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Occurrence Record of and Possible Invasion by Scarlet Sage (*Salvia coccinea* Buc'hoz ex Etl.) in South Africa

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Abstract—The scarlet sage, *Salvia coccinea*, was first detected in Northern Province, South Africa in 1905, in what is now Limpopo Province. However, its presence and suitability in South Africa remains undocumented. We conducted vegetation surveys to determine the actual distribution and to incorporate species distribution modelling in order to determine the potential distribution of this species. Twelve populations were documented from different localities. The species distribution model was successful in predicting areas that are climatically suitable for this species to survive in South Africa. The wide distribution and high density suggest a long residency time. Thus we conclude that its recent invasion of the wild has most probably originated in gardens.

Keywords: alien invasive species, Ornamental, *Salvia coccinea*, species distribution modelling, NEM:BA

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INTRODUCTION

Alien invasive species have major and negative impacts on biodiversity across the world (Bullock and Manchester, 2000; Sala et al., 2000; Blackburn et al., 2011). Horticulture and related activities are globally recognised as important drivers of the introduction of non-indigenous species (Hulme et al., 2018; Seebens et al., 2018, 2019). One such popular ornamental plant is scarlet sage *Salvia coccinea* Buc'hoz ex Etl. (Li et al., 2013). *Salvia coccinea* is a herbaceous perennial in the genus *Salvia* (Lamiaceae family), which has over 960 species (Li et al., 2013). They are used as garden ornamentals and traditional medicines throughout the world (Li et al., 2013). *Salvia coccinea*, commonly known as blood sage or red cherry sage, is a long-lived erect herbaceous plant that usually grows up to 1.5 m in height (Witt and Luke, 2017). It is believed to have originated in Mexico, the south-eastern United States, through Central America, and in north-western South America. In Africa, it has been reported as invasive in Kenya, and is currently recorded as an alien species in Malawi, Tanzania, and Zambia (Witt and Luke, 2017). The species invades places such as gardens, disturbed areas, roadsides, open spaces, and wetlands (Witt and Luke, 2017). Several species in the genus Salvia, such as *Salvia tiliifolia*, are regarded as invasive in South Africa and China, while *Salvia reflexa* has recently been reported to be invasive in China (Hu et al., 2013; Shao et al., 2019), in India, it is reported to cause death in goats and to be toxic for cattle (Nagal et al., 2014; Witt and Luke, 2017), and in Australia (Hindmarsh, 1932). *Salvia coccinea* is not listed in the National Environmental Management: Biodiversity Act (NEM:BA) inventories for South Africa (Department of Environmental Affairs, 2016). The aim of this paper is to report the naturalisation of *Salvia coccinea* in South Africa, and to describe its distribution.

MATERIALS AND METHODS

Study Sites

A *Salvia coccinea* population in Limpopo Province was first spotted in Tzaneen in July 2017 during a routine survey for alien species. Photographs were recorded to aid pre-verification of the identity of the species (Fig. 1). Subsequently, several more opportunistic records were found, during Invasive Alien Species (IAS) surveys in Tzaneen, Lekgalametsi, Pretoria, Tshakuma, Modjadjiskloof, Thohoyandou, Makwarela, Haenetsburg, and recently in Mbombela (formerly Nelspruit). Monitoring was carried out to estimate the flowering periods of the population in Tzaneen (23.4732 E, 30.0828 S) and Mbombela (25.4638 E, 30.9480 S) (Fig. 2).

Fig. 1. A photograph of scarlet sage *Salvia coccinea* taken during the survey in Tzaneen.

Determining Current Distribution in South Africa

In order to assess more detailed aspects of *Salvia coccinea* distribution, data from the Southern African Plant Invaders Atlas (SAPIA) and Herbarium records were collected to determine the status of *Salvia coccinea* distribution in South Africa (Henderson and Wilson, 2017). Occurrence records were pooled through SAPIA newsletter volunteers (Table 1) to determine the national status of *Salvia coccinea* distribution in South Africa. Herbarium records indicate that the first plant in Southern Africa was collected in 1905 by J. Burtt Davy in Manzini, Swaziland (Voucher PRE0116851-0). Until now, there have been no records of *Salvia coccinea* from targeted IAS field surveys (RSA distribution). Populations were classified into three categories: major (~500), medium (~200), and small (~less than 100). Specimens were deposited in the South African National Biodiversity Institute's Pretoria National Herbarium and Larry Leach Herbarium, University of Limpopo.

Determining Climatic Suitability in South Africa

Occurrence records were obtained from Global Biodiversity Information Facility (GBIF) and SAPIA to develop species distribution modelling. The records

Table 1. Population size of invasive scarlet sage (*Salvia coccinea*) in different landscapes in South Africa

Locations	Coordinates		Population extent, m^2	Population size, *n*	Landscape context
	latitude, S	longitude, E			
Haenetsburg	23.9471	29.9379	6	23	Valley
Lekgalametsi	24.1263	30.2069	120	299	Roadside
Makwarela	22.9362	30.4735	200	87	Roadside
Mbombela	25.4638	30.9480	130	114	Valley
Modjadjiskloof	23.2435	30.1214	450	2042	Roadside
Pretoria	25.7627	28.2204	50	87	Valley
Thohoyandou Botanical Garden	22.5815	30.2912	90	476	Protected area
Tshakuma	22.5815	30.3021	128	217	Roadside
Tzaneen	23.4732	30.0828	638	2886	River bank

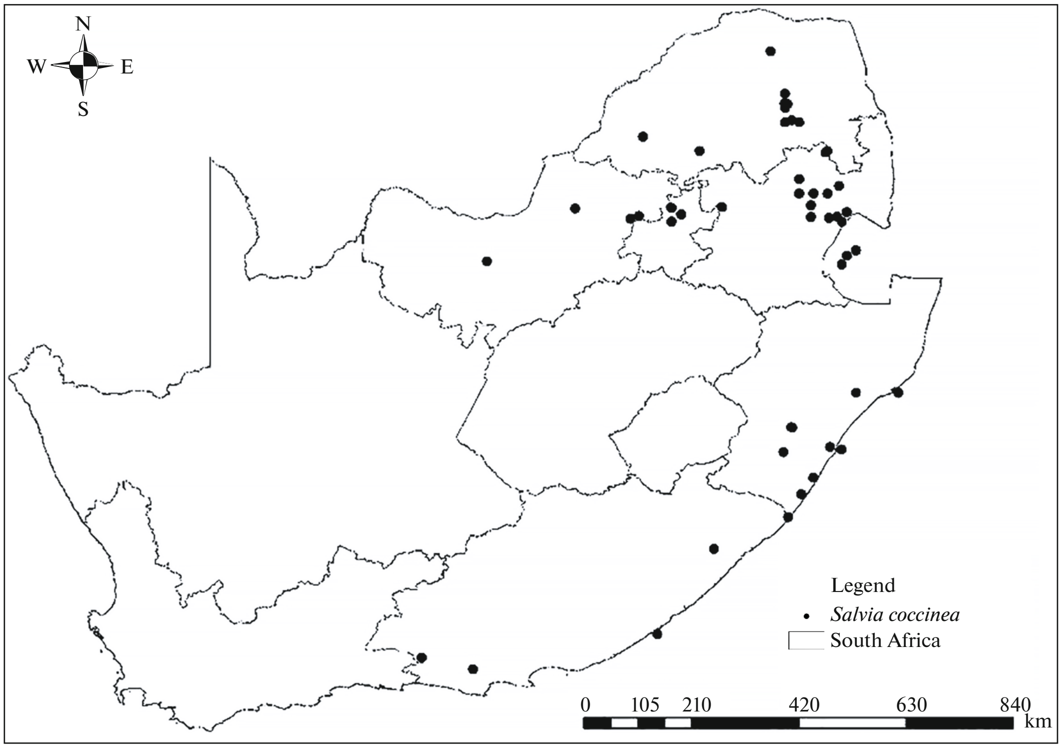

Fig. 2. Map showing current distribution of *Salvia coccinea* in South Africa.

included native and invaded ranges of this species, and were cleaned using the Biogeo package in R (Robertson et al., 2016). Bioclimatic variables were downloaded from Worldclim (www.worldclim.org), and were used as predictor variables (Fick and Hijmans, 2017). Only bioclimatic variables (Bio 1-19) that contributed the most to predicting potential species suitability were selected. The bioclimatic variables used included: temperature seasonality; annual precipitation; precipitation seasonality; minimum temperature of coldest month; mean temperature of warmest month; maximum temperature of warmest month; precipitation of warmest; and quarter precipitation of wettest quarter. The environmental variables were at 15-minute spatial resolution.

Maximum entropy (MaxEnt version 3.3.3.k; Phillips et al., 2006; Phillips and Dudík, 2008) was used to model the potential suitability of *Salvia coccinea* using all default settings. ArcGIS version 10.4 was used to produce the potential distribution maps of *Salvia coccinea* (Phillips and Dudick, 2008). The present report has gathered and collated this data in order to prepare an initial map of the present known distribution of this alien species in South Africa.

Model Evaluation

Model performance was evaluated using the area under curve (AUC) statistic (Fielding and Bell, 1997). Models with an AUC value of >0.9 are considered to be excellent; those with AUC values between 0.7 and 0.9 are considered to be good; and those with values below 0.7 are considered to be poor (Swets, 1988). Values greater than 0.9 were considered in this study.

Australian Weed Risk Assessment (AWRA)

The Australian Weed Risk Assessment (AWRA) system (Pheloung et al., 1999), adapted for South Africa, was used to evaluate the potential invasiveness of *Salvia coccinea*. The AWRA was designed as a preborder screening tool. This system has been sufficiently tested for the screening of new species; and thus, on average, the AWRA was found to identify potential invaders correctly more than 90 per cent of the time (Gordon et al., 2008). The AWRA is based on 49 questions, ranging from the distribution and climate requirements, to the cultivation and invasion history, to the biological traits of the species (Pheloung et al., 1999; Gordon et al., 2009). At least 10 questions need to be answered for the AWRA to be successful. For example, scores of 1 to 6 indicate that further evaluation is necessary before a prediction is possible, while with scores that are >6, the taxon is predicted to become invasive and should be rejected for import.

RESULTS

Determining Current Distribution in South Africa

A total of twelve populations were documented. The specimens collected at each site are reported in Table 1, together with the reference collection code. Among the 12 populations studied, nine are natu-

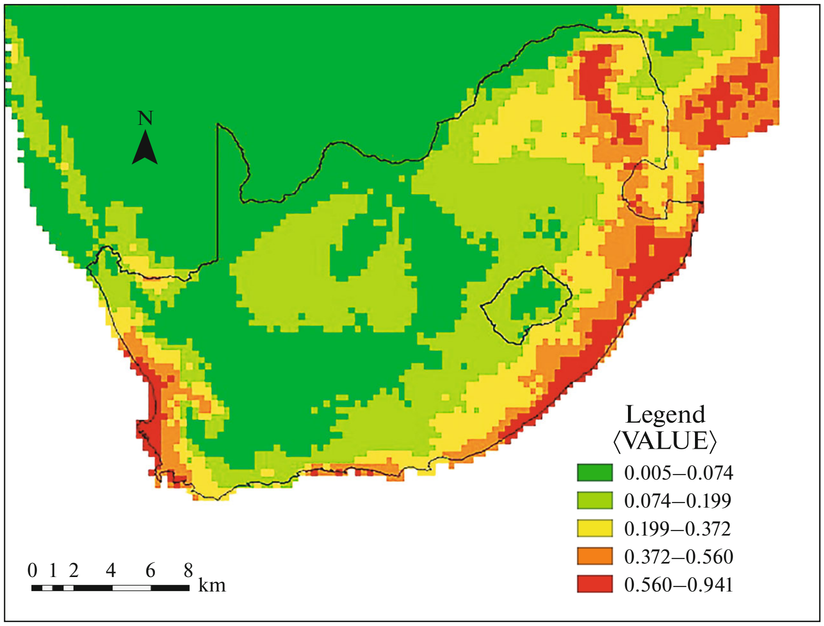

Fig. 3. Map showing areas that are potentially climatically suitable for *Salvia coccinea* in South Africa, as determined by maximum entropy. Red shades represent areas that are more climatically suitable.

ralised. The populations are spread across four provinces. Three records were reported through SAPIA newsletter distribution. Major populations were found in Tzaneen, Magoebaskloof, and Modjadiskloof, while moderate populations were found in the Tshakuma and Thohoyandou national botanical gardens; the rest were small populations. In its native ranges in the United States of America, this species is rarely found in large populations of more than 100 plants per site (Alison Northup, pers. comm).

Determining Climate Suitability in South Africa

The AUC value shows that the model performance was excellent (AUC > 0.9) in predicting areas that are climatically suitable for *Salvia coccinea* in South Africa. The projected suitable areas in South Africa vary considerably across provinces, with the most extensive distribution in the inland provinces and along the costal belt. There was no substantial difference between potential and real distribution in South Africa (Fig. 3).

Australian Weed Risk Assessment (Assessment of Invasive Potential)

Overall, in this study the data allowed us to answer 37 questions out of 49. The total AWRA score was found to be 30 (Table 2). This score would have led the species to be rejected, since it has the potential to be invasive. It was revealed that *Salvia coccinea* thrives in disturbed areas and along roads (Witt and Luke, 2018). One major impact noted was its toxicity for livestock (Hindmarsh, 1932; Nagal et al., 2014).

DISCUSSION

Field Surveys and Extent of Distribution

In this work, we report occurrences of *Salvia coccinea* and its potential invasiveness in South Africa. The known records of viable populations show that they are distributed throughout six provinces. This suggests that the species is naturalised; it also possibly implies that *Salvia coccinea* is becoming widespread, and so should be regarded as invasive in South Africa.

The current distribution pattern may reflect historical introductions and the dispersal of the species over the last 100 years, which could have gone unnoticed due to the lack of sampling effort across the study region (Guillera-Arroita et al., 2014; Moore et al., 2014) or an invasion lag phase (Kowarik, 1995; Sakai et al., 2001; Crooks, 2005; Aikio et al., 2010). It could also be attributed to a changing climate, which only now favours a population explosion (Bellard et al., 2013; Fournier et al., 2019). An alternative explanation could be linked to the rate at which the species was sold for gardening/horticulture and its subsequent escaping or being released to the wild (Hindmarsh, 1932).

The vector for the invasion of *Salvia coccinea* into South Africa is speculated to be from horticulture. The habitats in which *Salvia coccinea* was reported in this study include urban and rural landscapes, ranging from roadsides, wastelands, forestry plantations, disturbed areas, and riverbanks (Witt and Luke, 2017).

Table 2. Biological Invasions Weed Risk Assessment (South African National Biodiversity Institute)*

Family	Lamiaceae	Date re-assessed	Aug. 12, 2019
Taxon	*Salvia coccinea* Buc'hoz ex Etl.	Assessor	MC Moshobane
Common name	Blood sage, Scarlet sage, Texas sage, or Tropical sage	AWRA score	30
Synonyms	*Horminum coccineum* (Buc'hoz ex Etl.) Moench; *Salvia ciliata* Benth., nom. illeg.; *Salvia coccinea* L.f., nom. illeg.; *Salvia coccinea* var. *minima* Fernald; *Salvia coccinea* var. *pseudococcinea* (Jacq.) A. Gray; *Salvia coccinea* f. *pseudococcinea* (Jacq.) Voss; *Salvia filamentosa* Tausch; *Salvia galeottii* M. Martens; *Salvia glaucescens* Pohl; *Salvia mollissima* M. Martens & Galeotti; *Salvia pseudococcinea* Jacq.; *Salvia rosea* Vahl; *Salvia superba* Vilm.	Recommendation	Reject

* (Pheloung et al., 1999; Gordon et al., 2009).

Assessment of Invasive Potential

Based on the literature, and as observed in the results of the AWRA, *Salvia coccinea* is an aggressive invader. Therefore it should be managed in accordance with the NEM:BA. Although this is contrary to Henderson and Wilson (2017), who suggested that the species could be listed as 1b, based on citizen science reports, our findings suggest that the species should be regulated in terms of the NEM:BA AIS regulations, perhaps listed as Category 1a invasive species. Further monitoring, seed germination, eradication feasibility, and control methods investigations also need to be undertaken.

Several studies indicate that *Salvia coccinea* is poisonous to livestock and wildlife (Hindmarsh, 1932; Nagal et al., 2014). Since *Salvia coccinea* flowers all year round, it may further pose threats to native species through the disruption of pollination networks (Vanbergen et al., 2018). Personal communication with local residents (Alison Northup, pers. comm) in its native range revealed that the species is rarely seen in large populations.

Distribution Model

The distribution model results indicate that this species had a suitable climate that covers six provinces in South Africa. This suggests that, if no action is taken to manage the species, it could easily colonise the entire country. Therefore there should be concerted efforts to detect more populations in the areas indicated to be climatically suitable, and a surveillance programme should also focus on areas deemed to be less climatically suitable in order to detect new populations, if any. Perhaps citizen science would help to generate the distributional and ecological data of alien species on a national scale (Anderson et al., 2017). This information is essential for the management of invasive species, in order strategically to allocate surveillance and control efforts that are aimed at limiting the spread and impact of this land-invasive species (Moshobane et al., 2019).

CONCLUSIONS

Salvia coccinea is naturalised and possibly invasive in South Africa. Previously, only *Salvia tilliifolia* was known to be an invasive Salvia species in the country. *Salvia coccinea* should be listed as Category 1a according to NEM:BA. Since the species is an ornamental, it is further recommended that its management should strive to implement the recommendations outlined in Shackleton et al. (2019).

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DISCLAIMER

Any opinion, finding, and conclusion or recommendation expressed in this material is that of the author(s), and the funding agencies do not accept any liability in this regard.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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