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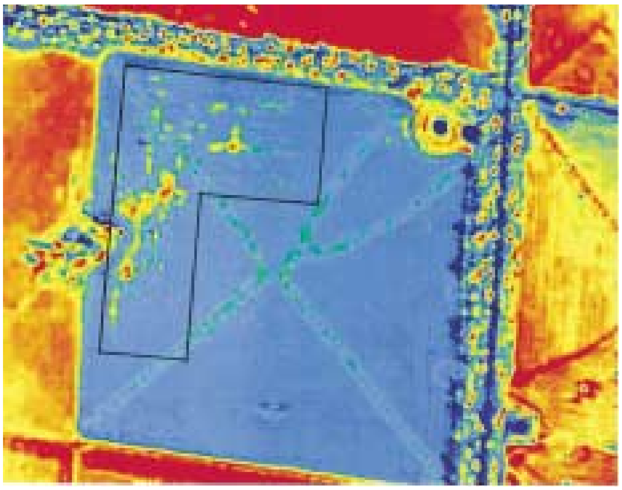

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Ecology and biogeography of *Cassia brewsteri*: assessment of potential sites for cultivation

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Abstract. *Cassia brewsteri* (F. Muell.) F. Muell. ex Benth. has been identified as a potential multipurpose agroforestry species, and also as a potential source of seed galactomannans (industrial gums). In this study, the natural and cultivated distributions of *C. brewsteri* were used as a basis for predicting potential sites for cultivation of the tree, using the climate modelling software ANUCLIM. The natural distribution was determined by compilation of data from herbaria and from field studies. The ecological parameters of natural occurrences were characterised in terms of soil and vegetation types by sampling 113 sites throughout the natural distribution in Queensland (18.583–26.150°S, 144.750–152.750°N). In addition to the natural occurrences, a further 11 sites were identified where the tree has been grown successfully in cultivation. Failures of the tree in agroforestry trials in Thailand may be explained by high temperature as a limiting factor in the distribution of the species. Failures of the species in trials in Australia, Zimbabwe and Malawi could not be attributed to climate or soil conditions at the trial sites, indicating that further research on culture of the tree is required to achieve high survival and growth rates.

Additional keywords: agroforestry, BIOCLIM, ecology, galactomannan, new crop.

Introduction

Utilisation

Cassia brewsteri (F. Muell.) F. Muell. ex Benth. (Caesalpiniaceae) is a small to medium-sized tree endemic to Queensland, Australia. The tree has the ability to coppice (Ryan and Bell 1989) and is resistant to termite attack in the field (Mitchell 1989). *C. brewsteri* wood is dense (850 kg/m^3), with potential as fuelwood or use as a general-purpose hardwood and cabinet timber. The wood is pale pink with yellowish sapwood, open grain and no figure (Turnbull *et al.* 1986). In addition to its wood products, the tree might possibly be utilised as a source of industrial gums (Cunningham and Walsh 2002).

Vercoe (1987, 1989) investigated the fodder value of *C. brewsteri* and 38 other Australian tree species. Dry matter digestibility (DMD) was estimated *in vitro* from chemical composition (e.g. crude protein level of 11.9%) by comparison with standard samples of species with known *in vivo* digestibility. The predicted *in vivo* DMD of 61.6% of *C. brewsteri* foliage was suggested to be adequate to provide subsistence forage. However, neither the foliage nor the twigs by themselves are adequate for the maintenance of sheep or cattle. The foliage is deficient in phosphorus and potassium and the twigs are deficient in crude protein, phosphorus, potassium and sodium. Further, while digestible *in vitro*, the foliage and fruit are unpalatable to cattle. There is, therefore, no potential for development of the plant as a fodder crop in Australia. Indeed, as the tree produces root suckers after clearing, graziers consider it a weed in parts of central Queensland (Kleinschmidt and Johnson 1977; Scanlan and Fossett 1981). Agricultural studies of *C. brewsteri* have focussed on means of killing the plant (e.g. Back 1974*a*, 1974*b*). The weediness of the tree is due in part to selective grazing; livestock avoid it but consume some of its competitors. Management practices such as physical clearing that disturb the plant promote multi-stemmed root suckers, exacerbating the problem.

Cassia brewsteri is useful as a shade tree and is reported to tolerate saline and alkaline soils (Doran *et al.* 1997). The floral blooms and deep green foliage make it an attractive ornamental species grown in Queensland, New South Wales and even Victoria under sheltered conditions (e.g. Francis 1981; Elliot and Jones 1982).

Positive alkaloid and negative anti-tumour tests of bark tissue extracts of *C. brewsteri* have been reported (Collins *et al.* 1990). Low levels of the anthraquinone chrysophanic acid have been detected in the seed (<5 mg/L) and pod wall (5 mg/L) but not in the pith surrounding the seeds

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(Cunningham *et al.* 2001). *Cassia brewsteri* has been investigated as a potential source of seed gums (galactomannans), which have many industrial applications, e.g. as a gelling agent in processed foods. The galactomannan content of the seed is very high, ranging from 28.3 to 39.7% (w/w), and the mannose to galactose ratio is also very high at 4.6–6.3. The gel strength of *C. brewsteri* galactomannans is comparable to the widely used seed gum derived from carob (*Ceratonia siliqua* L., Caesalpiniaceae) (Cunningham and Walsh 2002). In a cost–benefit analysis, and given stated assumptions on gum price, gum yield, and costs of production, Cunningham *et al.* (2001) estimated that production would not be economic, given observed yields. There is the potential that cultivated plots of selected genotypes might achieve higher yields.

Distribution

Cassia brewsteri is endemic to eastern Queensland, from around Gympie in the south to inland from Cairns in the north. Several authors have published distribution maps for the species. The map of Symon (1966) was based on only 15 herbarium collection records, which were not representative of the whole range of the species. Forster (1991) used only 4 collections, considering only the vineforest distributions, i.e. in the region surrounding the southern part of the distribution of the plant. Turnbull *et al.* (1986), Anderson (1993) and Randell and Barlow (1998) have produced distribution maps based on the work of Symon (1966) and Forster (1991) and personal knowledge of the tree. The Queensland Herbarium (BRI) database (HERBRECS) features a map output that can display all of the collections that have been entered into the database.

Cultivation

Although *C. brewsteri* has been used with success as an ornamental and shade tree in amenity horticulture, experimental agroforestry trials of the species have generally failed because of poor survival and growth performance. *C. brewsteri* has been included in 5 agroforestry trials of many species conducted at 8 sites in 4 countries. These include 2 sites in Queensland (Ryan and Bell 1989), 1 site in Malawi (Maghembe and Prins 1994), 3 sites in Thailand (Pinyopusarerk 1989) and 2 sites in Zimbabwe (Gwaze 1989; Mitchell 1989). The growth performance of *C. brewsteri* in all of the trials reported was among the worst of all the species grown for all of the parameters measured. In the best case, at Tuan, Queensland, the plants achieved 81% survival, a mean height of 82 cm, and a mean diameter at ground level of 1.7 cm after 31 months. In the worst cases, plantings have failed after 18–31 months (Wongi, Queensland; Makoholi, Zimbabwe; Makoka, Malawi). The reasons for the failure of the species in these trials were not analysed by the respective authors.

The aim of this study was to produce a comprehensive ecological description for *C. brewsteri*, which, combined with previously published work, could be applied to site selection for cultivation of the tree. The outputs of the bioclimatic analysis were provided as maps for ease of reference.

Materials and methods

Natural distribution

The BRI records for *C. brewsteri* were extracted from HERBRECS on 21 April 1997. Latitude and longitude records were provided for most collections, ranging in accuracy from no latitude or longitude to a GPS record made by the collector. Where there was no accurate position provided by the collector, an estimate was made by Herbarium staff on the basis of the locality description provided by the collector. The positional accuracy of localities, in minutes, was 0 or 1 or 2 significant figures. Where 2 significant figures were provided, the data were converted directly to decimal degrees and imported into the distribution data. Where 0 or 1 significant figure was provided, the latitude and longitude were determined on the basis of the locality description using the gazetteers of Anon. (1975) and AUSLIG (2000), and the maps of Aplin *et al.* (1994). Where the position could not be plotted within ± 10 min (about 16 km) due to the vagueness of the locality description, the record was not used for distribution mapping.

Further natural distributions and other information were extracted from unpublished data collected between 1978 and 1980 for a study of woody plant species in central Queensland pastures undertaken by the Queensland Department of Primary Industries (DPI) (Anderson *et al.* 1984). Information from sites where *C. brewsteri* occurred was obtained by examination of the original field datasheets from 460 sites covering 357 000 ha. The latitude and longitude records on the DPI datasheets had been determined from the 1:100 000 map series and recorded in degrees and minutes. In some cases, the locality description was able to clarify the position of BRI collections where ambiguous locality descriptions led to inaccuracies in latitude and longitude estimates, particularly in older collections. Further records were obtained from unpublished observations of native plants recorded from 1977 to 1999 (E. R. Anderson pers. obs.).

Cultivated distribution

Cultivated distributions were obtained from HERBRECS, published literature, personal communications and field surveys. An article requesting information was placed in the Society for Growing Australian Plants (SGAP) Queensland newsletter (December 1998), resulting in 2 detailed replies. The Australian Tree Seed Centre (ATSC) maintains collections of native tree seeds for use in forestry programs throughout the world. ATSC records showed 17 dispatches of *C. brewsteri* seed to 15 customers in 6 countries from 1984 to 1995. Letters to ATSC clients yielded information from 1 unpublished glasshouse study (N. Ashwath and N. E. Marcar unpublished data), but no additional field trials.

Population sampling

Forty field sites were located in 1998, representing the geographical range of the species determined using the methodology described above. Data for an additional 73 sites were incorporated from the unpublished datasheets of the Anderson *et al.* (1984) study. An attempt was made to extend the known distribution by travelling an additional 50+ km past the known distribution in several places. The position of each new location of the species was determined using a handheld Global Positioning System (GPS) receiver (Garmin) without differential correction. A locality description was recorded using the vehicle odometer to note the distance from the nearest town.

Vegetation structure and growth habit

Original vegetation communities were described in the field on the basis of remnant vegetation and regrowth, vegetation structure was classified after Specht (1970). Information from the datasheets of Anderson *et al.* (1984) was incorporated into the results for vegetation communities and site disturbance history.

Landscape and soil characterisation

The landscape of each site was characterised according to slope, aspect and topography. Slope was measured with a clinometer, aspect with a compass and the topography was classified according to a 7-point scale after Pressland (1992). Information from the datasheets used in the report of Anderson *et al.* (1984) was incorporated for slope, topography, soil texture down to 90 cm, 'pH at surface' and 'pH deeper'. Soil samples were taken at 0–10 cm and 40–50 cm from a single core and the pH and electrical conductivity were analysed after Rayment and Higginson (1992). Soil texture was estimated in the field by hand-ribboning after Northcote (1979) and changes were noted down the soil profile to a depth of 50 cm. A basic description of soil colour was also recorded in the field.

Climate modelling and site matching

The distribution records were geocoded by assigning a latitude, longitude and elevation to each unique site. The elevations of each distribution were determined by interrogation of a 30 arc second (about 800 m) grid Digital Elevation Model (DEM), GTOPO30, produced by the EROS Data Centre of the United States Geological Survey (USGS 1997). Tiles E100S10 and E140S10 of the DEM cover continental Australia and these were downloaded from a USGS File Transfer Protocol site (edcftp.cr.usgs.gov) then imported into ArcView (ESRI 1999). Elevations were extracted using 'spPntzval.ave', a script downloaded from the ESRI ArcScripts website (http://gis.esri.com/arcscripts/scripts.cfm).

The geocoded information was analysed with the software package ANUCLIM (Hutchinson *et al.* 1998). Climate profiles for the confirmed distributions in Australia were generated using the BIOCLIM and ESOCLIM elements of the software. Using the BIOMAP element of the software, these profiles were compared with a climate profile for the entire continent produced using the 30 arc second grid of the DEM, the results were mapped in ArcView and presented in Albers equal-area conic projection.

Two separate BIOMAP analyses were conducted. The first was based on the natural occurrences only and considered 4 bioclimatic parameters including rainfall, the cultivated occurrences were excluded because they were mostly watered and would therefore negate the influence of rainfall as a limitation in the model. The second analysis considered the potential distribution of the tree under irrigation by excluding rainfall as a limitation, the cultivated occurrences were still included as they could extend the tolerance limits for the temperature parameters.

Results and discussion

Natural distribution

A total of 310 distribution records were determined. However, many herbarium records represent the same site collected from at different times, or different sites that could not be differentiated on the basis of the broad locality description (e.g. 'Blackwater'). A total of 248 points were obtained which were unique to 3 decimal places in decimal degrees, i.e. the approximate accuracy of the non-differential GPS (with selective availability which was in place in 1998).

The species occurred in the latitude range 18°35′S–26°09′S and from the east coast of Queensland to about 350 km inland (Fig. 1). The natural distribution extended to offshore islands, Gloucester Island and Scawfell Island, both located less than 50 km off the coast between Bowen and Mackay. Elevations for all sites ranged from near sea level (4 m) to 640 m. The latitudes of the naturally occurring sites sampled for ecological data ranged from 19°00′S to 25°58′S. Of the 460 sites sampled for the report produced by Anderson *et al.* (1984), 73 included *C. brewsteri* and these ranged in latitude from 21°03′S to 23°10′S.

Anderson's (1993) map accurately represents the borders of the 2 main populations, while Randell and Barlow's (1998) map is a broad swathe across eastern Queensland representing large areas where the species is absent as well as its actual distribution. The HERBRECS database currently provides an adequate coverage of the range of *C. brewsteri*, with about 50 geocoded collections. The highest elevation calculated by the DEM matched the highest elevation of the BRI specimens (640 m) and disagreed with the 800 m estimate of Turnbull *et al.* (1986).

Cultivated distribution

Eleven unique locations were identified where the plant has been grown in cultivation with at least some success. HERBRECS included 4 collections of *C. brewsteri* in cultivation from 1966 to 1991. One locality was described only as 'Brisbane' and was not used in the climatic model, as more precise locations within the Brisbane area were available. Two locations were reported by SGAP members in response to the request for information, and the 2 trial sites reported by Ryan and Bell (1989) (age 11 years), located at Tuan and Wongi State Forests near Maryborough in south-eastern Queensland, were assessed. Although the Wongi trial was reported as a failure (Ryan and Bell 1989), enough trees had survived and grown well enough to consider the site in the climate model. An additional 4 cultivated sites were located during field work.

Wrigley and Fagg (1979) recorded the plant in cultivation as far south as Sydney (about 33.5°S), and Elliot and Jones (1982) extended that range to Melbourne, in a protected position (about 37.5°S). Randell and Barlow (1998) included a floral illustration from a specimen of *C. brewsteri* in cultivation at the Waite Institute in South Australia. These locations were not included because the plant is thought to be cold-sensitive and only moderately resistant to frost (Williams n.d.). Turnbull *et al.* (1986) estimated that in the natural range of *C. brewsteri*, there are only between 0 and 4 frosts per year.

Vegetation structure and growth habit

Cassia brewsteri occurred mainly in woodland, open woodland and open forest, with rare occurrences in tall open forest in the southern part of the distribution. The woodland and open-forest communities were dominated by *Eucalyptus populnea* (poplar box), *E. brownii* (Reid River box), *E. crebra* (narrow-leaved ironbark), *E. melanophloia* (broad-leaved ironbark) or *Acacia harpophylla* (brigalow). In tall open forest, *C. brewsteri* occurred with *Araucaria cunninghamii* (hoop pine), *Flindersia australis* (Crow's ash), *Eucalyptus siderophloia* (ironbark) and *Corymbia citriodora* (lemon-scented gum).

Three main growth habits of the tree were observed: single-stemmed with a spreading crown, multi-stemmed with a spreading crown and multi-stemmed root suckers regenerating after clearing. Single-stemmed specimens ranged in height from 2.8 m to about 30 m, but were relatively rare in occurrence. In tall open forest the crown height was a small proportion of the tree height, about 20%, while in all other vegetation structures the crown height exceeded about 80% of the tree height. The taller individuals were all located in the southern part of the natural distribution, which is geographically disjunct (Fig. 1).

Cassia brewsteri may potentially be divided into 2 subspecies, the northern and southern provenances. This division was first suggested by Symon (1966), based on differences in leaf shape, which in the southern provenance of *C. brewsteri* approaches that of *C. marksiana*. Stanley and Ross (1983) distinguished the 2 forms of *C. brewsteri* on the basis of the moist forest form (southern) having larger leaflets with broader sutures than the semi-arid woodland form (northern). They also note, along with Turnbull *et al.* (1986), that the southern provenance is much taller (up to 30 m compared with 12 m). Recent evidence based on DNA fingerprinting supports the division of *C. brewsteri* into 2 subspecies along the lines of the southern and northern provenances (Cunningham *et al.* 2002).

Cassia brewsteri was observed to regenerate well after clearing by pulling, ploughing and burning and was commonly found as a multi-stemmed root sucker in cattle-grazing regions. The number of stems ranged from 2 to 24. No small seedlings (<2 m) were observed, with all smaller individuals being root suckers.

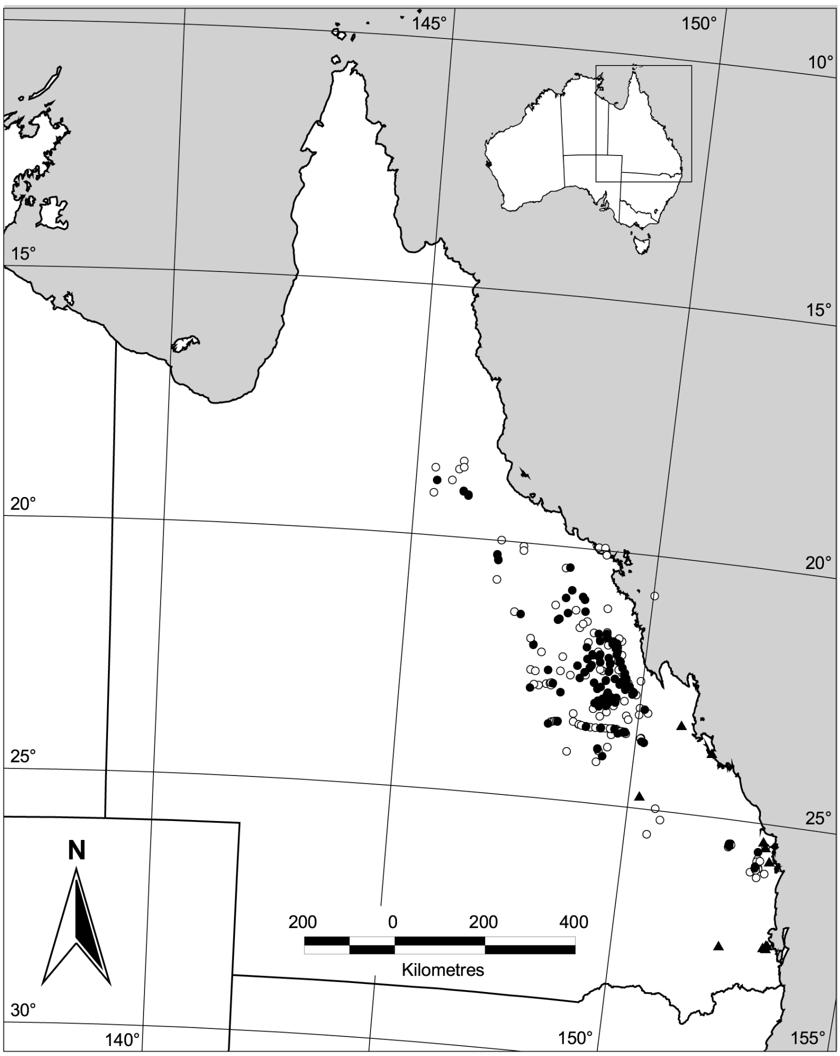

Figure 1. Distribution of *Cassia brewsteri* showing 248 natural occurrences (○) and 11 cultivated occurrences (▲), and 113 sites that were studied in detail (●).

Table 1. Frequency of topography classes for 113 natural occurrences of *Cassia brewsteri*

Topography class (average and max. slope, %)	Frequency (%)
Plains flat, alluvial (0.5, <1)	9.7
Plains flat, not alluvial (0.5, 1)	31.0
Plains with low relief (<3, 3)	25.7
Plains, undulating with low rises (<9, 12)	25.7
Hills, low (<18, 24)	8.0
Hilly to mountainous (24, no limit)	0
Tablelands (—, —)	0

Landscape and soil characterisation

Cassia brewsteri occurred on flat alluvial plains, flat non-alluvial plains, plains with low relief, undulating plains with low rises and on low hills (Table 1). It was not recorded on hilly to mountainous terrain or on tablelands despite these topographies being within the geographic range of the plant. Slope ranged from flat to 13° (n = 113). Aspect ranged from 20 to 340° (n = 17 non-flat sites).

Cassia brewsteri occurred on uniform, gradational and duplex soils, and on a range of soil textures from clayey sand to heavy clays (Table 2). Soil pH varied within each primary profile form, ranging from 4.2 to 9.0. This characterisation is consistent with previous reports. Turnbull *et al.* (1986), later updated in Doran *et al.* (1997), reported that inland occurrences of *C. brewsteri* were commonly on alluvial plains and undulating lowlands with a permeable loam at the surface and an impermeable, often alkaline, medium to heavy clay subsoil. Other occurrences were reported to be on undulating to hilly country and tablelands where soils range from shallow skeletal sands and stony clays to deep loamy and sandy red earths. The best development of the tree was reported on deep, fertile red clay loams or deep alluvial soils near watercourses. Diemer and Simms (1996) estimated a maximum soil pH for *C. brewsteri* of 6.5 and an optimal pH of 6.0. However, their values were very low compared to the majority of natural occurences of the plant, which are on neutral or alkaline soils (Table 2).

The EC of the A horizon ranged from 0.023 to 0.410 dS/m and the EC deeper in the soil profile was similar. Most

Table 2. Range and frequency of soil types for natural occurrences of *Cassia brewsteri*

Soil parameter	Frequency of sites (%)
Primary profile form (n = 101)	
Uniform soil, sandy loam to heavy clay (A horizon)	31.7
Gradational soil, sandy clay loam to light medium clay (A horizon)	5.9
Duplex soil, clayey sand to sandy clay (A), clay loam to heavy clay (B)	62.3
Colour (A horizon) (n = 32)	
Greys	15.6
Browns	56.3
Reds	28.1
pH surface (0–10 cm, n = 97)	
4.8–9.2	100
Very acid (pH<4.0)	0
Acid (pH 4.0–6.0)	21.3
Neutral (pH 6.1–7.4)	53.3
Alkaline (pH>7.4)	24.4
Very alkaline (pH>9.0)	1.0
pH deeper (≥40–50 cm, n = 95)	
4.2–9.0	100
Very acid (pH<4.0)	0
Acid (pH 4.0–6.0)	9.5
Neutral (pH 6.1–7.4)	25.3
Alkaline (pH>7.4)	65.3
Very alkaline (pH>9.0)	0
EC surface (0–10 cm, n = 26) (dS/m)	
0.023–0.410	100
Low (EC<0.16 dS/m)	50
High (EC>0.16 dS/m)	50
EC deeper (40–50 cm, n = 24) (dS/m)	
0.025–1.339	100
Low (EC<0.16 dS/m)	29.2
High (EC>0.16 dS/m)	70.8

Table 3. Six-point climate profiles for *Cassia brewsteri* (where cultivated sites extended the range of a parameter, the estimates from the cultivated sites profile are added in parentheses)

Parameter	Range
Mean annual rainfall (mm)	509–1616
Rainfall regime (winter, summer, uniform/bimodal)	Summer
Dry season length (consecutive months <40 mm)	0–8
Mean maximum temperature of the hottest month (°C)	(28.5)–29–34.9
Mean minimum temperature of the coldest month (°C)	(2.6)–4.7–14.8
Mean annual temperature (°C)	(16.3)–19.1–23.4

occurrences were on relatively saline soils (Table 2), quantifying the assertion by Turnbull *et al.* (1986) that the plant occurs at saline sites. In a study of salinity tolerance of 60 Australian tree species, *C. brewsteri* seedlings were found to be moderately salt tolerant, with an LD_{50} of 975 mol/m^3 and height growth ceasing at 640 mol/m^3 (N. Ashwath and N. E. Marcar unpublished data).

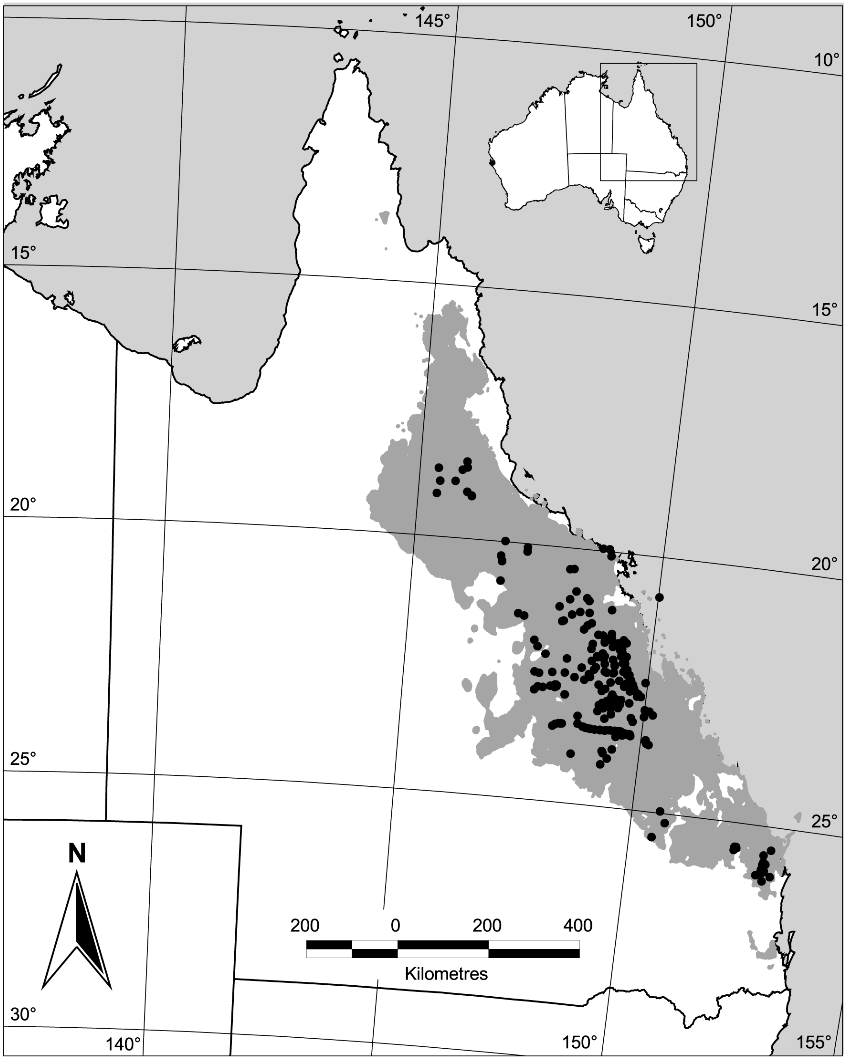

Figure 2. Areas (grey shading) potentially suitable for cultivation of *Cassia brewsteri* under rainfed conditions based on four bioclimatic parameters: mean annual rainfall (509–1616 mm), mean maximum temperature of the hottest month (29.0–34.9°C), mean minimum temperature of the coldest month (4.7–14.8°C) and mean annual temperature (19.1–23.4°C). Solid circles show 248 natural occurrences.

Climate modelling and site matching

Separate BIOCLIM and ESOCLIM climate profiles were generated for (i) the 248 natural occurrences of *C. brewsteri*, and (ii) these 248 plus the 11 cultivated occurrences. The full 35-point BIOCLIM profiles are reported in Appendix 1, while selected ESOCLIM outputs were used to calculate dry season length and rainfall regime in the 6-point profile discussed below. Climate profiles for the trial sites at Tuan and Wongi State Forests were generated separately to enable comparison with the climate profile of the natural occurrences.

Kriticos and Randall (2001) reviewed ANUCLIM/BIOCLIM and several other computer systems used to predict the distribution of species on the basis of climate. A number of approaches have been developed for site selection specifically for forest trees, as reviewed by Booth (1991, 1996) and Boland (1997). While the detailed climatic profiles generated by BIOCLIM are useful for some applications, a simpler approach is often more useful for predicting suitable sites for forest trees. One of the earlier computer-based systems for selection of tree species for particular sites was the INSPIRE system of Webb *et al.* (1980). INSPIRE searches a database of tropical species and selects those which match a profile of given climatic conditions. Six of the climatic parameters used by INSPIRE were selected for use in the simulation mapping programs (e.g. GROMAP) developed in Australia in the 1980s for forest trees. These parameters are listed in Table 3 for *C. brewsteri*, using data derived from the present study (where cultivated sites extended the range of a parameter, the estimates from cultivated sites are added in parentheses).

A seventh variable, absolute minimum temperature, is often used for Australian species that are under consideration for planting in overseas areas where extremes of cold may exceed those in Australian conditions, even where the mean minimum temperature is the same. Absolute minimum temperature could not be derived from ANUCLIM and hence is not reported here. The rainfall regime and dry season length cannot be screened in BIOMAP; these parameters were determined by analysis of the ESOCLIM output, which generates monthly values. Homoclimes were calculated in BIOMAP, using 3- and 4-point climate profiles for *C. brewsteri*.

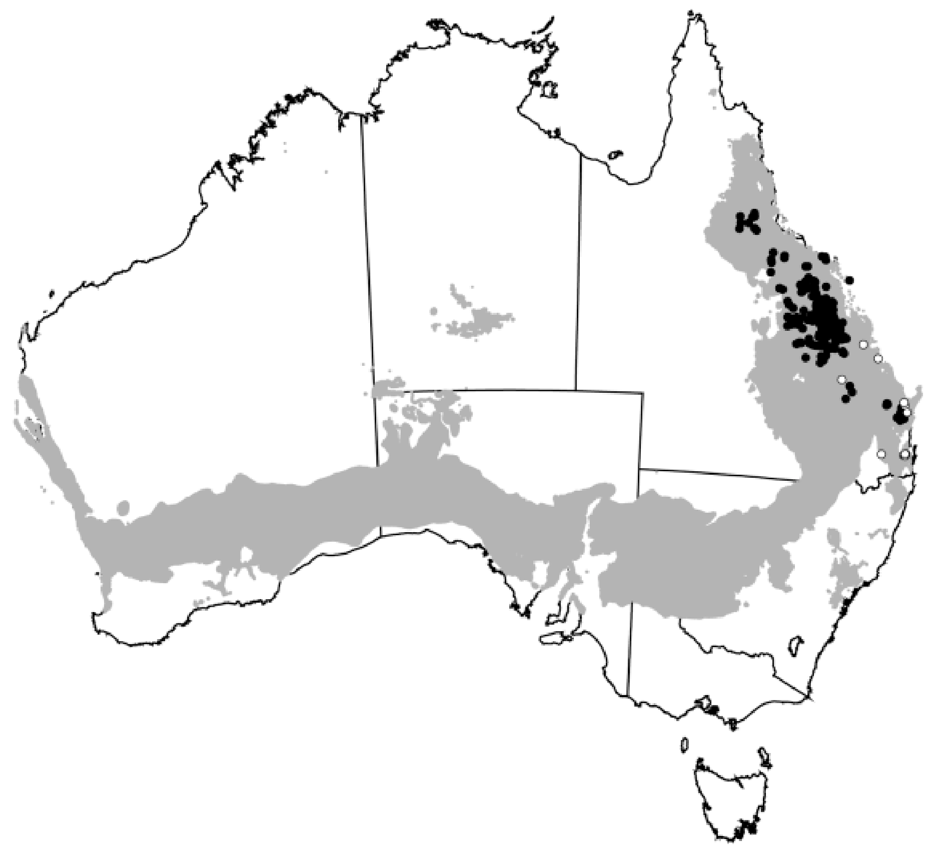

Figure 3. Areas potentially suitable for cultivation of *Cassia brewsteri* under irrigated conditions based on three bioclimatic parameters: mean maximum temperature of the hottest month (28.5–34.9°C), mean minimum temperature of the coldest month (2.6–14.8°C) and mean annual temperature (16.3–23.4°C). The 248 natural distributions (●) and 11 'successful' cultivated occurrences (○) are shown.

The predicted distribution under rainfed conditions (Fig. 2) is similar to the actual distribution of the plant in nature. The exceptions to this include the northern limits and the areas between the northern, central and southern parts of the species distribution. The potential distribution under irrigation covers a much wider area, including a large part of eastern Queensland and a large belt through southern Australia (Fig. 3). Of course, cultivation would not be practical in much of this area as water is not available for irrigation. The range is extended by the addition of areas with lower rainfall, but also by the tolerance of lower temperatures in the climate profile, resulting from the addition of cultivated occurrences of the tree. No cultivated occurrences were detected in areas that are warmer than the natural distribution (Table 3, Appendix 1).

Conclusions

The climate and soil profiles of reported field trial sites of *C. brewsteri*, both in Australia (2 sites) and overseas (6 sites), were matched to the profile for the natural distribution of the species. The climate profile for each of the trial sites matched the climate profile for *C. brewsteri*, with the exception of the 3 Thailand sites where the tree performed poorly in each case. At the Thai sites, mean annual temperature exceeded the climate profile for the species, 29.4, 26.6, 24.6°C for Ratchaburi, Si Sa Ket and Chiang Mai, respectively (Pinyopusarerk 1989). This result supports the conclusion that higher temperatures limit the northern and western distribution of the species in Australia (Fig. 3). Lower temperatures do not appear to inhibit survival or growth, with cultivated trees thriving in areas south of the natural distribution, with lower mean annual temperatures down to 16.3°C in southern Queensland.

Soil conditions (outside of moisture content) do not appear to be a major determinant on *C. brewsteri* distribution. In its natural distribution, *C. brewsteri* is most vigorous on deeper, fertile soils near watercourses but it tolerates a wide variety of soils and moderate salinity levels. For the 2 Australian trial sites, the 7 soil parameters assessed in the current study (Tables 1 and 2) matched the profile for the natural distribution of the species, with the exception of a slightly lower EC deeper in the profile at the Wongi site. The soil data for the overseas sites were far too incomplete to support any interpretation of site requirements.

Symon (1966) suggested that the southern part of the tree's population, which is geographically disjunct, may be subspecifically distinct. This has been supported by a recent DNA fingerprinting analysis, which also detected high genetic diversity in the species as a whole (Cunningham *et al.* 2002). Given this genetic diversity there is the potential to select provenances that are more closely matched to particular sites for any future trials. Thus far, field trials of the species have been based on ATSC seedlots sourced from Marlborough and Blackwater, both in the northern provenance. Future trials should assess the southern provenance instead or as well.

The poor survival and performance reported in some of the overseas trials could also be due to inappropriate management practices. Potential cultivation sites have been identified across Australia. Further work is required to explain poor survival rates in agroforestry trials and to identify optimal cultivation techniques for the species. Vegetative propagation has the potential to produce fast-growing cultivars with a single basal stem, thus enhancing the economic viability of commercial plantings.

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Appendix 1. BIOCLIM profile for 248 natural distributions of *Cassia brewsteri*

Parameter	Natural occurrences				Cultivated occurrences			
	Mean ± s.d.	Median	Max.	Min.	Mean ± s.d.	Median	Max.	Min.
	Temperature							
1. Annual mean temperature	21.4 ± 0.80	21.6	23.4	19.1	21.4 ± 0.88	21.5	23.4	16.3
2. Mean diurnal range [mean(monthly max.–min.)]	13.2 ± 1.32	13.4	15.1	6.3	13.2 ± 1.38	13.4	15.1	6.3
3. Isothermality (2/7)	0.53 ± 0.01	0.53	0.56	0.43	0.53 ± 0.01	0.53	0.56	0.43
4. Temperature seasonality (CV)	1.48 ± 0.14	1.48	1.75	1.06	1.48 ± 0.14	1.47	1.75	1.06
5. Max temperature of warmest month	32.6 ± 1.42	32.8	34.9	29	32.5 ± 1.53	32.7	34.9	28.5
6. Min temperature of coldest month	7.7 ± 1.44	7.5	14.8	4.7	7.7 ± 1.48	7.5	14.8	2.6
7. Temperature annual range (5–6)	25 ± 2.37	24.9	28.9	14.7	24.8 ± 2.45	24.8	28.9	14.7
8. Mean temperature of wettest quarter	26.1 ± 0.87	26.3	27.7	23.3	26.0 ± 0.95	26.2	27.7	21.7
9. Mean temperature of driest quarter	16.9 ± 1.09	16.8	21.6	14.2	16.8 ± 1.15	16.8	21.6	11.2
10. Mean temperature of warmest quarter	26.2 ± 0.85	26.3	27.8	23.6	26.1 ± 0.93	26.3	27.8	21.7
11. Mean temperature of coldest quarter	15.6 ± 0.96	15.5	19	12.9	15.5 ± 1.02	15.6	19	10
	Precipitation and moisture							
12. Annual precipitation	688 ± 153.4	652	1616	509	703 ± 169.35	658	1616	509
13. Precipitation of wettest month	121 ± 32.58	113	324	94	123 ± 33.3	113	324	94
14. Precipitation of driest month	16 ± 6.7	17	40	0	17 ± 7.35	16	44	0
15. Precipitation seasonality (CV)	66 ± 11.96	64	110	47	65 ± 12.14	63	110	46
16. Precipitation of wettest quarter	335 ± 82.5	315	857	238	340 ± 84.34	318	857	238
17. Precipitation of driest quarter	65 ± 21.12	65	149	0	67 ± 23.62	63	159	0
18. Precipitation of warmest quarter	330 ± 70.23	319	747	238	335 ± 72.74	321	747	238
19. Precipitation of coldest quarter	78 ± 23.52	73	196	30	81 ± 27.14	74	198	30
20. Annual mean radiation	20.0 ± 0.42	20.1	20.4	18.3	19.9 ± 0.51	20.1	20.4	17.9
21. Highest monthly radiation	25.1 ± 0.3	25.2	25.6	23.8	25.1 ± 0.35	25.1	25.6	23.7
22. Lowest monthly radiation	13.8 ± 0.57	14	14.9	11.9	13.7 ± 0.67	13.9	14.9	11.3
23. Radiation seasonality (CV)	19 ± 1.19	19	23	18	20 ± 1.42	19	25	18
24. Radiation of wettest quarter	22.8 ± 0.66	22.9	23.4	20.4	22.7 ± 0.74	22.9	23.9	19.9
25. Radiation of driest quarter	17.8 ± 0.74	17.9	21.2	16	17.8 ± 0.82	17.9	21.2	15.4
26. Radiation of warmest quarter	23 ± 0.30	23	24.2	22.2	23 ± 0.33	23	24.2	21.9
27. Radiation of coldest quarter	15.4 ± 0.56	15.4	16.5	13.6	15.3 ± 0.66	15.5	16.5	13
28. Annual mean moisture index	0.38 ± 0.11	0.35	0.86	0.26	0.39 ± 0.12	0.35	0.86	0.26
29. Highest monthly moisture index	0.51 ± 0.11	0.47	0.97	0.36	0.52 ± 0.12	0.48	0.97	0.36
30. Lowest monthly moisture index	0.24 ± 0.11	0.21	0.73	0.12	0.25 ± 0.12	0.22	0.73	0.12
31. Moisture index seasonality (CV)	25 ± 7.67	25	47	7	25 ± 8.03	25	47	7
32. Mean moisture index of high quarter MI	0.49 ± 0.12	0.45	0.96	0.33	0.50 ± 0.12	0.45	0.96	0.33
33. Mean moisture index of low quarter MI	0.26 ± 0.11	0.23	0.75	0.14	0.27 ± 0.12	0.23	0.75	0.14
34. Mean moisture index of warm quarter MI	0.39 ± 0.09	0.37	0.76	0.26	0.40 ± 0.10	0.37	0.76	0.26
35. Mean moisture index of cold quarter MI	0.39 ± 0.13	0.35	0.96	0.27	0.40 ± 0.14	0.35	0.96	0.27