Cottonbush invasion in Western Australia: ecology and social perspectives

Mariana Campos[1], Kathryn L. Batchelor[1], Karen L. Bell[1,3], Michael Davy[1] Mike Christensen[3], Raphael K. Didham[1,3], and Bruce L. Webber[1,3]
[1] CSIRO Health & Biosecurity, 147 Underwood Ave, Floreat, WA 6014, Australia
[2] South West Catchments Council, PO Box 5066, Bunbury, WA 6230, Australia
[3] School of Biological Sciences, UWA, 35 Stirling Highway, Crawley, WA 6009, Australia
(Email: mariana.campos@csiro.au)

Summary *Gomphocarpus fruticosus* (L.) W.T.Aiton (narrowleaf cottonbush, hereafter referred to as cottonbush) is a weed of concern in Western Australia (WA) threatening agricultural and natural ecosystems. It is a declared weed (C3 Management) in the state, widespread and established, for which eradication is unfeasible. Management currently attempts to reduce abundance or range and sometimes contain spread. However, the extent of the threat and most appropriate control solution(s) remain largely unknown, and there are strongly contrasting views on optimal management. Here we address priority knowledge gaps on biology and ecology of cottonbush invasions in WA and clarify social perspectives on the weed through citizen scientist elicitation and stakeholder survey.

Natural enemies were documented via 13 field surveys across five sites. Two new natural enemies were observed in WA: *Arocatus rusticus* (Stål, 1866), a seed-eating Lygaeidae, and a phytoplasma causing phyllody. Estimated population seed production came to ~1.7 million filled seeds.ha-1.year-1, of which 1.36 million are viable and not dormant. Seeds readily germinate in optimal conditions 1-30 days after forming, indicating no after-ripening period. The stakeholder survey assessing cottonbush impacts with 101 respondents indicated that perceived environmental and economic impacts are not of significant concern. The issue of poorly managed neighbouring properties (private and government) was repeatedly raised.

The outcomes of cottonbush management in WA are ineffective at present and we expect that threats from this weed could worsen. We recommend further work to reassess the risk profile of cottonbush at regular intervals and prioritise improvements in the efficiency, effectiveness, and equitability of management programs.

Keywords narrowleaf cottonbush, weed, social science, *Gomphocarpus fruticosus,* impact.

INTRODUCTION

Gomphocarpus fruticosus (L.) W.T.Aiton (narrowleaf cottonbush, hereafter referred to as cottonbush) is an upright perennial plant native to southern and eastern Africa and the Arabian Peninsula with a slender shrubby habit that grows to 2 m, opposite leaves that are narrow or elongated (4-12.5 cm long and 5-15 mm wide), and white or cream-coloured flowers in clusters of 3-10 (ALA, 2021). The primary dispersal mechanism is wind. When released from 2 m high, more than 75% of seeds are dispersed within 10 m from the source, but 6% of seeds are carried beyond 40 m, reaching 100 m (DPIRD, unpublished data). Seeds usually germinate in spring or autumn, but can germinate any time in warm, moist conditions (Lloyd and Rayner, 2012).

In its natural range, it is frequently described as a plant of disturbed areas (Goyder and Nicholas, 2001). Within *Gomphocarpus fruticosus* sensu lato there are five recognised subspecies (Goyder and Nicholas, 2001). Cottonbush is known to hybridise with the closely related *G. physocarpus* E.Mey. (Hussey *et al*., 2007) which is also present in Australia, and hybrid seedlings had viable seeds (Ward *et al*., 2012).

Cottonbush is present in all Australian states and territories, except the Northern Territory (ALA, 2021). Cottonbush has been categorised as a threatening invasive species; and recorded as a weed of the natural environment, agriculture, and an escapee from cultivation (Randall, 2007).

The first records of *G. fruticosus* in Australia date to the late 19th century, with specimens from South Australia, New South Wales and Victoria. It was first declared a noxious weed in WA in 1923, and targeted for control in the Shire of Dardanup by the Agriculture Protection Board from 1966. Its current distribution in WA is from Yanchep to Esperance, mostly from Perth to Busselton (ALA, 2021).

A detailed map of occurrences between 2000 and 2014 showed cottonbush infested an estimated 5,000 hectares or more in WA (Reeves and Dodd, 2014).

Eight natural pests and pathogens of cottonbush have been documented worldwide from the non-native range, two documented in WA: the non-native wanderer butterfly *Danaus plexippus* (Linnaeus, 1758), native to North America, whose larvae feed on cottonbush foliage (Lloyd and Rayner, 2012) and the native lesser wanderer *D. petilia* (Stoll, 1790), which visit the flowers.

Through this work we aimed to widen the ecological understanding on cottonbush and explore social perspectives on it to help inform management.

MATERIALS AND METHODS

Demography, phenology, natural enemies Six sites were selected to assess population density and phenology, and a total of 13 visits were made: Lake Cooloongup (-32.31, 115.78), 13/10/20; Preston Beach (-32.88, 115.66), 07/12/20; Serpentine National Park (-32.36, 116.02), 13/01/21; Wungong (-32.13, 116.06), 03/03, 03/06, 22/07/21; Yalgorup (-32.79, 115.65), 28/05, 21/07, 13/09/21; Glen Mervyn (-33.56, 116.07), 08/12/20, 29/04, 22/07, 13/09/21.

In each site visit, three transects (2 m x 50 m) were established to count number of seedlings, juvenile and mature plants. Ten random adult plants were selected to estimate number of flowers (categories: <100, 100-1,000, >1,000) and fruits (categories: <50, 50-100, 100-200 and >200). Counts of filled and unfilled seeds per fruit were taken (30 fruits from Serpentine, 30 from Wungong).

Natural enemies were recorded at each site (except Lake Cooloongup) and identified by the authors or forwarded to DPIRD for specialist identification.

Soil cores and germination Ten soil cores (10 cm diameter, 10 cm depth) were randomly collected beneath each of three cottonbush infestations (Glen Mervyn, Serpentine and Preston Beach) in December 2020 and January 2021. Samples were air dried then wet sieved (1 mm mesh, tap water), and cottonbush seeds separated from debris, visually sorted into intact/damaged via forceps pressure test and counted.

Intact seeds were surface-sterilised (10-minute immersion in 70% ethanol, then 20-minute in 20% bleach), then plated on sterile 90 mm Petri dishes with filter paper soaked with 0.1% Plant Preservation Mixture (Plant Cell Technology®) and placed in an incubator at 30°C, 14D:10N light cycle.

Germination was scored daily for 30 days, seeds considered germinated when the radicle protruded 2 mm from the seed coat. On day 31, ungerminated seeds were dissected to determine if alive or dead by visual inspection of the embryo and endosperm.

Data analyses were undertaken with R software v4.1.0 (R Core Team, 2021); counts of number of seeds per soil core were analysed with a Poisson generalised linear model (GLM), and proportion of seed germination analysed with a binomial GLM.

Perceived impacts An online survey (human ethics approval CSIRO 003/21) including questions on the land being managed, impact of cottonbush and other weeds assessed perceived impacts of cottonbush.

The survey link was circulated through South West Catchments Council (SWCC) newsletters, Facebook and Twitter, and promoted through NRM workshops held by collaborators. To reach a wider audience, the survey was also run by SWCC over the phone in an abbreviated format, targeting farmers in their database. The survey ran from 5 October to 14 December 2021. The data were analysed quantitatively when applicable, or for trends and significant responses. Because all questions were optional, sample sizes varied for each question.

RESULTS

Demography, phenology, natural enemies All six cottonbush populations studied were of mixed ages, with seedlings, juvenile, mature (i.e., reproductive adults), and dead plants. This indicates that these stands had been present for multiple years or that recruitment was staggered across multiple time points. When all transects were combined, a total of 2 825 plants were counted in 1.3 hectare; a mean of 2 173 plants per hectare, of which 522 were dead, and 858 were reproductive adults.

No individuals in flower were observed during field visits conducted from April to October, whereas most plants were in flower in December and January, and a single outlier plant at Wungong bore flowers in March. Of 135 plants measured, 27 were flowering: four estimated to have more than 1 000 flowers; ten to have 100-1 000 flowers; and 13 to have fewer than 100 flowers each. Fruits were observed in every field trip, with 50-100% of plants bearing fruits depending on month of visit. Of 135 plants, 71 were fruiting: 51 (40.8%) estimated to have fewer than 50 fruits; 11 (8.8%) to have 50-100 fruits; seven (5.6%) to have 100-200 fruits; and two (1.6%) to have more than 200 fruits. Seed counts showed an average of 55 filled seeds per fruit at Wungong, and 107 at Serpentine.

The natural enemies *Danaus plexippus, D. petilia,* and *Aphis nerii (*Boyer de Fonscolombe, 1841) were observed at four, one and three out of the five sites studied. Two new natural enemies of cottonbush for WA were recorded: *Arocatus rusticus* (Stål, 1866) (four sites) and a phytoplasma causing phyllody (two sites). All were qualitatively observed to cause negative impacts on plant above-ground biomass, but these were not quantified in our study.

Soil cores and germination Sites varied significantly in number of seeds per soil core: from an average total seed of 1.1 (Preston Beach, a site that gets inundated periodically) to 9.3 (Glen Mervyn) to 28.7 (Serpentine) per core per site, equating 140 to 3 654 seeds.m^{-2}. The average proportion of intact seeds was low (28.4%) and did not vary significantly between sites.

Germination of seeds collected from fresh, nearly erupting fruit from Serpentine was over 54.8% in two weeks, with an additional 27% considered viable under dissection (total viability of 81%).

Germination of intact seeds from soil cores was 33.9% on average, and the proportion of intact seeds germinating within 30 days did not vary significantly between sites. An additional 4% of non-germinated intact seeds were considered viable upon dissection.

Perceived impacts We received 57 responses to the online survey and 44 responses from the abbreviated phone survey. Respondents represented 34 Local Government Areas, with a predominance of land holders or managers in 'commercial agriculture' (58 of 105) followed by 'lifestyle property' (30 of 105).

When asked if cottonbush had ever occurred on their land, to the best of their knowledge, 30 respondents answered yes, currently present; 27 said present in the past, and 35 said it was never present. Within the group with cottonbush currently or previously present, the most common control methods were 'hand-pulling only' (35%) and 'combination of herbicide and hand-pulling' (30%). Respondents who answered that cottonbush had never occurred on their property were disproportionately those in large commercial agricultural lands (21 of 35 have >1,000 ha of cropping and livestock).

Estimates of yearly cost and time to control cottonbush ranged from zero to AUD$3,000 per property (average $435; n=37). The estimated number of days controlling cottonbush ranged from zero to 52 days per year. Both cost and time estimates showed no direct relationship with size of property.

Perceived economic impact answers (n=44) were grouped in themes: toxicity was mentioned 12 times, restricted land access and reduced productivity were mentioned 9 times. Eight people believed that cottonbush has little or no economic impact on them. As for perceived environmental impacts, 27 people mentioned negative environmental impacts, 11 respondents believed this species is of little or no ecological concern. The two impacts most commonly mentioned were competition with native flora (7 times) and changes in habitat (4). Finally, the survey asked participants to describe social impacts, where issues of people disagreeing on the need for control (4), lack of awareness (2) or that people don't care (1) were mentioned (n=66).

The answers and comments had a dominant trend of mentions that cottonbush comes from adjacent properties, be that their neighbours (31 mentions), government lands (10), Department of Biodiversity, Conservation and Attractions (DBCA) managed land (4) or Forest Products Commission lands (3).

Cottonbush was ranked as the most impactful weed on the environment by four respondents and was mentioned another 11 times in the second to fifth most impactful categories (n=58). In relation to economic impacts, 8 respondents ranked it as the top weed, and 11 respondents placed it between second and fifth place (n=75). On both fronts, the weed named most impactful overall across the study area was blackberry (*Rubus anglocandicans* A.Newton).

DISCUSSION

Our study found cottonbush densities an order of magnitude lower than a Botswana study, where it is native but opportunistic on disturbed sites reaching 23 333 plants.hectare^{-1} (Teketay *et al*., 2021).

The phenology observed for the six sites and times of year visited was in accordance with existing knowledge for WA, although the flowering period range in our study was more restricted than that previously described (Florabase 2021), likely because our study was limited to a time span of one year. Although our study used estimate categories rather than counts, flowers per plant aligned with the 437 mean flowers per plant in the native range (Teketay *et al*. 2021). Teketay at al. (2021) recorded a range of 0-75 (mean 29) fruits per plant in their study, indicating some plants in WA were producing comparatively large amounts of fruits. Seed production at Wungong was half of that previously described, but seed production at Serpentine was close to mean reference values of ovules per ovary (107.5, Wyatt *et al*., 2000) and seeds per fruit at two sites in Botswana (93 and 105, Teketay *et al*. 2021).

Using our average of reproductive plants and the fruiting body outputs from our results, we can extrapolate that in one hectare at least 20 988 fruits are produced. With an average of 81 filled seeds per fruit, we conservatively estimate ~1.7 million cottonbush seeds produced per hectare per year in a mixed stand. This estimate is far lower than those recorded in a 'weedy' block in the native range of the species, where ~62.3 million seeds per hectare were estimated (Teketay *et al*. 2021); largely due to the higher density of plants recorded in that study.

Our soil results indicate there is significant predation and other damage to the seeds over time, and that because of this a minority of seeds in the soil are viable. When considering soil cores, we were unable to find out the history of the Preston Beach infestation and whether the site has been chemically treated in the past, so the results for that site should be interpreted with caution.

We extrapolated that the number of viable seeds in the soil under a cottonbush infestation was zero (Preston Beach); 891 200 (Glen Mervyn); or 3 819 700 (Serpentine National Park) per hectare. To understand propagule pressure, the seed bank values should be added to the fresh output of seeds, of which approximately 81% were found to be viable in our results, resulting in an added ~1.36 million viable seeds per hectare per year). It will be important to understand seed viability change over time to more comprehensively assess seed bank risk. This work is already underway, with around 50% decline observed in the first 12 months of burial (unpublished data). Our germination trials used the optimum treatment (30ºC with no water stress), based on our controlled germination trials on 36 temperature-water potential treatments (unpublished data).

On the social aspects of cottonbush management in WA, we hypothesise that fewer records of cottonbush on large agricultural properties arises from a combination of their relatively lower rainfall and regular weed control. The current control methods available are considered effective for moderately sized infestations (Reeves and Dodd 2014, Petersen 2014). Cost and time to control cottonbush were not proportionate to land size, as these are likely related to infestation size rather than property size. We did not elicit cost of surveillance or monitoring (related to property size) nor account for synergies controlling multiple weeds.

The insight gained from the social survey was in broad agreement with qualitative observations made during our field work and jointly indicate that the environmental and economic impacts from cottonbush are not of the highest order relative to other weeds in the region.

There was agreement between respondents on social impacts, where frustrations were recurrently expressed when adjacent privately- or government-managed properties have no control and act as a reservoir of seeds. We infer that cottonbush lends itself to such social conflicts because it is a large and easily identifiable shrub; it is a prolific producer of seeds; and the wind-dispersed pappi can be seen from afar (whether or not the pappus is carrying a seed or has already detached), which may generate a level of helplessness and discord. Coordinated control of poorly or unmanaged lands appears to be essential to resolve the social issues.

The recommendations arising from our research were to: (1) consider further studies to monitor species distribution with structured annual surveys of presence/density, absence, and control efforts to inform whether the species range is expanding and how active management is influencing distribution; (2) quantify impacts of the natural enemies already present in WA; and (3) investigate approaches and investment to improve the coordination and effectiveness of control.

ACKNOWLEDGMENTS

We thank DPIRD and CSIRO for funding this research. Simon Merewether, Paul Tholen, Davin Gibellini, Jonelle Cleland, Teele Hooper-Worrell, Kate Duzevich, Shania Willison, and Wolfgang Lewandrowski are thanked for contributions to the project. John Scott, John Moore and Michael Robertson for reviews of the manuscript.

REFERENCES

ALA (2021). Atlas of Living Australia. Weeds Australia Profiles: *Gomphocarpus fruticosus* (L.)W.T.Aiton. https://profiles.ala.org.au/opus/weeds-australia/profile/Gomphocarpus%20fruticosus. (accessed 9 November 2021).

Florabase (2021). *Gomphocarpus fruticosus* (L.) W.T.Aiton. (The Western Australian Herbarium) https://florabase.dpaw.wa.gov.au/browse/profile/6587 (accessed 9 November 2021).

Goyder DJ and Nicholas A (2001). A revision of *Gomphocarpus* R. Br. (Apocynaceae: Asclepiadeae). Kew Bulletin 56(4):769-836.

Hussey BM, Keighery GJ, Dodd J, Lloyd SG, Cousens RD (2007). Western weeds. A guide to the weeds of Western Australia, Second Edition (The Weeds Society of Western Australia, Victoria Park).

Lloyd S and Rayner B (2012). Narrow-leaf cotton bush and its control. Farm Note 498 (Department of Agriculture and Food, Western Australia).

Petersen E (2014). Industry economic performance impact assessment on narrow leaf cotton bush (*Gomphocarpus fruticosus*). Community consultation report. Prepared for Department of Agriculture and Food, Western Australia by Advanced Choice Economics Pty Ltd.

R Core Team (2021). R: A language and environment for statistical computing. https://www.R-project.org/ (R Foundation for Statistical Computing, Vienna, Austria).

Randall RP (2007). The introduced flora of Australia and its weed status. CRC for Australian Weed Management (Department of Agriculture and Food, Western Australia).

Reeves A and Dodd J (2014). Situation statement: cotton bush in Western Australia (Department of Agriculture and Food, Western Australia).

Teketay D, Mafote T, Puodipe KK, Mompati PB, Nkoborwane N, Mathowa T, Mojeremane W (2021). Reproductive traits that foster the invasion of four alien plant species in Botswana. Chapter 2 in Invasive Alien Species: Observations and Issues from Around the World, Volume 1: Issues and Invasions in Africa, First Edition, eds T. Pullaiah and Michael R. Ielmini (John Wiley & Sons Ltd).

Ward M, Johnson SD, Zalucki MP (2012). Modes of reproduction in three invasive milkweeds are consistent with Baker's Rule. Biological Invasions 14(6):1237-50.