**Supplementary Materials**

Table S1. Sites in Western Australia where evidence supports extirpation of boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Location** | **LGA** | **Site** | **Rationale** | **Extirpation year** | **Year most recently inspected** |
| Regional | Albany | Rae Rd and Francis Street | Properties developed, risk removed | 2007 | 2021 |
| Regional | Northampton | Nabawa | Herbarium record no evidence of naturalisation | 1954 | 2021 |
| Regional | Pingelly | Tutanning Nature Reserve | Herbarium record no evidence of naturalisation | 1969 | 2021 |
| Regional | Toodyay | Morangup | Herbarium record no evidence of naturalisation | 1984 | 2021 |
| Regional | Wyalkatchem | White Dam Reserve and Rubbish tip | Recorded in APB report and FIS dataset records | 1994 | 2021 |
| Urban | Applecross | Mt Pleasant | Herbarium record, property developed | 1974 | 2021 |
| Urban | Mundaring | John Forrest National Park, Hovea | Small infestation, intensive control 2007-2009, including topsoil removal and grubbing. Annual surveillance, burn in 2017. No evidence of infestation in the park and an active landcare group is monitoring the park | 2009 | 2021 |

Table S2. Sites in Western Australia with a ‘watch’ status recommended for boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*) as of December 2023.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | LGA | Population | Tenure | Site summary | Year fruiting last observed |
| Regional | Narrogin | Narrogin 8 | Private | 114 Doney St | 2007 |
| Regional | Narrogin | Narrogin 8 | Private | 116 Doney St | 2007 |
| Regional | Narrogin | Narrogin 8 | Private | 2 Pitt St | 2009 |
| Regional | Narrogin | Narrogin 8 | Private | 8 Touhy St | 2007 |
| Regional | Narrogin | Narrogin 8 | Private | 86 Kipling St | 2007 |
| Regional | Wandering | Wandering 2 | Government | Moramocking Rd Gravel Pit | 2006 |
| Regional | Woodanilling | Woodanilling 1 | Private | Great Southern Hwy | 2006 |
| Regional | Woodanilling | Woodanilling 3 | Private | 20-23 Carlton St | 2006 |
| Urban | Kalamunda | Gooseberry Hill | Private | Noel Rd | 2007 |
| Urban | Kalamunda | Gooseberry Hill | Private | Railway Rd | 2007 |
| Urban | Mundaring | Darlington 1 | Government | Mount St | 2009 |
| Urban | Mundaring | Darlington 2 | Private | Helena College | 2008 |

Table S3. Regional sites in Western Australia recommended for an extirpation approach to management of boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*) as of December 2023. \*Surveillance effort is on site time only based on engaging experienced personnel, excluding logistics and travel to site.

| **LGA** | **Population** | **Vestiture** | **Site Summary** | **Year fruiting last observed** | **Predicted extirpation year** | **Years until extirpation** | **Estimated annual surveillance effort (hours)\*** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Albany | Manypeaks | Government | North road verge | 2021 | 2037 | 14 | 3 |
| Albany | Manypeaks | Government | South road verge | 2020 | 2036 | 13 | 3 |
| Albany | Manypeaks | Private | 137 Waychinicup Rd | 2021 | 2037 | 14 | 3 |
| Albany | Manypeaks | Private | 275 Waychincup Rd | 2021 | 2037 | 14 | 3 |
| Boddington | Boddington | Government | Hotham River | 2012 | 2028 | 5 | 3.75 |
| Busselton | Vasse | Government | Creekline | 2020 | 2036 | 13 | 2.5 |
| Busselton | Vasse | Government | Chugg Rd | 2020 | 2036 | 13 | 2.5 |
| Narrogin | Narrogin 1 | Government | Narrogin High School | 2021 | 2037 | 14 | 3.75 |
| Narrogin | Narrogin 2 | Government | Fleay Rd | 2010 | 2026 | 3 | 1.25 |
| Narrogin | Narrogin 3 | Government | Fox Lair Arboretum | 2008 | 2024 | 1 | 1.25 |
| Narrogin | Narrogin 3 | Government | Fox Lair Commonage | 2008 | 2024 | 1 | 1.25 |
| Narrogin | Narrogin 4 | Government | Narrogin-Wandering Rd | 2012 | 2028 | 5 | 1.25 |
| Narrogin | Narrogin 5 | Government | New Rubbish Tip | 2012 | 2028 | 5 | 3.75 |
| Narrogin | Narrogin 5 | Government | Old Rubbish Tip | 2014 | 2030 | 7 | 3.75 |
| Narrogin | Narrogin 6 | Government | Pioneer Dve | 2022 | 2038 | 15 | 2.5 |
| Narrogin | Narrogin 7 | Government | Touhy Reserve | 2012 | 2028 | 5 | 2.5 |
| Narrogin | Narrogin 7 | Government | Water Corp Earl St | 2008 | 2024 | 1 | 1.25 |
| Narrogin | Narrogin 7 | Government | 46-47 Fairway | 2008 | 2024 | 1 | 1.25 |
| Narrogin | Narrogin 7 | Private | 83 Felspar St | 2012 | 2028 | 5 | 1.25 |
| Wandering | Wandering 1 | Government | Old Mill | 2020 | 2036 | 13 | 1.25 |
| Wandering | Wandering 1 | Government | Primary School | 2011 | 2027 | 4 | 1.25 |
| Wandering | Wandering 1 | Government | Caravan Park | 2016 | 2032 | 9 | 2.5 |
| Wandering | Wandering 1 | Government | Gravel Pit | 2021 | 2037 | 14 | 3.75 |
| Wandering | Wandering 1 | Government | Rubbish Tip | 2020 | 2036 | 13 | 5 |
| Wandering | Wandering 1 | Government | Water Corp | 2020 | 2036 | 13 | 5 |
| Williams | Dardadine | Government | Old School site | 2008 | 2024 | 1 | 2.5 |
| Williams | Dardadine | Government | Dardadine South Road | 2008 | 2024 | 1 | 2.5 |
| Woodanilling | Woodanilling 2 | Government | Shenton Rd | 2020 | 2036 | 13 | 5 |
| Woodanilling | Woodanilling 1 | Government | Haddelton Rd | 2010 | 2026 | 3 | 1.25 |
| Woodanilling | Woodanilling 1 | Government | Rubbish Tip | 2022 | 2038 | 15 | 5 |
| Woodanilling | Woodanilling 3 | Private | 3346 Robinson Rd | 2021 | 2037 | 14 | 2.5 |
| Woodanilling | Woodanilling 3 | Private | 4-6 Mouritz Rd | 2021 | 2037 | 14 | 2.5 |
| TOTAL |  |  |  |  |  |  | 85.75 |

Table S4. Urban sites in Western Australia recommended for an extirpation approach to management of boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*) as of December 2021.

| LGA | Population | Tenure | Site Summary | Year fruiting last observed | Predicted extirpation year | Years until extirpation | Estimated annual surveillance effort (hours)\* |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Armadale | Armadale | Government | Bedfordale HIll Rd | 2008 | 2024 | 1 | 2.5 |
| Armadale | Armadale | Private | 117 Burrows-147 Albany Hwy | 2021 | 2037 | 14 | 5 |
| Armadale | Armadale | Private | 144-156 Albany Hwy | 2008 | 2024 | 1 | 2.5 |
| Armadale | Armadale | Private | 93-115 Burrows Retreat | 2009 | 2025 | 2 | 2.5 |
| Armadale | Roleystone 1 | Government | 60 Peet Rd Watertank | 2011 | 2027 | 4 | 2.5 |
| Armadale | Roleystone 2 | Government | Springdale Tip | 2009 | 2025 | 2 | 2.5 |
| Kalamunda | Gooseberry Hill | Private | Gooseberry Hill Rd | 2013 | 2029 | 6 | 2.5 |
| Kalamunda | Gooseberry Hill | Private | Landor Rd | 2021 | 2037 | 14 | 2.5 |
| Kalamunda | Lesmurdie 1 | Private | 48 Recreation Rd | 2008 | 2024 | 1 | 1.25 |
| Kalamunda | Lesmurdie 1 | Private | 180-187 Grove Rd | 2010 | 2026 | 3 | 1.25 |
| Kalamunda | Lesmurdie 1 | Private | Parry House | 2016 | 2032 | 9 | 2.5 |
| Kalamunda | Lesmurdie 2 | Government | Falls Road Primary | 2010 | 2026 | 3 | 1.25 |
| Kalamunda | Lesmurdie 3 | Private | 25 Gilchrist Rd | 2009 | 2025 | 2 | 1.25 |
| Kalamunda | Lesmurdie 4 | Government | Alan Anderson Reserve | 2014 | 2030 | 7 | 1.25 |
| Kalamunda | Kalamunda 1 | Private | 2 East Tce | 2008 | 2024 | 1 | 1.25 |
| Kalamunda | Kalamunda 1 | Private | 3-12 Roach Rd | 2008 | 2024 | 1 | 2.5 |
| Kalamunda | Kalamunda 1 | Private | 41-47 Heath Rd | 2011 | 2027 | 4 | 1.25 |
| Kalamunda | Kalamunda 1 | Private | Croxton Rd | 2009 | 2025 | 2 | 1.25 |
| Kalamunda | Kalamunda 2 | Government | MRP near Brine Rd | 2020 | 2036 | 13 | 2.5 |
| Kalamunda | Kalamunda 2 | Government | MRP near Moran Rd | 2008 | 2024 | 1 | 2.5 |
| Kalamunda | Pickering Brook | Government | Carinyah Rd | 2022 | 2038 | 15 | 5 |
| Kalamunda | Pickering Brook | Private | 121 Merrivale Rd | 2009 | 2025 | 2 | 1.25 |
| Mundaring | Darlington 1 | Government | Towerhill Crt | 2010 | 2026 | 3 | 2.5 |
| Mundaring | Darlington 1 | Government | Camfield/Pitterson Rd | 2011 | 2027 | 4 | 2.5 |
| Mundaring | Darlington 2 | Government | Leithdale Rd | 2021 | 2037 | 14 | 2.5 |
| Mundaring | Darlington 2 | Private | 10-100 Ryecroft Rd | 2020 | 2036 | 13 | 2.5 |
| Mundaring | Darlington 2 | Private | 175-245 Ryecroft Rd | 2020 | 2036 | 13 | 2.5 |
| Mundaring | Darlington 2 | Government | Hillcrest Dr | 2011 | 2027 | 4 | 2.5 |
| Mundaring | Mahogany creek | Private | 2145 Jacoby St | 2016 | 2032 | 9 | 1.25 |
| Mundaring | Mahogany creek | Private | 6260 GE Hwy | 2016 | 2032 | 9 | 1.25 |
| Mundaring | Parkerville 1 | Private | Seaborne St | 2008 | 2024 | 1 | 1.25 |
| Mundaring | Parkerville 2 | Private | Brooking Rd | 2021 | 2037 | 14 | 5 |
| Mundaring | Sawyers Valley | Private | Forrest St | 2008 | 2024 | 1 | 2.5 |
| Swan | Henley Brook | Private | 130 Rookwood St | 2021 | 2037 | 14 | 2.5 |
| Swan | Henley Brook | Private | 131 Rookwood St | 2008 | 2024 | 1 | 2.5 |
| Swan | Henley Brook | Private | 63 Saunders St | 2012 | 2028 | 5 | 2.5 |
| TOTAL |  |  |  |  |  |  | 82.5 |

Table S5.Urban sites in Western Australia where an extirpation of boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*) is unlikely in the short term, and containment is first required while delimitation is achieved. \*Extirpation could be still a reality if delimitation can be performed in the near-term

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **LGA** | **Population** | **Tenure** | **Site Summary** | **Last fruiting observation** | **Predicted extirpation year** | **Years until**  **extirpation\*** | **Estimated Annual Surveillance Effort (hours)** |
| Armadale | Armadale | Government | Neerigan Brook | 2020 | 2036 | 13 | 7.5 |
| Armadale | Wungong | Government | Wungong Regional Park | 2021 | 2037 | 14 | 15 |
| Armadale | Roleystone 1 | Government | Beales Ct Culvert | 2021 | 2037 | 14 | 5 |
| Armadale | Roleystone 1 | Private | 33 Mackie Rd | 2021 | 2037 | 14 | 1.25 |
| Armadale | Roleystone 1 | Private | 39-51 Mackie Rd | 2021 | 2037 | 14 | 5 |
| Armadale | Roleystone 1 | Private | 455-469 Brookton Hwy | 2020 | 2036 | 13 | 2.5 |
| Armadale | Roleystone 1 | Private | 516-538 Brookton Hwy | 2016 | 2032 | 9 | 2.5 |
| Kalamunda | Lesmurdie 5 | Government | Lower Lesmurdie Falls | 2017 | 2033 | 10 | 5 |
| Swan | Henley Brook | Government | 77 Saunders St | 2021 | 2037 | 14 | 5 |
| Total |  |  |  |  |  |  | 48.75 |

A graph of numbers and graphs

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Figure S1. Distance of individual boneseed (*Chrysanthemoides* *monilifera* subsp. *monilifera*) plants to mean centroid for each population in regional (A) and urban (B) locations.

**Supplementary Appendix S1**

**Case Study 1: Manypeaks - City of Albany, WA**

In 2007 Hillary Cherry described a previously unrecorded infestation of at least 100 mature boneseed and 500 seedlings along a 2 km stretch of Waychinicup Rd in Manypeaks, WA. Boneseed was recorded in the remnant bushland on two private landholdings, 137 and 275 Waychinicup Rd, and on both the north and south road verges (making four sites). In 2021 large plants were found in the house garden of 275 Waychinicup Rd, which were missed in the 2006 - 2007 surveys. In addition, the Manypeaks boneseed population is 160 km from the nearest active infestation in Woodanilling making garden planting the most likely pathway of invasion. Currently the Manypeaks infestation is contained, but an ongoing risk to nearby Mt Manypeaks Nature Reserve until extirpation is achieved.

**Site description**

The road verges in this section of Waychinicup Rd are 5-10 m deep, thickly vegetated and boneseed was mostly found at the base of trees. 137 Waychinicup Rd has been a blue gum (*Eucalyptus globulus*) plantation from at least 2000 and the main agriculture on properties 154, 275 and 332 Waychinicup Rd is sheep/cattle grazing. The boneseed in remnant bushland areas of 275 Waychinicup Rd is fenced off from the main farm, and the bushland to the east of the homestead is protected under a conservation covenant and subject to winter water inundation.

**Management history**

The boneseed plants found in 2006-2007 were removed by the City of Albany in September 2007. It is not known if follow up surveillance occurred between 2008-2010. The next inspection was in 2011 by Perth NRM and jointly (but not necessarily co-ordinated) between City of Albany and DPIRD 2012 - 2021. Information about location of plants was compiled from Perth NRM and DPIRD data. The Manypeaks site has had annual surveillance since 2011, but missed plants and the lack of a central, accessible data repository to detail the extent of the infestation has hampered progress toward extirpation.

**Delimitation**

In September 2021, DPIRD and CSIRO undertook a delimitation survey of the Manypeaks site, covering the known extent plus a buffer area of 500 m (Figure S1). No new plants were found beyond the known extent. However, the shelter belts on 154 Waychinicup Rd still require inspection as the paddocks were inundated with water at the time and therefore not accessible for surveying. In addition, the vegetation at Manypeaks is quite dense, making it difficult to locate boneseed amongst other yellow flowering vegetation. While the total delimitation area for Manypeaks was 250 ha, the area at risk from boneseed infestation is far smaller (i.e., grass paddocks and tree plantations were excluded), covering approximately 22 ha of verge and remnant vegetation.

**Future management**

With annual surveillance (two people for one day), but without measures to stimulate the seedbank extirpation is achievable but not expected until 2035 based on current methods and knowledge on seed longevity (Figure S2). The City of Albany have designed a program of prescribed burns covering the north and south road verges for autumn of 2023, which could stimulate the seedbank to germinate, improving the likelihood of containment and reducing the scale of surveillance. The City of Albany have also suggested ‘mulching to a depth of 0.5 m’ as an outcome for the house garden of 275 Waychinicup Rd. Such an approach would simulate deep burial, which has been successful for the suppression of *Acacia longifolia* germination elsewhere in the City. They will discuss this possibility with the property owner.

A satellite view of a land

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**Figure S3.** Delimitation survey area of the boneseed extent at Manypeaks. Background image: Google Maps (2021).

A graph of a chart

Description automatically generated with medium confidence

**Figure S4.** Manypeaks boneseed location management timeline.

**Case Study 2: Vasse - City of Busselton, WA**

First recorded in the WA Herbarium in 1993 by Greg Keighery, the location was noted as “Crump Rd, base Whicher Range, 15 km SSE Busselton”. As there is no Crump Rd near Busselton or Whicher Range, the authors contacted the collector to clarify the location. We were able to confirm that it was at Chugg Rd, adjacent to the former Department of Agriculture Research Station in Vasse. Recorded as site 34 (Cherry, 2010b), the nearest other infestation of boneseed is in Boddington, 150 km away.

DPIRD are the property owners of the Former Vasse Research station, but the associated dairy at 4711 Jalbarragup Rd has been leased-out to private tenants since 2012. The buildings of the old Vasse Research station were recently leased to DBCA Blackwood Region Fire Unit. The road verge on Chugg Rd is the responsibility of City of Busselton.

**Site description**

Vasse is described as one population over two sites. Boneseed is found along both sides of Chugg Rd reserve, up to 450 m from the intersection with Jalbarragup Rd and along the banks of a fenced creek line extending from the bridge on Chugg Rd up to 650 m to the north (Figure S3). The understory of the creek line and Rd edge is quite degraded, with kikuyu (*Cenchrus clandestinus*) and annual grasses in the understory below eucalypts. Cattle are often let inside the fenced creek area to keep the grass under control.

**Management history**

The earliest control efforts against boneseed were undertaken by DPIRD staff in 2001 on Chugg Rd. Control (described as compliance in the dataset) is listed against every year between 2006-2014, and while plant size is not specifically mentioned, they were probably mostly seedings since surveillance was consistent. A small area around the Chugg Rd bridge was burnt in August 2011 that resulted in up to 78 seedlings over a 0.25m2 9 weeks later (B. Rayner, ex-DPIRD pers. comm.).

The earliest control effort against boneseed in the creek line was in 2006. Control was applied between 2006-2009 then 2011-2014. No inspection occurred in 2010. No plants were recorded in any dataset between 2015-2018, but large plants were found along both Chugg Rd and the creek line in 2019, effectively replenishing the soil seedbank with fresh seed (Figure S4). The creek line area has been fenced off from the main farm since at least 1996, but it is not known for how many years cattle have been able to graze in the area.

**Delimitation**

In September 2021, DPIRD and CSIRO undertook a delimitation survey of the Vasse infestation (Figure S3), covering the known extent plus a buffer area of 500 m, based on a likely realised bird dispersal distance. No new plants were found beyond the known extent.

A map of a farm

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Figure S5. Boneseed infestation along Chugg Rd in Vasse. Background image: Google (2021).

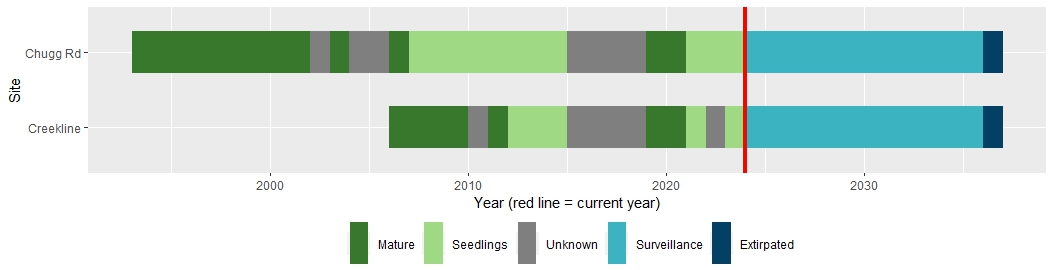


Figure S6. Vasse boneseed management timeline.

**Future management**

Without measures to stimulate the seedbank, and with continued annual surveillance, extirpation is not expected until 2035 (Figure S4) and annual surveillance covering the known extent can be achieved with one person and approximately five hours each year. Enhanced management in the form of a controlled burn has been discussed with DPIRD and the City of Busselton and may be possible with the assistance from DBCA due to the risk this infestation poses to nearby Whicher Range.

**Supplementary Appendix 2**

**Databases with information on boneseed sites**

At least six organisations have maintained their own database of boneseed sites and historical management activities in Western Australia (WA). Other organisations and individuals have been able to provide an oral history of on ground works and events at some sites.

Seven databases were maintained before and during the 2021 survey.

1. WA Herbarium (1948-2007) and WA Boneseed Eradication Strategy. Cherry (2010) accessed all boneseed specimens in the WA Herbarium in 2006 and formed a dataset of populations based on the collection details, site surveys and expert knowledge of local APB staff at the time. From this synthesis, Cherry (2010) determined there were 42 discrete sites in WA where boneseed has been found, six of which were presumed extirpated.
2. Annual reports of the Western Australian Agriculture Protection Board (1983-1996). Boneseed was first mentioned in a 1983 annual report and in most years until 1996, when reporting of P5 weeds in the annual report ceased. Boneseed was generally mentioned in either paragraph text or in a table with the number of sites, along with area or number of sites controlled.
3. Between 1986 and 2018, the Department of Primary Industries and Regional Development (DPIRD) maintained a database, the Field Inspection System (FIS), that recorded populations of declared pest species against agricultural and other property parcels in Western Australia. FIS is not a publicly available dataset. In this system boneseed observations were attached to polygon features. Relevant fields were Property ID, Date, Infestation size (light, medium or heavy) and OBS (compliance, surveillance, audit). The Property ID field was indexed in a publicly available DPIRD spatial layer called Client Property Event System (<https://catalogue.data.wa.gov.au/dataset/client-property-event-system-properties>). Information from this database was used to compile plant demography at each site. Information on boneseed mentioned in APB annual reports was included in FIS.
4. WA Roadside Conservation Committee database. The WA Roadside Conservation Committee database catalogues records of flora found in roadsides in Western Australia (<https://catalogue.data.wa.gov.au/dataset/roadside-conservation-committee-rcc-status-map-dpaw-042>). As boneseed is often found along road verges, this dataset was considered a potential source of potential new locations. The publicly available dataset was last updated in 2017. Boneseed was recorded twice in the shire of Dandaragan in this database.
5. Perth NRM (2009-2018). Luke McMillan at Perth NRM was the WA State Boneseed Coordinator between 2009-2018 and in this role, he arranged the removal of large quantities of boneseed at several locations in the Perth Hills area. He also undertook annual surveillance and control of sites each year until 2018 and assisted with surveillance in regional areas. Records from his surveillance database, field GPS and personal knowledge were used to populate many of the points in the aggregated database and compile plant demography at each site.
6. DPIRD IQC records (2019-2021). DPIRD have adopted a point location approach to pest plants on properties since 2019, using ESRI Field Collector. The Inspection Quarantine Compliance (IQC) database is very recent and includes observations of individuals between 2019-2021. It allows for better recording of absence data at an individual level.
7. South East Regional Centre for Urban Landcare, SERCUL (2020-2021). SERCUL received a grant to manage Perth infestations of boneseed between 2020-2021. They coordinated the annual surveillance and management as part of delivering this grant. Data from their field GPS was captured in the form of waypoints, describing maturity and number of individuals and whether seed had dropped if mature plants were found.

**Lost or unretrieved data**

The City of Albany, Shire of Kalamunda and Shire of Mundaring Landcare staff have all been involved in boneseed removal in Western Australia and may have data on old devices or computers within each organisation. Staff turnover and retirements have made these data difficult to track down. While it was not possible to include such data in this synthesis, there would be merit in continuing to pursue these sources as a part of future management programs. Previous DPIRD staff now long retired evidently also have recorded boneseed locations which were kept offline in *ad hoc* databases. Furthermore, DPIRD FIS data between 2015-2018 was requested but not provided, however functional summaries of these data were interpreted with clarification from DPIRD staff.

**References**

Cherry H (2010) Western Australia Boneseed Eradication Strategy. Unpublished Report. 23 p