Phenology of bellyache bush (*Jatropha gossypiifolia* L.) in northern Queensland

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Abstract
An understanding of the seasonal patterns of leaf, flower and seed production of weeds is valuable when determining the most appropriate timing of control activities. This 12 month study determined the seasonal changes in leaf density and the timing of flowering and capsule production of the exotic weed bellyache bush (*Jatropha gossypiifolia* L.) located within both riparian and sub-riparian zones of northern Queensland. Monthly measurements of sugar concentrations were also undertaken to determine if seasonal variations in the level of sucrose fraction occurs. Prevailing environmental conditions (ambient temperature, soil temperature, soil moisture content, light density and rainfall) were monitored, with correlation analysis identifying any significant relationships with the ecological parameters measured.

Maximum leaf density of bellyache bush plants occurred during the wet season (November–April), with up to 17 (January) and 20 (January) leaves per stem present on plants within sub-riparian and riparian zones, respectively. Leaf density then declined during the dry season and remained at one leaf or fewer per stem for the cooler months in the dry season (June–August). Flowering occurred from June to April (11 months) in riparian zones and from September to April (8 months) in sub-riparian zones. Capsule production commenced in September and October within riparian and sub riparian infestations, respectively. Capsules were present on plants for 10 months within both zones. A low sugar concentration phase (14–17%) lasted for seven months from November to May and a high one (19–23%) lasted for five months from June to October. These results suggest that in northern Queensland, the wet season may be the optimum time to implement control techniques dependent on plants having high leaf cover and/or low energy reserves.

Keywords: ***Jatropha gossypiifolia*, bellyache bush, phenology, riparian zone, sub-riparian zone, deciduous, chemical control.**

Introduction
Bellyache bush (*Jatropha gossypiifolia* L.) is a weedy deciduous shrub, native to tropical America (Csurhes 1999). Its seeds are toxic and the plant has the capacity to form dense thickets which interfere with pasture growth, obscure fence lines, impede mustering, harbour feral pigs, poison livestock, spoil natural landscapes, affect recreational use of natural areas and displace native vegetation (Miller and Pitt 1990, Parsons and Cuthbertson 2001).

In Queensland, the threat of these socio-economic and environmental impacts has seen bellyache bush formally recognised in pest management plans for 24 of the 46 local Government Shires located north of the tropic of Capricorn (Bebawi *et al.* 2002). It also recently became a declared weed in Queensland following the introduction of the Land Protection (Pests and Stock Route Management) Act 2002. Under the Act, bellyache bush is listed as a Class 2 plant, which incorporates those weeds established in Queensland that have, or could have, an adverse economic, environmental or social impact. The management of these pests requires coordination and they are subject to local government, community or landowner led programs.

Initial research undertaken to develop control options for bellyache bush resulted in the identification of several techniques that could be utilised, including fire, chemicals and machinery (Csurhes 1999). Anecdotal evidence suggests that land managers have achieved mixed results using the available options, with efficacy ranging from poor to extremely high.

To improve the reliability of control options, further research has been undertaken on the ecology of bellyache bush. A major aim of this research is to identify treatment times that coincide with susceptible stages of the plants life cycle. Estimates of the potential scale and duration of post treatment regrowth from seed may also provide land managers with necessary information on which to plan control programs.

The benefits of such information for bellyache bush management are already becoming apparent. For example, testing of available control options has found that bellyache bush plants are extremely sensitive to fire, yet complementary ecological studies reveal that a large portion of the seed bank will survive allowing large-scale seedling recruitment to occur in the following wet season (Bebawi and Campbell 2002a). The implications for management are that one-off burns could exacerbate the problem if not followed up by secondary control activities.

This paper reports results of a field study undertaken to quantify seasonal changes in leaf density and sugar concentrations, and the timing of flowering and capsule production within riparian and sub-riparian zones. Prevailing environmental conditions (ambient temperature, soil temperature, soil moisture content, light density and rainfall) were measured, with correlation analysis used to identify any significant relationships with the ecological parameters measured. The implications of these findings on the methods and timing of control activities for management of bellyache bush are also discussed.

Materials and methods
Site description
This investigation was undertaken between April 1999 and March 2000 on a 4 ha site at Southern Cross Creek (20°01'S, 146°01'E), 15 km northwest of Charters Towers, in northern Queensland. It was located within a 1000 ha paddock grazed by cattle at an approximate stocking rate of one animal per 9 ha. Throughout the study, the site remained unfenced. The site had not been burned for at least 10 years prior to this investigation (Dave Chapman, Landholder Almora Station, personal communication).

Vegetation at the field site was open woodland with a canopy dominated by *Eucalyptus* spp., a mid-storey dominated by bellyache bush and false sandalwood (*Eremophila mitchellii* Benth.) and an understorey dominated by buffel grass (*Cenchrus ciliaris* L.). Distinction between 'riparian' and 'sub-riparian' zones within the site was based on dominant vegetation type and distance from creek bank. Riparian zones were dominated by *Eucalyptus* spp. and were generally within 15 m of the creek bank whereas sub-riparian zones were dominated by false sandalwood and were between 20 and 40 m away from the creek bank. The understorey of both zones consisted of mono-specific adult bellyache bush plants (>1 m high).

Average annual rainfall at nearby Charters Towers is 657 mm (Bureau of Meteorology 1988). The daily maximum temperature range during the wet season

(November to April) is between 30 and 37°C and the cooler months in the dry season (June to August) the range is between 21 and 27°C (Bureau of Meteorology 1988). Day length from November to April ranges between 11 h 16 min and 13 h 29 min and from June to August ranges between 10 h 56 min and 11 h 28 min (Geoscience Australia 2003).

Experimental design
Three sites along Southern Cross Creek were chosen randomly. At each site, a 10 × 40 m plot, was randomly selected with its short axis parallel to the creek, was marked out on the southern side abutting the creek bed, and a similar plot also randomly selected was marked out on the northern side. The two plots were separated by 4–10 m of creek bed. Within each of the six plots a sub-plot (9 m^2) was randomly located within the riparian zone and a similar one randomly selected within the sub-riparian zone. Sub-plots contained on average four bellyache bush plants per m^2 (40 000 plants ha^{-1}).

Plant Measurements
Ten bellyache plants (>1 m height) were randomly selected from each sub-plot, permanently tagged, and monitored monthly over the following 12 months.

For each tagged plant, changes in plant size over the experimental period were recorded through monthly measurements of stem basal diameter (recordings taken at the base of plants using digital callipers). Determination of the seasonal pattern of leaf production involved counting on a monthly basis the number of leaves, both mature (green) and immature (bronze) present on six randomly selected branches on each tagged plant. Measurements of flower and capsule incidence were based on presence or absence of flowers or capsules on shoots of tagged bellyache bush plants at the time of sampling.

A hand-held refractometer was used to determine percent sugar concentration (percent sucrose) of bellyache bush cell sap. The cell sap was obtained from apices of bellyache bush branches that were randomly selected from the shoot system. These apices were cut (approximately 3 mm deep) with a sharp blade to release cell sap. Branches previously damaged by cutting were not used in subsequent monthly determinations of sugar concentration.

Environmental conditions
Records of monthly rainfall at the experimental site between April 1999 and March 2000 were obtained from the Bureau of Meteorology (http://nrm.dnr.qld.gov.au/silo/datadrill) and compared against long-term records for nearby Charters Towers (Bureau of Meteorology 1988). At each monthly sampling time, soil moisture content was determined gravimetrically from six randomly selected soil samples (0–5 cm depth) located beneath the bellyache bush canopy within each zone. Soil samples were stored in waterproof glass jars and transferred to the laboratory where wet weights were recorded. The samples were then oven-dried at 105°C for 48 h, dry weights recorded and gravimetric soil moisture content calculated for each zone.

A hand-held infrared thermometer (Cole-Parmer single laser sighting) was used to determine ambient and soil temperatures between 10:00 am and 10:30 am. When measuring ambient temperature, the infrared thermometer was pointed at the surface of a white A4 (210 × 297 mm) copy paper sheet held at random in space above the canopy of bellyache bush infesting riparian and sub-riparian zones within each plot and the temperature recorded. Six duplicate temperature readings were taken at each recording date. The same procedure was repeated for measuring soil temperature except that the infrared thermometer was pointed at the soil surface beneath the bellyache bush canopy within each zone.

A digital hand-held light meter (Cole-Parmer) was used to determine light density between 10:00 am and 10:30 am at ground level beneath the canopy of bellyache bush plants. Six randomly selected locations beneath the canopy of bellyache bush within each sub-plot were sampled.

Data Analysis
The six plots were considered as blocks for a two-way analysis of variance to compare responses between the riparian and sub-riparian zones at each recording time. Data from individual tagged plants, and duplicate measures taken of temperature and soil moisture were regarded as samples. A repeated measures analysis on each variable was then performed across the 12 months, to test for time of year effects and also any interactions between zones and time of year. Percentage data (eg per cent of tagged plants that were flowering) were transformed (arcsine) for analysis and back-transformed percentages were calculated. Correlations between variables, based on 12 months data from 12 sub-plot zones, were also estimated. All means for plant responses are given ± s.e.

Results
Environmental conditions
Rainfall Rainfall received during the experiment totalled 945 mm, some 287 mm more than the long-term mean reported for nearby Charters Towers (Figure 1). Its occurrence followed the typical dry season (May to October)/wet season (November to April) pattern associated with the dry tropics of northern Queensland. However, rainfall during the dry season was very low, averaging just 26% of the long term mean. In contrast, the wet season received 70% more than average, with the months of November (237 mm) and February (297 mm) being particularly high rainfall periods.

Soil moisture Soil moisture generally followed a similar pattern to that of rainfall, with high levels associated with the wet season and low levels occurring

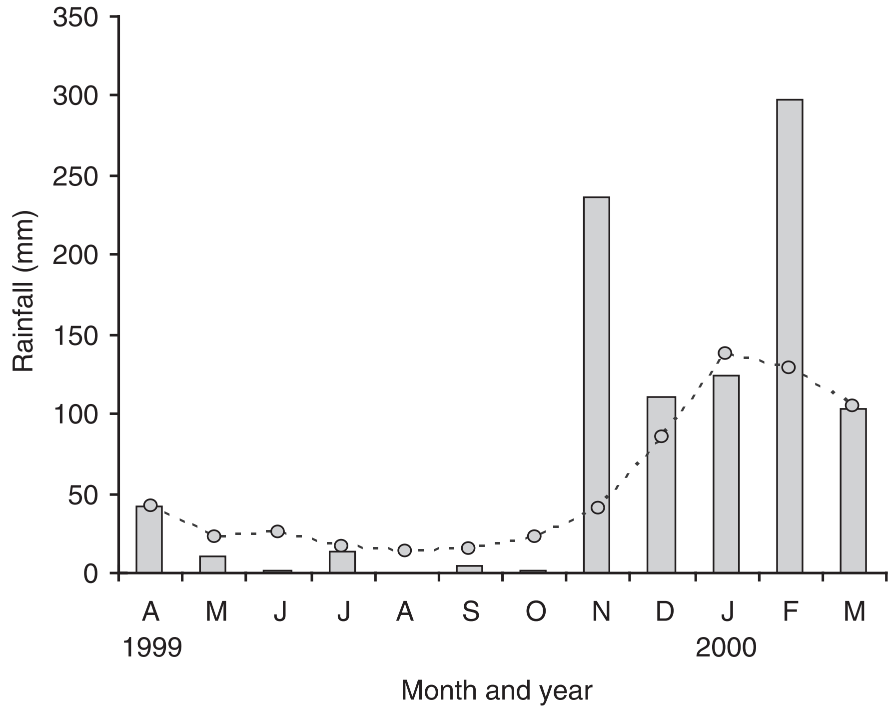

Figure 1. Monthly rainfall (columns) at Southern Cross Creek and 100 years mean rainfall at Charters Towers (points).

Table 1. Monthly ambient temperature, soil temperature, soil moisture and light density beneath the canopy of bellyache bush plants in riparian and sub-riparian zones at Southern Cross Creek.

	Ambient temp. (°C)	Soil temperature (°C)	Soil moisture (%)	Light density (Lux)	
Month (year)	A[A]	A[A]	A[A]	R[B]	SR[C]
April (1999)	28.8	25.6	3.2	2656	18517
May (1999)	30.9	36.8	2.1	25147	96483
June (1999)	22.2	22.2	1.3	11227	29867
July (1999)	24.0	23.8	3.4	91050	62878
August (1999)	25.8	28.0	1.1	8850	13783
September (1999)	29.5	36.2	1.2	42737	30800
October (1999)	28.7	29.6	1.2	17617	28267
November (1999)	27.5	24.6	4.5	5377	9930
December (1999)	29.2	27.5	2.3	3150	7317
January (2000)	27.5	31.7	2.5	4387	24312
February (2000)	35.6	24.8	4.0	990	35628
March (2000)	27.2	24.9	3.0	770	9970

[A] A average of two zones, [B] R riparian, [C] SR sub-riparian.

during the dry season (Table 1). Irrespective of time of year, a highly significant difference (P <0.01) occurred between zones, with soil moisture in riparian zones averaging 40% higher than sub-riparian zones.

Temperatures Both ambient and soil temperatures followed similar seasonal patterns, characterised by highest and lowest temperatures generally being recorded during the wet and dry season, respectively (Table 1). Whilst significant differences (P >0.05) between zones were not apparent for ambient temperatures, the soil temperature below the canopy of bellyache bush was on average 3.6°C higher (P <0.01) in sub-riparian zones compared with riparian zones.

Light density beneath canopy of bellyache bush plants The zone in which plants were growing and time of year significantly (P <0.01) interacted to affect light density beneath the canopy of bellyache bush (Table 1). For example, in May, significant (P <0.01) differences in light density occurred between riparian and sub-riparian zones, but not in June. Light density was, on average, 72% greater in sub-riparian than riparian zones. Maximum light density beneath canopy of bellyache bush plants was recorded in July, in both zones.

Plant responses

Data of plant responses is based on data from 60 plants each in two zones (riparian and sub-riparian) over 12-month period.

Stem basal diameter No significant changes (P >0.05) in stem basal diameter were detected over the experimental period between zones or month of year, with plants averaging 47.4 ± 0.4 mm in size.

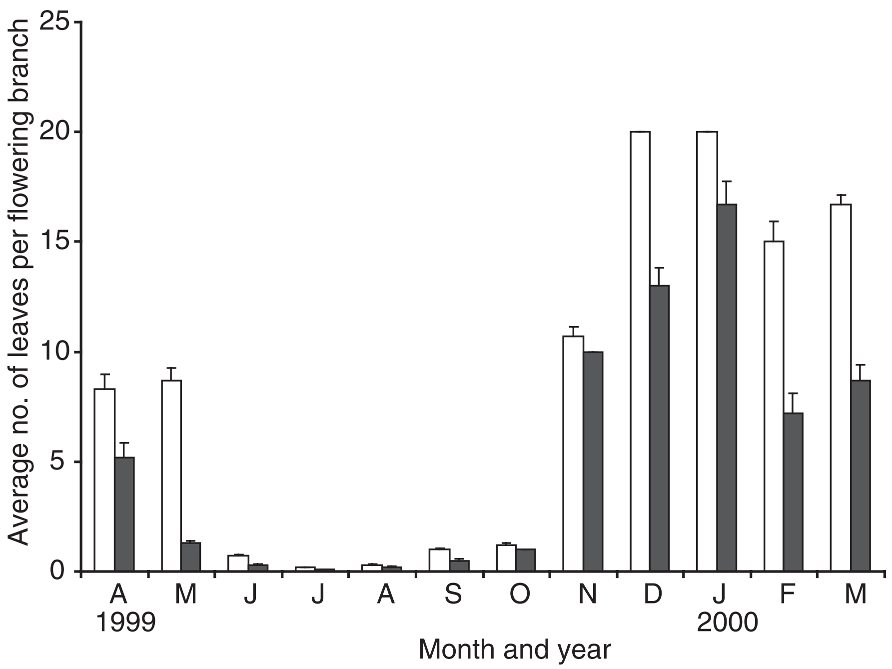

Figure 2. Monthly leaf density of bellyache bush in riparian (open columns) and sub-riparian (closed columns) zones at Southern Cross Creek. Bars indicate the s.e. of the mean.

Leaf density There was a significant interaction (P <0.01) between zones (riparian and sub-riparian) and time of year for leaf density (Figure 2). Plants in riparian zones generally had higher leaf densities than those in sub-riparian zones except during some months within the dry season (between June and November).

Irrespective of zones, plants went through periods of low, medium and high leaf density (Figure 2). A high leaf density phase commenced with new season leaf production in November and lasted until January, with the greatest number of leaves present averaging 17 (January) and 20 (January) per stem, for sub-riparian and riparian zones, respectively. Between the months of February and May leaf density ranged from 2–8 and from 9–16 for sub-riparian and riparian zones, respectively. A period of low leaf density occurred for five months during the dry season, with an average of just 1.0 ± 0.5 leaf per stem present.

Increased leaf density was associated with increased ambient temperatures, soil moisture content, and rainfall, and with decreased light density beneath the canopy of bellyache bush and decreased sugar concentration (Table 2).

Flowering incidence A significant (P <0.01) interaction occurred between zones and time of year on flowering incidence of bellyache bush (Figure 3). For example, flowering incidence was reduced in July and August in sub-riparian sites when compared with that of riparian sites (Figure 3) and rapidly climbed to 100% during September and October, while only 82% of plants in riparian zones were in flower.

Flowering in riparian zones occurred over a longer time span (11 months per year) than in sub-riparian zones (9 months per year) (Figure 3). Nevertheless, a similar pattern occurred between zones, with a four month period of low flowering incidence (May to August) followed by an eight month period where in excess of 80% of plants exhibited some degree of flowering (September to April). The absence of any flowers on tagged plants was reported once in riparian zones (May) and three times in sub-riparian zones (May, July, August).

Flowering incidence was significantly (P <0.05) correlated with other plant and environmental variables (Table 2). Increased flowering incidence was associated with increased capsule incidence, leaf density, ambient temperatures, soil moisture content, and rainfall, and with decreased light density beneath canopy of bellyache bush and decreased sugar concentration.

Capsule incidence As for flowering, significant (P <0.01) interactions occurred between zones and time of year for capsule incidence (Figure 4). In both zones, capsules were present for at least 10 months of the year and a period of low capsule incidence (capsules present on less than 40% of plants) lasted for four months (from June to September). For two of these months there was a complete absence of capsules in both riparian (July/August) and sub-riparian (August/September) zones.

An increase in flowering from September onwards resulted in a subsequent increase in the presence of capsules during October and proceeding months (Figure 4). On average, time to develop viable seeds was 29.6 ± 2.6 days after flowering depending on availability of pollinators, plant density, and climatic conditions (Faiz Bebawi unpublished data). By November all plants within riparian zones had capsules present on branches and this trend continued for the remainder of the experimental period (until March 2000). In contrast, sub-riparian infestations exhibited a lower incidence (83%) of capsules until February.

Table 2. Correlation coefficients between variables investigated in this study.

Variable	Flowers	Capsules	Leaves	Sugar
Capsules	0.470*			
Leaves	0.511*	0.608*		
Sugar	- 0.383*	- 0.585*	- 0.657*	
Ambient temperature	0.386*	0.408*	0.522*	- 0.458*
Soil temperature	- 0.060	- 0.083	- 0.118	0.020
Soil moisture	0.195*	0.313*	0.419*	- 0.385*
Light	- 0.424*	- 0.354*	- 0.459*	0.261*
Rainfall	0.533*	0.590*	0.668*	- 0.681*

* Significant at P <0.05.

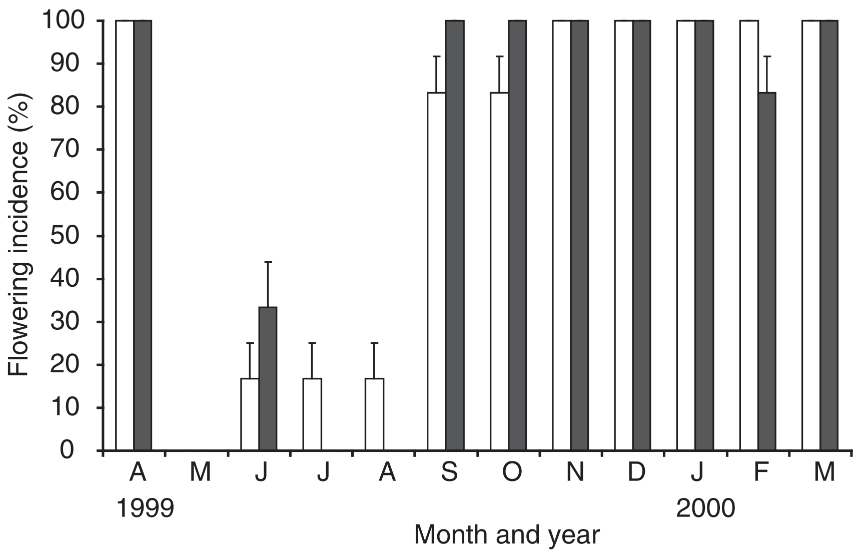

Figure 3. Monthly flowering incidence of bellyache bush in riparian (open columns) and sub-riparian (closed columns) zones at Southern Cross Creek. Bars indicate the s.e. of the mean.

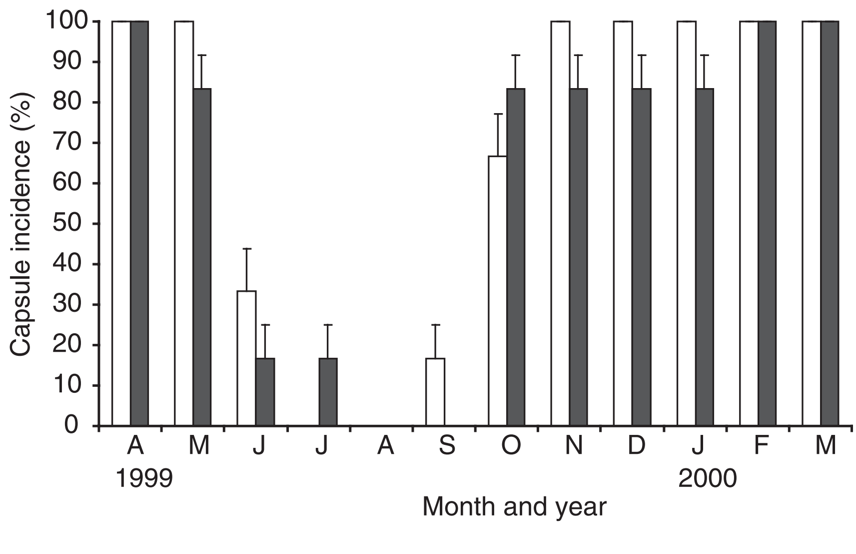

Figure 4. Monthly capsule incidence of bellyache bush in riparian (open columns) and sub-riparian (closed columns) zones at Southern Cross Creek. Bars indicate the s.e. of the mean.

Increased capsule incidence was associated with increased flowering incidence, leaf density, soil moisture content, rainfall, ambient temperatures, and with decreased sugar concentration and decreased light density beneath canopy of bellyache bush plants (Table 2).

Sugar concentration Time of year significantly (P <0.01) affected sugar concentration of bellyache bush (Figure 5), but there were no significant difference between zones (P >0.05).

A period of relatively low sugar concentration (14–17% sucrose) lasted for seven months of the year, from November to May (wet season). This was followed by a period of relatively high sugar concentration (19–23% sucrose), which lasted for five months, from June to October (dry season).

Increased sugar concentrations were associated with decreased flowering and capsule incidence, leaf density, soil moisture content, ambient temperatures and with rainfall (Table 2).

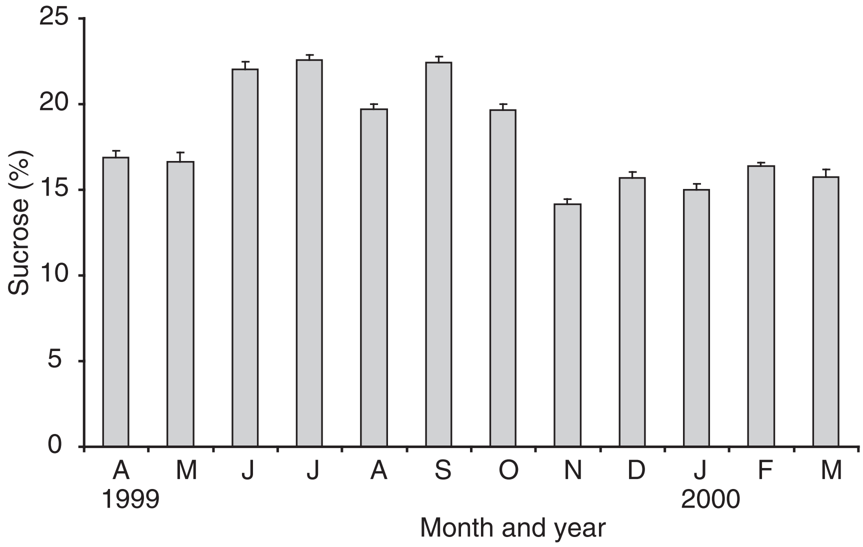

Figure 5. Monthly sugar concentration of bellyache bush at Southern Cross Creek. Bars indicate the s.e. of the mean.

Discussion

Bellyache bush, growing in northern Queensland, has a potential for prolonged flowering and capsule production, a deciduous leaf habit, and seasonal variation in stem sugar content.

During the 12 months of the study, bellyache bush produced capsules for 10 months of the year in both zones. Rainfall followed a similar seasonal pattern to the long-term mean, but was 43% higher, despite a below average season. Whether the pattern of flowering and capsule production would be similar in years where rainfall is average or below average cannot be predicted from the current study, but warrants further investigation. Information from some relatively dry environments suggests that it could possibly be shorter. For example, in the Kimberley region of Western Australia bellyache bush generally flowers and fruits for four months of the year from February to May (Wheeler 1992). Similarly, in India, flowering occurs for five months only from June to October with peak blooming occurring during July-August (Reddi and Reddi 1983).

While moisture availability appears to be a key driver of reproduction, the close correlations observed with other environmental parameters, particularly temperature, suggests that they may also influence its timing and duration. This theory is supported by personal observations of flushes in leaf, flower and pod production during September/October, following prolonged dry periods and prior to the commencement of the wet season. The collection of ecological and environmental information from a number of geographically dispersed locations over several years should enable the key environmental parameters to be distinguished. This approach is currently being used for the woody weed parkinsonia (*Parkinsonia aculeata* L.) and is providing insight into where this weed may spread into the future based on the environmental conditions favouring growth and reproduction (van Klinken personal communication).

The deciduous nature of bellyache bush resulted in distinctive periods where plants were either in full leaf or almost leafless with the transition between the two states being fairly rapid. This has important implications for foliar herbicide applications, since efficacy is dependant on good foliage cover. Vitelli *et al*. (1988) found that 95–100% mortality could be achieved in all months when bellyache bush plants were in full leaf. The strong inverse correlation observed between leaf density (phenological condition) and sugar concentration (physiological condition) may have survival significance for the plant.

Low sugar concentrations mark a stage of the plant's seasonal cycle when it is possibly most vulnerable to control methods. Other species, including some forest trees, shrubs and fruit trees have been found to exhibit similar behaviour (Stoeckler 1947, Wenger 1953). These findings support the results of a previous field study (Bebawi and Campbell 2002b) which showed that bellyache bush cut during the dry season between June and September had much higher survival than similar bushes cut during the wet season, between January and March. The recommendation from this study was that land managers should slash plants whilst these are actively growing. This contrasts directly with the standard recommendations for mechanical control of most woody weeds in northern Queensland, such as prickly acacia (*Acacia nilotica* L.) and mesquite (*Prosopis* spp.) (Vitelli 2000), which are to apply treatments during the dry period when soil moisture is low, and plants are consequently stressed and less capable of reshooting.

In conclusion, this study has identified several phenological features of bellyache bush such as seasonal changes in leaf density, flowering and seed production, and stem sugar concentration, that warrant consideration when determining the most appropriate control options to use and the time that they should be applied. Some potential research opportunities have also been identified, including determination of the key environmental parameters such as riparian zones influencing the growth and reproduction of this species.

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