Progress towards eradication of bitou bush, *Chrysanthemoides monilifera* subsp. *rotundata* in Western Australia

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Summary Bitou bush (*Chrysanthemoides monilifera* (L.) Norlindh subsp. *rotundata* (DC.) T.Norl.) was first detected in Western Australia in 2012 at Kwinana, an industrial area south of Perth. Since 2012 we have undertaken annual surveys of the population, including mature plants, seedlings and the seed bank, as part of assessing the potential for bitou bush to spread or be eradicated. With the collaboration of landholders, plants found each year were eliminated by weeding, herbicide or excavation with earth moving equipment; leading to a marked decline in plant numbers. Very few mature plants are now found on annual surveys and most new discoveries are of plants of up to one year old and seedlings. The seed bank is also declining, but a residue of viable seeds is still present four years after the removal of adult plants. Any new plant discoveries have been within the delimited area of infestation, as defined by the original surveys made in 2012–2013. However the ongoing inaccessibility of some adjoining areas with dense vegetation prevent the achievement of absolute population delimitation. We discuss the plant characteristics that influence the potential for eradication, and the future prospects for management in Western Australia of this weed of national significance.

Keywords *Chrysanthemoides monilifera* subspecies *rotundata*, delimitation, eradication, invasion ecology, seed bank, WoNS, Western Australia.

INTRODUCTION

In 2012 bitou bush (*Chrysanthemoides monilifera* (L.) Norlindh subsp. *rotundata* (DC.) T.Norl. (Asteraceae)) was discovered in the Kwinana region, an industrial and port area south of Perth, Western Australia (Scott and Batchelor 2014). Bitou bush is a Weed of National Significance and a major threat to coastal dune ecosystems (Weiss *et al.* 2008). This subspecies is listed under state legislation in the C1 control category, which includes organisms that are prohibited and should be excluded from part or all of WA. We have been measuring the plant population since its discovery. The aim of this paper is to describe the progress we have made towards assessing the feasibility to eradicate bitou bush from the only known infestation in Western Australia, at Kwinana.

MATERIALS AND METHODS

Survey methods The majority of the area surveyed was prohibited public access and was either a classified mine site, construction site, petroleum refinery or secure maritime access zone. Time was needed to negotiate access and to complete the specific site inductions and orientation. Some sites required us to have drug and alcohol screen tests, a driving test, and the wearing of fire retardant suits with meters for detecting hydrogen sulphide. At least 20 hours per person has been spent in specific site inductions since 2012. Further details of the survey methods are given in Scott and Batchelor (2014). By 2016 over 500 person hours have been spent between three people actively undertaking visual surveillance ground surveys searching the Kwinana estate for plants.

RESULTS AND DISCUSSION

Annual survey for plants Since 2012, we found 651 plants and 1078 seedlings at Kwinana. All but 5 plants were within 500 m of a dilapidated jetty; a possible entry point for the plant invasion.

The majority of plants were removed between October and December 2012 (Table 1). Most were small, <1 m in diameter, but over 130 plants were large (implying capable of reproduction), averaging 3.5 m in diameter with the largest over 11 m in diameter. The number of new plants found in subsequent years has decreased considerably (Figure 1), and by 2016 we found mostly small plants and seedlings (Table 1, Figure 1). Some large plants were found every year, confounding the authors as to how they were missed previously (Figure 1).

After 2012, the annual survey took place between March and May. Bitou bush at Kwinana has its main flowering period at this time and the green leaves and

stem, and flowers if present, contrasted well against the dead grass. Plants were often found under trees or fence lines. This is not surprising given that birds would eat the ripe fruits and disperse the seed to suitable perches near the plant of origin. Seed germination occurred throughout the months that soil was moist (usually June to November).

Remote sensing There are frequent aerial photography surveys of the Kwinana area, and available online on a bimonthly basis for Nearmap (http://www.nearmap.com.au/) or on an annual basis by Landgate (https://www.landgate.wa.gov.au/). The photos viewed online are sufficiently detailed to identify bitou plants over 1 m in diameter, particularly if the plant was isolated from other vegetation. However, it was not possible to separate bitou bush from the form and colour of the invasive tree *Schinus terebinthifolius* Raddi (Anacardiaceae**)** (Brazilian pepper) in these images. Brazilian pepper is abundant in the Kwinana area, and caused many false positives during the search for bitou bush.

The fleshy fruits of bitou bush means that birds and mammals are major means of dispersal (Gosper 2004, Meek 1998). This also results in many of the new plants being found under established vegetation (e.g. tobacco bush, Eucalypts) or other perches (fence lines, buildings, light posts). This distribution pattern where bitou is located under other vegetation makes detection difficult by remote means.

Table 1. Number of individuals and average diameter of plant canopy, excluding seedlings at Kwinana.

Year	Number of plants measured	Diameter (cm) (average ± SE)
2012	487	101.1 ± 7.4
2013	26	62.2 ± 14.9
2014	40	27.9 ± 4.8
2015	56	42.2 ± 6.4
2016	42	26.4 ± 5.2

Controlling plants Initially we thought that most seedlings would succumb over summer. However, rainfall events over summer, and perhaps the coastal environment, meant sufficient moisture was available for some seedling survival. There appeared to be multiple germination events following rain which resulted in early seedlings being sufficiently large to survive summer.

Plants up to ~3 m wide were readily hand weeded ensuring the entire stem and upper roots were removed. Plants are shallow rooted, which facilitates their removal by hand. No regeneration was observed from roots remaining in the soil after the aboveground and small section of below ground stem had been removed.

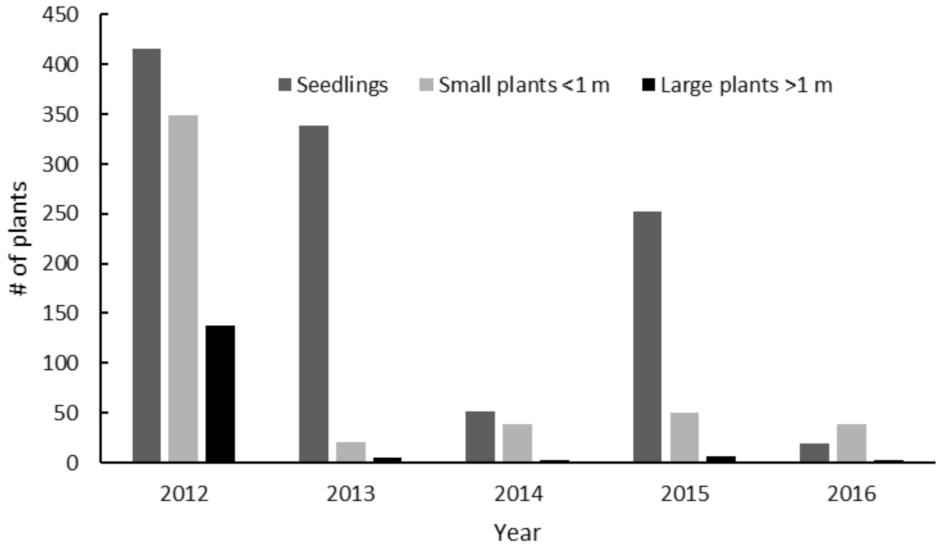

Figure 1. Progress towards eradication of *Chysanthemoides monilifera* subsp. *rotundata* at Kwinana, Western Australia. Plants at different stages (seedling, small (<1.0 m canopy diameter), large (>1.0 m canopy diameter) found since the start of surveys (October 2012).

We did however find one or two examples each year of plants that had regrown from the stem broken off at ground level in the previous year.

Larger plants required considerable physical strength to remove and in some instances needed earth moving machinery. Herbicide (this was organized by the landholder) was also used to kill large plants. However, hand removal was the quickest option, particularly where plants were growing next to buildings or other infrastructure or over potential buried services.

Large plants in areas with shifting sand (such as sand dunes near the beach) can be partially covered by sand such that the main stem is underground. Side branches in this situation will develop roots and become independent of the original plant, a process called 'layering'. Our experience was that it was difficult to find and extract all the layered stems, especially if the plant was large and in situations of considerable sand movement.

Mechanical plant removal was sometimes counterproductive. Land owners helped with digging machinery of a range of sizes from bobcats to large front end loaders. The main issue was the risk of burying pieces of stem from which future plants could arise. Revisiting the area at yearly intervals for up to three years enabled us to find and remove any surviving layered stems.

We left the stems on the soil surface next to where they grew. Dead plants were still visible four years after removal which helped in the relocation of sites with high potential for seedlings.

Herbicide spraying was very effective, and the contractor used was skilful to recognize bitou bush from the very similar bush *Scaevola crassifolia* Labill. (Goodeniaceae). Bitou bush has yellow daisy-like flowers and the growth apex and small new leaves covered with white fur (called an indumentum), whereas *S. crassifolia* has blue, zygomorphic flowers (petals on one side) and no indumentum. When neither is flowering, they look remarkably similar.

The complex land use and infrastructure at Kwinana meant that some plants were growing in locations too dangerous to access. This included access points for conveyor belts, steep-sided storm water drainage points and similar confined spaces. Binoculars at these locations were useful to determine if a plant was bitou or *S. crassifolia*. Confirmed bitou plants could then be killed by herbicide sprayed from a safe access point, as usually that did not require entry into the confined space.

Annual assessment of seed bank The most suitable time to assess the seed bank is late summer, while the soil is dry and easily sieved. Soil was first passed through a course sieve (10 mm) to remove leaves and larger material then a 2 mm sieve. Bitou bush seeds have a hard putamen and do not break easily, thus the soil can be gently forced through the sieve using a gloved hand to removed most of the material – leaving the seeds and seed fragments In 2013, cores were collected under the canopy area of 15 plants. By 2016, only nine of these areas could be sampled due to substrate relocation by heavy machinery as part of port activities. From the nine plants sampled throughout, the viable under-canopy seed bank averaged 39.3 ± 35.9 seeds m^{-2} in 2012, decreasing to 7.1 ± 12.5 in 2016.

It has now been four years since reproduction has occurred at the study site and we continue to find abundant seed parts under plants targeted for seed bank sampling. The finding of putamen fragments is a useful check that sampling is in the right place where seeds could be potentially found.

Is not known for how long viable seeds can persist in the soil. Noble and Weiss (1989) found the viability of seeds decreased over two years, and viability was greater for seeds buried up to 6 cm than on the surface. Soil cores collected in 2016 presented a low number of viable seed, indicating seeds can survive at least four years.

There is circumstantial evidence that bitou bush requires outcrossing pollen to produce seed. Isolated plants (500 m from other plants) were either non-reproductive or had very few seeds. This was verified by sampling the soil under four of the isolated plants in 2013 to find no seeds or seed parts from previous years. Another observation has been that plants in heavily shaded environments have long branches and no flowers, or if a few flowers they were on branches that have grown out from the shade.

Smoke water trial Fire can be used to control bitou bush and stimulate germination of the seedbank (Weiss *et al*. 2008), but this was not a practical option given that the infestation's proximity to an oil refinery, gas plants and other explosive infrastructure.

Smoke water is known to increase germination in dormant Boneseed, *Chrysanthemoides monilifera* subsp. *monilifera* (Reynolds *et al.* 2013). However, an experimental treatment on the under canopy area of five former plants with smoke water (Regen 2000 Smokemaster© at 10%) in 2014 known to have a viable seed did not produce adequate germination for assessment.

Delimitation It is highly unlikely that delimitation of bitou bush can be achieved for Western Australia. By delimitation we mean that we have established the limits or boundaries of the entire distribution

including potential areas of distribution based on species distribution modelling.

There are numerous means by which seed, and plants, could have left the Kwinana bitou infestation and potentially started another population. Frugivorous birds (e.g. ringneck parrot, *Barnardius zonarius* were observed at the Kwinana estate) and mammals (e.g. foxes (Meek 1998)) are the usual means of seed dispersal in eastern Australia. There has been major disturbances of the area during the time bitou has been present, including: levelling and construction of a laydown area on Mason Road (southern edge of bitou distribution; 40 ha); decommissioning and transport to China of an iron smelting plant (eastern edge of distribution; 13 ha); construction of facilities related to cement production (northern edge of distribution; 10 ha). Potential seed dispersal from Kwinana also include the following vectors; ships (to and from eastern Australia, China), boats (fishing and recreational), trains (transporting iron ore, coal), trucks (carrying clinker, bauxite), horse floats (the adjacent public beach was a horse exercise area where the parking was surrounded by bitou plants), suspected drug dealers (a large plant was found at a meeting point in the parking area mentioned previously), other vehicles (port staff parking in the centre of the bitou distribution), road sweepers (plants overlapped road edges that were cleaned), and gardeners (removal of plant material for composting). What can be seen from this extensive list is that despite the general area having controlled access, there are more than enough means for seed to leave the site, and consequently we must assume that this has happened. Indeed, it is surprising that other bitou infestations have not been detected.

Conclusions It is likely that the threat of invasion is largely tempered by the unsuitability of climate and habitat across most of Western Australia. However, the abundance of seedlings and small plants without apparent morality strongly indicates that the Kwinana area, at least, is suitable for plant naturalisation. Bitou bush is largely found on the coastline in eastern Australia and this implies that the coastal region in Western Australia such as Cockburn Sound could be suitable. Further work on species distribution modelling is needed to determine if climate is limiting for bitou bush.

The next surveys for plants will be made in autumn (March–April) 2017. Seed densities are now so low that it is becoming marginally feasible to continue the seed bank survey. A proxy for the seed bank counts can be obtained by counts of seedlings within the canopy area sampled previously. It is still too early to state that eradication is possible because of the delimitation issue and because of the continued presence of a seed bank.

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