Flowering and capsule production of bellyache bush (*Jatropha gossypiifolia* L.)

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Abstract
In this paper we conducted flower initiation and subsequent capsule production of the exotic weed bellyache bush (*Jatropha gossypiifolia* L.). A field trial observed times to first flowering and capsule production, and growth rate at three sites (cleared, rocky embankment and grazed pasture). A pot trial examined the effects of five plant density treatments (20, 40, 80, 160, and 320 plants m^{-2}) on flowering and capsule production of bellyache bush. After one and a half years, the proportion of tagged plants that had flowered and produced capsules in the cleared, rocky, and grazed pasture sites had a mean 95, 26, and 32% and 95, 15, and 25%, respectively. For those bellyache bush plants that reached reproductive maturity, time to first flowering had a mean 74.0 ± 0.9, 294.0 ± 48.2, and 454.0 ± 1.9 days in the cleared, rocky, and grazed pasture sites, respectively. In the density trial, the percentage of bellyache bush plants that flowered and produced capsules reduced exponentially with increased density. In contrast, increasing plant density caused exponential increases in times to first flowering and capsule production. At the lowest density (20 plants m^{-2}) of bellyache bush all plants produced capsules, with the time taken a mean 64.8 ± 7.7 days following germination. In contrast, no plants within the highest density (320 plants m^{-2}) had reached reproductive maturity after three and a half years. These results highlight the speed at which bellyache bush can flower and set seed, but also suggest that competition should be investigated further with regard to its potential role in slowing down the process.

Introduction
Bellyache bush (*Jatropha gossypiifolia* L.) is one of the most toxic and aggressive weeds in the dry tropics of north Queensland. Three seeds could kill a child and dense infestations interfere with pasture growth, obscure fence lines, impede mustering, harbour feral animals, poison livestock, destroy natural landscapes, affect recreational use of natural areas and displace native vegetation (Kingsbury 1964, Miller 1982, Miller and Pitt 1990, Parsons and Cuthbertson 2001, Bebawi and Campbell 2002a).

Lazarides and Hince (1993) indicated that bellyache bush has the potential to spread over 75% of the Australian continent including the Northern Territory, Queensland and Western Australia. Hence the risk of widespread invasion has to be seriously considered. Invasiveness is defined as the ability to establish, reproduce and disperse within an ecosystem to which a plant is not native. Species that are highly invasive often spread rapidly (Lonsdale 1993, Hobbs and Humphries 1995).

There are different views on whether certain ecological traits of organisms might confer high invasive potential. One of the ecological traits used in ranking species invasiveness is the length of the juvenile period (Rejmánek and Richardson 1996) or maturation rate of the plant (Timmins and Owen 2001).

The juvenile period is the time between the germination of the seed and the onset of flowering (Reichard 2001). Rejmánek and Richardson (1996) indicated that invasiveness of woody species in disturbed landscapes is associated with a short juvenile period (<10 years), which allows a population to establish more rapidly. Baker (1974) also theorized that the ideal weed would have rapid growth through the vegetative stage to reproduction.

Time to first reproduction was one of several criteria adopted in the national survey system to determine the national significance of weeds in Australia (Virtue *et al*. 2001). A 'don't know' answer to this question may have excluded some weeds from the top 20 list of 'Weeds of National Significance in Australia". Bellyache bush was one of those weeds that just missed out on being included (Virtue *et al*. 2001). If we had known the phenological data and the control program implemented two years ago, bellyache bush might have been more highly ranked and made it on to the list.

Ecological understanding of 'times to first flowering and seed production' is important not only in weed risk assessments but also in developing effective management strategies. With such knowledge, the timing and duration of control techniques may be more precisely planned. The present studies observed the effects of mechanical disturbance and plant density on the times to first flowering and capsule production, and growth rate of bellyache bush. These studies form one component of a larger investigation into the control and ecology of bellyache bush in north Queensland.

Materials and methods
Survey and site selection
Times to first flowering and capsule production, and growth rates of bellyache bush were studied during 2001–2003 at three sites in the vicinity of Charters Towers, north Queensland. Each site (about 1 ha in size) was cattle-grazed and highly infested with bellyache bush (10–20 thousand plants ha^{-1}). Bellyache bush infestations for management purposes were classified into three densities: light (up to 1000 plants ha^{-1}), medium (1001–10 000 plants ha^{-1}), and high (over 10 000 plants ha^{-1}) (J. Vitelli unpublished data).

The first site was located at 'Barkla Cattle Station', Southern Cross Creek (20°01'S, 146°01'E). This site had been mechanically disturbed during construction of a firebreak in September 2001, which required clearing all vegetation using the front blade of a tractor, and is hereafter referred to as 'Cleared site'.

The second site was located at 'Riverview Cattle Station' (19°53'S, 146°14'E) on the Burdekin River. It had been mechanically disturbed using an excavator that dug trenches several metres deep for laying telephone cable lines in 1988 (M. Penna personal communication). This process resulted in the creation of scattered rocky embankments (approx. 5–6 m above ground) that were sparsely vegetated with buffel grass (*Cenchrus ciliaris* L.). This site is referred to as 'rocky' site.

The third site was located at 'Larkspur Cattle Station' on the Lynd Highway (19°54'S, 146°13'E). This site was not mechanically disturbed, and is referred to as 'grazed pasture' site. It was a grazing paddock dominated by buffel grass, black speargrass (*Heteropogon contortus* (L.) P.Beauv. ex Roemer & Schultes.) and kerosene grass (*Aristida* spp.).

The maximum distance between the three sites was 5 km. The three sites were monitored daily (except for 17 and 18 November 2001 weekend days) for signs of bellyache bush seed germination, after the first incidence of rainfall that started on 11 November 2001, after a prolonged dry spell. Viable ant-discarded seeds of bellyache bush normally germinate within five to nine days after exposure to adequate soil moisture conditions (Bebawi and Campbell 2002b, Bebawi and Campbell 2004).

Fifty bellyache bush seedlings that germinated on 20 November 2001 were randomly selected at each site, tagged, and monitored weekly until March 2003. Seedlings of similar age, i.e. with only cotyledonary leaves, were selected to reduce variability between seedlings. First flowering of individual plants was confirmed when the spike bearing the apical inflorescence opened to show the first flower. Seed production was confirmed when flowers visibly produced a green capsule. Flowering in bellyache bush is protogynous, *i.e.* female flowers open first (Reddi and Reddi 1983).

Records of the amount of monthly rainfall received at the three sites between November 2001 and March 2003 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).

Pot trials

A single-factor experiment was replicated six times in a randomized block design to evaluate the effects of five plant density treatments (20, 40, 80, 160 and 320 plants m^{-2}) on times to first flowering and capsule production, and on percentages of plants that flowered and capsulated. Plants were established from seed on 14 January 2000.

Seeds dispersed by ants were selected for this study because they were highly germinable compared to intact seeds (Bebawi and Campbell 2002b). Seeds were sown 1 cm deep in plastic pots (24 cm diameter) filled with garden soil (supplied by a registered landscaping contractor). They were sown at double the required amount and thinned to the required density two weeks later. All pots were placed in the open air at a site located on the grounds of the Tropical Weeds Research Centre in Charters Towers (20°09'S, 146°26'E), and irrigated regularly to field capacity. This was achieved by adding water until it drained through the perforated base of the pot. Plants were monitored daily (until August 2003) for flowering and capsule production using the same classifications as those implemented for the field survey.

Data analysis

Plant height (from ground level to uppermost leaf) and basal stem diameter (stem diameter taken at ground level) were recorded for individual plants at the time of first flowering. At the end of the survey period, the percentage of plants that had flowered and capsulated was calculated. Average growth rate was also determined by dividing plant height (cm) by the number of days to first flowering. Regression analysis was used to relate time to first flowering, percentage flowering, capsule production, and percentage capsule producing plants to plant density. Data were arcsine transformed before means were calculated.

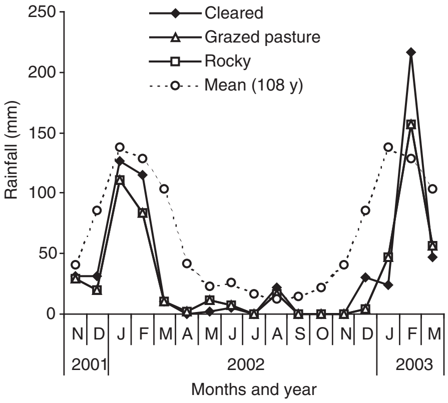

Figure 1. Monthly rainfall at the cleared, rocky embankment and grazed pasture sites and 100 years mean rainfall at Charters Towers.

Results

Survey – rainfall conditions

Rainfall received during the survey period was 43, 52 and 52% less than the long-term mean at the cleared, rocky, and grazed pasture sites, respectively (Figure 1). All sites experienced very dry conditions during the first two months following germination (November/December 2001). The proceeding wet season resulted in slightly below mean rainfall at all sites. This was followed by very dry autumn, winter and spring periods. During this time the cleared, rocky and grazed pasture areas received 82, 87 and 87% less than the long-term mean, respectively. Similarly, the 2002/2003 wet season produced below mean rainfall conditions throughout the region, except for the month of February, which received above mean rainfall.

Survey – time to first flowering and capsule production

After one and a half years (over two wet seasons), the proportion of initial tagged plants that had flowered and produced capsules in the cleared, rocky, and grazed pasture sites had a mean 95, 26, and 32% and 95, 15, and 25%, respectively (Figure 2). Five percent of plants that failed to reach reproductive maturity within the cleared site, died within the survey period. In contrast, mortality of plants within the rocky and grazed pasture sites had a mean 70 and 48%, respectively.

For those bellyache bush plants that reached reproductive maturity, time to first flowering had a mean 74.0 ± 0.9 days, 294.0 ± 48.2 days, and 454.0 ± 1.9 days in the cleared, rocky, and grazed pasture sites, respectively (Figure 3).

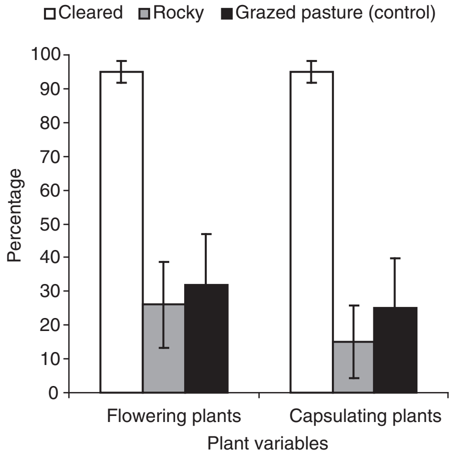

Figure 2. The percentage of bellyache bush plants that flowered and produced capsules when growing within the cleared, rocky embankment and grazed pasture sites. Vertical bars indicate the SE of the mean.

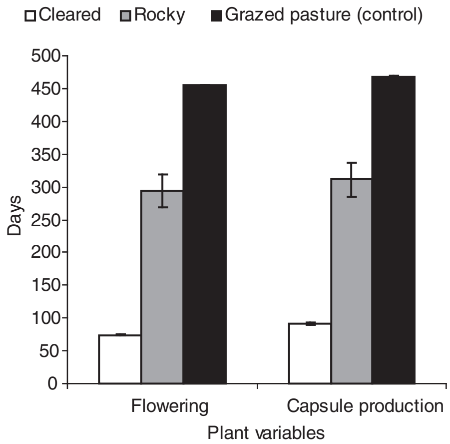

Figure 3. Average time to first flowering and capsule production for bellyache bush plants that reached reproductive maturity during the study period. Vertical bars indicate the SE of the mean.

At the time of flowering plants were similar in size, having a mean height of 47.0 ± 0.9 cm and a basal stem diameter of 1.4 ± 0.1 cm. The rate at which they grew to reach reproductive maturity was the distinguishing factor, with plants having a mean 0.61, 0.32 and 0.1 cm in height per day in the cleared, rocky, and grazed pasture sites, respectively.

The first capsules were produced 18, 17 and 14 days after commencement of flowering in the cleared, rocky, and grazed pasture sites, respectively (Figure 3). The least

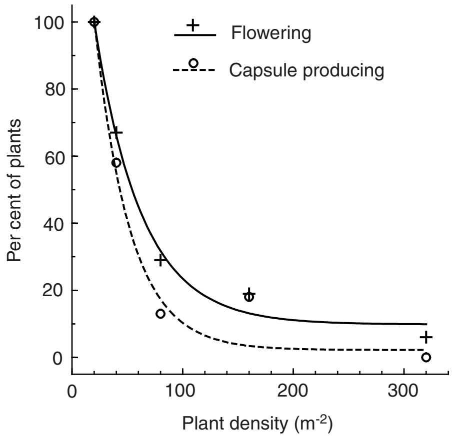

Figure 4. Density effects on percent flowering [% of plants flowering = 9.8 + 144.7 (0.9767^{Density}) (R^2 = 98%)] and capsule production [% of plants producing capsules = 2.2 + 184.6 (0.9692^{Density}) (R^2 = 98%)] of bellyache bush in the pot experiment.

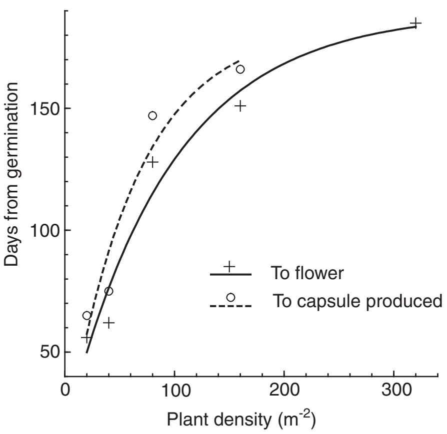

Figure 5. Density effects on time to first flowering [Days to flower = 189.5 – 172.1 (0.9896^{Density}) (R^2 = 93%)] and capsule production [Days to capsule = 184.1 – 172.7 (0.9846^{Density}) (R^2 = 81%)] of bellyache bush plants in the pot experiment.

time taken for an individual tagged plant to reach reproductive maturity occurred within the cleared site, with flowering commencing at day 53 and first capsules produced 27 days later.

Pot trial – flowering at different plant densities

Density treatments significantly (P <0.05) affected percentage of flowering plants (Figure 4) and time to first flowering (Figure 5). Increasing plant density caused exponential reduction in percentage of bellyache bush that flowered. In contrast, times to first flowering increased exponentially with increased density.

At the lowest density of bellyache bush all plants reached the flowering stage, with the time taken a mean 55.5 ± 6.4 days following germination. In contrast, only 6.3% of plants within the highest density had reached flowering after three and a half years.

Pot trials – capsule production at different plant densities

Plant density significantly (P <0.01) affected the percentage of capsule producing plants (Figure 4) and the time to first capsule production (Figure 5) in a similar manner to that recorded for flowering.

The highest percentage of capsule producing plants (100%) occurred at the lowest density of 20 plants m^{-2}, with the time taken for these plants to produce capsules averaging 64.8 ± 7.7 days. In contrast, no plants within the highest density treatment (320 plants m^{-2}) had produced capsules after three and a half years.

Discussion

This study has highlighted the potential of bellyache bush to reach reproductive maturity within a short time frame. Some young plants growing in areas that had been cleared were able to flower within 53 days of germination and produce capsules after 80 days. Whether bellyache bush could become reproductive even earlier under more favourable conditions such as above average wet years is plausible, given that below mean rainfall conditions were experienced for much of the field study period, including the critical first two months. However, in the pot trial where plants received unlimited moisture, the least time recorded for any individual plant to reach flowering and capsule production was fairly similar to the field study, having a mean 55 and 65 days, respectively. 'Time to first flowering' of physic nut (*Jatropha curcas* L.), a sister species of bellyache bush, has been estimated at two years (Parsons and Cuthbertson 2001). The ability of bellyache bush to reach reproductive maturity quickly may assist its colonization of new areas and/or increase the likelihood that seed banks will be replenished at sites where control activities have been initiated.

The major implications from these findings for management are that those responsible for undertaking control programs may need to survey treated sites around every two months in order to minimize the opportunity for new plants to set seed and replenish the seed bank. The results also suggest that this duration could possibly be extended in areas where bellyache bush is subjected to competition.

In the field trial bellyache bush growing within pasture tended to take longer to reach reproductive maturity. While this is most probably associated with direct competition from the grasses present, the layout of the field survey did not allow statistical comparisons between sites and some of the differences could also have possibly been associated with slight variations in rainfall. Nevertheless, in the density trial, intraspecific competition was pronounced, with plants taking much longer to grow as the density of bellyache bush increased.

A competition experiment that directly compares bellyache bush growth under various levels of grass competition is warranted. This would clarify whether bellyache bush is a competitive species or an opportunist that takes advantage of situations where competition is reduced either through anthropogenic or natural processes.

If bellyache bush is susceptible to competition, control practices that kill bellyache bush but not the pasture, such as selective spraying, will be most advantageous for achievement of long-term control. Preliminary findings from a study being undertaken to identify integrated control strategies has found that selective foliar herbicides such as metsulfuron (Brushoff®) are capable of causing high mortality of bellyache bush, whilst allowing pasture grass to grow uninhibited and compete with surviving plants and new seedlings for resources. In contrast, the use of broad scale clearing techniques such as bulldozing directly affects all plants, including the pasture species present. If this occurs, re-establishment of a ground cover should be a priority through either replanting or spelling from grazing for a period of time.

The length of time for which revisitation of treated sites would need to be undertaken depends largely on the longevity of the seed bank, which has not been clarified to date. A field trial is currently in progress, with preliminary results suggesting that viable seeds may be present for at least three years under average rainfall conditions and possibly for much longer during dry periods.

It can be concluded that the rapid rate at which bellyache bush can reach reproductive maturity and the potential long-lived nature of the seed bank makes the task of eradicating bellyache bush from an area a difficult proposition. As such, land managers will need to undertake a thorough planning process to ensure they have the necessary resources to implement follow up activities at the intervals required and for the necessary duration. This process will help determine how much of the infestation to treat at any one time. A containment strategy should then be put in place for the rest of the infestation until it can also be actively controlled.

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