

Climate-based prediction of potential distributions of introduced *Asparagus* species in Australia

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Summary

The potential distributions of all exotic *Asparagus* species established in Australia were modelled using CLIMEX. Maps showing native and introduced distributions are compared with the predicted distributions for *Asparagus aethiopicus* L., *A. africanus* Lam., *A. asparagoides* (L.) Druce (widespread and western Cape forms), *A. declinatus* L., *A. densiflorus* (Kunth) Jessop, *A. officinalis* L., *A. plumosus* Baker, *A. scandens* Thunb. and *A. virgatus* Baker. In many cases the models are limited by the lack of information on the species and further study is needed of taxonomy, biology and distribution. The model for the western Cape form of *A. asparagoides* indicates a much wider distribution than where it is currently found in Australia implying that it should be a priority for further investigation. In contrast the model for the widespread form of *A. asparagoides* matches most of the observed distribution in Australia. Most of the other *Asparagus* species have potential distributions covering different regions of Australia and appropriate management strategies should be developed to prevent further invasion.

Introduction

Decisions on whether or not to eradicate, establish quarantine boundaries or containment areas, and/or instigate other control options are often based on a perception of the future threat posed by a weed. The perception of threat is usually that of further spread to new areas, although future increases in density are also important within sites or regions. A weed (or indeed any species) has a potential distribution based on climatic and other abiotic factors (e.g., soil), and a smaller realized distribution that is influenced by biotic factors such as dispersal ability, predation, parasitism, disease and competition from other species. The distribution that we observe at any point in time may be incomplete because the invasion process is still underway, or accidents of the history of introduction have placed the species in a suboptimal habitat. Information on climate is the most readily accessible data, and intuitively a good place to start, for predicting the potential distribution of a species. A detailed discussion on the use

of climate for modelling species distributions can be found in the documentation for CLIMEX, a computer program used to predict species distributions (Sutherst *et al.* 1999).

Australia has one native species in the family Asparagaceae, *A. racemosus* Willd., recorded in northern Australia (Clifford and Conran 1987). All other *Asparagus* in Australia are introduced either from Europe (one species, crop asparagus *A. officinalis* L.) or southern Africa (at least 18 species, Batchelor and Scott 2006). Eight species have become established and some are

weedy in many parts of Australia. In this paper we predict the potential distribution of all established exotic Asparagaceae species in Australia using CLIMEX.

Methods

The computer program CLIMEX (Sutherst *et al.* 1999) was used to build models that estimate the potential growth and survival of species at different geographical locations based on climatic data. The models calculate an Ecoclimatic Index (EI) for species at each meteorological station, which can then be used to infer their potential distribution. A full explanation of CLIMEX is provided in Sutherst *et al.* (1999) and examples of the approach used here are given in Matsuki *et al.* (2001) and Scott and Yeoh (1999).

The procedure adopted was as follows. In the first step, we developed a model that matched, as well as possible, the distribution of each *Asparagus* species in southern Africa, or in Europe in the case of *A. officinalis*. CLIMEX models are defined by parameters that describe effects of temperature and moisture on growth and

Table 1. Parameter values used to model *Asparagus* species distributions in CLIMEX.

CLIMEX parameter	<i>A. aethiopicus</i>	<i>A. africanus</i>	<i>A. asparagoides</i> 'widespread'	<i>A. asparagoides</i> 'Western Cape'	<i>A. declinatus</i>	<i>A. densiflorus</i>	<i>A. officinalis</i>	<i>A. plumosus</i>	<i>A. scandens</i>	<i>A. virgatus</i>
Limiting low temperature	10	10	10	10	10	18	14	16	10	16
Lower optimal temperature	16	15	15	15	16	22	18	22	16	22
Upper optimal temperature	24	18	18	18	24	32	24	32	24	32
Limiting high temperature	28	30	30	30	28	40	28	40	28	40
Limiting low moisture	0.05	0.15	0.15	0.15	0.05	0.2	0.25	0.25	0.1	0.25
Lower optimal moisture	0.15	0.5	0.5	0.5	0.1	0.35	0.8	0.4	0.2	0.4
Upper optimal moisture	1.5	1.2	1.2	1.2	1.196	1.0	1.5	1.0	1.5	1.0
Limiting high moisture	2.0	1.5	1.5	1.5	1.5	3.0	2.5	3.0	2.0	3.0
Cold stress temperature threshold	5.0	2.1	2.1	4	5	1.5	5	-	5	-
Cold stress temperature rate	-0.01	-0.1	-0.1	-0.1	-0.1	-0.05	-0.2	-	-0.03	-
Heat stress temperature threshold	-	-	-	-	30	-	30	-	30	-
Heat stress temperature rate	-	-	-	-	0.01	-	0.005	-	0.01	-
Dry stress threshold	0.05	-	-	-	0.035	0.15	0.2	0.25	0.1	0.25
Dry stress rate	-0.01	-	-	-	-0.05	-0.05	-0.005	-0.01	-0.05	-0.01
Wet stress threshold	-	-	-	-	2	-	2.5	-	2	-
Wet stress rate	-	-	-	-	0.1	-	0.002	-	0.0015	-
Cold-wet degree day threshold	-	-	-	-	-	-	-	5	-	5
Cold-wet moisture threshold	-	-	-	-	-	-	-	0.4	-	0.4
Cold-wet stress rate	-	-	-	-	-	-	-	0.07	-	0.07
Hot-dry temperature threshold	-	-	-	-	-	28	-	30	-	30
Hot-dry moisture threshold	-	-	-	-	-	0.25	-	0.2	-	0.2
Hot-dry stress rate	-	-	-	-	-	0.15	-	0.05	-	0.05
Hot-wet temperature threshold	20.0	-	20	20	20	28	-	-	-	28
Hot-wet moisture threshold	0.5	-	1.2	0.7	0.5	0.7	-	-	-	0.7
Hot-wet stress rate	0.75	-	0.5	0.6	0.5	0.5	-	-	-	0.5

development. Usually these parameters are gathered from the literature, but in most cases little is known for the *Asparagus* species in this study. In the absence of precise data we started with a general Mediterranean or subtropical climate model and iteratively adjusted the parameter values to maximize the match to the known distribution. The known distribution in southern Africa was obtained from the records of the Pretoria Herbarium.

Secondly, the model was tested against the known distribution of the same *Asparagus* species in a region other than the native or Australian distribution. This method of checking and fine-tuning the model was only possible on one species, *A. scandens* Thunb. Finally, the model was used to predict the distribution in Australia. Note that the current Australian distribution, based on Australia's Virtual Herbarium online data (www.chah.gov.au/avh/) or published information, was not used to develop the prediction. However, it is given here for comparison with the predicted distribution for each species.

Because the models are based on very minimal data we have indicated a ranking on each model that reflects our confidence in the model's predicted distribution based on climate: very low, low, medium, high to very high. Very low is for models based solely on the distribution in the region of origin without any physiological data for the species. Very high is for models where the temperature and moisture requirements for development, the phenology at many locations and the distribution (including where the species is absent) is accurately known. Matsuki *et al.* (2001) is an example of a predicted distribution approaching a high level of confidence.

Results and discussion

The parameter values used in CLIMEX for each species are given in Table 1. The results presented for each species include a summary of the information that helped build the model, a map of the distribution in the native habitat, the CLIMEX prediction in the native region, the prediction to another area of the world where it was possible to test the model (only in the case of *A. scandens*), the predicted distribution in Australia and the recorded distribution in Australia.

Asparagus aethiopicus L. (Figures 1a, b) The CLIMEX model is based on the distribution of *A. aethiopicus* in southern Africa (Figure 1a). The limiting lower temperature and lower optimal temperature are based on Bowden and Rogers (1996) for Australian material identified at the time as *A. densiflorus* (Kunth) Jessop. Following Green (1986), *A. aethiopicus* is the accepted name for specimens formerly identified as *A. densiflorus* in Australia (Batchelor and Scott 2006). Cold stress, dry stress and

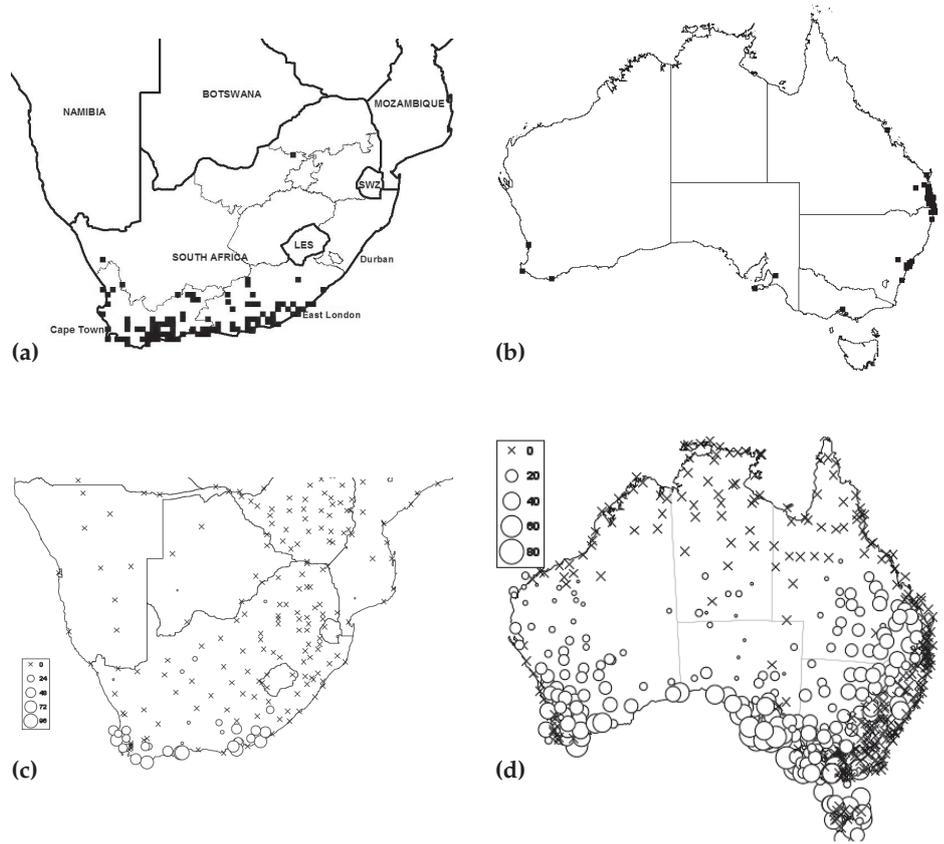


Figure 1a. *Asparagus aethiopicus*; observed distribution in southern Africa (a) and Australia (b) based on herbarium records (for both *A. aethiopicus* and *A. densiflorus* in Australia); CLIMEX prediction of Ecoclimatic Index (EI) showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (c) and Australia (d).

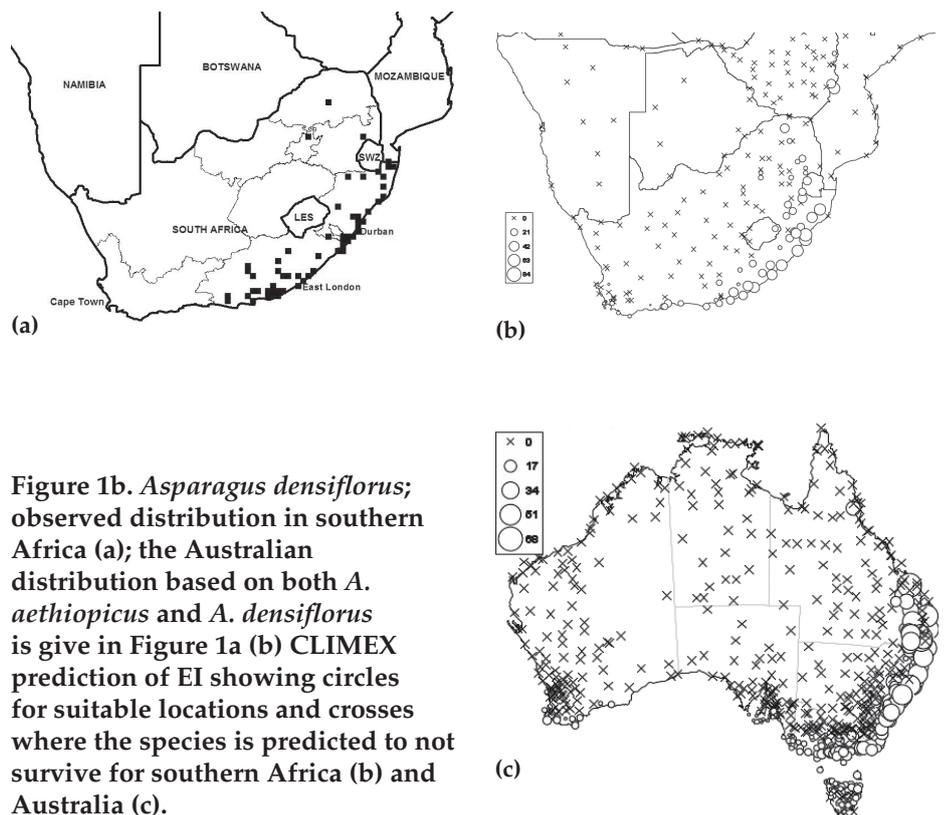


Figure 1b. *Asparagus densiflorus*; observed distribution in southern Africa (a); the Australian distribution based on both *A. aethiopicus* and *A. densiflorus* is give in Figure 1a (b) CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (b) and Australia (c).

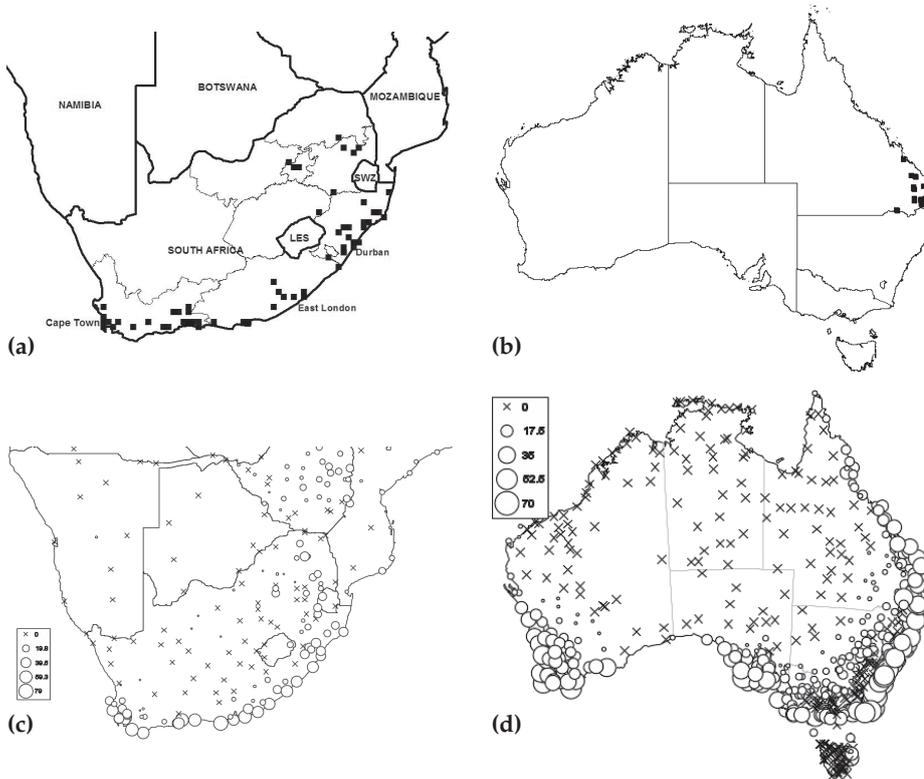


Figure 2. *Asparagus africanus*; observed distribution in southern Africa (a) and Australia (b) based on herbarium records; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (c) and Australia (d).

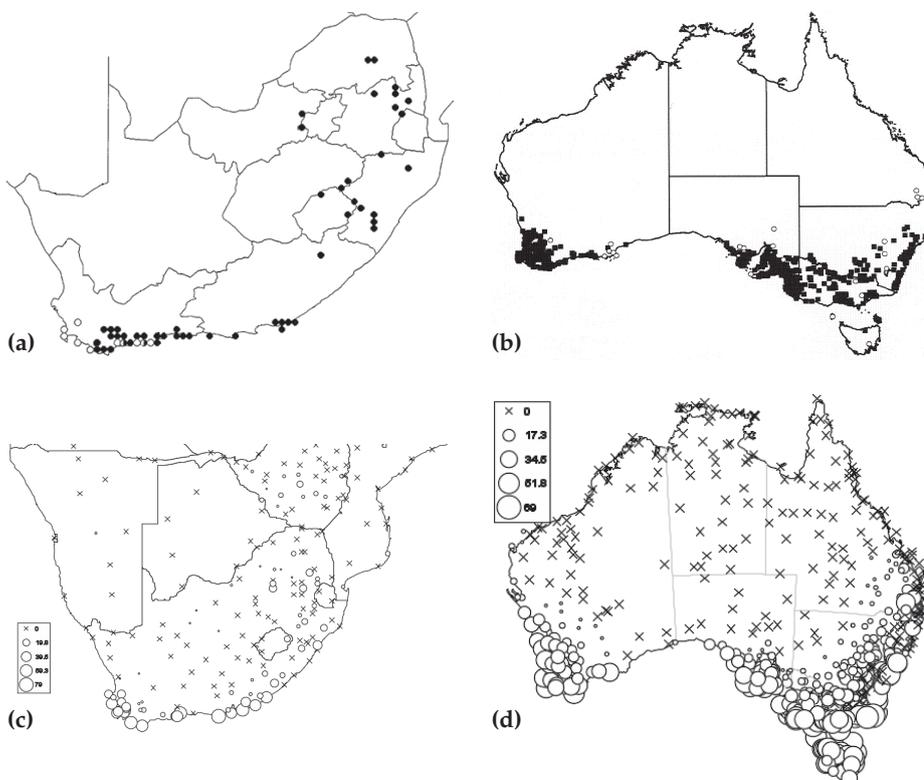


Figure 3. *Asparagus asparagoides* widespread form; observed distribution in South Africa (a) from Kleinjan and Edwards (1999) (open dots are the western Cape form, closed dots widespread form, half dots have both) and (b) observed distribution in Australia (Morin *et al.* 2006); CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (c) and Australia (d).

hot-wet stress were applied to confine the predicted distribution to the southern parts of South Africa. *Asparagus aethiopicus* is not widely established elsewhere so the model was not tested on the distribution in other countries.

Asparagus aethiopicus is naturalized in south-east Queensland and along the coast of New South Wales where it has invaded coastal littoral rainforest, rainforest, frontal dunes and sclerophyll woodlands (Swarbrick and Skarratt 1994). Extensive infestations occur at Burleigh Heads National Park and Fleays Environmental Park in Queensland (Qld) and in coastal vegetation from Noosa Heads to Batehaven (Bowden and Rogers 1996). In New South Wales (NSW) it is a serious weed in bushland, chiefly in coastal districts north of Sussex Inlet and it is declared noxious on Lord Howe Island (Harden 1993). It has naturalized on Norfolk Island (Green 1986). In South Australia (SA) it has naturalized at Normanville Dunes, Back Valley (Anon 2003b) and on Kangaroo Island (Anthony Maguire personal communication) (Figure 1b). The model (Figure 1d) provides a very poor prediction of the existing distribution, in that it does not predict any of the east coastal distribution of the weed.

The poor prediction may be alerting us to a taxonomic problem. Figure 1b shows a model based on *A. densiflorus*, with its east coastal distribution in southern Africa (Obermeyer and Immelman 1992), that corresponds much more closely to where the plant is flourishing in Australia. Until the identification issue is resolved it is not possible to judge the degree of confidence in either model.

***Asparagus africanus* Lam. (Figure 2)**

The CLIMEX model is based on the distribution in southern Africa (Figure 2a). The minimum and lower optimal temperature used (Table 1) correspond to the seed germination temperature measured by Stanley (1994) for Australian material. No stress thresholds were used. Obermeyer and Immelman (1992) note that it occurs in 'fairly moist places' which could imply that this species is found in microhabitats that may not be captured in models such as CLIMEX that use broad climatic parameters. Even so, the model (Figure 2c) corresponds reasonably well to the observed distribution in South Africa, but with an extension into Zimbabwe, which will need further investigation. *Asparagus africanus* does not appear to be established elsewhere in the world to an extent to enable testing and refinement of the model in regions of introduction.

In Australia, *A. africanus* has become naturalized at a number of localities in south-east Qld and in the coastal districts north of Lismore, NSW to Rockhampton Qld (Stanley 1994). It is most prominent in remnant semi-evergreen vine thicket/

brigalow forest communities, particularly in the Marburg-Boonah districts (Conran and Forster 1986) (Figure 2b). The model predicts a very wide distribution in Australia (Figure 2d). The model could be improved by confirmation that the distribution in southern Africa is for one species (and that the Australian material is the same) and by experimental assessment of the temperature and moisture requirements for growth. Because of these uncertainties we give the model a rank of low confidence.

***Asparagus asparagoides* (L.) Druce (widespread form) (Figure 3)**

The distribution of the 'widespread' form of *A. asparagoides* in southern Africa has been determined by Kleinjan and Edwards (1999) (Figure 3a). This was used to determine the CLIMEX model with the temperature values the same as used in Pheloung and Scott (1996) (Figure 3c). The CLIMEX model predicts the distribution to extend to the western Cape region, which is known to be occupied by another form of *A. asparagoides*, otherwise the model matches the known distribution. *Asparagus asparagoides* is established in scattered locations around the world (Morin *et al.* 2006), but not sufficiently widespread to help modify the model. The CLIMEX model predicts that *A. asparagoides* will establish in California similar to the prediction given in Randall and Lloyd (2002), plus also parts of Washington, Texas, Georgia and South Carolina, but not elsewhere in USA.

Asparagus asparagoides is widely naturalized in southern Western Australia (WA), SA, Victoria, Lord Howe Island, NSW and Tasmania (Morin *et al.* 2006) to the extent that it matches that of the modelled distribution. We concluded that *A. asparagoides* has reached the limits of its potential distribution in Australia, except for potential spread into southern Qld, Tasmania and potential spread within the current distribution.

CLIMEX is suitable for predictions at a continental scale. At a finer scale, the Department of Primary Industries, Victoria (2006) gives an example of a regional scale prediction of spread within Victoria using the program Climate. Similar studies at a higher scale of resolution than that shown in Figure 3 are needed to ascertain if *A. asparagoides* would become widespread within Tasmania (the CLIMEX model indicates that it will) as this has implications for any eradication program. The model's confidence is ranked as high, mainly because the plant's distribution in its native habitat is well understood.

***Asparagus asparagoides* (western Cape form) (Figure 4)**

The distribution of the 'western Cape' form is given in Kleinjan and Edwards (1999) (Figure 3a). The CLIMEX model used the

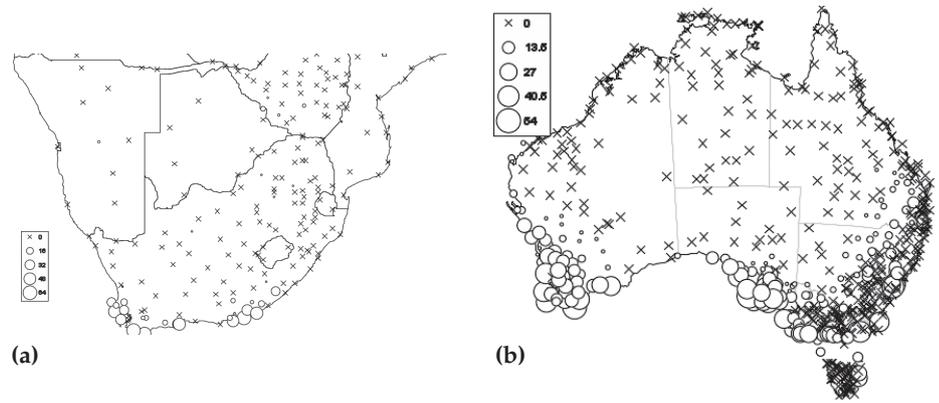


Figure 4. *Asparagus asparagoides* western Cape form; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (a) and Australia (b).

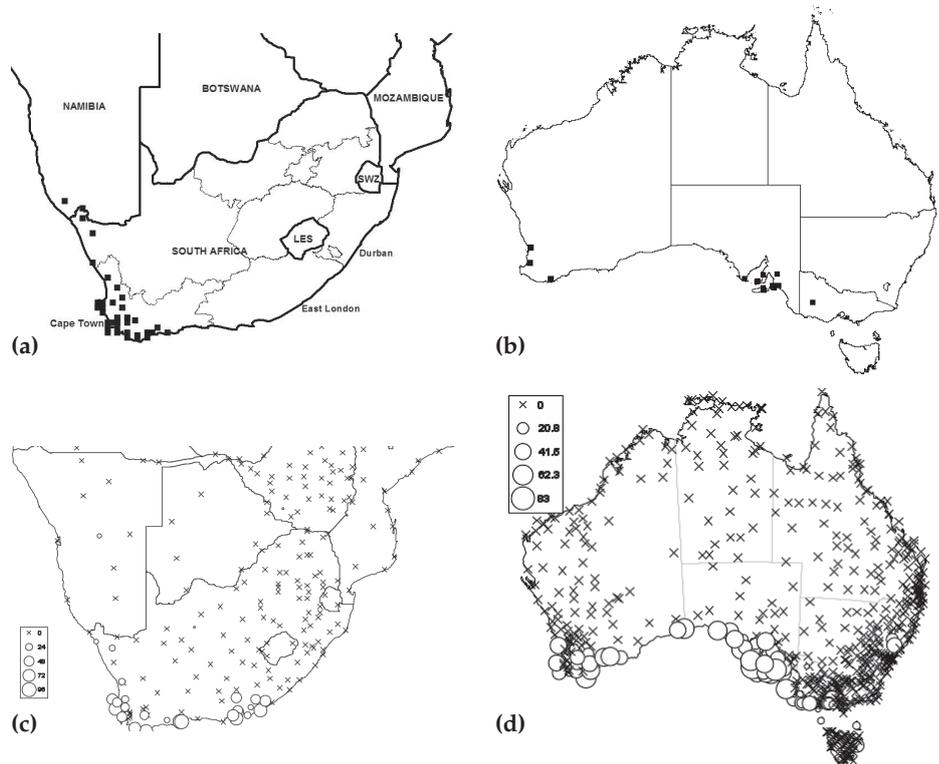


Figure 5. *Asparagus declinatus*; observed distribution in southern Africa (a) and Australia (b) based on herbarium records; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (c) and Australia (d).

same parameters as for *A. asparagoides* (widespread form) except for a change in the cold stress and hot-wet stress. It was not possible to predict sites in the southwest Cape region without also including coastal sites in the eastern Cape. There are no physical barriers preventing spread eastwards and perhaps the plant is blocked by climatic factors e.g. the southern Cape region of even rainfall (Kleinjan and Edwards 1999) or biotic factors, perhaps competition from the very similar 'widespread' form. The plant taxon is not known as established other than in Australia.

The present distribution in Australia is very restricted (Figure 3b), but the

CLIMEX predicted distribution is widespread in WA and SA indicating that this plant is a threat to these regions and that there is a potential to replace 'widespread' bridal creeper weakened by biological control as it is found over a similar area. There is need to determine the conditions for growth of the western Cape form so that the model can be improved. Because of this and the lack of information on this species the confidence of the model is classed as low.

***Asparagus declinatus* L. (Figure 5)**

In the absence of physiological data and information on the biology in its native

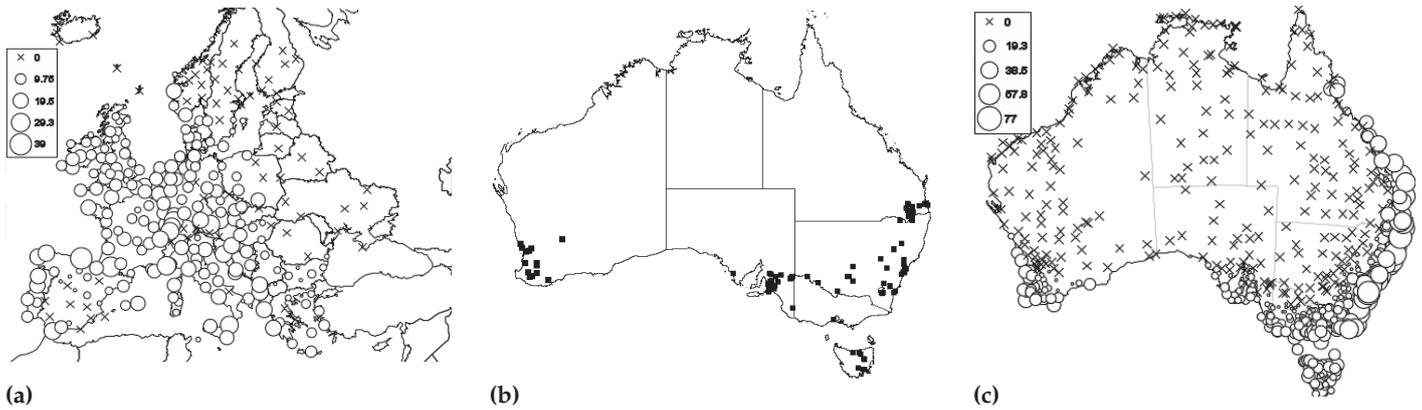


Figure 6. *Asparagus officinalis*; observed distribution in Australia (b) based on herbarium records; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for Europe (a) and Australia (c).

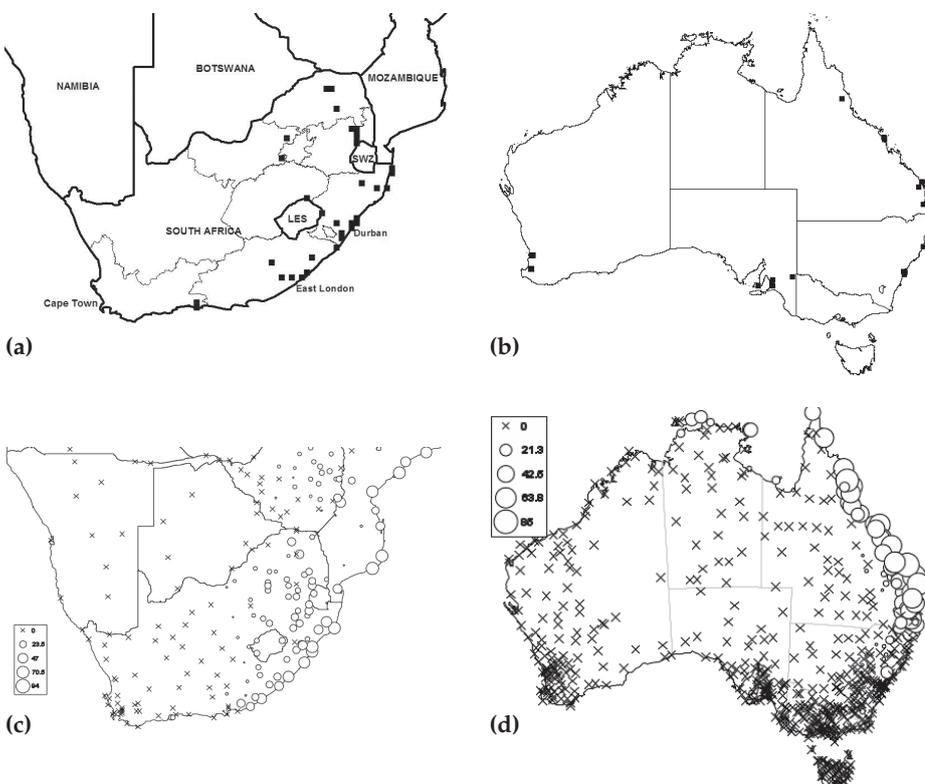


Figure 7. *Asparagus plumosus*; observed distribution in southern Africa (a) and Australia (b) based on herbarium records; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive in South Africa (c) and Australia (d).

habitat, the distribution in South Africa and the temperature data given in Pheloung and Scott (1996) (also derived from the South African distribution) was used to develop the CLIMEX model. The model predicts a more eastern distribution than that observed in South Africa.

Asparagus declinatus is present in SA on southern Eyre Peninsula, Yorke Peninsula, Kangaroo Island and Fleurieu Peninsula (Anon 2003a). In Western Australia populations occur in Kings Park Botanic Garden and Bunbury (Dixon 1996, Pheloung

and Scott 1996) and near Mt. Barker (Graeme Blacklock personal communication.). In Victoria, a population was recorded in Eucalypt woodland near Horsham, but was subsequently destroyed (Walsh and Entwisle 1992).

The potential distribution in Australia modelled in Figure 5d is not as widespread as the earlier version (Pheloung and Scott 1996). In the intervening ten years *A. declinatus* has spread in SA and WA, but within the confines of the modelled distribution. However, without biological information

to back the model (already requested in Pheloung and Scott 1996) its confidence level has to be given as medium.

Asparagus officinalis L. (Figure 6)

Edible asparagus, *A. officinalis*, is widely naturalized throughout the world. The native range is uncertain, but it is thought to be of eastern European or western Asian origin (Kay *et al.* 2001). A CLIMEX model was made based on its wide distribution in Europe with cold stresses to define the northern edge of the distribution, which excludes most of Scandinavia (Royal Botanic Garden Edinburgh 2006).

Asparagus officinalis has naturalized in all Australian states (Figure 6c). At least 13 feral populations have been documented in southern WA where it is frequently found persisting around old market gardens and especially in swamps and river edges in the Perth metropolitan area (Keighery 1996) and a similar situation would be expected in other States. The CLIMEX prediction for Australia indicates a widespread establishment in southern Australia.

A more detailed model would need to incorporate physiological information, but despite literature searches including online abstracting sources and Hung (1975), there is little information on the temperature and moisture requirements for this plant grown in natural conditions, as opposed to managed agriculture. The model also underestimates the distribution of *A. officinalis* in North America in colder regions, where this plant is widely naturalized (http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=200027573). It is likely that with more information the model would show a wider distribution in Australia, similar to the observed distribution. Thus the model should be rated at having a low accuracy.

Asparagus plumosus Baker (Figure 7)

Asparagus plumosus is found in eastern South Africa (Figure 7a) and north to

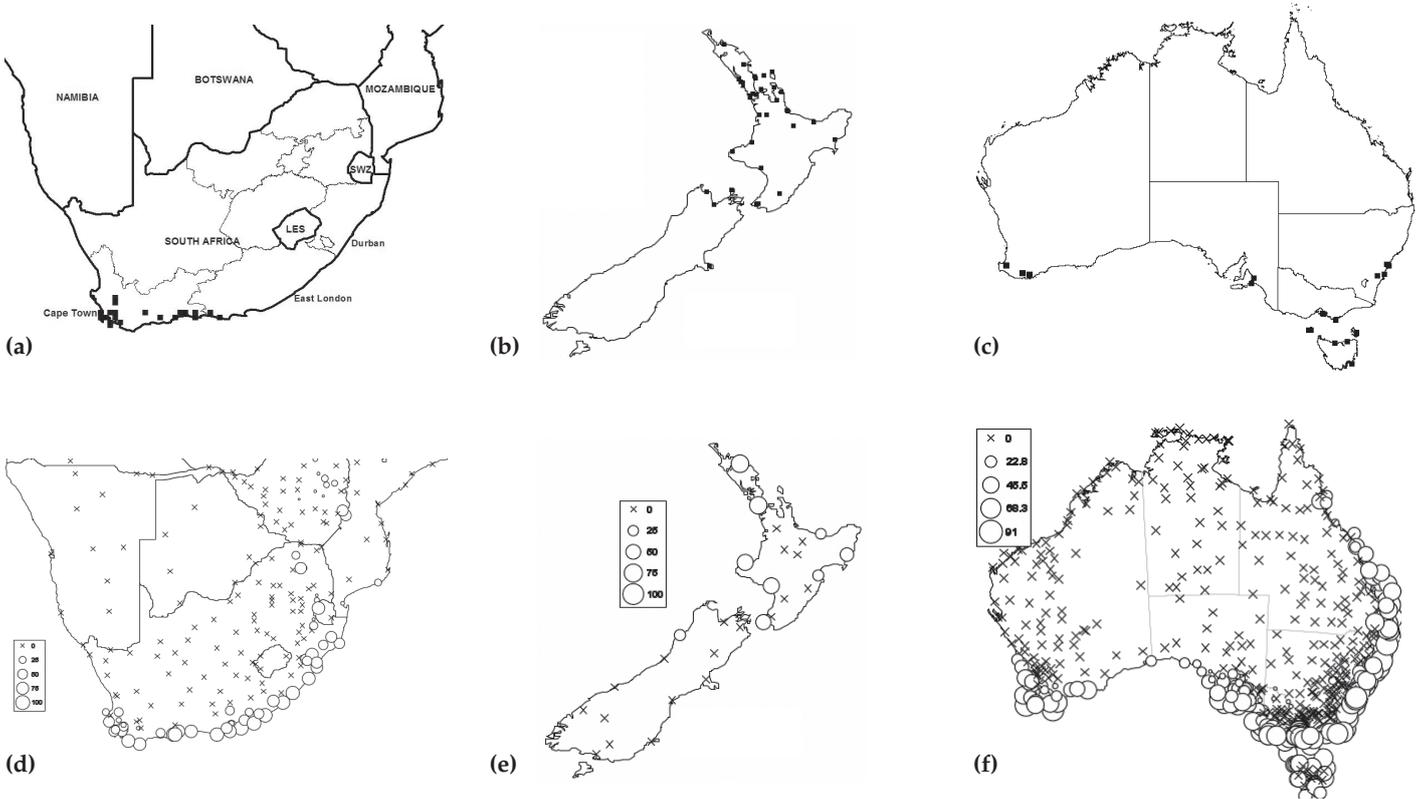


Figure 8. *Asparaguscandens*; observed distribution in southern Africa (a), New Zealand (b, redrawn from Timmins and Reid 2000) and Australia (c) based on herbarium and published records; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for southern Africa (d), New Zealand (e) and Australia (f).

tropical East Africa (Obermeyer and Immelman 1992). It is frequently recorded in 'dune forest' (Obermeyer and Immelman 1992) and this type of area in coastal KwaZulu-Natal region of South Africa is shown with the highest climate match in the CLIMEX prediction to the native region (Figure 7c). There is no physiological information to use in the model and comparisons to distribution elsewhere were not made.

Asparaguscandens is naturalized in southern Qld, NSW, SA and WA (Figure 7b). It has extensively naturalized in coastal districts north of Royal National Park, NSW and is declared noxious on Lord Howe Island (Harden 1993). In WA populations occur in Bunbury (Keighery 1996) and Bold Park (Stephen King personal communication). In SA there are a few, minor infestations in coastal areas near housing and adjacent to irrigated orchards in the Riverland (John Virtue personal communication).

The CLIMEX model does not indicate establishment in southern Australia, but a high Ecoclimatic Index (EI) for coastal Qld. There are identification issues to be resolved for this species (see Batchelor and Scott 2006) to establish if *A. setaceus* (Kunth) Jessop is confounded in the reported Australian distribution. Because of

this, and the lack of other evidence, the model is rated as low confidence.

Asparaguscandens Thunb. (Figure 8)

A model based on the South Africa distribution (Figure 8a) is similar to that of *A. asparagoides* (western Cape form) (Figure 4c). However microclimatic factors may be important as Obermeyer (1992) notes that *A. scandens* is found in shady areas and appears to need moisture all year round.

It is a major weed of New Zealand (NZ) where it prevents regeneration of native seedlings and smothers understorey shrubs and saplings (Timmins and Reid 2000). The distribution map of the weed in NZ allowed a test of the model based on the South African distribution, but a poor match was found. As a consequence, the cold stress and hot-wet stress were modified to incorporate the NZ data. When predicted back to South Africa it is evident that *A. scandens* may have a potential distribution much larger than observed (Figure 8c).

Asparaguscandens has naturalized in central-eastern NSW, Phillip Island in Victoria (Clifford and Conran 1987) and northern Tasmania (Timmins and Reid 2000). In Victoria its distribution is limited but some infestations are described as medium-large (Timmins and Reid 2000). In

WA, *A. scandens* has naturalized in bushland on Mt. Clarence, Albany, Denmark and Margaret River (Kate Brown personal communication). In SA, infestations occur in the Southern Hills Region and central Mt. Lofty Ranges (Anon 2003b). The prediction to Australia (Figure 8d) indicates that *A. scandens* will naturalize across a wide area of mainly coastal regions, from WA to Qld. While physiological data and an explanation for the limited distribution in South Africa including possible microclimatic requirements are lacking, the test using information from New Zealand enables this model to be ranked at a confidence level of medium.

Asparaguscandens Baker (Figure 9)

Figure 9a shows the distribution of *A. virgatus* in southern Africa. The CLIMEX model based on this distribution has a combination of heat, dry and wet stresses restricting the species to the more subtropical regions, including into Zimbabwe, where the species is recorded (Obermeyer and Immelman 1992). The model is identical to that for *A. plumosus* except for the addition of hot-wet stresses. There appears to be no studies of the physiology of this species and it is not widely established elsewhere than southern Africa and Australia.



Figure 9. *Asparagus virgatus*; observed distribution in southern Africa (a) and Australia (b) based on herbarium records; CLIMEX prediction of EI showing circles for suitable locations and crosses where the species is predicted to not survive for Europe (c) and Australia (d).

Asparagus virgatus has become naturalized in south-east Qld (Clifford and Conran 1987). Populations also occur in the Sydney districts and central coast of NSW (Harden 1993). The CLIMEX prediction produces a close match to the current distribution in Australia (Figure 9b) without predicting a major spread elsewhere. This model has medium confidence because there is no controversy over the name and there is a good southern African match.

Conclusions

Ranking the CLIMEX models is a new approach which will need further development. It is important to indicate the degree of confidence in the models as this becomes part of the risk assessment process that can be used in the selection of management options. It also indicates that more information is needed and thus provides a guide to the requirement for further research. Examples of further research are the resolution of taxonomic issues (e.g. *A. aethiopicus*, *A. africanus*, *A. plumosus*), and the study of the biology of each species. The western Cape form of bridal creeper would be a priority species for the measurement of the plant's relationship to temperature and moisture because at present there is very little on which to base

a model, and yet the prediction of future distribution is essential if decisions are to be made on containment or eradication. Other implications from the models are that most species have the potential for further spread, some species are more a threat to northern Australia than southern Australia and containment strategies should be developed accordingly.

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Ecology and management of subtropical invasive asparagus (*Asparagus africanus* Lam. and *A. aethiopicus* L.)

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Abstract

Two *Asparagus* species invasive in subtropical Australia are basket asparagus (*Asparagus aethiopicus* L.) and the orange-fruited, climbing asparagus (*A. africanus* Lam.). In Queensland, both species are Declared Class 3 Pest Plants under the *Land Protection (Pest and Stock Route Management) Act 2002*. This legislation prevents sale of the species and requires that landholders take responsibility for their control. Based upon invasiveness and frequency scores, both species are considered serious environmental weeds in south-east Queensland, with *A. africanus* ranked sixth and *A. aethiopicus* ranked 23rd of 200 environmental weed species (Batianoff and Butler 2002). Both species were introduced for ornamental purposes, with later naturalization and spread following dumping of garden waste, and seed dispersal by native birds.

Asparagus aethiopicus was introduced to Australia late in the nineteenth century and is still commonly grown in gardens as a ground cover and in outdoor hanging baskets. The species has a broad tolerance of environmental conditions and invades exposed headlands, woodlands, rainforests, frontal dunes, coastal heath,

and sandy coastal fringes in south-east Queensland and coastal New South Wales. Frequently the species produces a dense mass of underground rhizomes and tubers and dense foliage, suppressing native plant species.

Asparagus africanus has been reported as naturalized in areas west of Ipswich since the 1940s. It is now distributed from Rockhampton to Lismore, New South Wales, and grows prolifically in remnant, semi-evergreen, vine thicket and brigalow forest communities, wetter eucalypt communities and moist gullies. It frequently climbs and covers native vegetation, reducing tree health and forming a dense ground cover that suppresses recruitment of native species. We present an overview of both species, including some aspects of recent research into their dispersal and seed bank ecology, and the outcomes of recent management trials in south-east Queensland.

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