Management of *Chrysanthemoides monilifera* subsp. *rotundata* in Western Australia

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One of Australia's most serious weeds, *Chrysanthemoides monilifera* subsp. *rotundata* (bitou bush) was recently found for the first time in Western Australia as a well established population in Kwinana, a major port and industrial area south of Perth, the State's capital. This population is remote from other bitou bush infestations in Australia and had escaped detection despite extensive surveys in the same State for the other subspecies that is present in Australia, *Chrysanthemoides monilifera* subsp. *monilifera* (boneseed). The main reasons it went undetected are thought to be the tightly controlled access to this area because of mineral processing and port activities, the unusual invasion route via a heavy industrial area and the morphological similarity to a native species when it is not flowering. Two surveys defined the core population of 1038 plants that are spread along the coast over a 25-ha semi-circle with about a 500-m (1640 ft) diameter. Subsequent surveys of first a 500 m buffer zone and later a 1-km (0.621 mi) buffer found four additional plants, indicating that there is considerable potential for dispersal. We concluded that the survey has not delimited the distribution because of the potential and evidence for long distance dispersal. Cooperation by the various land managers has led to all plants being killed, as an initial step to management of this species. Other steps to be undertaken include an awareness campaign in the area that would need to be surveyed for delimitation of the spatial distribution and seed bank assessment to measure potential dispersal both in space and through time. It remains to be determined what is the best strategic response: eradication or containment.

Nomenclature: Bitou bush, *Chrysanthemoides monilifera* (L.) T. Norl. subsp. *rotundata* (DC.) T. Norl.

Key words: Delimitation survey, distribution, environmental weed, eradication, industrial landscape, weed of national significance.

One of Australia's most serious weeds, *Chrysanthemoides monilifera* (L.) T. Norl. subsp. *rotundata* (DC.) T. Norl. (Asteraceae) (hereafter, bitou bush) was recently found for the first time in Western Australia (WA) as a well established population in Kwinana, a major port and industrial area near Perth, the State capital. The Kwinana population of bitou bush is some 3,300 km (2,049 mi) west of the main bitou bush population in Australia (Figure 1). Here we document the weed's presence on the basis of an initial delimitation survey and consider management options, in particular, some of the issues related to the weed's presence in an industrial, port and mineral processing area.

Bitou bush was possibly originally introduced into Australia in ship ballast, but was planted in the 1940s to 1960s for dune stabilization in New South Wales (Weiss et al. 2008). Today dispersal is mainly by birds and some mammals ingesting fruits and carrying seeds to new locations (Gosper 1999; Meek 1998; Weiss et al. 2008). Bitou bush has spread to such an extent that it covers about 44,000 ha (108,724 ac) of coastal dune vegetation in eastern Australia, increasing its distribution 20% since 2001. It is largely (90.3%) found within 2.5 km of the coastline in New South Wales, with incursions northwards into Queensland and southwards into Victoria subject to containment lines and localized eradication (Hamilton et al. 2012). It is considered a major threat to biodiversity with at least 150 native plant species identified as being at risk because of bitou bush invasion (Weiss et al. 2008). The importance of bitou bush is recognized in it being one of the original Weeds of National Significance in Australia (Thorp and Lynch 2000; Weiss et al. 2008).

Bitou bush was discovered in Western Australia by chance, recognized in July 2012 by natural resource managers involved in surveillance for a second subspecies, *Chrysanthemoides monilifera* subsp. *monilifera* (L.) T. Norl. (boneseed), which is also a Weed of National Significance

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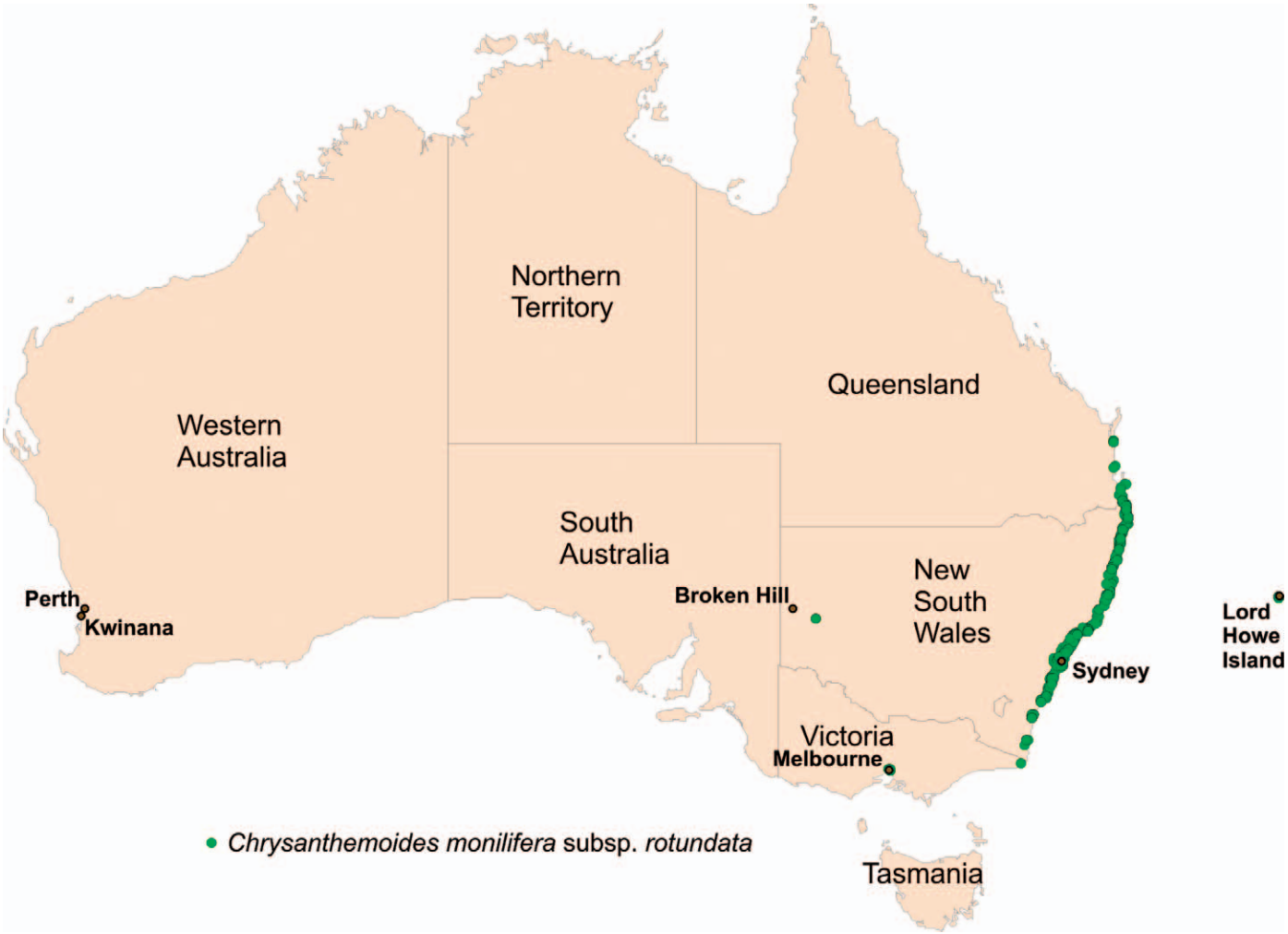

Figure 1. Distribution of *Chrysanthemoides monilifera* subsp. *rotundata* in Australia (green dots), based on records in the Atlas of Living Australia (http://www.ala.org.au/) (three erroneous records were removed). Also shown is the location of Kwinana, Western Australia, site of the new infestation. (Color for this figure available in the online version of this paper.)

in Australia. Boneseed has a more southern Australian distribution, primarily Victoria and South Australia, and is not restricted to coastlines (Weiss et al. 2008) (Figure 2). Since 2006, a community awareness program (the "boneseed blitz") has operated in WA for the detection and eradication of boneseed (Cherry et al. 2008). Indeed, WA State weeds legislation lists both subspecies in the P1/2 category, which requires eradication of the weed and prohibits its trade, sale or movement. In this paper we test the idea that the plant has a limited distribution as would be expected for a new incursion and make the first steps towards identifying the strategies for management of bitou bush in WA.

Materials and Methods

Identification. Identification of the plant as *Chrysanthemoides monilifera* subspecies *rotundata* was based on the descriptions in Norlindh (1943) and Weiss et al. (2008). Characteristics used included the presence of an indumentum covering new growth, the oval shape of leaves, the number of ligulate florets ("petals", around 13) on the capitula, the presence of fleshy fruits containing one seed, and the shape of seeds (oval as opposed to round for boneseed). A herbarium specimen of *C. monilifera* subsp. *rotundata* has been deposited at PERTH.

Surveys in Kwinana. Access to land controlled by different companies required various levels of safety inductions lasting for a few hours up to a day for every person, drug and alcohol tests, and inspection of vehicles to determine if they were equipped for mine sites. Even so, in some cases access was only possible while accompanied because of the potential dangers. The range of companies, agencies and organizations involved in providing access included a port exporting minerals, an iron smelter, a petroleum refinery,

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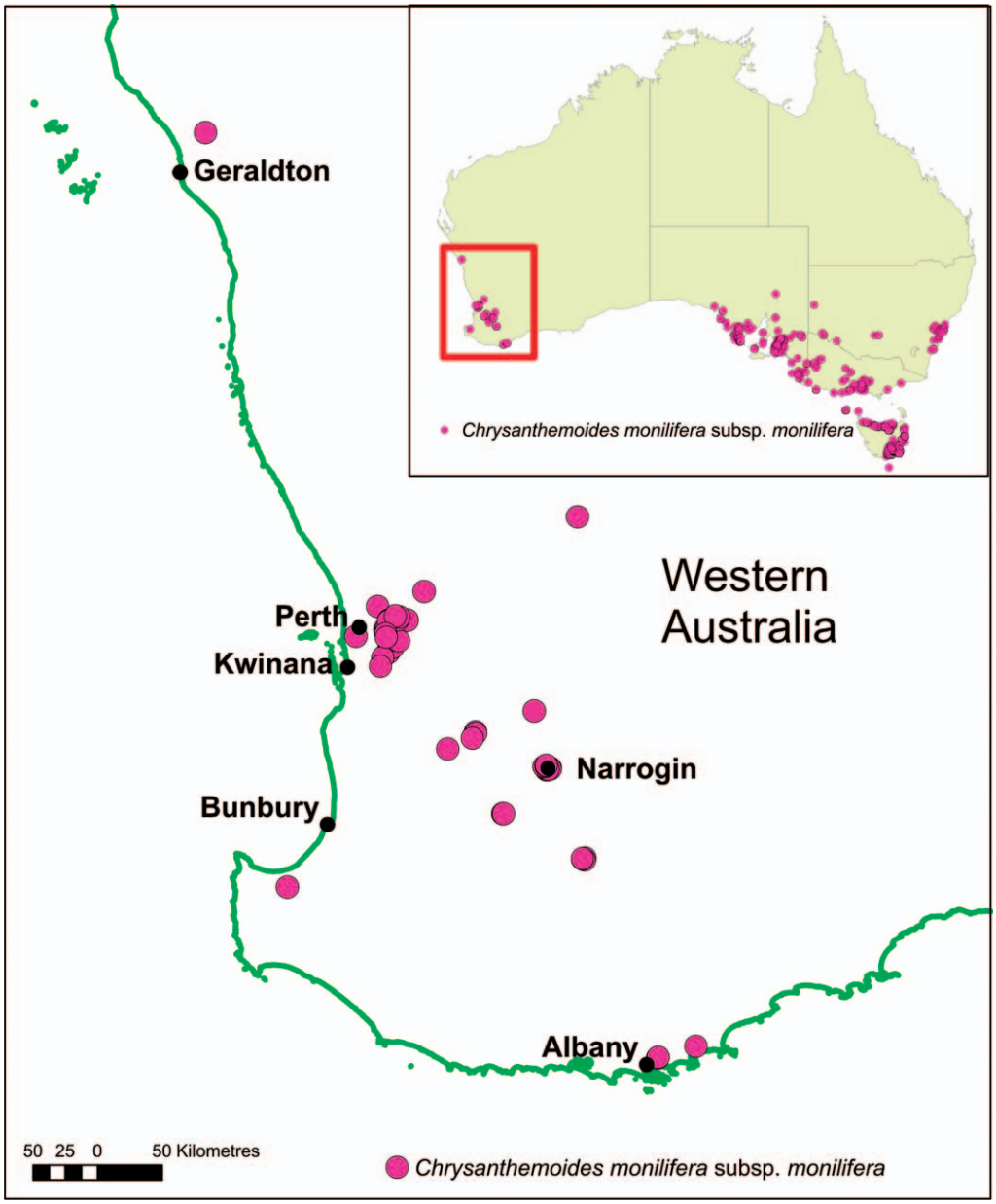

Figure 2. Distribution of *Chrysanthemoides monilifera* subsp. *monilifera* in south western Australia based on collection data provided in http://www.weeds.org.au/WoNS/bitoubush/docs/Appendix_A-WA_Boneseed_Eradication_Strategy-Jan_2012.pdf. The Australian distribution (insert), based on records in the Atlas of Living Australia (http://www.ala.org.au), does not include all the WA records. (Color for this figure available in the online version of this paper.)

oil and gas companies that use laydown (storage) area within the site, pipe and cement manufacturers and the State Government land manager.

An initial survey, which involved three people over 2 d searching on foot and using a vehicle, established the extent of the core infestation as falling within a semi circle of about 500-m (1640-ft) diameter centered on the coast. This survey mapped mainly mature plants using a differential GPS and identified landholders with whom to negotiate access. This provided an assessment of the feasibility of a second, more detailed survey. Initial surveys were also made along the beach to the north and south of the population.

The second phase was to map all individual plants within the known population using a differential GPS with the data managed in ArcMap10. Plants were classed as seedlings if the cotyledons were still green. Various measurements were made on each plant and these will be reported elsewhere. Two or three people searched a defined area, on foot. Personnel were positioned about 10 m apart

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for the searches, although the diverse nature of the terrain, and the need to remain in visual contact meant that searchers were often closer than 10 m. An area was searched in strips, one way then returning along the same path meaning that each area was examined twice. The insides and tops of buildings, conveyor belts or other infrastructure such as paved areas were not searched (but were examined by aerial photography), although gutters were examined from ground level, if visible as these are areas that could receive bird dispersed seed. New laydown areas and hard stands (paved areas for vehicles and operations) were not examined; however, older laydown areas become invaded by plants and were searched. Mineral stockpiles (iron, coal) that were being worked actively and were devoid of vegetation were not examined. The surface of chipped and composted stockpiles of soil and bunds were examined. Binoculars were used to confirm the identification of plants growing in inaccessible locations (such as steep sided pits, soaks, old slag heaps). The dunes and beach were examined wherever there was vegetation.

The third phase of the survey was to examine a buffer zone of 500 m around the core distribution, calculated in ArcMap10. The buffer distance was based on the core distribution having a diameter of about 500 m (and hence the maximum realized dispersal based on the observed population). The area defined by the 500-m buffer zone was searched in the same manner as the core population. Transects were also made out to 1 km, north and south along the coast and east, inland, some of which was searched less intensively [e.g. in extensive areas covered by the exotic grass *Cenchrus setaceus* (Forssk.) Morrone].

Results and Discussion

Identification. Bitou bush was easy to identify. However, a native dune-inhabiting species, *Scaevola crassifolia* Labill. (Goodeniaceae), looks very similar to bitou bush when not in flower, but can be identified by the absence of an indumentum and the shape and number of serrations on the leaf edge. When flowering, its blue asymmetric flowers easily distinguish it from bitou bush which has yellow capitula. Other plants, such as *Schinus terebinthifolius* Raddi (Anacardiaceae), appeared similar in aerial photography limiting the usefulness of this approach.

Initial Survey in Kwinana. The initial survey found 117 plants on four properties (results not shown, but plants were located within the core population as shown in Figure 3). Most of the plants were on two industrial properties that were technically classified as mine sites and were involved with mineral storage and processing.

Subsequent Surveys. A more detailed survey was considered feasible based on the limited distribution evident from the initial survey. The survey of the core infestation (Figure 3) found 1038 plants, including 507 seedlings in an area of about 25 ha. These plants varied in size with the largest 11.6 m in crown diameter and 5.5 m high. It should be possible to determine plant age because stem sections show growth rings and a more detailed analysis of these rings will be undertaken, including assessing whether the rings are annual or seasonal. Most plants had few or no capitula, but one large individual had over 600 capitula present, however few (nine) were fruiting.

Surveys in the 500 m buffer zone found five more plants; one small plant $<$ 1-yr-old (not reproductive) to the north-east of the main population, and four larger plants to the south of the main population and leading to the extension of the survey area (centered around 500 m from the southern-most plant) (Figure 3). These plants ranged from 2.4 to 8.0 m in crown diameter, but appeared to be in their first or second year of flowering (none or only single capitula present, no fruits evident). In all, 246 ha were surveyed (Figure 3) using 221 person hours.

All seedlings and 446 small plants were up-rooted by hand. One had been killed previously by herbicide treatment of a grassed area and 14 were killed in previous years, apparently by herbicide treatments along fence lines. Eighty plants too big to remove by hand or too difficult to access were killed by herbicide or uprooted using earth moving equipment.

Extent of Bitou Bush in WA. Based on plant size (Scott 1996) and aerial photography it is apparent that this bitou bush population has been present for some time, possibly up to 20 years. During this time bitou bush was recognized as a serious weed in State invasive species legislation and active surveillance was undertaken for its relative, boneseed, mainly in forested areas away from the coast.

Failure to detect bitou bush is caused by the very restricted access to the area, including the beach and dunes, which are surrounded by security fencing, the unlikely invasion route through a heavy industry area, and its similarity to a native dune species, *Scaevola crassifolia*, when not flowering. Also, the understanding that WA was well outside the potential distribution of bitou bush (Adair et al. 2012; Winkler et al. 2008) reduced the expectation that it might be present in the State.

The location of boneseed populations (Figure 2) indicates that this weed is widespread in south west WA. However, the survey for boneseed was focused inland rather than on coastal regions although the coasts are the populated regions where weed detection would be more likely. Failure to detect bitou bush during the boneseed survey, despite the large area covered and the survey duration (over 6 yr, mainly during the spring flowering season), provides strong support for the view that the bitou bush population at Kwinana is a unique occurrence in WA. In addition, various agencies, groups and individuals

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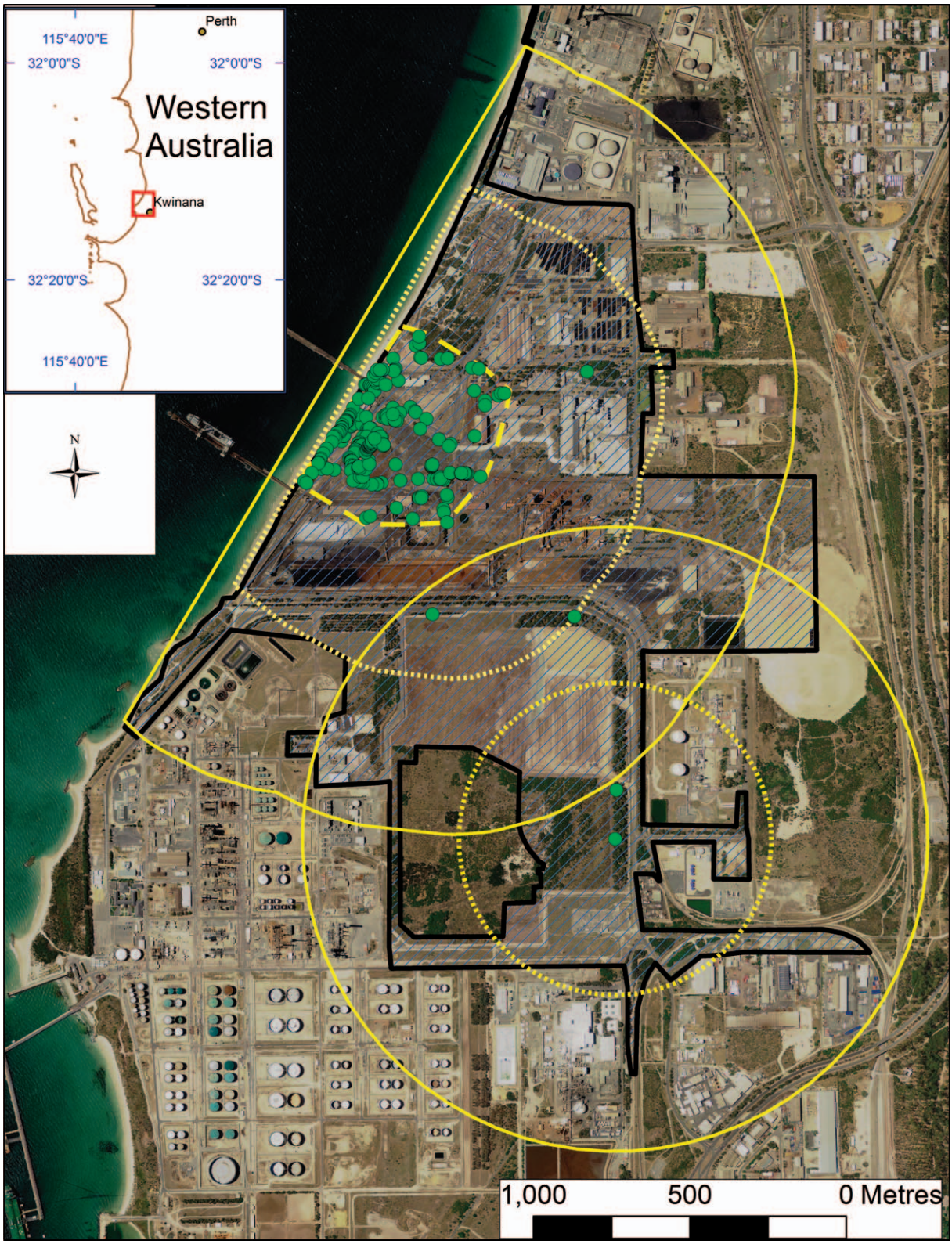

Figure 3. Distribution of *Chrysanthemoides monilifera* subsp. *rotundata* (green dots) in Kwinana, Western Australia. The yellow dashed line shows the core area, the yellow dotted lines show the 500 m buffer beyond the core population and the southern-most plant. The solid yellow lines show the buffers measured at 1 km. The blue hatching covers the area surveyed up to the end of 2012. The background aerial photography was taken 8 Jan 2012 and is reproduced by permission of Western Australian Land Information Authority, CL05-2013. (Color for this figure available in the online version of this paper.)

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involved with coastal management, including the authors of this paper who have been studying the ecology of the coastal dune plant, *Euphorbia paralias* L. (Euphorbiaceae), had not encountered bitou bush during their activities around Kwinana and other parts of the south west of WA.

Source of Infestation (Trace Backwards). How the plant arrived in Kwinana is still unknown. Long distance dispersal of seeds to Kwinana by ocean currents from southern Africa or south eastern Australia seems unlikely despite the view that bitou bush can be dispersed via the sea in Queensland (Batianoff 1997). The plant's location in a highly modified human habitat and centered around two jetties (Figure 3) indicates that arrival of seed by boat is more likely.

The only public access to part of the area is along a road on the northern edge of the core infestation and, coincidently, where large plants were found. People were observed visiting the area for beach access or fishing and others use it for exercising horses. Despite the distance, it is possible that seeds could have arrived via tourists cleaning caravans/fishing gear of sand collected from bitou bush infested NSW beaches (a similar vector route is hypothesized for boneseed). We will be analyzing early aerial photographs of the infested area with the aim of identifying the location, date and associations of the initial infestation.

Vectors and Dispersal Agents (Trace Forward). Major earthworks and land clearing associated with new industrial developments could lead to seed infested soil and seed-bearing plants being moved. Within the last year up to 35.8 ha of vegetation in the survey area was cleared and chipped with a small amount of plant material moved offsite for composting.

Bitou bush is an attractive species and was found in old garden beds during our survey, indicating either that they were planted or, more likely, they were tolerated following their appearance (as volunteers) in the garden bed. This opens the possibility that workers from the survey area may have taken plants home (seedlings and cuttings readily transplant). Similarly, boneseed occasionally appears as a garden plant in WA (records included in Figure 2).

Perhaps the most likely dispersal agents are birds and mammals. Many bird species are recorded as dispersal agents (Dodkin and Gilmore 1985; Gosper 1999) and several potential dispersal agents were observed during site surveys (e.g. Australian raven, Silvereye, Mistletoe bird). Mammalian dispersal agents include foxes (Meek 1998) and one was observed on site. No actual seed dispersal was observed. However, there is potential for dispersal to occur over considerable distances. Bird dispersal of seeds is often characterized as occurring at distances up to 1 km. But Mokotjomela et al. (2013) have recently shown that *Zosterops pallidus* Swainson, a similar bird to the silvereye observed in our study, could disperse *C. monilifera* seeds up to 9.4 km. Note these are estimates not based on recovering seeds from dispersing birds.

Each day there are numerous movements of trucks and trains to and from the infested area. Workers also bring their vehicles on site. The most likely means for a seed to arrive on a vehicle is by bird dispersal, in particular by birds alighting on trees overhanging vehicles. The trains transport coal and iron ore from locations hundreds of km away, and trucks transport imported clinker (a component of cement) from the site to other industrial areas, this considerably expanding the potential dispersal area.

Has Delimitation Been Achieved? Further analysis is needed to model the probability of plant presence in relation to habitat favorability. For example, the presence of plants on the southern edge of the distribution at Kwinana indicates that areas vegetated with trees and shrubs are likely pathways for invasion and this may be related to bird dispersal.

The entire area infested with bitou bush is under negotiation between government and business for possible redevelopment as a major port. Quantification of the bitou bush seed bank will be important to inform policies for management of earth-moving vehicles, soil and vegetation. Preliminary assessment shows that there is a seed bank under the larger plants and this will be measured in the future. The industries operating at the infestation site have been very cooperative in facilitating surveillance and research activities on bitou bush and in some cases the bitou bush situation is now included in the environmental component for site induction for personnel and visitors. Cooperation from the various land managers has also led to all known plants being killed, as an initial step to management of this species. Other steps to be undertaken include an awareness campaign in the area that would need to be surveyed to help delimit the spatial distribution. Western Australia's economy is dominated by mining and mineral processing and it is important to engage these industries in the control of this nationally important weed. At this stage we consider that delimitation has not been achieved in this initial survey, so the best strategic response, whether it be eradication or containment, remains to be determined.

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