	Current biological control negligible
Ambrosia artemisiifolia	Annual ragweed	2	29	TRUE	TRUE	
Mirabilis jalapa	Four-o' clock	7	52	TRUE	FALSE	
Helianthus annuus	Common sunflower	5	42	FALSE	TRUE	
Acer negundo	Ash-leaved maple	1	21	TRUE	FALSE	
Pinus roxburghii	Chir OR longifolia pine	2	25	FALSE	FALSE	
Opuntia humifusa	Creeping prickly pear	25	99	TRUE	FALSE	Under complete biological control where the agents have established
Sphagneticola trilobata (= *Thelechitonia trilobata*)	Singapore daisy	1	19	TRUE	FALSE	
Salvia coccinea	Scarlet sage	0	12	FALSE	TRUE	
Flaveria bidentis	Smelter's-bush	12	60	TRUE	TRUE	

Appendix table continued on the next page →

Appendix 3: (Continued...) The 50 alien plants that have seen the relatively greatest increase in the recorded distribution in SAPIA over the past 15 years. This is based on residuals from the model (Appendix 3, Figure 2) and ordered from the taxon that has seen the greatest relative increase downwards. Note that many of these species are herbaceous weeds associated with human disturbance. There was a deliberate effort by the curator of SAPIA (the lead author, L.H.) to collect such distribution data from 2000 onwards as it had previously not been collected in detail. Notably, however, these taxa are still likely to be underestimated in SAPIA and in many cases have not been found to have invaded areas not subject to high levels of human disturbance.

Scientific name	Common name	Range up to 2000	Range up to 2016	Recorded as very abundant at a site	Previously under-recorded in SAPIA (and so the observed spread is likely to be a sampling artefact)	Biological control
Bryophyllum delagoense	Chandelier plant OR mother of millions	4	32	TRUE	FALSE	
Cryptostegia grandiflora	Rubber vine	1	18	TRUE	FALSE	
Pennisetum setaceum	Fountain grass	66	174	TRUE	FALSE	
Cosmos bipinnatus	Cosmos	48	137	TRUE	TRUE	
Ulmus parvifolia	Chinese elm	2	21	FALSE	FALSE	
Calotropis procera	Giant milkweed	1	16	TRUE	FALSE	
Agave americana var. *expansa*	Spreading century plant	1	16	TRUE	FALSE	
Foeniculum vulgare	Fennel	9	45	FALSE	FALSE	
Cirsium vulgare	Spear thistle	188	365	TRUE	FALSE	Biological control negligible
Papaver rhoeas	Corn poppy	0	10	FALSE	TRUE	
Cylindropuntia pallida	Pink-flowered sheathed cholla	0	10	TRUE	FALSE	
Carduus nutans	Nodding thistle	0	10	TRUE	TRUE	

Appendix 4

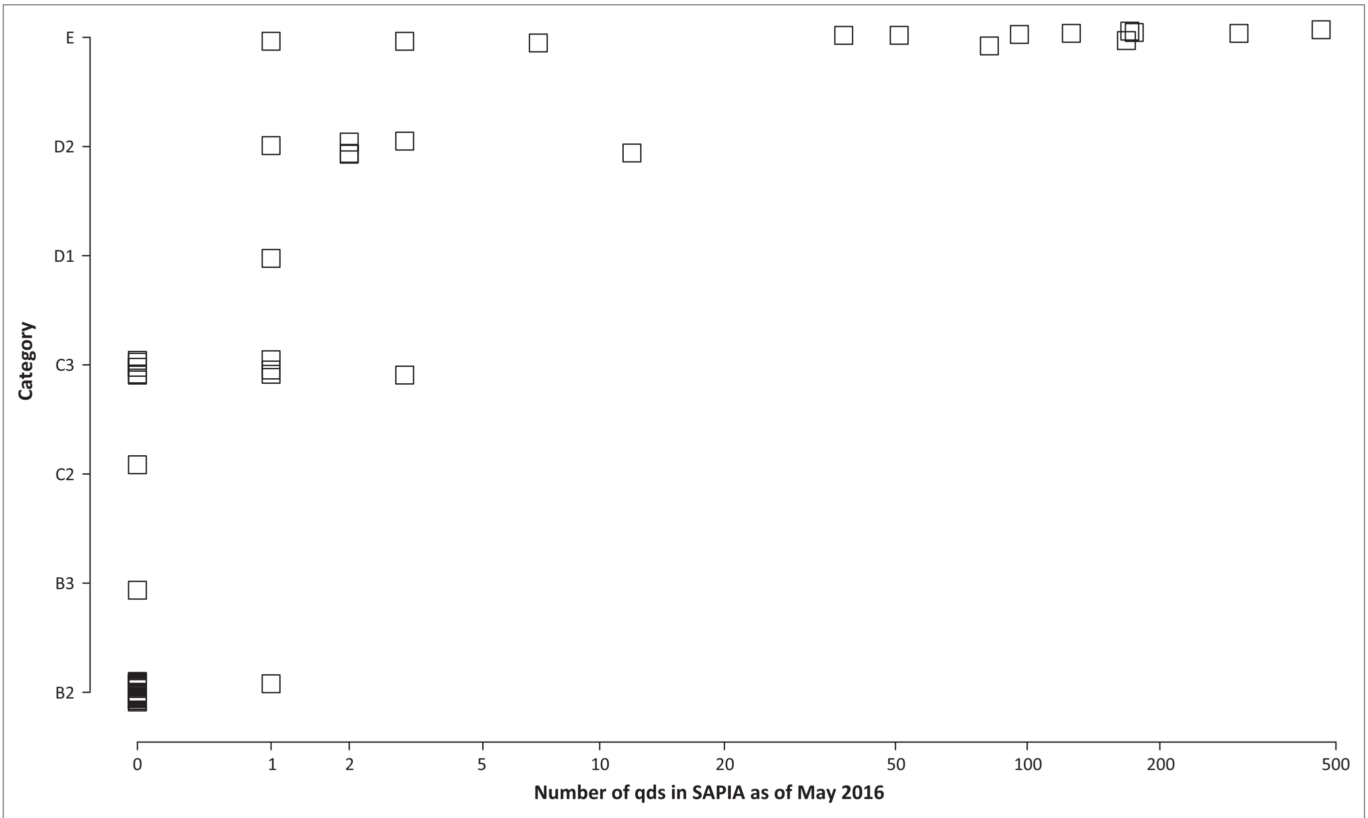


FIGURE 1-A4: The relationship between species introduction status and the number of records and distribution in SAPIA. Introduction status is based on Jacobs et al. (2017) for *Melaleuca* spp. and N. Magona unpublished data for *Acacia* spp. using the Blackburn et al. (2011) scheme (see Appendix 2a for details). All naturalised taxa and those with records in SAPIA are included, but introduced taxa with no records in SAPIA are not included for the Australian acacias but they were for the melaleucas. Data are from SAPIA up to May 2016. The graph is a strip plot of the introduction status of different species as per Blackburn et al. 2011 code against the number of qds a species is recorded in SAPIA. If there was a range of possible codes for introduction status we took the code furthest along the introduction-naturalisation-invasion continuum.

Species	Introduction status	Code as per Blackburn et al. 2011 Scheme	Number of quarter-degree squares occupied
Acacia adunca	Naturalised	C3	1
A. cultriformis	Naturalised	C3	1
A. cyclops	Invasive	E	175
A. dealbata	Invasive	E	302
A. decurrens	Invasive	E	126
A. elata	Invasive	E	51
A. fimbriata	Invasive	D2	2
A. implexa	Invasive	E	3
A. longifolia	Invasive	E	96
A. mearnsii	Invasive	E	463
A. melanoxylon	Invasive	E	171
A. paradoxa	Invasive	D2	1
A. pendula	Introduced	B2	0
A. podalyriifolia	Invasive	E	82
A. pycnantha	Invasive	E	38
A. retinodes	Naturalised	C3	0
A. saligna	Invasive	E	168
A. stricta	Invasive	E	7
A. ulicifolia var. brownei	Introduced/Naturalised	C2	0
A. viscidula	Naturalised	D1	1
Melaleuca alternifolia	Introduced	B2	0
M. armillaris subsp. *armillaris*	Naturalised	C3	0
M. brachyandra	Introduced	B2	0
M. bracteata	Introduced	B2	0
M. citrina (= *Callistemon citrinus* in SAPIA)	Naturalised	C3	1

Appendix table continued on the next page →

Appendix 4: (Countinued...)

Species	Introduction status	Code as per Blackburn et al. 2011 Scheme	Number of quarter-degree squares occupied
M. cuticularis	Introduced	B2	0
M. decora	Introduced	B2	0
M. decussata	Introduced	B2–B3	0
M. diosmifolia	Introduced	B2	0
M. elliptica	Introduced	B2	0
M. flammea	Introduced	B2	0
M. fulgens	Introduced	B2	0
M. huegelii subsp. *huegelii*	Introduced	B2	0
M. hypericifolia	Invasive	D2	2
M. incana subsp. *incana*	Introduced	B2	0
M. incana subsp. *tenella*	Introduced	B2	0
M. lanceolata	Introduced	B2	0
M. lateritia	Introduced	B2	0
M. linariifolia	Introduced	B2	0
M. linearis var. *linearis* (= *Callistemon linearis* in SAPIA)	Invasive	D2	3
M. nesophila	Introduced	B2	1
M. nodosa	Introduced	B2	0
M. pachyphylla	Introduced	B2	0
M. paludicola	Introduced	B2	0
M. parvistaminea	Invasive	E	1
M. phoenicea	Introduced	B2	0
M. quinquenervia	Naturalised	C3	3
M. rhaphiophylla	Introduced	B2	0
M. rugulosa (= *Callistemon rugulosus* in SAPIA)	Invasive	D1–D2	2
M. salicina	Naturalised	C3	0
M. squarrosa	Introduced	B2	0
M. styphelioides	Naturalised	C3	0
M. subulata	Introduced/Naturalised	B2–C3	0
M. teretifolia	Introduced	B2	0
M. thymifolia	Introduced	B2	0
M. viminalis subsp. *viminalis* (= *Callistemon viminalis* in SAPIA)	Invasive	D2	12

References

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarošík, V., Wilson, J.R.U. & Richardson, D.M., 2011, A proposed unified framework for biological invasions, *Trends in Ecology & Evolution* 26, 333–339.

Jacobs, L.E.O., Richardson, D.M., Lepschi, B.P. & Wilson, J.R.U., 2017, Quantifying errors and omissions in the listing of alien species: Melaleuca in South Africa as a case-study, *Neobiota* 32, 89–105.

Magona, N. unpublished data.

Appendix 5

Statistical models of the increase in recorded distribution of alien plants in SAPIA between 2000 and 2016 as a function of their distribution in 2000.

a) The first model includes the full data set

Deviance residuals					
	Min	1Q	Median	3Q	Max
	-2.3485	-0.929	-0.5429	0.0036	5.1898

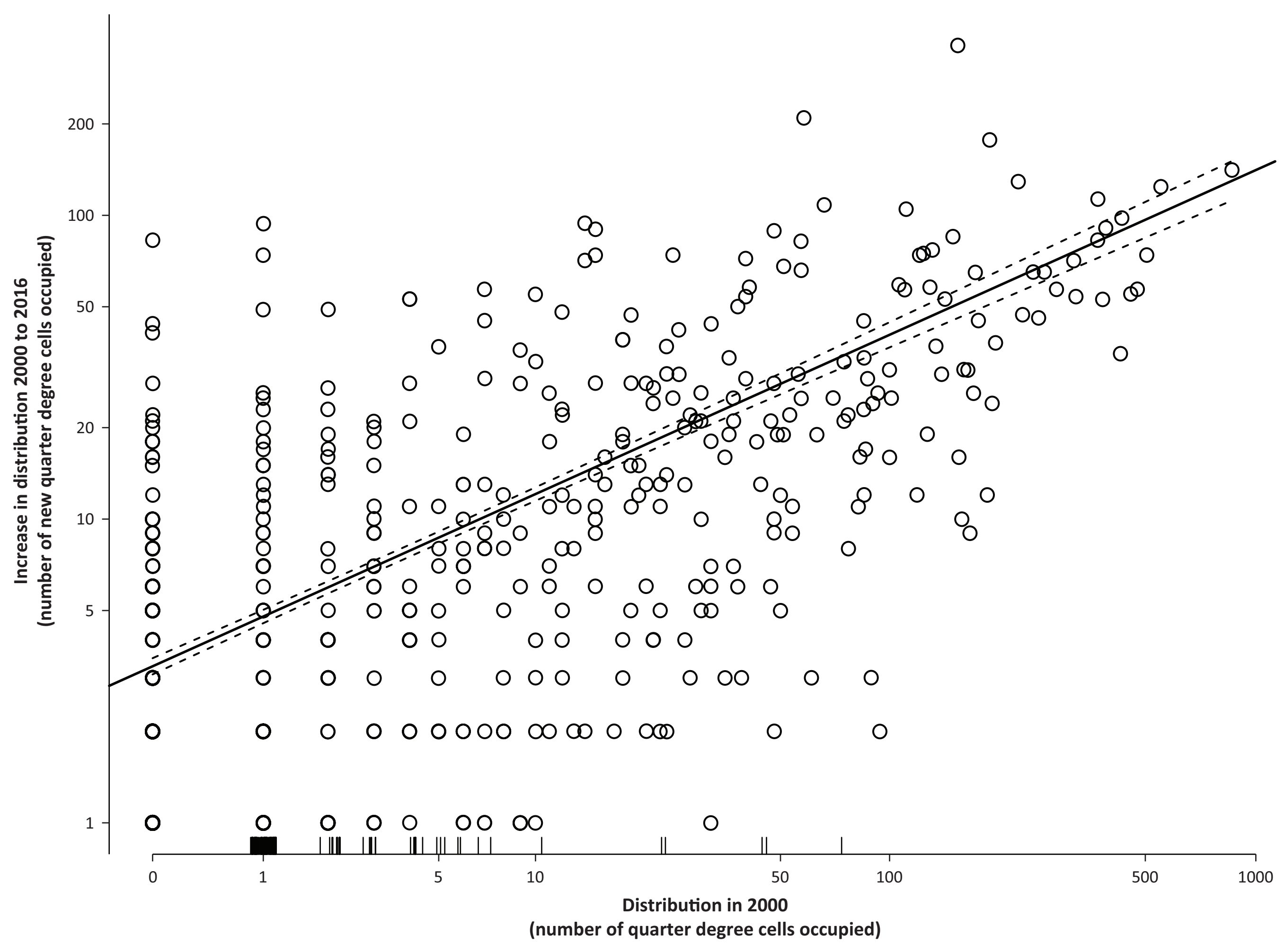
Coefficients				
	Estimate	Std. Error	z	Pr(>|z|)
Intercept	1.19	0.0615	19.31	<2e-16
Slope	0.544	0.0272	20.01	<2e-16

Call: glm.nb (formula = increase in number of qds occupied 2000 to 2016 ~ log(distribution in 2000 + 1), init.theta = 0.713, link = log).

Dispersion parameter for Negative Binomial (0.7321) family taken to be 1.
Null deviance: 1373 on 771 degrees of freedom.
Residual deviance: 857 on 770 degrees of freedom.
AIC: 4675.1.

Number of Fisher Scoring iterations: 1.
Theta: 0.7312
Std. Err.: 0.0403
2 x log-likelihood: -4669

Plotted out this looks like



b) The second model is restricted to only those taxa which are known not to be systematically under-reported in SAPIA, and is plotted in the main paper as Figure 2. Notably removing taxa that were known to previously have been under-reported improved the fit of the model (cf. dispersion parameters and deviance residuals).

Deviance residuals					
	Min	1Q	Median	3Q	Max
	-2.551	-0.879	-0.481	0.107	6.635

Coefficients				
	Estimate	Std. Error	*z*	Pr(>|*z*|)
Intercept	0.918	0.0695	13.2	<2e-16
Slope	0.592	0.0268	20.09	<2e-16

Call: glm.nb(formula = increase in number of qds occupied 2000 to 2016 ~ log(distribution in 2000 + 1), init.theta = 0.852, link = log).

Dispersion parameter for Negative Binomial (0.915) family taken to be 1.
Null deviance: 1212.45 on 564 degrees of freedom.
Residual deviance: 622.7 on 563 degrees of freedom.
AIC: 3416.6.

Number of Fisher Scoring iterations: 1.
Theta: 0.915.
Std. Err.: 0.0634.
2 x log-likelihood: -3410.

c) The final model including the influence of regulatory status (for a description of the regulatory categories see Appendix 2c).

Deviance residuals

	Min	1Q	Median	3Q	Max
	-2.77	-0.984	-0.39	0.121	5.24

Coefficients

	Estimate	Std. Error	z	Pr(>|z|)
Slope	0.518	0.0304	17.06	<2e-16
Intercept (category 1a)	1.1	0. 185	5.95	2.62E-09
Change in intercept (category 1b)	0. 385	0.208	1.85	0.0645
Change in intercept (category 2)	-0.0944	0.27	-0.349	0.727
Change in intercept (category 3)	-0.0367	0.238	-0.154	0.878
Change in intercept (not listed)	-0.554	0.198	2. 797	0.00515

Call: glm.nb(formula = increase in number of qds occupied 2000 to 2016 ~ log(distribution in 2000 + 1) + NEM:BA A&IS category, init.theta = 0.852, link = log)

Dispersion parameter for Negative Binomial (1.0458) family taken to be 1
Null deviance: 1352.26 on 564 degrees of freedom
Residual deviance: 612.25 on 559 degrees of freedom
AIC: 3354.6

Number of Fisher Scoring iterations: 1
Theta: 1.046
Std. Err.: 0.0744
2 x log-likelihood: -3341