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Research Article

Syzygium australe (J.C.Wendl. ex Link) B. Hyland (Myrtaceae) in South Africa: current distribution and invasion potential

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Abstract

Syzygium australe (Australian brush-cherry; the names *Eugenia australis* and *Syzygium paniculatum* have been misapplied to this species in some regions) is native to Australia. It has been introduced and used as an ornamental plant in several regions outside its native range and is invasive in Hawaii and New Zealand. The species was first recorded in South Africa in 1968 and has become a popular and widely traded and planted ornamental species. The first reports of naturalisation in the country appeared in the first decade of the 21st century; the species was subsequently flagged as a priority for investigation and potential regulation as an invasive species. In this paper we mapped the current distribution of *S. australe* in South Africa, determined its introduction status, and modelled its potential distribution. We also investigated whether cultivated plants are producing fertile seeds and compared such seeds with those produced by plants growing outside cultivation. We recorded *S. australe* at 268 sites across the country, clustered primarily in the Western Cape province. Naturalised populations have established at three sites, all in the Western Cape. Surveys of these established populations revealed ~ 4000 plants covering an area of ~ 7 ha (representing ~ 2 ha condensed canopy area). These populations were flourishing in riparian habitats in urban areas. Species distribution models suggest that *S. australe* has the potential to expand its current range in South Africa, primarily in coastal regions. Seeds of both cultivated and naturalised plants showed similar high levels of germinability (both 100%). Building on these findings, we conducted a risk analysis using the Risk Analysis of Alien Taxa Framework, and found *S. australe* to be of high invasion risk in South Africa. We recommend that all populations outside cultivation be controlled, and that propagation and trade be prohibited. However, except where they occur near riparian habitats, garden plantings do not need to be prioritised for immediate control, and can rather be phased out over time.

Key words: biological invasions, Myrtaceae, ornamental horticulture, tree invasions

Introduction

The ornamental horticulture industry plays an important role in introducing and disseminating invasive plants globally (Hulme et al. 2018). Seventy percent of invasive alien trees and shrubs in South Africa are, or were, used primarily as ornamentals (Richardson and Rejmánek 2011). Species with strong human associations have high probabilities of becoming

invasive once naturalised as they benefit from repeated human dissemination. Consequently, strategies directed at managing such species often lead to controversies and intense debates between users and conservation agencies (Zengeya et al. 2017).

Many species of Myrtaceae are important in ornamental horticulture (Mitra et al. 2012). Of the 29 alien fleshy-fruited Myrtaceae taxa in South Africa, 23 were introduced as ornamentals (Richardson and Rejmánek 2011; Mbobo et al. 2022). *Syzygium australe* (J. C. Wendl. ex Link) B. Hyland (Myrtaceae) (Australian brush-cherry) is a tree species native to Australia where it grows in open forests and along watercourses. The species has been introduced to and planted as an ornamental in several regions around the world, including Brazil, Florida, and Germany (CABI's Invasive Species Compendium (CABI-ISC)); with records of invasion in Hawaii and New Zealand (GLONAF; Pacific Island Ecosystems at Risk (PIER)). The first record of *S. australe* in South Africa was in 1968 (the Southern African Plant Invaders Atlas (SAPIA); the South African database of herbarium records: http://posa.sanbi.org/, accessed March 2022)). It should be noted that the names *Eugenia australis* (H.L. Wendl. Ex Link) B. Hyland and *Syzygium paniculatum* Gaertn. have been misapplied to what is currently accepted as *S. australe* in South Africa (Henderson 2020). *Syzygium australe* was recorded for the first time in Kruger National Park in 1998, and Foxcroft et al. (2008) provide evidence of naturalisation (although the name *Syzygium paniculatum* Gaertn. was misapplied for *S. australe*; L. Henderson, *pers. comm.*); however a repeat survey in 2020 did not find the taxon (Keet et al. 2022). Also in 2008, invasive populations of *S. australe* were recorded along the Eerste River in Stellenbosch in the Western Cape (Meek et al. 2010; 2013). Wilson et al. (2013) noted that the species had been included in a 2007 draft list of taxa to be considered for listing under the Conservation of Agricultural Resources Act. However *S. australe* has never been formally listed as an invasive species in South Africa.

Over the period 2017–2020 there was a surge in the number of *S. australe* records, especially from the citizen science platform iNaturalist (https://www.inaturalist.org/projects/syzygium-australe-in-south-africa; accessed August 2022). The species has become a conspicuous feature of many South African landscapes, especially in urban areas. This study aimed to document the current distribution and invasion status of *S. australe* in South Africa, and predict the potential distribution of the species using species distribution models. The final aim was to use the information gathered to conduct a risk analysis on the species for South Africa and thereby develop recommendations for regulation.

Materials and methods

Species description

Syzygium australe (J.C.Wendl. ex Link) B. Hyland is a shrub or tree up to 25 m tall that is native to New South Wales and Queensland in Australia

Table 1. Surveyed sites with naturalised populations of *Syzygium australe* in South Africa. Localities, description, and proposed actions for each site are given. Degree of establishment is as per the Darwin Core term dwc:degreeOfEstablishment (Groom et al. 2019).

Locality	Geographic coordinates	Degree of establishment	Proposed actions
George, Western Cape	–33.949203; 22.455886	Invasive (D2) Plants are found > 100 m from nearest putative source trees (so D rather than C3). Trees in the Camphersdrift River are fruiting, with seedling emerging under the canopy (so D2 rather than D1). However, populations are still within the George area, certainly < 3 km from putative sources (so D2 rather than E).	Individuals along the Camphersdrift River should be prioritised for clearing. Engagement with landowners to prevent future spread is recommended (e.g., by trying to reach agreement to remove cultivated plants close to the river). It is still a small population ~ 35 adult plants, all with ripe fruits.
Newlands, Western Cape	–33.97278; 18.445696	Established (C3) No evidence of plants > 100 m from the neighbouring houses, all close to suburbia at present.	This population comprises adult plants, but these are not clustered together. Further searches are needed to detect naturalised individuals > 100 m from any currently recorded locality. All plants outside of cultivation should be cleared and landowners close to the naturalised populations informed of the risk posed and what can be done to reduce future spread.
Stellenbosch, Western Cape	–33.9413; 18.8536	Invasive (D2) Plants are found > 100 m from nearest putative source trees (so D rather than C3). Trees in the Eerste River are fruiting, with seedlings emerging under canopies and in the rocky river bed (so D2 rather than D1). However, populations are still within urban areas of Stellenbosch, certainly < 3 km from putative sources (so D2 rather than E).	This is the largest naturalised population recorded in our study. An attempt should be made to extirpate the naturalised population. Substantial landowner consultation will likely be necessary as many gardens near the river still have *S. australe* planted that will need to be removed if the invasion is to be stopped.

(Juniper and Britton 2010). Its fruit are oblong to obovoid with crimson-purple colour, carrying one or very few seeds. The seeds are primarily dispersed by birds (www.hear.org/pier/wra/pacific/Syzygium/_australe.pdf).

Identifying sites and conducting field surveys

Populations of *Syzygium australe* were identified through searches of iNaturalist, the Global Biodiversity Information Facility (GBIF; www.gbif.org) (both accessed August 2022), and the Southern African Plant Invaders Atlas (SAPIA). Additional localities were identified through field observations and personal communication with managers and researchers. We conducted field surveys in George, Newlands Forest, and Stellenbosch – sites where the species is known to be commonly cultivated and where populations have been recorded outside of cultivation.

GPS coordinates were collected for each plant using a Garmin GPSMAP 64s unit. We recorded plant height and noted whether the plants were flowering or fruiting. Populations of *S. australe* were assigned an introduction status following the Unified Framework for Biological Invasions (Table 1; Blackburn et al. 2011) as interpreted for trees by Wilson et al. (2014) and modified by Groom et al. (2019). Furthermore, a "project" on iNaturalist was created to document the distribution of the species in Stellenbosch (https://www.inaturalist.org/projects/syzygium-australe-in-urban-stellenbosch). The populations were then categorised as planted and/or naturalised using images provided on iNaturalist and Google Street View and by visiting

many sites. The habitats where the records occurred were classified as: private garden, public park/open area or natural habitat. We noted whether plants occurred in riparian habitats.

Potential distribution

Maximum entropy (MaxEnt v 3.4.3; Phillips et al. 2006) modelling was used to estimate the potential geographic distribution of *S. australe* globally and in South Africa. Species occurrence data from the native and invaded ranges were downloaded from GBIF (May 2022) using "*Syzygium australe*" as the species name, noting that the downloaded records included data for synonyms. We included the South African records collected from field surveys in May 2022 in the models. Data were cleaned manually: points in the ocean, duplicate records, coordinates with two decimals or fewer, or where accuracy was not specified were removed, resulting in 293 records. We used default MaxEnt settings: 10,000 random background points were used as pseudo-absences from which response curves were created to evaluate *S. australe*'s response to individual climatic variables; output was logistic allowing for a continuous map to be produced. A jackknife procedure was used to measure variable importance. The "area under the curve" (AUC) of the receiver operating characteristic curve was used to evaluate model performance (with the data split five times). The bioclimatic variables used to create the model were obtained from the WorldClim dataset (www.worldclim.org) at 10-minute resolution. We selected four non-correlated (< 0.7; Pearson correlation coefficient) bioclimatic variables: annual precipitation, mean annual temperature, maximum temperature of the warmest month, and precipitation of driest quarter (for further details on the model output see Supplementary material Figure S1). These variables were selected as temperature and precipitation are important factors for *S. australe* survival (Juniper and Britton 2010).

Germination experiments

Germination experiments were conducted to investigate aspects of the reproductive biology of *S. australe*. We specifically wanted to know whether cultivated plants produce fertile seeds, and to compare such seeds with those produced by plants growing outside cultivation. Fruits were collected haphazardly from 22 trees: twelve from cultivation (six as hedges and the other six as stand-alone trees) and twelve from outside cultivation (six from along the Eerste River in Stellenbosch and six from Newlands Forest). 120 seeds were used for the experiments, half of which were scarified. Each treatment (cultivated and not cultivated) had three replicates, five seeds per Petri dish. Seeds were placed on filter paper in Petri dishes with 6 ml of distilled water; 3 ml of benomyl fungicide was used to prevent rotting or decaying of seeds. The experiments were conducted in a growth chamber

with alternating day/night temperatures (10 °C during the night and 20 °C during the day). Artificial lights were installed, and ibuttons were used to monitor the temperature. The light was on a 10/14-hour photoperiod. Seeds that germinated were counted, and the number of days taken for the radicle to appear was recorded. The germination experiment was discontinued after 22 days when there were no signs of any new seeds germinating for four days.

Risk analysis

Observations made during this study, together with an evaluation of impacts reported elsewhere in the world, were used to assess the invasion risk of *S. australe* to South Africa by applying the Risk Analysis for Alien Taxa framework (RAAT) (Kumschick et al. 2020, Table S2). This risk analysis framework provides a structured way to assess whether a species (in this case *S. australe*) is likely to become invasive, to identify any existing or potential impacts, and to identify management options. It is specifically designed to provide evidence for listing alien species in South Africa under the National Environmental Management: Biodiversity Act (Act 10 of 2004) Alien and Invasive Species Regulations (the NEM:BA A&IS Regulations hereafter).

Results

Current distribution

We found 253 "Research Grade" records of *Syzygium australe* on iNaturalist (https://www.inaturalist.org), and on GBIF (www.GBIF.org, 2022) we found 149 records. Of the 149 records from GBIF, 144 were from iNaturalist, and five are herbarium records. The SAPIA database had 43 records of the species.

We recorded 268 sites of occurrence of the species across the country, most of which (91%) were clearly in private gardens. *Syzygium australe* is present in six of South Africa's nine provinces (Figure 1B), clustered primarily in Gauteng and the Western Cape provinces. There were signs of naturalisation at three sites (all in the Western Cape: George, Newlands, and Stellenbosch) where individuals had fruits and were reproducing with no apparent direct interference from humans. Surveys of these established populations revealed ~ 4 000 plants covering an area of ~ 7 ha (though this only represented ~ 2 ha condensed canopy area). Several properties in George, Newlands, and Stellenbosch have *S. australe* cultivated as ornamental plants; these plantings seem to have been the source of naturalised populations recorded along the Camphersdrift (George) and Eerste (Stellenbosch) rivers (Table 1; Figure 2A–F). Both George and Stellenbosch populations consisted of mature and immature plants with plant heights ranging from 0.3 to 20 meters (Figure 3); several plants had ripe fruits that had already fallen to the ground (Figure 2F). Given the extent and abundance of the *S. australe* in South Africa, the species was classified as category D2 under the Darwin

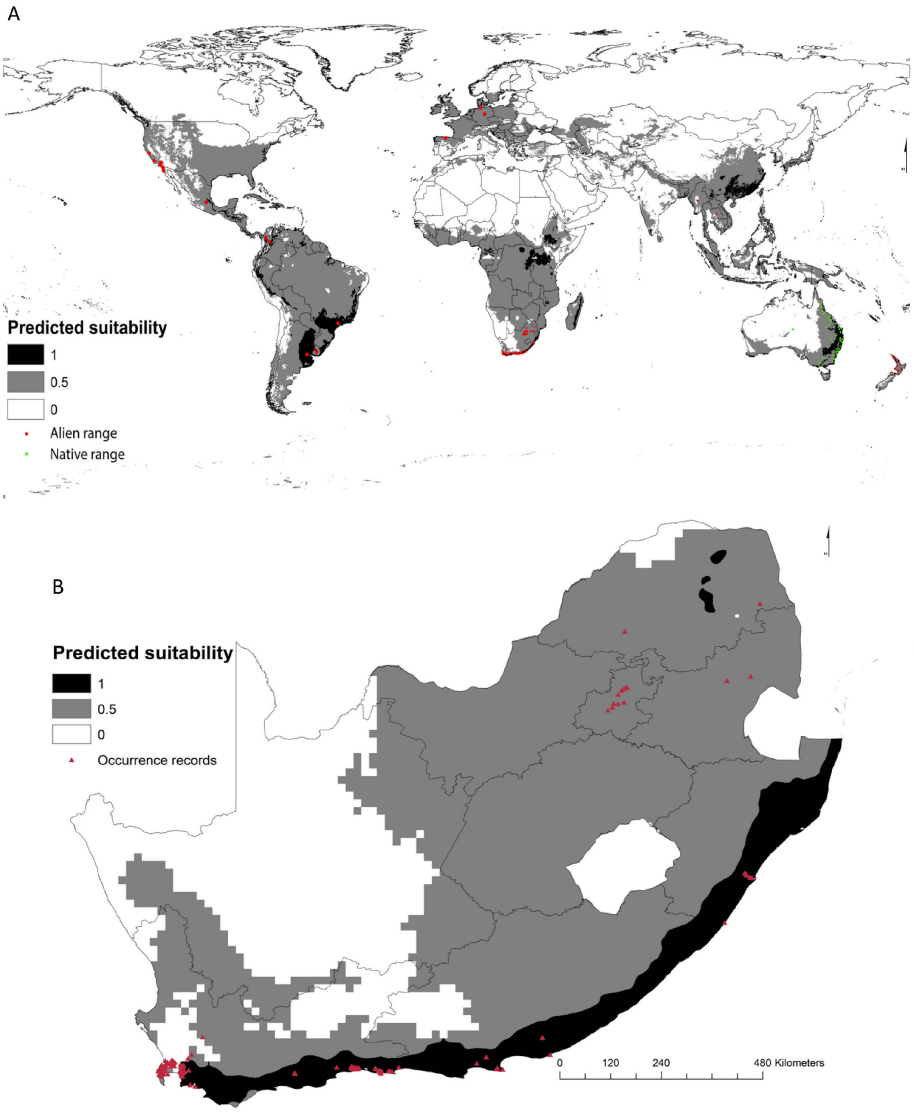

Figure 1. Average suitability map showing the potential distribution of *Syzygium australe* globally A) based on existing occurrence data and climate variables modelled using MaxEnt. The dark red circles indicate occurrence records from alien, light green circles indicate occurrence records from the native range. B) is potential distribution of *S. australe* in South Africa. The dark red circles indicate current distribution of *S. australe* in South Africa (Table S1). Darker shading indicates more suitable climatic conditions.

Core term (dwc: degree of Establishment) (Groom et al. 2019). This category classifies *S. australe* as invasive. However, since there are multiple self-sustaining populations in riparian ecosystems, it is highly likely that the species will meet the criteria for classification as a widespread invader (category E) very soon.

Potential distribution

Based on the AUC statistic the model performed well (AUC value > 0.9). Many coastal tropical and sub-tropical regions are suitable for the species (Figure 1A), including parts of Central and South America, southern and east central Africa, and several localities in Asia including parts of China and India. For South Africa, the model predicted that the coastline of South

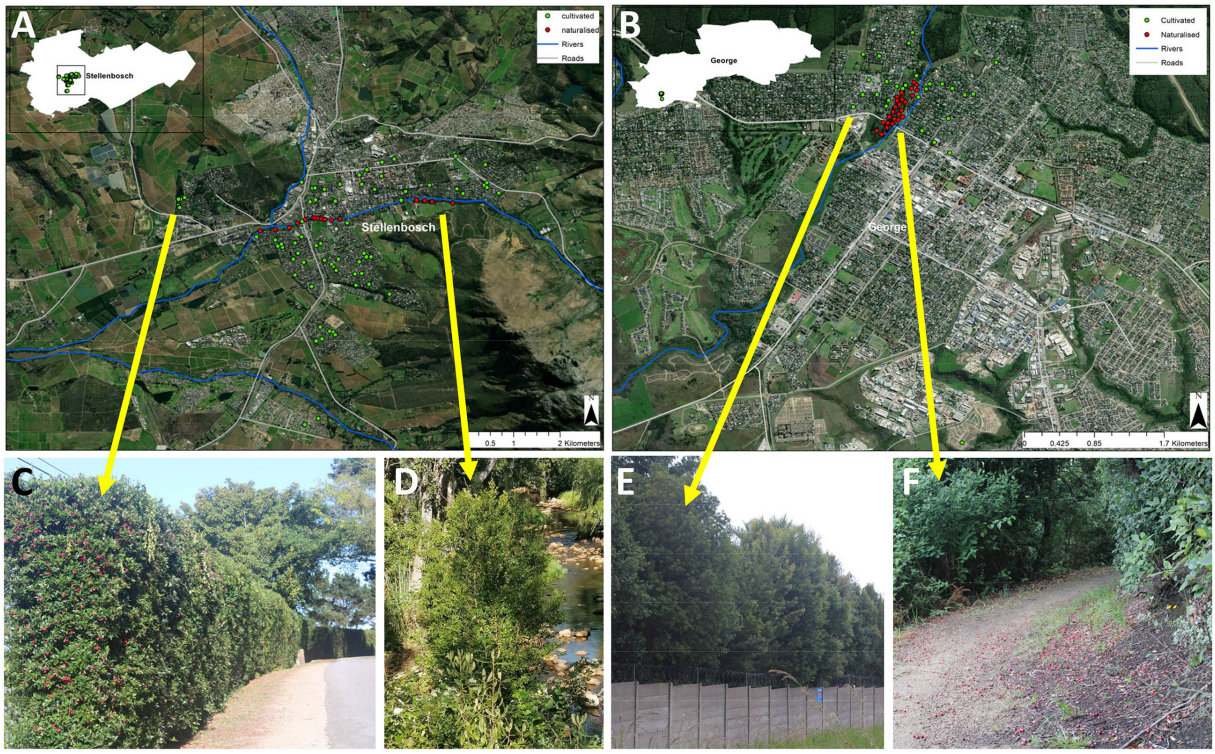

Figure 2. Examples of *Syzygium australe* cultivation and invasion in South Africa. A, C, D) Stellenbosch population, light green dots indicate planted individuals, dark red dots indicate naturalised populations. B, E, F) George population. Data for Stellenbosch are from the iNaturalist project "*Syzygium australe* in urban Stellenbosch" and for George from our own fieldwork. Photos by: A, B: Google Maps; D: T. Mbobo; C, E, and F: M.C. Rapetsoa.

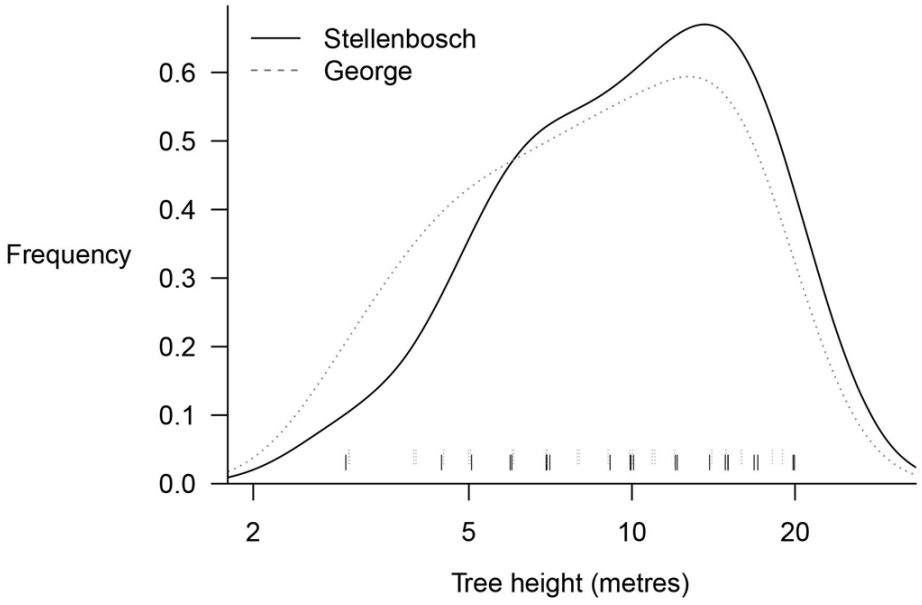

Figure 3. Frequency distributions of heights of Syzygium australe plants at the George and Stellenbosch study sites (see Table 1 for details) Only trees larger than 1m were considered, as, while there were some smaller plants present at both sites, clear identification of seedlings was not straight-forward. Trees were selected haphazardly, with 22 trees selected at the Stellenbosch site and 27 at the George site. The frequency distributions were produced using the function "density" on log-transformed data in R (R Core Team 2022).

Africa, from the Western Cape through to Eastern Cape and KwaZulu-Natal, is climatically suitable for the species. Suitable sites extend inland into the Mpumalanga and Limpopo provinces (Figure 1B). Regions where

we recorded the species as occurring in large numbers overlap with the parts of the country that were predicted to be most climatically suitable for *S. australe*, except for the Gauteng Province (Figure 1B). Variables that contributed most to the model were mean annual temperature and minimum precipitation of the driest month (more details on the species distribution model in Figure S1).

Germination experiments

Mature *S. australe* seeds began germinating within five days of sowing. There were no differences between the proportion of scarified and non-scarified viable seeds tested between those from hedges and normal trees (Wilcox test, $W = 5.5$, $p = 0.82$). There were also no differences between non-scarified seeds from cultivated populations (Stellenbosch and Newlands Forest) (Wilcox test, $W = 5.5$, $p = 0.80$) although non-scarified seeds took longer to germinate than scarified seeds. No differences were recorded between naturalized sites ($W = 5.2$, $p = 0.72$).

Risk analysis

The risk score for *S. australe* in South Africa came out as "high" (Table S2). This is a combination of the Consequences section with a score of "Moderate" and the Likelihood score of "fairly probable" (Kumschick et al. 2020). The ease of management was scored as "medium". This is because plants are easy to distinguish (especially when in fruit), plants take more than a year before reproduction, and the three naturalising populations are easily accessible. These factors contribute to the high risk of the species becoming an important invasive species in South Africa (Table S2). However, *Syzygium australe* is economically important to the ornamental horticulture industry in South Africa. It is used as a potted plant, as an ornamental feature plant, for bonsai, and especially as a hedge plant (Henderson 2020; personal observations). The species is also used in folk medicine (Okoh et al. 2019) and for its edible fruits (Atyosi et al. 2019; Henderson 2020). For these reasons, *S. australe* should be considered as a potential conflict-generating alien plant species in South Africa (Zengeya et al. 2017), and recommendations for its management must consider such potential conflicts.

Based on these findings, we recommend listing the species as category 1b under the NEM:BA A&IS Regulations with existing garden plantings to be phased out rather than prioritised for control, except when such plantings are near riparian areas.

Discussion

Plant species that are used by humans tend to be introduced often and disseminated regularly, resulting in high propagule pressure – a factor that is clearly linked to successful plant invasions (e.g., Castro-Díez et al. 2011). *Syzygium australe* is such a species; it is an important ornamental plant

that has been widely cultivated in South Africa (Foxcroft et al. 2008; Richardson and Rejmánek 2001), especially in the provinces of Gauteng and the Western Cape. Almost all records (91%) of *S. australe* in this study are from urban areas, mostly private gardens, but also along urban roads and in parks. Unsurprisingly, sites where naturalisations were recorded are in urban areas. For example, in Stellenbosch it was easy to trace the source of invasions; the species is widely cultivated in suburban gardens and is widely used for fencing or as a hedge, and as a street tree. The use of the species as a hedge requires several or many individuals to be planted, thus ensuring high propagule pressure, enhancing the likelihood of invasion (Colautti et al. 2006; Donaldson et al. 2014), particularly where invasible habitats are abundant, as in George and Stellenbosch, where the species flourishes along riverbanks (Figure 2A, B). Thick carpets of fallen *S. australe* fruits were often observed where the species is used as a street tree or hedge, or where the branches of large trees hang over garden walls (e.g., www.inaturalist.org/observations/72461001). This provides a massive source of propagules. In Stellenbosch, seed dispersal in water via stormwater drains following rainfall events probably led to the invasion of habitats along the Eerste River.

Syzygium australe already has a wide cultivated distribution across South Africa (55% of records in https://www.inaturalist.org/projects/syzygium-australe-in-south-africa are tagged as "casual"; accessed 16 March 2023). If left unmanaged, the species is very likely to naturalise at more sites and expand its range substantially. The species benefits from a suite of traits that are well known to enhance invasiveness in fleshy-fruited plants (Richardson et al. 2000; Mbobo et al. 2022). These include high introduction effort, substantial human usage, colourful fruits, vertebrate-mediated seed dispersal, and rapid germination rates. The proximity of naturalised populations to riverbanks and roads highlights the importance of these vectors in facilitating seed dispersal. Urban areas have are important launching sites for plant invasion in South Africa (McLean et al. 2017); this is especially the case where rivers provide conduits for rapid propagule dispersal.

We recorded gaps of knowledge corresponding to impacts, and management of *S. australe* in both South Africa and globally. Consequently, the species scored DD (Data Deficient) under the Environmental Impact Classification for Alien Taxa (EICAT). We do not know what impacts widespread invasions of *Syzygium australe* would have in South African ecosystems. However, it is expected that the impacts would be similar to those of other invasive *Syzygium* species, for example *S. jambos* which is known to outcompete native plants and prevent their regeneration (Kingston and Waldren 2003; Avalos et al. 2006). Based on this information, we recommend that the species be listed under the NEM:BA regulations as category 1b. However, if this recommendation was strictly enforced (i.e., requiring all plants be removed as part of a management plan) the potential for conflict with those who own *S. australe* trees is significant. We therefore recommend that all plants outside cultivation, and all cultivated

individuals close to or in riparian zones, should be targeted for removal, but that otherwise existing trees in cultivation should not be prioritised for removal. Rather, the sale of the species should be prohibited, the threat the species poses communicated to stakeholders, and trees in suburban gardens that are not close to riparian areas could be allowed to die off naturally.

Managing conflict-generating invasive tree species is challenging; it demands high levels of public awareness and effective stakeholder engagement (van Wilgen and Richardson 2012). The challenges are especially daunting in urban areas in South Africa where diverse stakeholders have diverging views and priorities (Gaertner et al. 2016; Potgieter et al. 2020). Effective management of *S. australe* in this country requires further attention to enhance awareness of the invasion risk posed by the species and engagement with stakeholders to consider long-term options for management. Results of this study suggest controlling naturalised populations of *S. australe* may still be possible, given the relatively small area affected (the total condensed area is ~ 2 ha) and the small number of plants recorded per naturalised populations. Although we did not examine the capacity of *S. australe* seeds to survive in the soil, the species is probably similar to other *Syzygium* species (e.g., *S. jambos*; Schmitt and Riviere 2022) in not accumulating long-lived seed banks in the soil. Hand-pulling of seedlings and saplings will have a major impact on these naturalising populations. Older plants resprout vigorously after cutting; as with *S. jambos* (Motooka et al. 2002; Avalos et al. 2006), and application of herbicide to cut stumps will be essential for dealing effectively with older plants.

In conclusion, *Syzygium australe* is already widespread in South African gardens. The species is at an early stage of invasion in the country, and most naturalised populations occur along riparian zones in urban areas. If left unmanaged, the species will very likely become a widespread invader over large parts of the country. To minimize the threat, we recommend that: 1) stakeholders should be made aware of the invasion risk posed by the species; 2) all populations outside cultivation and those in cultivation near riparian areas should be targeted for removal; 3) plants in gardens away from riparian areas should not be prioritised for management, but rather phased out over time; and 4) propagation and trade of *S. australe* should be prohibited.

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Authors' contribution

Conceptualization, TM, DMR, JRW; methodology, TM, DMR, JRW; field work, TM; data analysis, TM, JRW; original draft preparation, TM, DMR, JRW; writing – review and editing, TM, DMR, JRW. All authors have read and agreed to the published version of the manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Occurrence records for *Syzygium australe* in South Africa from field work conducted in April 2022.

Table S2. Risk analysis of *Syzygium australe* for South Africa.

Figure S1. More information on species distribution models.

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