

Geraldton carnation weed

Euphorbia terracina

Draft strategic plan for the Swan NRM Region

December 2009



Department of
Environment and Conservation



ACRONYMS

DEC – Department of Environment and Conservation
DAFWA – Department of Agriculture and Food Western Australia
SCC – Swan Catchment Council
SRT – Swan River Trust
LGA – Local Government Authority
NRM – Natural Resource Management
IBRA – Interim Biogeographic Regionalisation of Australia
SERCUL – South East Regional Centre of Urban Landcare WA
NHT – Natural Heritage Trust
EWAN – Environmental Weeds Action Network

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Cover photographs: left to right: mass flowering of Geraldton carnation weed (K. Bettink), invasion of edges of Lake Walyungup in Rockingham Lakes Regional Park, ant feeding on nectar (K. Brown) and foliage (K.Bettink).

FOREWORD

Geraldton carnation weed or false spurge (*Euphorbia terracina*) is a short-lived perennial herb of the Mediterranean, now naturalised in Western Australia. Despite given the name Geraldton carnation weed, it occurs in extensive areas from north of Geraldton across the south-west corner to Cape Arid near Esperance. Large, widespread populations occur in the western portion of Swan Natural Resource Management (NRM) Region, or Swan Coastal Plain, which is also home to the majority of the State's population.

Geraldton carnation weed is predominantly found on well-drained sandy calcareous soils on road sides and degraded bushland, but it also has the ability to successfully invade intact coastal heath, coastal shrublands, wetlands and tuart woodlands. With rapid rates of growth, prolific seed production and the ability to form thickets which compete with native species, the weed presents one of the most serious threats to the biodiversity of the Swan NRM Region and beyond.

Although already widespread in the region, Geraldton carnation weed has the potential to further increase in extent and abundance, both inside and outside its current range. The result would be further severe impacts on local native flora, fauna and plant communities.

Managing the weed and its impacts presents major challenges. While some infestations are small and localised, many are widespread and threaten sites with significant biodiversity value, such as those containing rare or endemic species. Currently it is not declared plant in Western Australia, so there is no legal requirement for infestations to be eradicated. As with many other weeds, it occurs across a range of tenures, making communication, coordination and cooperation integral to implementing an effective management program.

This strategy has therefore been developed to guide the management of Geraldton carnation weed on a regional scale. It aims to facilitate, encourage and provide support to regional and local efforts to reduce the impacts of Geraldton carnation weed and raise awareness among land managers and the public. This objective will be met through an asset-based protection approach to management. The priorities will be controlling, containing and/or eradicating infestations which threaten high biodiversity assets. Providing appropriate resources to achieve this goal will help provide long-term protection of the region's biodiversity.

This strategy is designed to be an evolving document as more knowledge and understanding of the weed comes to light. It provides information on Geraldton carnation weed:

- biology and ecology
- current distribution
- impacts and threats
- best practice control methods
- guidelines for management

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1. CONTEXT AND PREPARATION OF STRATEGY

This strategy has been developed as an outcome of a Natural Heritage Trust-funded Invasive Environmental Weed Project for the Swan NRM Region. The project forms part of the 2006-2008 Swan Catchment Council (SCC) Investment Plan and is being completed by the Department of Environment and Conservation (DEC). Among the project's outcomes are the development of strategic plans for six of the region's high priority environmental weeds, including Geraldton carnation weed. Each of the species presents a major threat to the region's rich biodiversity values. The six species represent a range of life forms and different management objectives and approaches, so the plans could be used as models for other environmental weeds in the region and beyond.

2. AREA COVERED

This strategy centres on the Swan NRM Region in the southwest of Western Australia. It is made up of the Swan and Jarrah Forest Interm Biogeographic Regionalisation of Australia (IBRA) regions and numerous, overlapping management boundaries. These include NRM sub-regions, DEC regions and districts and Local Government Authority (LGA) boundaries, as shown in Figure 1.

3. DESCRIPTION

Taxonomic relationships

Geraldton carnation weed belongs to the genus *Euphorbia* in the Euphorbiaceae or 'spurge' family. Euphorbiaceae is one of the largest plant families in the world and includes around 300 genera and 7,500 species, with around 870 of these species regarded as succulent (International Euphorbia Society 2008).

In the Euphorbiaceae family, *Euphorbia* is a complex and diverse genus made up of about 2,160 species. Unsuccessful attempts have been made to sub-divide the genus into smaller genera. Euphorbia species are primarily found in the tropical and sub-tropical regions of Africa and the Americas but also in temperate zones worldwide. They are annual or perennial herbs, woody shrubs or trees with fine or thick and fleshy or tuberous roots. Many species are more or less succulent, thorny or unarmed. The stipules are mostly small, partly transformed into spines or glands, or missing. Many species have caustic milky latex that exudes when cut (Wikipedia 2008).

All Euphorbiaceae have unisexual flowers and in the *Euphorbia* genus these are greatly reduced and grouped into cyathia called pseudanthia. There are also monocious species (with male and female flowers on the same plant) and dioecious species (Watson and Dallwitz 1992).

Geraldton carnation weed features

Geraldton carnation weed or *Euphorbia terracina* derives its name from the Italian coastal town of Terracina, where it occurs in the surrounding sandhills. Its common name is a reference to its growth in the Geraldton region of Western Australia, with the similarity of its leaves to those of the carnation. It gets its other common name 'false caper' due to its similarity in appearance to the 'true caper', *Capparis spinosa* (Parsons and Cuthbertson 1992).

Geraldton carnation weed is an erect or ascending short-lived perennial herb growing up to 1m high. It has a robust vertical taproot with horizontal lateral roots at several levels. Stems are green to reddish, glabrous, erect or ascending, slender, 20 to 80cm long, unbranched at first but dividing into four to five primary flower stems. It exudes a milky white sap when cut or damaged. Leaves are bright green and are alternate, sessile, narrowly linear-lanceolate, 1.5 to 4cm long (Parsons and Cuthbertson 1992).

In south-west Western Australia, it flowers mainly from August to November, however, flowering periods may vary depending on the season and microclimates. Flowers are green, cup-shaped, and are subtended by a pair of large bracts in the forks and at the tips of the branchlets of the inflorescence. Each cup contains eight to 15 single stamen male flowers and a solitary female flower with three exerted styles. Fruits are a smooth three-lobed capsule, 3 to 5mm long. The seed is smooth, broadly ovate, about 2mm long with a fleshy auricle at one end. Fruits open explosively upon ripening (Parsons and Cuthbertson 1992).

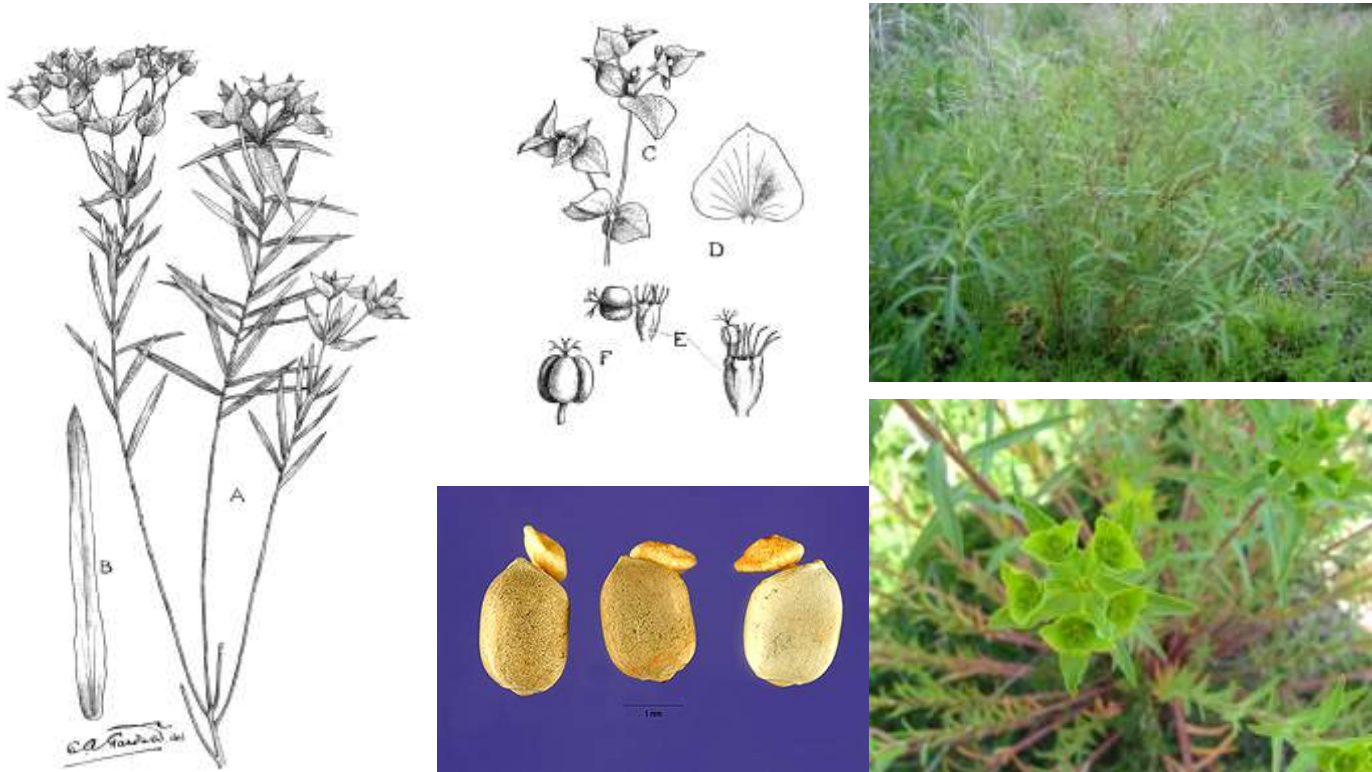


Figure 2 (left to right): Illustration of Geraldton carnation weed with labels representing (A) habit of plant and (B) leaf, (C-F) various detail of flower parts and fruit (illustrations by C.A. Gardner, reproduced from Meadly 1965), close-up of seed (Photo by Carole Ritchie @ USDA-NRCS PLANTS Database), vegetative form and inflorescence (Photos: K.Bettink).

Similar species - native and exotic

In Western Australia, out of a total of 44 *Euphorbia* species, there are 30 native species and 14 alien species (WA Herbarium 2008). These are not restricted to the south-western corner but occur evenly throughout the State. Geraldton carnation weed does not closely resemble most native *Euphorbia* species, however, it is similar to several of the other introduced herbaceous *Euphorbia*, particularly in the seedling/juvenile phase. It bears particular close resemblance and often co-occurs with the common petty spurge (*E. peplus*) and sea spurge (*E. paralias*) found on coastal shorelines and dunes (Hussey *et al* 2007). These two species, as well as asthma plant (*E. hirta*) are major widespread environmental weeds (Keighery and Keighery 2007).

4. HISTORY OF INTRODUCTION AND SPREAD

Many *Euphorbia* species are grown as ornamentals throughout the world, for example Poinsettia (*E. pulcherrima*). Several species are used in traditional Chinese medicine or for various other herbal treatments, particularly involving the skin (Wikipedia 2008). While many other *Euphorbia* species have been valued and propagated throughout the world as ornamentals, no evidence for this was found in relation to Geraldton carnation weed, indicating that it was potentially introduced accidentally into Australia.

5. HABITAT AND DISTRIBUTION

Native range

Geraldton carnation weed is native to the Mediterranean region, where it prefers well-drained, coastal sandy soils and a warm temperate climate with winter dominant rainfall (Parsons and Cuthbertson 1992). In Northern Africa it occurs in Algeria, Egypt, Morocco and Tunisia. It is found in temperate areas of western Asia including Cyprus, Israel, Jordan, Lebanon, Syria and Turkey and south-eastern and south-western Europe including Albania, Greece, Italy, Yugoslavia, France, Portugal and Spain (USDA *et al* 2008).

Outside its native range

Outside its native range it has been recorded as naturalised in Australia and more recently in Pennsylvania and California in the United States. The first recorded population was from disturbed coastal area in the Solstice Canyon in the 1980's, and from there populations increased gradually throughout the region. From 2005, populations have been observed to rapidly expand and large scale movement has occurred, with populations now being found in other coastal and inland areas of California. It is found colonising a wide range of habitats including coastal scrub, grasslands and chaparral edges, both in cool, wet areas as well as hot dry areas (Brigham 2006). It is declared a noxious weed in the State of California and is listed on the US state noxious weed list (USDA *et al.* 2008).

Australia

Geraldton carnation weed has a much longer naturalised history in parts of southern Australia, where it was introduced during settlement. It was introduced in the early South Australian settlement in the coastal sand dunes of Adelaide, where it spread slowly along the coastline, peninsula and along the Murray River to north-western Victoria. Smaller scattered infestations were most likely the result of later introductions near Portland, the north-east of Victoria and the south-west plains of New South Wales (Parsons and Cuthbertson 1992).

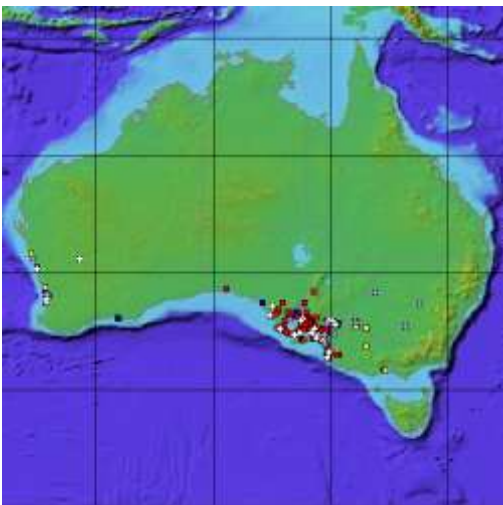


Figure 3: Current distribution of Geraldton carnation weed in Australia (Australia's Virtual Herbarium 2008).

Geraldton carnation weed is now common along roadsides and other degraded areas in coastal sites in South Australia, Victoria, New South Wales and southern Western Australia. These sites have typically sandy soils with high calcium carbonate content (Parsons and Cuthbertson 1992).

Infestations have also been uncovered in Queensland and the Australian Capitol Territory. In total, there are over 400 herbarium collections of Geraldton carnation weed Australia-wide, most of these being from South Australia and Western Australia (Australia's Virtual Herbarium 2008). Geraldton carnation is a serious problem in South Australia where it has been a declared plant for some time (Government of South Australia 2005).

Western Australia

In Western Australia Geraldton carnation weed is present on sandy coastal soils north of Geraldton across the south-west to Esperance (Figure 4.1). It was noted as common around Geraldton in 1914, although the first herbarium record is from Geraldton in 1919 (WA Herbarium 2007). Most populations are concentrated around the Perth region and Geraldton, with isolated outbreaks around Esperance, Bunbury and near the south-west capes. It has been spreading slowly south and east over the past 60 years and has been predicted to spread further over the next 50 years (Keighery and Keighery 2007). Although the species prefers sandy calcareous soils, it is known to spread onto fertile inland soils in eastern Australia (Parsons and Cuthbertson 1992) and several inland populations have been recorded in Western Australia (WA Herbarium 2008).

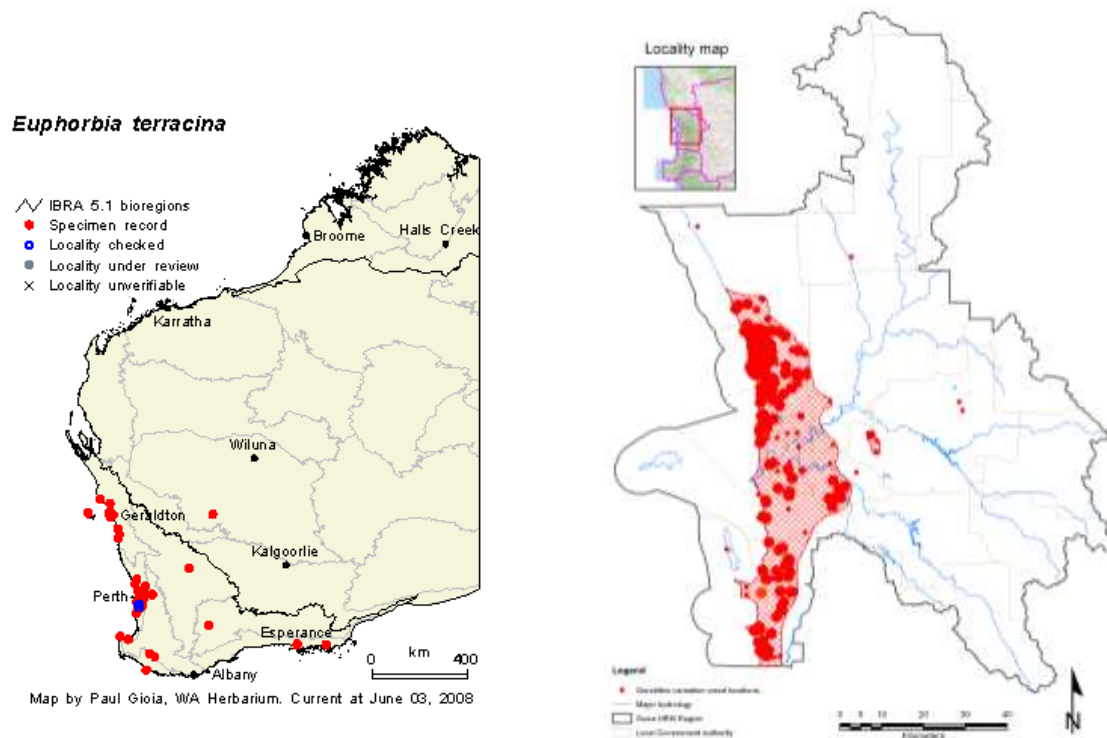


Figure 4.1: Left; state-wide distribution of Geraldton carnation weed based on Herbarium records (Western Australian Herbarium 2007) and Figure 4.2: right; distribution in the Swan NRM Region.

Swan NRM Region

Geraldton carnation weed occupies a vast area of the swan coastal plain, which makes up the Perth metropolitan area in the Swan NRM Region of Western Australia (Figure 4.2). The true extent is

difficult to accurately assess, as the species is widespread and abundant and full survey would be difficult and time consuming. However, it is clear from data collated from herbarium records, reserve assessments and observations that Geraldton carnation weed is abundant and widespread on the western coastal plain from the south of the region (Golden Bay and Stakehill) to the north (Burns Beach and beyond).

Fewer populations are found on the eastern coastal plain, Darling Scarp and Plateau, however, there are significant clusters in the City of Gosnells and Kalamunda, and satellite populations in Mundaring and Gingin to the north-east. Recent infestation has been discovered on Garden Island, introduced from soil from the mainland (Keighery 2007).

Infestations range from large, high density populations to scattered or small clusters of plants. Populations are commonly found on road verges, wasteland, paths, firebreaks and bushland of varying condition. Examples of habitats readily invaded by the weed are shown in Figure 5.

Keighery and Keighery (2007) listed the following plant communities as being currently invaded:

- coastal dune heath
- limestone heath
- acacia shrubland
- tuart woodland
- banksia woodland
- ephemeral wetlands.

Entry into bushland seems to be via disturbance events such as by fire, soil disturbance, movement of contaminated limestone and grazing. Its spread has been enhanced by soil movement and disturbance associated with fragmentation of urban bushland and formation of new roads. It appears to rapidly spread in and between sites along roadways and move inland from the coast via roads and movement of soil, particularly limestone. This is well-illustrated in a Guildford population, established by the dumping of contaminated soil and limestone (Figure 6).

6. BIOLOGY AND ECOLOGY

Geraldton carnation weed is a short-lived perennial herb growing up to a metre in height from a basal woody stem. It loses most of its leaves during summer and the stems die back to the woody base. Although some plants may be killed in extreme fires, many are able to resprout from the woody bases following fire. They have also been shown to resprout readily when cut or grazed (Ventura County Resource Conservation District 2007).

It produces new stems from the crown and base in the following Autumn. Mature plants are then a mixture of last year's fruiting stems and new seasonal vegetative growth. The older stems may continue to flower as the current seasons stems later develop new inflorescence (Parsons and Cuthbertson 1992).

Seeds germinate in late summer and autumn with flushes of germination following autumn rain and the resulting plants growing during winter. Seeds may germinate with other heavy rain throughout the year. Seedlings can mature in several months, producing several stems from one crown. In late winter each of these stems can form an umbel of four to five primary branchlets, which then branch repeatedly to form numerous pendulous flowering branchlets (Parsons and Cuthbertson 1992). Even small plants are able to flower and set seed any time following rain (Brown and Brooks 2002).

Table 1: Calender of Geraldton carnation weed biology and management.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Growth												
Flowering												
Seed production												
Germination/resprouting												
Physical removal												
Herbicide application												

In Western Australia, flowering starts in spring from August through to November. Plants may continue to flower beyond this time if conditions remain suitable, with flowers and mature fruit regularly occurring on the one plant (Parsons and Cuthbertson 1992).

Flowers are yellow-green, lack petals and are displayed in a large compound head of small inflorescence known as cyathia, which are made up of male and one female flower enclosed by bracts forming a cup shape. Nectary glands are found at the junctions of the bracts and are visited by a range of small to medium-sized insects, including native and European bees, flies, wasps and ants. As well as being a generalist insect pollinated-species that out-breeds, it is also capable of self-pollination (Keighery 2007).

Hard-coated seed occurs in locules of three per fruit, and are 3 to 5mm long with a white oily aril (Brown and Brooks 2002). These seeds are released explosively when fruits ripen. Prolific numbers of seed can be produced over several months from October onwards. In California, seed production, has been observed to be sustained over three or more months annually in a population (Ventura County Resource Conservation District 2007). The seedbank is thought to remain viable in the soil from three to five years (Brigham 2006).

Fire response

Fire plays a significant role in the reproduction and expansion of Geraldton carnation weed, especially in bushland. Fire can stimulate mass germination of Geraldton carnation weed seedlings from the soil seed bank and provide optimal conditions for the expansion and establishment of new populations, as well as some resprouting of plants from the base. Many native coastal plant communities, particularly open coastal heathland, shrubland and grassland with previously only scattered infestations, appear to become dominated by Geraldton carnation weed once a fire passes through (Brown and Brooks 2002).

With or without fire, it has the ability to invade a range of habitats with differing levels of shade and vegetation cover. Research on the morphological traits and invisibility in southern California, Riordan *et al* (2006) found that Geraldton carnation weed is successful in both shaded and high light environments, and showed the ability to adapt morphologically to high and low light environments.

Dispersal

As in other *Euphorbia* species, local dispersal of several metres occurs by the explosive opening of ripe fruits. Longer distance dispersal occurs through seed spread by the movement of soil by machinery and vehicles involved in road construction, animals (including wild doves) and water movements along road drains, streams and other drainage lines. Disturbance and/or direct transfer of seed in soil, particularly via contaminated limestone, track construction through or next to bushland, has been a major vector of spread.

Toxicity

Like other *Euphorbia* species, Geraldton carnation weed contains a toxic milky white sap in the leaves and stems. The sap is under pressure, exuding from any wound in the plant, congealing in several minutes of contact with the air. It helps to reduce water loss by evaporation as the water is bound in the sap. It also acts as a deterrent for herbivores and aids the weeds invasion into bushland (Keighery and Keighery 2007). Although some evidence of grazing, most likely by kangaroos and/or rabbits, has been observed (Brown pers. comm. 2008). The sap is caustic and irritating to the skin and if in contact with eyes, nose or mouth can produce painful inflammation. Handling any of the spurses therefore needs to be done with caution.

7. ECOLOGICAL IMPACTS AND THREATS

Its ability to proliferate on road verges and degraded land, as well as aggressively invade intact bushland, makes Geraldton carnation weed one of the most major environmental weeds in Western Australia and the Swan NRM Region. Particular habitats at risk have been identified by Keighery and Keighery (2007) and include offshore Islands and calcareous communities throughout southern Western Australia.

It is already present in abundance throughout bushland reserves on the coastal plain, many of these include regionally significant bushland, Threatened Ecological Communities (TEC's), nature reserves, other conservation reserves, remnant bushland and areas with other significant values.

Large areas of the Swan NRM Region are already heavily infested and impacted by Geraldton carnation weed, while others have been more recently invaded or have lower levels of infestation or are at high risk of invasion.

It is well known that, once established, it is difficult to control and hard to eradicate Geraldton carnation weed, however, its ecological impacts are poorly documented and less understood. Forming thickets and a monoculture, it is capable of out competing native species for space, light and nutrients. It effectively displaces native plant species and hinders recruitment and survival of native plants. Impacts on native fauna are not understood but are likely to also be significant.

The full economic cost of managing Geraldton carnation weed in bushland throughout the region is unknown; however, some local government agencies have spent from \$30,000 to \$75,000 annually on controlling the weed. It is likely that the total cost of controlling it in the region is in excess of several hundred thousand dollars per annum.

There are likely to be other economic impacts, particularly on agriculture. The plant can be highly competitive with pasture plants and is toxic to stock, with stock deaths attributed to hydrocyanic acid. However, this is uncommon because its milky sap makes the plant unpalatable (Parsons and Cuthbertson 1992).

8. CONTROL METHODS

There are several control methods available to treat Geraldton carnation weed. Physical removal and herbicide spraying are presently the most common and effective methods, however, other treatments have been trialed, and other options such as biological control may be future alternatives (Scott 2007). Each method varies in effectiveness and the situation to which it should be applied. First knowing the distribution of infestations with accurate up-to-date maps will enable targeted control and assessment of the effectiveness of the control program.

Physical control

Parsons and Cuthbertson (1992) suggest that mechanical cultivation can be an effective control method on arable land, however, this is not an option in bushland situations. Hand removal is an effective option in the case of scattered individual plants or small infestations, particularly if plants are fruiting, as seed can be prevented from spreading and plants would not respond to herbicide treatment. Plants as young as three weeks must be completely removed with their roots or they will regrow and go on to produce the same amount of seed as an ungrubbed plant (Randall and Brooks 2000). Cutting plants at ground level at the base by hand or with a brushcutter is an alternative, although this is effective only after plants have seeded. Any material, particularly any containing flowers or fruit, should be disposed of appropriately off-site otherwise plants left on the soil surface can go on to produce seed (Brown and Brooks 2002).

There are several drawbacks to physical control. With the risk of contact with the caustic sap, personal protective equipment including safety glasses, gloves and protective clothing are essential to avoid irritation to the skin and eyes. Removal of plants can stimulate massive germination of the seedbank in cleared areas and the soil disturbance can encourage growth of other weeds or, in some circumstances, exacerbate wind erosion. Care must therefore be taken to minimise soil disturbance. Follow-up treatment of the germinated seed is highly recommended.

Herbicide control

There is limited published information on effective control of Geraldton carnation weed in native plant communities (Brown and Cullity 2007). Herbicides can give good results where physical removal is not viable and several herbicides have been trialed with varying success. They need to be suitable for use and applied appropriately in bushland.

Triclopyr, chlorsulfuron, metsulfuron methyl, 2,4-D and glyphosate may all kill plants depending on the growth stage (Randall and Brooks 2000). Chlorsulfuron has been found to be successful on young plants whilst triclopyr effective on older plants (Parsons and Cuthbertson 1992). Trials in southern California using glyphosate resulted in 100 per cent mortality of plants. However, this resulted in mass recruitment of seedlings shortly afterwards and may not be appropriate in good condition bushland (Brigham 2006).

More commonly used, metsulfuron methyl (Brushoff[®]) at 0.1g in 15 ltr of water + Pulse[®] (2mls/litre) has been found to be reasonably effective but may not kill adult plants. Mature plants can be sprayed before flowering and the current years' seedlings can be controlled at the same time. If heavy rains initiate a flush of germination a second or third control later in the season may be necessary (Brown and Brooks 2002). Recent trials using a range of herbicides in the Holocene dune swales at Point Becher, has shown promising results for controlling the weed in threatened sedgeland plant communities. Logran[®] (triasulfuron) at a rate of 12.5 g/100 L was shown to have little impact on native species but was effective at controlling the carnation weed (Brown and Cullity 2007). The effectiveness and impacts of using this herbicide in other types of plant communities is yet to be determined and requires further research.

Integrated weed management

It is likely the best approach to managing Geraldton carnation weed involves a combination of control methods and a view toward increasing resilience against reinfestation. A combination of herbicide control of plants and seedlings followed by hand removing large mature plants is often recommended. Fire can provide a window of opportunity to best control and prevent the spread of populations in bushland. Resprouting plants are accessible and receptive to herbicide and clusters of seedlings are easily targets with the reduced native vegetation cover (Brown and Brooks 2002).

Trials using a thick mulch layer to reduce germination of seed in disturbed sites and restoration areas showed it can be effective in reducing the recruitment of seedlings from the soil seed bank in the short term. This would need annual follow-up treatment as Geraldton carnation weed numbers can quickly recover to original levels (Brigham 2006).

After seeing the ineffectiveness of herbicide used alone, research was undertaken in southern California to look at the effect of native plant competition on Geraldton carnation weed, using a fast-growing coastal species in restoration planting. It was found that older plantings were able to exclude Geraldton carnation and other weeds but take three years to achieve canopy closure and suppression of the weed. Until then, a combination of herbicides and intensive hand removal was required (Brigham 2006).

Biological control

Given Geraldton carnation weed is already widespread and abundant, and has the potential to occupy an even greater area, biological control is likely to be the only option that provides a permanent and ecological form of control (Scott 2007). Early indications are that Geraldton carnation weed would be a suitable target for biological control in Australia, because it is not related to agricultural crops or native species in the same genus. Although potential agents are yet unknown, *Euphorbia* species similar to *E. terracina* have been successfully controlled elsewhere in the world using insect biological control agents. However, research is required in understanding the ecology and impacts on the environment, including the effect of its removal. Sufficient resources would also need to be made available for the process of nomination, risk assessment, release and assessment of potential agents (Scott 2007).

9. LEGISLATION

In Western Australia Geraldton carnation weed was previously declared a 'P1, P4' plant in the Albany and Esperance areas, however it no longer has this status. It may be declared a 'pest plant' in Local Government by-laws, such as those in the Shire of Gingin (Parsons and Cuthbertson 1992), but is more commonly classed as a priority weed, which has more implications for management rather than legislative control.

10. MANAGEMENT

Objective

The main objective of this strategic plan is **to reduce impacts, contain the spread and eradicate** Geraldton carnation weed at key sites, thereby protecting the region's high biodiversity value assets.

Strategy

Because Geraldton carnation weed is abundant and widespread in the Swan NRM Region, the main management strategy adopted in this plan is asset-based protection.

Targets

To fulfill the aims of the strategy, the following targets should be met within the Swan NRM Region by 2011, unless otherwise stated:

1. no nett increase in movement eastward from current containment line (Figure 7)
2. control and eradication of mature plants at selected* high biodiversity value sites.

Goals

The following goals are high priorities to meet the objectives of this strategy:

- contain spread to existing range
- control outlying populations

- exclude, control, contain and/or eradicate infestations to reduce the impacts at high priority sites (Bush Forever sites, TECs and areas with other significant attributes).

Actions to date

The following actions have been completed:

1. Review of current management and distribution of Geraldton carnation weed in the region.

Collation of distribution and abundance information was carried out using a range of sources, including herbarium records held in the Western Australian Herbarium, natural area assessments undertaken by LGAs as part of the Perth Biodiversity Project, survey from land managers and friends groups and field observations. Point data has been combined to give an overview of the regional distribution with various other data layers, which may be viewed at different scales (Figure 8 and 9).

2. Identify and prioritise susceptible sites

This step involved developing a basic prioritisation framework to identify the highest priority areas currently infested and/or at risk from invasion, shown in Table 2. As Geraldton carnation weed is widespread and abundant, rather than management based on particular populations, the strategy will focus on asset protection, the types of sites, biodiversity values (asset at risk), level of infestation and protectability. The biodiversity prioritisation has been based on the four criteria:

- | |
|---|
| <ol style="list-style-type: none">1. regional significance (Bush Forever site listing)2. threatened ecological community status3. size and condition4. other significant attributes. |
|---|

Volume 2 of *Bush Forever* (2002) has been the main source of this information, with updated information gained from DEC datasets.

4. Determined management categories

Management categories have been developed factoring in the level of Geraldton carnation weed infestation and protectability (or proximity to known infestations) to the biodiversity values. Sites are listed in the management categories also in Table 2. These management categories are:

A. Uninfested and protectable

High biodiversity value areas currently uninfested but at high risk - protect by exclusion.

B. Low level infested and protectable

High biodiversity value areas with low levels of infestation, or infestations largely restricted to boundaries, where management and eradication is feasible - manage by control and containment.

C. Infested and protectable

High biodiversity value areas with moderate to high levels of infestation but with large areas uninfested and protectable - manage by containment.

D. Infested and unprotectable

High biodiversity value areas with established, widespread and/or abundant infestations where management provides limited return on investment. Low levels of management may be undertaken to protect remaining intact/high priority areas, or the protection of other sites from invasion.

Table 2: Prioritisation framework to identify the highest priority areas currently infested and/or at risk from invasion

Management Category /site	Geraldton carnation weed extent	Geraldton carnation weed notes	Bush Forever Site number	TEC	Other values	Size HA	Overall condition (WA Government 2000)	Protectability (H=high, M=moderate, L=low)	Management strategy	Recommendations
1. Uninfested and protectable (= high biodiversity value areas currently uninfested but at high risk, protect by exclusion)										
Rottneest Island	Absent	Status unknown, no records, presumed absent			Wetlands of National Importance (WA089), tourism	1900		H	Surveillance & detection	Liaise with Rottneest Island Authority regarding current status of weed, potential survey.
2. Low level infested and protectable (= high biodiversity value areas with low levels of infestation, or infestations largely restricted to boundaries, where management and eradication is feasible, manage by control and containment)										
Shire View Hill	Isolated, uncommon	Outbreaks on hill	293	26a		268.1	Very good	H	Eradication	Continue control program
Garden Island	Isolated, uncommon	One outbreak	63	30a	Significant flora, Register of National Estate, JAMBA/C AMBA spp, EPBC Act	956.9	Very good	H	Eradication	Continue control program
Paganoni Swamp (part of Rockingham Lakes Regional Park)	Scattered, uncommon	Occurs on edges and several outbreaks within interior. Chances of invasion have increased with adjacent disturbance associated with railway construction	395		Significant flora and fauna	705.5	Very good	M	Control	Continue control program, map outbreaks, liaise with adjoining landmanagers to control source populations
Mount Henry Peninsula Bushland	Isolated, uncommon	Some edge outbreaks from road run-off, other internal outbreaks below roosting trees, most likely from bird wild doves	227		Significant flora, Register of National Estate, EPBC Act	11.9	Very good	M	Eradication	Continue control program
Kings Park	Isolated, uncommon	Spot outbreaks	317		EPBC Act	320.8	Very good	M	Eradication	Continue control program
Becher Point, Port Kennedy Scientific Park	Scattered, uncommon		377	19	Register of National Estate, EPBC Act, Nationally Important Wetland WA071	674.9	Good	M	Control	Continue control program, remap
Muchea limestone communities				Y				M		
Koondoola Bushland			201	20a	EPBC Act	123.5	Very good	M	Control	Survey and map, treat outbreaks
Landsdale Rd Bushland			199	20a	Significant flora and fauna, EPBC Act 1999	15.8	Excellent			

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3. Infested and protectable (=high biodiversity value areas with moderate to high levels of infestation, but with large areas uninfested and protectable, manage by containment)										
Shenton Bushland	Scattered		218			19.7	Good	M	Control	Treat as required
Trigg Bushland	Scattered		308	Y	Significant flora, Register of National Estate	134.6	Very good	L	Control	Treat as required
Woodman Point		Need to verify extent	341	30a	Significant flora, Register of National Estate, EPBC Act	91.7	Good	L	Containment/control	Treat as required
Burns Beach bushland		Need to verify extent	322			407.9	Excellent	?	Control?	Treat as required
Point Peron	scattered, common		355		Significant fauna	part of 107	Good	L		Treat as required
Lake Richmond, Rockingham	scattered, common	need to verify extent post wildfire	358	19	TEC-stromatolite-like community of freshwater lakes, JAMBA/C AMBA species, EPBC Act 1999	28.7	Good, localised disturbance		Control/containment	Treat as required
4. Infested and unprotectable (=high biodiversity value areas with established, widespread and/or abundant infestations where management provides moderate return on investment. low levels of management may be undertaken to protect remaining intact/high priority areas, or the protection of other sites from invasion)										
(examples only - there are many more sites that are managed locally at this level)										
Rockingham Lakes Regional Park (Lakes Cooloongup/Walyungup, Point Peron, Anstey)	Widespread, abundant	Occurs throughout	356	19	Significant flora, fauna, Register of National Estate, JAMBA/C AMBA spp, EPBC Act 1999	1617	Good, varied	L	Containment	Map, prioritise populations within sites
Bold Park	Widespread, abundant	Occurs throughout	312		Significant flora, fauna	361.7	Good to degraded	L	Containment	Prioritise populations within site
Sir Frederick Samson Park	Widespread, common	Occurs in varying numbers throughout	59		EPBC Act 1999, Significant flora and fauna	12.6	good to degraded	L	containment	Treat as required
Beeliar Regional Park (Manning lake, Spectacles, Market Garden Swamp, Lake Coogee, Mount Brown)	Widespread, common		247, 261		EPBC Act 1999, Significant flora and fauna, JAMBA/C AMBA species					
Star Swamp Bushland	Widespread, common		204		Significant flora, fauna	94.4	Good	L	Containment	

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Yanchep National Park			288		Significant flora, fauna, EPBC Act	2706	Very good	M	Containment	
Forestdale Lake Nature Reserve	Scattered									
Woodvale Nature Reserve	Scattered, common		407		Register of National Estate	35.6	Good	L	Containment	Prioritise populations within site
Yellagonga Regional Park			299		Significant flora and fauna, JAMBAC AMBA species, Nationally important wetland, EPBC Act 1999	380.9	Good	M	Containment	
Warwick Open Space Conservation Area		Recent outbreaks	202			58.1	Very good	M		
5. Protection of other areas (=infested sites such as road verges, wasteland, miscellaneous reserves, sites in poor condition, where management of Geraldton carnation weed will provide protection to other high biodiversity value areas)										
TBA										
6. Further assessment required (=high biodiversity value areas in need of further survey to determine status of Geraldton carnation weed)										
Penguin, Seal, Bird and Gull Islands and Shag Rock		No herbarium records, need survey	367		Significant flora, fauna, JAMBAC AMBA spp, Register of National Estate, EPBC Act	6.1				Survey, mapping, treat as required
State Forest 65-Pinjar plantation, Central Bushland, Yanchep			1, 127, 128, 408-11, 414, 415			456	Very good			Survey, mapping, treat as required
State Forest 65-Pinjar plantation south bushland, Nowergup/Yanchep/Neerabup						61.5	Very good			Survey, mapping, treat as required
Whiteman Park			304		Significant flora and fauna, EPBC Act 1999	1547				Survey, mapping, treat as required
Southwest link from Wilbinga to Yanchep NP			284		Tamala limestones, significant flora, fauna, EPBC Act	550.6	Very good			
East link from Wilbinga to Yanchep National Park			396		EPBC Act	480.5	Excellent			
Link between Yanchep and Neerabup NPs			130		EPBC Act	94.3	Very good			
Coastal strip from Wilbinga to Mindarie	Likely scattered infestations		397		Significant flora, fauna	404.7	Excellent			
Ningana Bushland, Yanchep/Eglinton			289			551.5	Very good			

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Link from Burns Beach bushland to Neerabup NP			323				Good			
Coastal strip from Burns Beach to Hillarys	Likely moderate to heavy infestations		325			195.3	Large range			
7. Satellite infestations (=outlying sites with Geraldton carnation weed present, targeting areas preferentially based on biodiversity values, extent of infestation and distance from main containment line)										
Mundaring		Herbarium records							Survey & eradicate	
Shire of Kalamunda									Survey & eradicate	
Bullsbrook/Gin Gin									Survey & eradicate	

E. Protection of other areas

Infested sites such as road verges, wasteland, miscellaneous reserves, sites in poor condition, where management of Geraldton carnation weed will provide protection to other high biodiversity value areas.

F. Further assessment required

High biodiversity value areas in need of further survey to determine status of Geraldton carnation weed.

G. Satellite infestations

Outlying sites with Geraldton carnation weed present, target preferentially based on biodiversity values, extent of infestation and distance from main containment line.

5. Development of recommendations

Recommendations

The following actions are recommended:

1. on ground surveys to determine the status of Geraldton carnation weed at high priority sites, including TEC's and large (over 100ha) intact bushland to north, east and south of the region where there are no historical records of occurrences
2. undertake mapping to reveal extent of remaining populations
3. develop site-based plans for high priority management areas
4. undertake strategic on-ground management of infestations at high priority areas
5. manage road verge, upstream, uphill and other source populations
6. manage human activities to limit the spread of seed and establishment of new infestations including stopping the transfer of contaminated limestone in fill and road construction
7. foster and continue to develop partnerships with land managers such as local Government
8. facilitate research into understanding the ecology and impact of Geraldton carnation weed in natural environments
9. encourage nomination as a target for biological control
10. maintain a detection and surveillance program outside the current known range and in identified protectable and uninfested areas, with a process of detecting, reporting and eradicating new infestations
11. expand research trials to assess effectiveness and suitability of select herbicides in plant communities most at risk
12. increase understanding and awareness of the weed and best practice control methods
13. keep fire and other disturbance factors out of high biodiversity value sites.

Stakeholders

A regional cross-tenure approach to managing Geraldton carnation weed means there are considerable numbers of stakeholders involved. Developing partnerships with these organisations is integral to achieving the desired outcomes of the strategy. Some of the key agencies include:

- Swan Catchment Council
- Department of Environment and Conservation
- Local government agencies
- Department of Agriculture and Food Western Australia (DAFWA)
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Main Roads Western Australia
- Department for Planning and Infrastructure
- Community members
- Water Corporation
- Friends groups
- Private landholders.

11. MONITORING AND EVALUATION

Monitoring and evaluation are key parts of measuring the successful implementation of this strategy. New information can also provide the basis to adapt the management program. After three years (July 2011), the strategy should be reviewed and evaluated against the management targets. Data needs to be recollected in 2011 to assess the change of Geraldton carnation weed in high priority sites, the spread in relation to the identified containment line and evaluate the success or progress toward management targets. Indicators to show this include:

- maps - spatial data can allow show changes in distribution at local, sub-regional and regional scales
- records of numbers of plants (separating adults, juveniles/seedlings) at key sites
- surveys for expansions in existing populations and new populations.

12. CONTACTS

Swan Catchment Council, PO Box 2206 Midland WA 6936, Phone: (08) 9374 3333.

Department of Environment and Conservation, Swan Region, PO Box 1167 Bentley Delivery Centre, Bentley WA 6983, Phone (08) 9423 2900.

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City of Armadale

City of Gosnells

City of Cockburn

Shire of Mundaring

City of Rockingham

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13. FIGURES AND TABLES

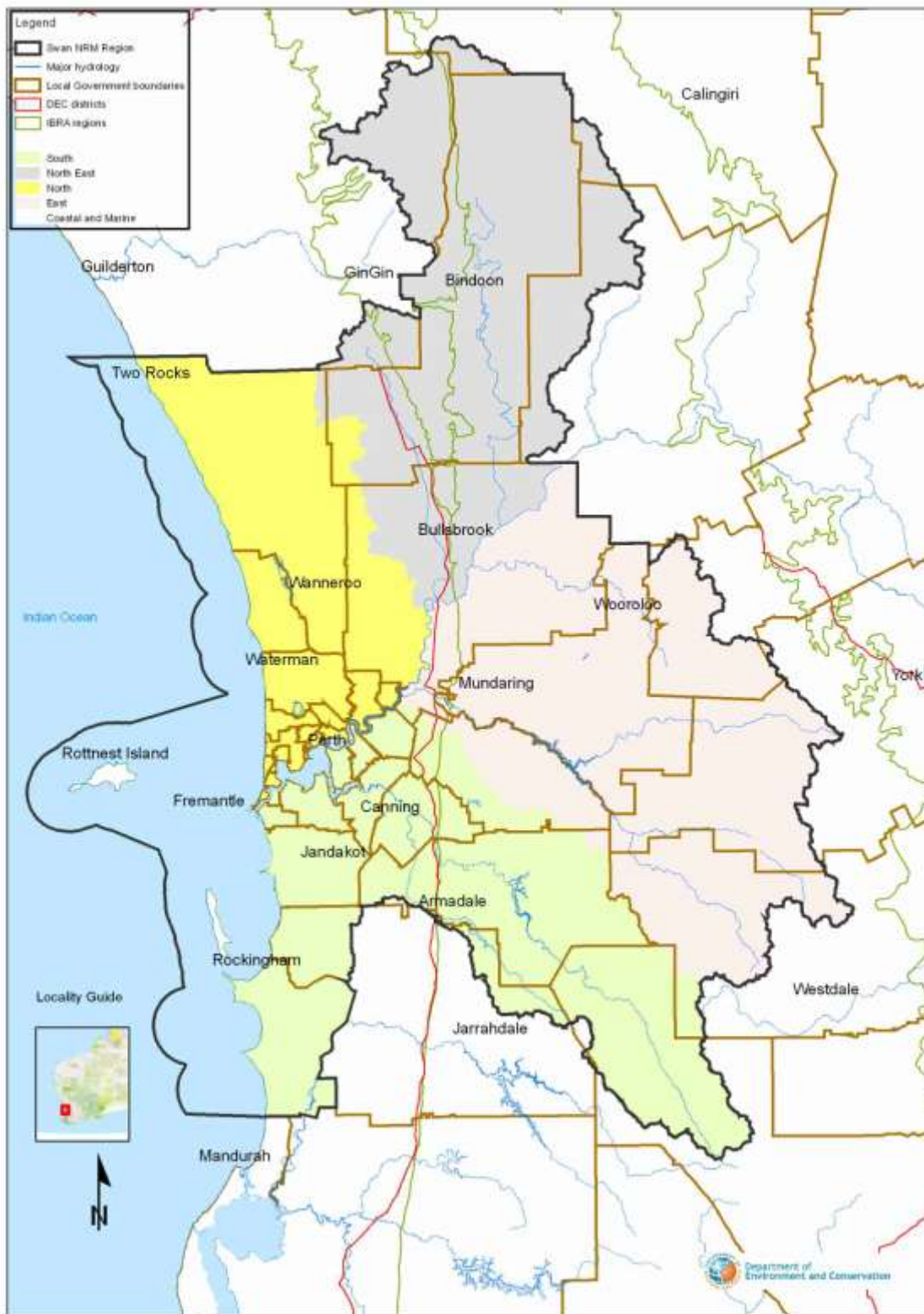


Figure 1: Map of the Swan NRM Region, showing NRM sub-regions, DEC regions, districts and Local Government Authority boundaries.



Figure 5: Types of habitat invaded clockwise from top left ; tuart woodland south of Rockingham; two images of sedgelands in dune swales; limestone heathlands near Wanneroo and exposed, disturbed road verges (Photos: K. Brown and K.Bettink).



Figure 6: soil mixed with limestone dumped at a site near Guildford has led to a new population establishing well outside of its original range (photo: K.Bettink).

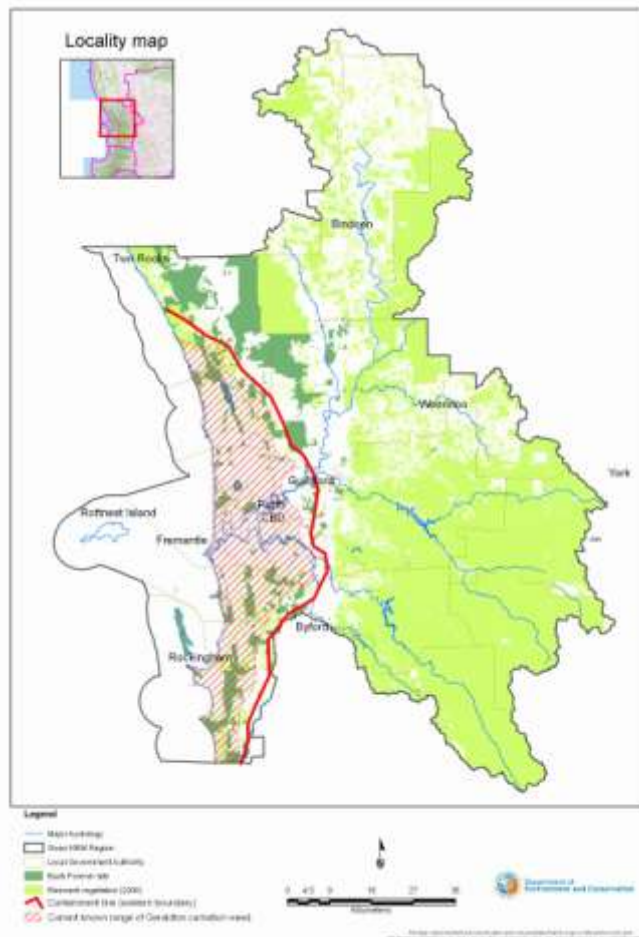


Figure 7: Regional containment line for Geraldton carnation weed.

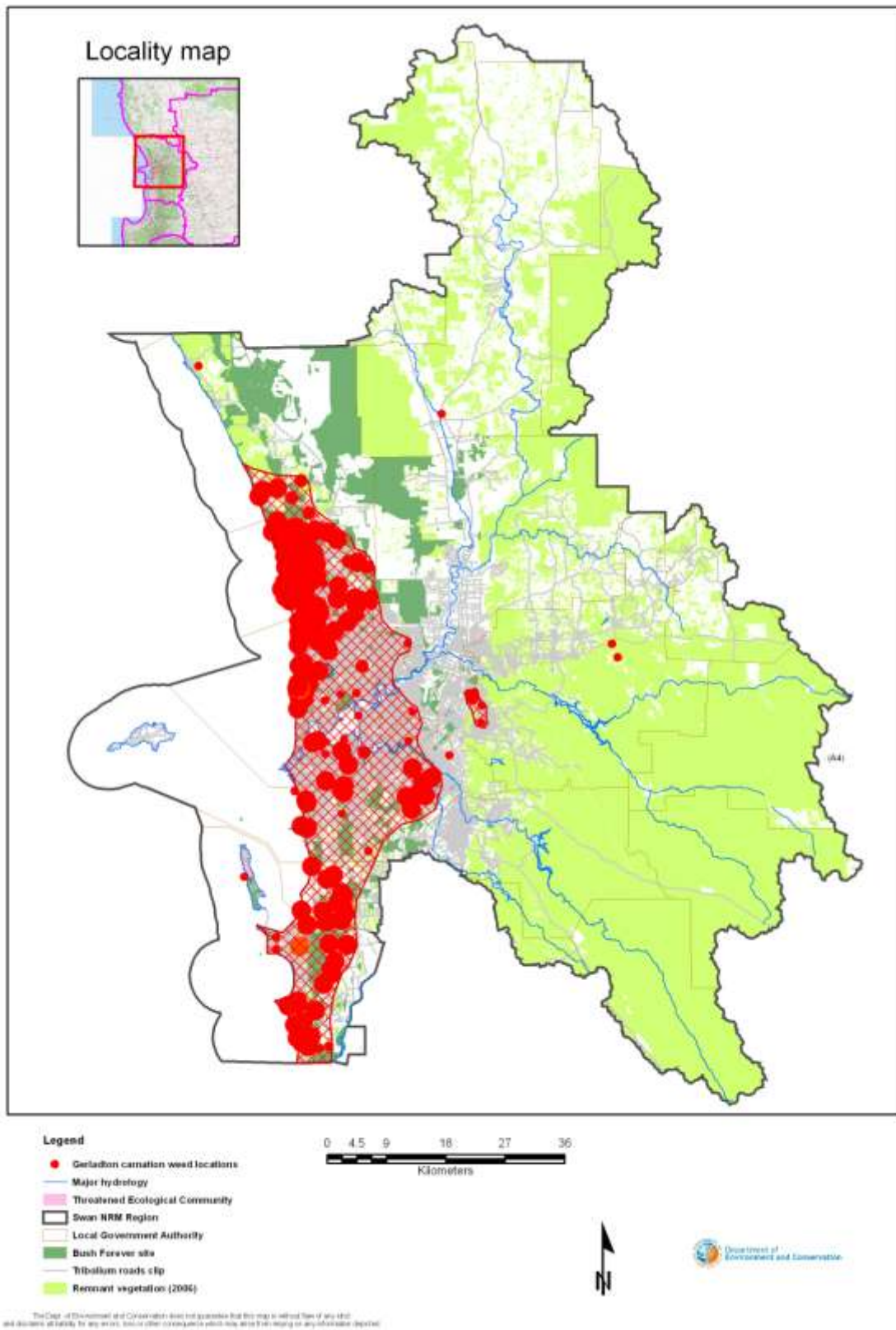


Figure 8: Distribution of Geraldton carnation weed in the Swan NRM region, showing regionally significant bushland, remnant vegetation, major hydrology and sealed roads.

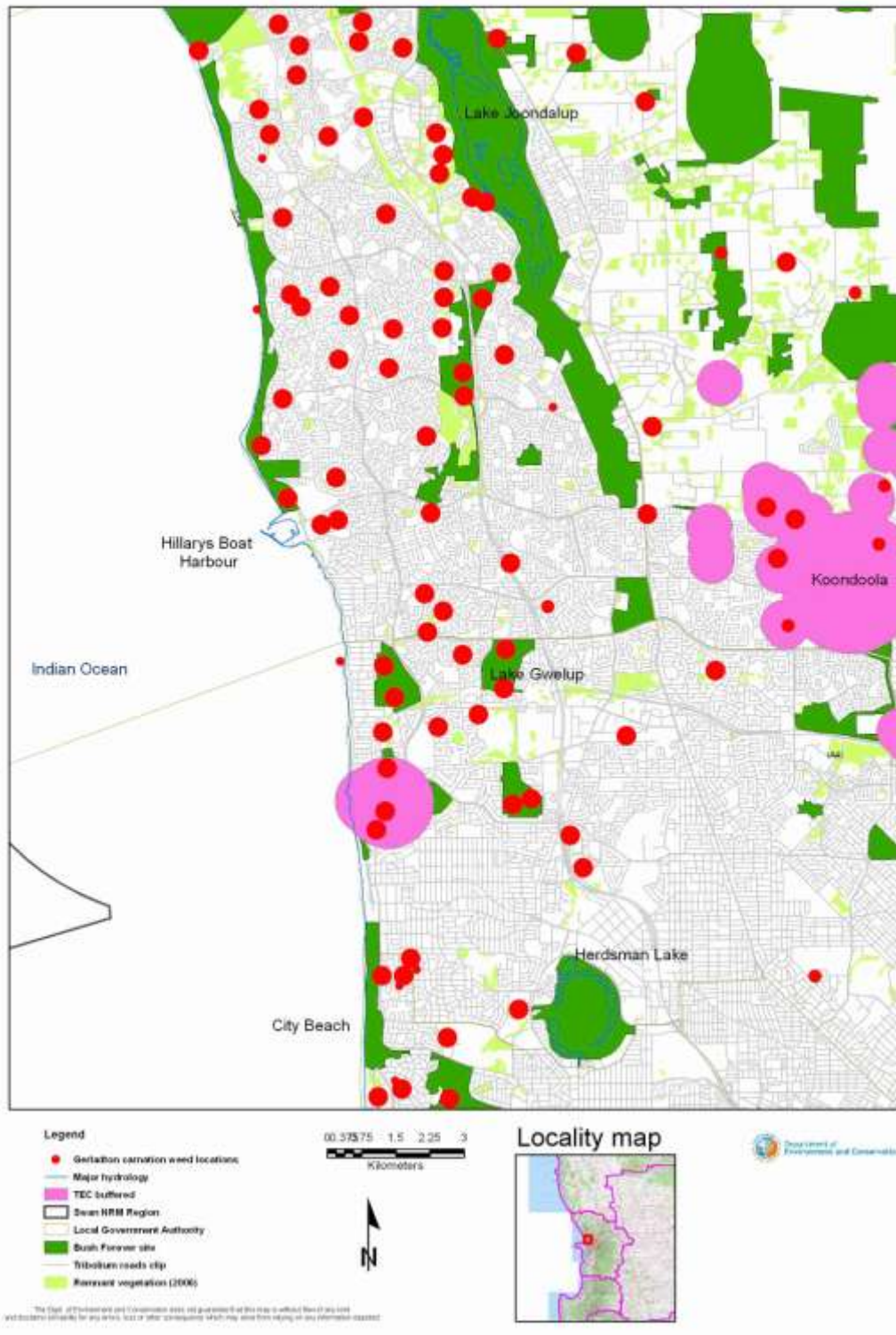


Figure 9: Example of detail of Geraldton carnation weed distribution in the north west of region, based on herbarium collections (WA Herbarium 2006), local Government survey data (WALGA/PBP undated) and recent survey.

