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Rapid Communication

First record of *Opuntia pubescens* H.L.Wendland *ex* Pfeiffer, 1835 naturalised in South Africa

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Abstract

Opuntioid cacti have caused some of the most damaging plant invasions globally. While many of these invaders were introduced for ornamental and some agriculture use, there are an increasing number of records of invasive ornamental species. Here we report the first detailed invasion by *Opuntia pubescens* and investigate the potential for eradicating the species from South Africa. We found the species only at one location (Pretoria National Botanical Gardens) where the population was approximately 5023 plants over the undeveloped area of 3.66 ha. The plant was not found during surveys of neighbouring natural areas. We believe it was introduced to staff gardens as an ornamental plant, but we have not found it on sale in nurseries nor mentioned in historical literature. However, as the species was initially confused with *O. aurantiaca*, surveys were conducted in the neighbouring hills and Gauteng province for all known *O. aurantiaca* infested farms. Initial efforts on surveying the Limpopo, KwaZulu-Natal and Eastern Cape provinces with the assistance of Department of Agriculture, Forestry and Fisheries Land Use and Soil Management Resource Auditors have been initiated, but more work still needs to be done. Therefore, while preliminary control efforts in the garden looking promising; it is not clear whether nation-wide eradication is feasible. The Australian Weed Risk Assessment was used to collate information and determine the invasive potential of *O. pubescens* in South Africa. This method has been used worldwide and within the programme to determine risk potential of invasive species in the country. To determine the potential distribution of *O. pubescens* we developed a species distribution model using MaxEnt 3.3.3e based on native and non-native range. This study highlights the need to discourage the use of Opuntioid cacti as ornamental species due to their invasiveness, even if they are not yet known to be invasive.

Key words: alien succulent, cacti, eradication, feasibility, *Opuntia pubescens*

Introduction

The family Cactaceae, with about 1800 species, is native to North and South America (Anderson 2001). Several species of this family have transformed large areas of South Africa's natural landscape, in particular species in the genus *Opuntia* (Smith et al. 2011). All Cactaceae species are alien to Africa with the only exception of a slender epiphyte, *Rhipsalis baccifera* (J.S. Muell.) Stearn, (Walters et al. 2011). In South Africa Opuntioid cacti were introduced for ornamental or economic purposes. For example, *Opuntia ficus-indica* (L.) Mill was introduced as a multiuse commercial crop for arid regions (Boatwright et al. 2011). Historically botanical gardens in South Africa were actively involved in the introduction of invasive species either accidentally or deliberately, as mentioned in Hulme (2011).

Most cacti species are found in dry parts of South Africa (Walters et al. 2011), although some species such as *Cereus jamacaru* DC and *Harrisia martini* (Labour.) Britton also occur in other areas (Glen 2003) such as semi-tropical or coastline areas. South Africa has been recorded amongst the three hotspots of cacti invasion with 35 invasive species recorded (Novoa et al. 2014), and 11 genera are known to be naturalised in southern Africa (Henderson 2012, Walters et al. 2011). Out of the 11 genera, *Opuntia* is the most problematic genus in South Africa with about 14 species that are naturalized or invasive (Novoa et al. 2014).

Opuntia pubescens has already started spreading showing signs of potential invasiveness. Recent studies show that there are 1922 species of Cactaceae from 130 genera with 193 of those species from the genus *Opuntia* (Novoa et al. 2014), which are mostly

characterised by their compressed branches, modified and easily detachable cladodes, as well as hairlike spines or glochids (Cindi and Jaca pers.obs.). Taxonomic challenges in the Opuntioid cacti often exist. For example, in South Africa *Cylindropuntia fulgida* (Engelm.) F.M. Knuth var. *fulgida* was misidentified for *Cylindropuntia rosea* (DC.) Backeb. since the 21st century. It was only up until 2003 when the cochineal insect, *Dactylopius tomentosus* (Lamarck) collected from *C. rosea* in Mexico, failed to develop on *C. rosea* in South Africa that a case of incorrect identification was discovered (Henderson and Zimmermann 2003). This shows how critical accurate identification is for managing invasive species (Pyšek et al. 2013). In this study we report the first detailed invasion by *Opuntia pubescens*, and investigate the potential for eradicating the species from South Africa.

Description of *Opuntia pubescens*

An unknown *Opuntia* sp. was discovered at the Pretoria National Botanical Garden (PNBG) in 2003 and brought to the attention of Invasive Species Programme in 2012 after being initially misidentified as *O. aurantiaca* Lindl. Trials were conducted at the botanical garden's nursery to test whether the *O. aurantiaca* cochineal (*D. austrinus*) was effective on this cactus species. We filled one box with *O. aurantiaca*, one with the unknown *Opuntia sp.* (the species invading the Pretoria National Botanical Garden) and a third box with a mixture of the two species. The cochineal *D. austrinus* was added to each box in the form of cochineal-infested cladodes of *O. aurantiaca*. After two months we observed that all the *O. aurantiaca* cladodes in the first box had been infested with cochineal and were dying; in the second box, the cochineal had not infested the unknown *Opuntia* sp. cladodes at all, while in the third box, only the *O. aurantiaca* cladodes had been infested but none of the unknown *Opuntia* sp.

These results were discussed with a cactus specialist in South Africa (Dr. Helmuth Zimmerman) who guided and initiated talks with Mexican cacti taxonomists. Pictures and specimens were then sent to Mexico National Herbarium. The species was confirmed to be *O. pubescens* by Dr. Léia Scheinvar of the UNAM (Universidad Autonoma de Mexico).

Opuntia pubescens is a succulent shrub 15–35 cm or more, strongly branched; branch segments slightly flattened, linear-oblong, terete at the base, 3–8 × 1–3 cm. Cladodes (stem segments) easily detach, alternate or opposite, surface nearly smooth to pubescent. Areole subcircular to oblong, flattened 2–3 × 1–1.5 mm, ca 3.5 mm apart. Glochids yellowish, ca. 1 cm long, in a bundle on top of the areola. Spines 3–8, sharp, subulate, ascending, divergent, 3–25 mm long, reddish brown (or greyish to whitish). Flowers of 5 × 4 cm, greenish yellow; perianth 1.5 × 0.7 cm, pericarpel narrowly obovate, arranged in 3–5 series, fitted with white felt, prominent, and few deciduous glochids; stamens greenish yellow, numerous; style white, stigma lobes 5, greenish (Figure 1A, B and C). This description was compiled from specimens examined in the South African National Herbarium, Pretoria (PRE) supplemented by Anderson (2001) and Britton and Rose (1919) descriptions.

The species morphologically resembles two invasive cacti species in South Africa: *O. aurantiaca* and *Salmiopuntia salmiana* (J. Parmentier ex Pfeiffer) Guiggi. However, the latter differs in that the surface of the cladodes is softly velvety, with the growth tips particularly velvety. For full details of sample description and comparison with related species, see Supplementary material (Table S1, Figure S1).

Methods

We filled one box (1m² in size) with *O. aurantiaca*, another box with unverified species (the species invading the Pretoria National Botanical Garden) and a third box with a mixture of the two species (40 cladodes of each species in box). The cochineal *D. austrinus* was added to each box in the form of cochineal-infested cladodes of *O. aurantiaca*. After two months we observed that all the *O. aurantiaca* cladodes in the first box had been infested with cochineal and were dying in the second box, the cochineal had not infested the unverified species cladodes at all, while in the third box, only the *O. aurantiaca* cladodes had been infested but none of the other species.

To determine its potential invasiveness and feasibility of eradication in South Africa we did the following:

Bioclimatic suitability and invasive risk assessment

The Australian Weed Risk Assessment (Pheloung et al. 1999) was used to collate information and determine the invasive potential of *O. pubescens* in South Africa. This method has been used worldwide and within the programme to determine risk potential of invasive species in the country.

To determine the potential distribution of *O. pubescens* we developed a species distribution model using MaxEnt 3.3.3e (Phillips et al. 2006) based on native and non-native range. Following recommendations by Elith et al. (2011) and Phillips

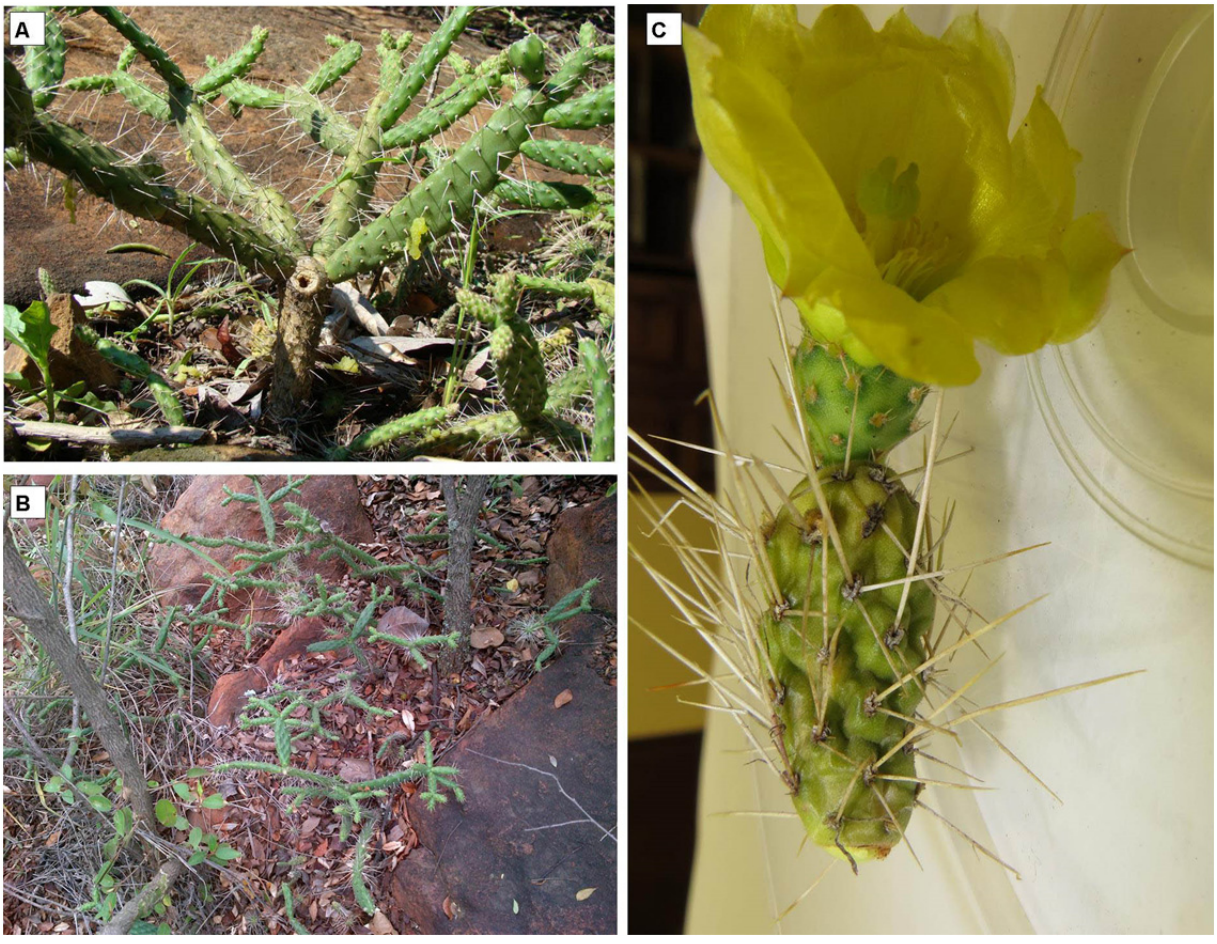

Figure 1. *Opuntia pubescens*: (A) strongly branched stem, (B) preferred habitat at the Pretoria National Botanical Garden and (C) flower. Photographs by: Dan'sile D. Cindi.

et al. (2009) we restricted the background points from countries with sample locations, restricting the background points to areas assumed to have been surveyed for the species. Therefore the background file used in MaxEnt will have the same bias as the presence locations. 10,000 background points were created by sampling random points within a defined environmental mask.

We used the MaxEnt default settings; only selected random seed (to generate different training and test sample per replicate) and changed replicate run type to subsample. The random test percentage was set to 75 and number of replicates to 25. Hence executing multiple runs also provides a way to measure the amount of variability in the model. We obtained global occurrence data from Global Biodiversity Information Facility (GBIF 2015) and records with missing spatial data or occurring in the ocean were removed using ArcGIS 10.1. The area under the receiver operating characteristic curve (AUC) was used to examine the predictive power of the model. For bioclimatic variables, environmental data at a spatial resolution of 2.5 arc-minutes grids were downloaded from the Worldclim database (www.worldclim.org). We used jackknife to measure variables that were more likely to be directly relevant to *O. pubescens*.

Local surveys and extent of distribution

The PNBG was exhaustively surveyed to measure the extent and density of the infestation, these surveys were conducted March to May and again November to January just after the first rains of the season. We also surveyed the neighbouring hills, parks and nature reserves. All trails were walked based on a random survey technique that extended 50 m beyond the route trails of the reserves. Trails

Table 1. Analysis of bioclimatic variable contribution and permutation importance to the MaxEnt distribution model.

Variable	Percent contribution	Permutation importance[#]
Isothermality	29.6	20.8
Annual precipitation	25	19
Mean temperature of the coldest quarter	23.7	52.2
Temperature seasonality	21.7	7.9

[#] indicates variable contribution on the final MaxEnt model, determined by varying the predictors' values between presence and background points and examining the change in AUC.

were walked by 3 people 2 m apart on a 50 m stretch, and repeated for each site to determine if there is any *Opuntia pubescens* infestation. Pamphlets and posters were distributed to relevant stakeholders in and around the Pretoria National Botanical Garden with the objective of raising awareness and to get information from the people who might have seen the species. Pamphlets were also distributed nationally (Supplementary material Figure S2). Five nurseries (Lynwood, Rietfontein, Derdepoort and Weavind Park) in the vicinity of the Pretoria National Botanical Garden were inspected.

Transect layout

In June 2014 five transects were set up to estimate the density of the population in the Pretoria National Botanical Garden, before and after the herbicide applications to enable us to determine the efficacy of the control methods to be used. The total area of each transect was 60 m². The total number of plants found within the 5 transects was 5023 plants and 77 clumps before herbicide application. The transects were monitored by counting all plants within four size categories (loose joints / 1–3 cladodes; medium plants / 4–7 cladodes; large plants / 8 and more cladodes and clump / 45 cm diameter or more). Four herbicide applicators were appointed in July 2014. Clearing operations were carried out for a period of 30 days (July – August 2014). Transects were again surveyed five and eight months after clearing operations. There are no registered herbicides for this species in South Africa, and so we used the control method approved for the closely related species, *O. aurantiaca*: foliar spray of glyphosate at 480 g/1 SL in 5 l water. Four herbicide applicators walked parallel to each other about 2 m apart on a 10 m wide transect between two landmarks, for example roads or tracks. This method ensures that most plants could be detected and treated. One person walked behind the four herbicide applicators to locate any plants that may have been missed. Isolated joints or small plants were carefully collected and sprayed collectively in a safe spot for example, on top of a rock to avoid unnecessary contamination.

We also used a framework for eradication feasibility from Panetta (2015). The rationale of this framework is that it considers both relative feasibility of extirpation and containment and thus generates eight different eradication scenarios. In this framework genera and species can be classified according to an algorithm for assessing eradication feasibility, based upon time to maturity, seed bank persistence and feasibility of containment. The eight syndromes are: (1) J_LP_S + HDM; (2) J_SP_S + HMD; (3) J_LP_S − HMD; (4) J_SP_S − HMD; (5) J_LP_L + HMD; (6) J_SP_L + HMD; (7) J_LP_L − HMD and (8) J_SPL – HMD [J_L = long juvenile period; P_L = long seed persistence; J_S = short juvenile period; P_S = short seed persistence; SD = short-distance dispersal; HMD = human-mediated dispersal].

Results and discussion

Bioclimatic suitability and invasive risk assessment

The results of the distribution model indicate that *O. pubescens* is potentially suitable to the temperate (warm-hot dry summer to hot dry winter) and arid (cold arid steppe to hot arid steppe) regions of southern Africa (Figure 2). In South Africa the east and north-eastern regions are shown to be climatically suitable for *O. pubescens*. These regions include Eastern Cape, KwaZulu-Natal, Mpumalanga, Limpopo and northern parts of the North West Province. These climate conditions match closely to the native distribution of *O. pubescens* in Mexico (AUC= 0.964, (Supplementary material Figure S3). Out of the 19 environmental variables used to develop the model only four variables were relevant (isothermality, annual precipitation, mean temperature of the coldest quarter and temperature seasonality) with isothermality as the best contributor to the model (Table 1).

In terms of invasive risk assessment, 42 of the 47 questions relevant to *O. pubescens* were answered, leading to a score of 12, which would have resulted in the species being rejected in a pre-border evaluation (Supplementary material Table S2). According to the assessment, both agriculture and environmental sectors are at risk from invasion by *O. pubescens*.

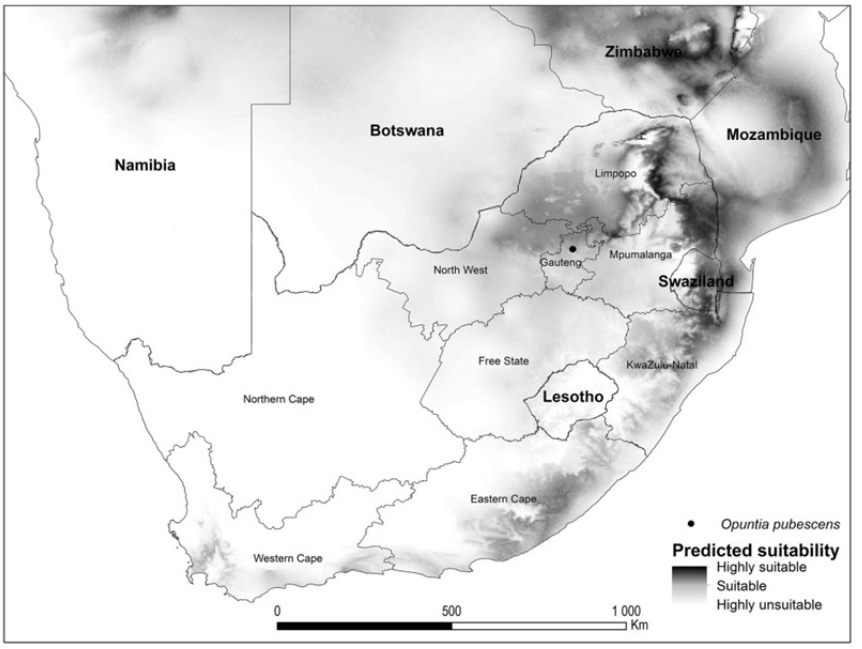

Figure 2. Bioclimatically suitable areas (darker areas more suitable) predicted for *O. pubescens* in South Africa, AUC = 0.964.

The impacts of this species are likely to be similar to other invasive succulents in the region that form impenetrable stands. Habitats that are likely to be invaded are natural grasslands, transformed pastoral lands, savanna and thicket vegetation (dense bush vegetation with small trees).

Local surveys and extent of distribution

Opuntia pubescens was not found in any of the adjacent natural areas surveyed and was also not found in the five nurseries inspected. The only area that was infested with *Opuntia pubescens* was the undeveloped section of the PNBG. At this site the species has begun to form dense thickets. The small bristle-spiny cladodes of the plant adhere to animal fur and this can potentially spread the plants vegetatively over considerable distance. This is evident from the fact that this species was found to occur only in the ridge where rock hyrax (*Procavia capensis*) normally browses.

Opuntia pubescens has been identified as a species of concern that requires urgent attention and classified as category 1a (invasive species that may not be owned, imported into South Africa, grown, moved, sold, given as a gift or dumped in a waterway and require compulsory control) in the NEM:BA (2014) regulation. We further used the unified framework for biological invasions proposed by Blackburn et al. (2011) to determine the stage of invasion and to categories populations. The latter framework recognises the invasion as a process that can be divided into a series of stages (transport, introduction, establishment and spread), that in each stage there are barriers that need to be overcome for a species or population to pass on to the next stage and that different management interventions apply at different stages. Different parts of this framework emphasise views of invasions that focus on individual, population, process and species. There are six categories ranging from A (populations not transported beyond limits of native range) to 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). According to the latter scheme *O. pubescens* falls within the establishment stage and category C3 (Individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining) (Blackburn et al. 2011). Thus the populations are still limited in distribution and should be managed or eradicated.

History of introduction

The botanical garden was established in 1946 on a land that was previously an experimental farm for the University of Pretoria. There were also private properties or smallholdings on the northern part of the garden and many species of introduced plants

were planted in the gardens of the smallholdings. Historical records of plantings in the botanical garden do not indicate *O. pubescens* had been planted in the garden. It is suspected that the *O. pubescens* in the PNBG may have been introduced as an ornamental plant by those who occupied the houses within the PNGB before 1946. Similarly to a number of conservation areas previously inhabited, for example in Kruger National Park a number of alien species were introduced through staff villages and tourist camps (Foxcroft et al. 2008), botanical gardens can thus be hotspots for invasion, increasing responsibility to manage invasions (Hulme 2011).

Feasibility of eradication

All detached cladodes and fruit can root and grow to form new plants. In the eradication framework, *O. pubescens* fitted the first scenario best (J_LP_S+ HMD). This scenario has the highest extirpation feasibility as it combines long juvenile period with low seed persistence. This implies that the management programme for *O. pubescens* should involve a containment strategy over a short period of time and is therefore less expensive with a high probability of success (Panetta 2015).

Clearing team herbicide control results

There is only one known locality of the species in South Africa so far and this makes the species a good target for eradication. A total number of 4020 loose cladodes/small plants, 228 medium sized plants, 106 large plants and 77 clumps in all five transects were recorded and treated. The clearing team overlooked 14.3% of the isolated cladodes and small plants because of difficulties in detection amongst other vegetation and accessibility in dense vegetation. An additional 2.6% of the medium sized plants were missed. All large plants and clumps were effectively treated; there are no longer large plants or clumps along transects and around the garden.

Conclusion

Taxonomic certainty is the key to successful detection and treatment of invasive species. Historically, *O. pubescens* was misidentified due to a lack of taxonomic expertise or an absence of identification tools (sensu Pyšek et al. 2013). This hindered progress in ecological research and management of this species. The lesson is that other new species risk not being detected or considered potential invaders, particularly as they usually occur in low densities. We endorse that any new material found in South Africa be incorporated into the ongoing phylogenetic work to improve the taxonomy and identification of Cactaceae species.

We recommend that chemical control (using Glyphosate foliar spraying method) should be done in winter when annual grass cover is low and that follow-up treatments and monitoring be continued for the next five years before any claim of extirpation can be made. We also recommend a broader national survey to detect if a similar incident of misidentification might be the case elsewhere.

Horticultural trade has increased greatly in importance to the point that it is currently the only pathway of introduction for new cacti species (Novoa et al. 2014) into South Africa. We plan to continue conducting awareness-raising programs (distribute pamphlets, present exhibitions and talks) for both the horticultural industry and the general public.

Acknowledgements

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References

Anderson EF (2001) The Cactus Family. Timber Press, Portland Oregon, USA, pp 513–514

Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP, Jarošík V, Wilson JRU, Richardson DM (2011) A proposed unified framework for biological invasions. *Trends in Ecology and Evolution* 26: 333–339, https://doi.org/10.1016/j.tree.2011.03.023

Boatwright JS, Smith GF, Zimmermann HG, Jaca TP, Motloung RF, Malotsha TD (2011) Biology and impact of invasive succulent plants. In: Walters M, Figueiredo E, Crouch NR, Winter PJD, Smith GF, Zimmermann HG, Mashope BK (eds) Naturalised and invasive succulents of southern Africa. *Abc Taxa* 11: 3–12

Britton NL, Rose JN (1919) The Cactaceae: descriptions and illustrations of plants of the Cactus family. Gibson Brother Press, Carnegie Institution of Washington, Washington, DC, 1(248), pp 100–101

Elith J, Phillips SJ, Hastie T, Dudík M, Chee YE, Yates CJ (2011) A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17: 43–57, https://doi.org/10.1111/j.1472-4642.2010.00725.x

Foxcroft LC, Richardson DM, Wilson JRU (2008) Ornamental plants as invasive aliens: problems and solutions in Kruger National Park, South Africa. *Environmental Management* 41: 32–51, https://doi.org/10.1007/s00267-007-9027-9

GBIF (2015) Global Biodiversity Information Facility (GBIF), http://www.gbif.org (accessed 6 Nov 2015)

Glen H (2003) Cactaceae. In: Germishuizen G, Meyer NL (eds), Plants of southern Africa: an annotated checklist. *Strelitzia* 14: 335–336

Henderson L (2012) Focus on Cacti in South Africa. ARC-Plant Protection Research Institute. *SAPIA News* 25: 1–8

Henderson L, Zimmermann HG (2003) Chainfruit cholla (*Opuntia fulgida* Engelm.) misidentified as rosea cactus (*Opuntia rosea* DC.) in South Africa. *South African Journal of Plant and Soil* 20: 46–47, https://doi.org/10.1080/02571862.2003.10634905

Hulme PE (2011) Addressing the threat to biodiversity from botanic gardens. *Trends in Ecology and Evolution* 26: 168–174, https://doi.org/10.1016/j.tree.2011.01.005

National Environmental Management: Biodiversity Act (2004) Department of Environmental Affairs, Pretoria, South Africa, pp 3–80, https://www.environment.gov.za/sites/default/files/legislations/nemba10of2004_alienandinvasive_speciesregulations.pdf

Novoa A, Le Roux JJ, Robertson MP, Wilson JRU, Richardson DM (2014) Introduced and invasive cactus species: a global review. *AoB Plants* 7: plu078, https://doi.org/10.1093/aobpla/plu078

Panetta FD (2015) Weed eradication feasibility: lessons of the 21st century. *Weed Research* 55: 226–238

Pyšek P, Hulme PE, Meyerson LA, Smith GF, Boatwright JS, Crouch NR, Figueiredo E, Foxcroft LC, Jarošík V, Richardson DM, Suda J, Wilson JRU (2013) Hitting the right target: taxonomic challenges for, and of, plant invasions. *AoB Plants* 5: plt042, https://doi.org/10.1093/aobpla/plt042

Pheloung PC, Williams PA, Halloy SR (1999) A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal *of Environmental Management* 57: 239–251, https://doi.org/10.1006/jema.1999.0297

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modelling of species geographic distributions. *Ecological modelling* 190: 231–259, https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips SJ, Dudík M, Elith J, Graham CH, Lehmann A, Leathwick J, Ferrier S (2009) Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. *Ecological Applications* 19: 181–197, https://doi.org/10.1890/07-2153.1

Smith GF, Figueiredo E, Boatwright JS, Crouch NR (2011) South Africa's ongoing *Opuntia* Mill. (Cactaceae) problem: the case of *Opuntia microdasys* (Lehm.) *Bradleya* 29: 73–78

Walters M, Figueiredo E, Crouch NR, Winter PJD, Smith GF, Zimmermann HG, Mashope BK (2011) Naturalised and invasive succulents of southern Africa. *Abc Taxa* 11: 1–346

Supplementary material

The following supplementary material is available for this article:

Table S1. Distinguishing features among three morphologically similar species of *Opuntia*.

Table S2. Evaluation of invasive risk of *Opuntia pubescens* using the Australian Weed Risk Assessment method.

Figure S1. Distinguishing among three morphologically similar species of *Opuntia* present in South Africa (A: *O. pubescens*, B: *O. aurantiaca*, C: *S. salmiana*). Photographs by: A = Helmuth G. Zimmermann; B = Thulisile P. Jaca; C = Dan'sile D. Cindi.

Figure S2. Publicity pamphlets distributed to relevant stakeholders around the Pretoria National Botanical Garden and country wide.

Figure S3. Bioclimatic suitability of *O. pubescens* in its native range in Mexico with native distribution records.

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