Landscape transformations following blackberry decline in the south-west of Western Australia: successful restoration or back to blackberry?

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Summary In recent years there has been a rapid decline in blackberry (*Rubus anglocandicans* A.Newton) populations along waterways within the Warren Catchments region located in the south-west of Western Australia. The soil pathogen, *Phytophthora bilorbang* S.Aghighi, G.E.S.J.Hardy, J.K.Scott & T.I.Burgess, is thought to be instrumental in the decline of these populations. For most waterways in the region, blackberry has dominated the forest understorey for decades. Consequently, the weed's rapid decline typically results in areas of bare soil or grassed landscapes lacking structure.

The blackberry decline created the opportunity to access and restore what were previously often inaccessible but, with the exception of blackberry, fairly pristine landscapes. However, the post-decline absence of blackberry plants within impacted populations is not absolute; scattered individuals persist. Moreover, the decline is not known to impact on what could be a significant blackberry seedbank. Without intervention to restore the landscape, therefore, new blackberry individuals or other weed species could just replace the previous blackberry infestations.

Consequently, a follow-up restoration project is underway to increase the resilience of the post-decline community to future weed invasion, including possible blackberry re-invasion. Here we outline the efforts being undertaken to understand these threats and to encourage the successful restoration of these areas within the Warren Catchments region.

Keywords Biological control, blackberry, community resilience, decline, *Phytophthora bilorbang*, restoration, *Rubus anglocandicans,* seed ecology, weed management.

INTRODUCTION

'Blackberry' comprises numerous species of which *Rubus anglocandicans* A.Newton (Rosaceae) is the most widespread and weedy in Australia, being found across all of temperate southern parts (Evans and Weber 2003). It is also the dominant weedy species of riparian areas in the Donnelly and Warren Catchments of south-west Western Australia, an area targeted for ecosystem restoration.

Blackberry can normally be effectively suppressed within accessible agriculture grazing systems especially if grazing can be integrated with herbicide and/or physical control methods. However, control is usually difficult and expensive within native ecosystems as the risk of off-target negative impacts on native flora or fauna limits control options, access for chemical/physical control is usually difficult and ongoing control is usually required (Adair and Bruzzese 2006). As such, very large blackberry infestations in native vegetation and rugged terrain remain untreated in Australia. In addition, blackberry is a riparian species and its presence on water courses makes chemical control more difficult. Riparian ecosystems are also known to favour alien plant invasions due to naturally higher levels of disturbance (which is associated with decreased competition and increased light and nutrient availability) and because water flow provides an effective method of rapidly spreading weed propagules (Richardson *et al.* 2007). For all of these reasons, biological control is considered to be the preferred strategy for controlling blackberry in Australia (Adair and Bruzzese 2006, Aghighi *et al.* 2012, Morin *et al.* 2006).

In 2004, eight European strains of the leaf-rust fungus, *Phragmidium violaceum* (Schultz) Winter were approved for release in Australia to improve prospects of biological control over a wider range of blackberry taxa over a broader range of habitats, relative to the two rust fungal strains introduced in the 1980–90s, which were effective but only in localized areas (Adair and Bruzzese 2006, Morin *et al.* 2006). Whilst conducting impact assessment and integrated control trials as part of the *P. violaceum* biological control release program, patches of 'blackberry decline' were discovered, where populations of mature

R. anglocandicans, hereafter referred to as 'blackberry', suddenly collapsed at a rate far greater than expected from the leaf-rust alone (Yeoh and Fontanini, unpublished). The areas of decline were subsequently mapped and the phenomenon considered to be a result of a combinations of stresses but in which the oomycetes *Phytophthora bilorbang* and '*P. cryptogea*' (but which, following DNA sequencing, is now believed to be *P. pseudocryptogea* T. Burgess pers. comm.) were consistently found associated with affected plants (Aghighi *et al.* 2014).

The blackberry decline appears to be highly specific with no other plant species recorded as impacted by the decline in any of the locations examined (Aghighi *et al.* 2014). The rapid demise of the thick blackberry infestations (previously the dominant forest understorey species) has, however, significantly altered the vegetation structure of the riparian zone. This situation is known to potentially also negatively affect ecosystem function, including riverbank stability, water quality and animal assemblages (Richardson *et al.* 2007). The newly created space, therefore, is vulnerable to future weed dominance once again (Cherry *et al.* 2006).

The aim of our project was to increase the resilience of riparian ecosystems within the Donnelly and Warren catchments, Western Australia. Approximately 25% of the area being actively restored by a large restoration program in the catchments are those where blackberry decline has occurred. These areas (Figure 1) will be the focus of this paper, while the remaining areas have been degraded primarily by grazing and other farming practices and will be discussed elsewhere.

Richardson *et al*. (2007) lists five main management actions that relate to biotic components of riparian environments and that are potentially available for facilitating the restoration of these plant communities affected by alien plant invasions

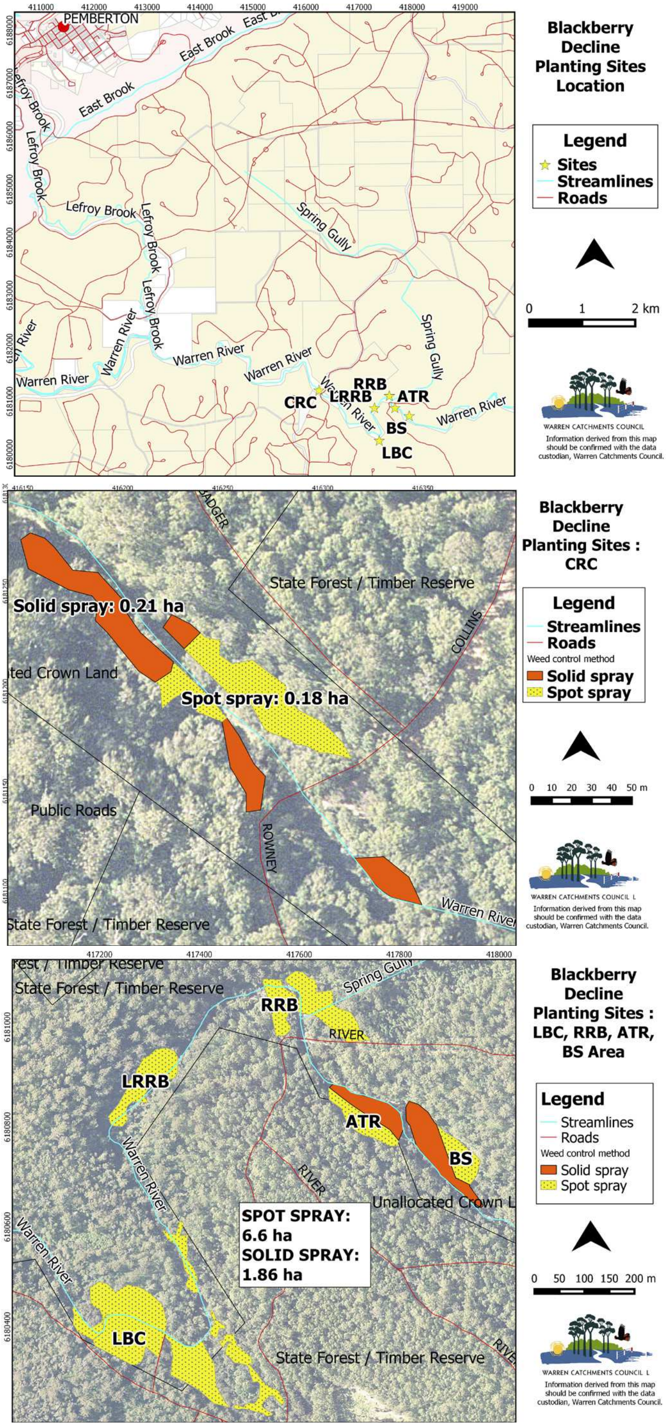

Figure 1. Location of decline sites under restoration in south-west Western Australia and their spray regimes. Collins Road Crossing (CRC), Log Bridge Crossing (LBC), River Road Bridge, (RRB), Andy T. Russell's site (ATR) and Billabong Site (BS).

(numbered i to v in the following discussion section). We will discuss our strategies addressing these and similar actions.

RESULTS AND DISCUSSION

i) Clearing the alien stands In regard to blackberry; only one of the sites where native vegetation is currently being restored was surveyed prior to and then after their decline (See Aghighi *et al.* 2014, Figure 1). General characteristics were, however, measured for heavy infestations of blackberry (*R. anglocandicans*) over a variety of habitats within the Donnelly and Warren catchments region prior to decline being discovered (Yeoh, Fontanini and Scott, unpublished data). As such, these metrics can be used as a general indication for blackberry population dynamics typical of the region. In general (based on site means ± SE, n = 8), densities were 5.4 ± 0.54 plants m^{-2} with 2.2 ± 0.17 canes per plant. Primocanes typically extended 2.2 ± 0.23 m from the crown but with the largest individuals exceeding 5 m reach. Basal diameters of the stems averaged 7.8 ± 0.48 mm and seed production was estimated at approximately 10,000 ± 3200 seeds per plant or 8600 ± 2000 seeds m^{-2}. One plant was estimated to have produced over 30,000 seeds within a season.

The measurement of the size of individual plants after the population had declined is currently ongoing. Most of the areas of declined blackberry thickets would now be considered to be successfully controlled if we used Adair and Bruzzese (2006) definition for a 'successful biocontrol program' (i.e: <1 plant m^{-1}, canes extending <1 m from crown and <2 canes per plant). Prior to populations showing decline symptoms, heavy infestations of blackberry typically extended 40 to 50 m from the river's edge. After populations of blackberry had declined, individuals of the size/density observed in pre-decline infestations now appear restricted to a 3 to 4 m wide zone growing on the steep banks where the plant's foliage is overhanging the river.

Within the restoration project, these individuals are being sprayed using metsulfuron-methyl ('Brush-off' at a rate 10 g 100 L^{-1}) with a vegetable oil based spreader ('Endorse' at a rate 300 mL 100 L^{-1}). This mixture has proven to have less off-target effects and to be more effective at killing the blackberry compared to mixtures containing glyphosate (see Anon 2009, case study p. 40).

Other alien species such as *Atriplex prostrata* DC. and *Cyperus eragrostis* Lam. or *C. congestus* Vahl were also common in some locations and spray trials (either cover spraying of whole areas of dense weeds or spot spraying of isolated individuals using backpack spray units) occurred at the sites (Figure 1, Table 1). The spraying of the exotic *A. prostrata* and *Cyperus* spp. was of dubious benefit as there was rapid re-establishment of seedlings (likely from soil seed bank), regardless of whether the areas were sprayed or not (Carley and Fontanini, unpublished data). A combination of spraying followed by the dense planting of suitable native species may prove to be the best option to establish a resilient native flora community to out-compete these alien species. Survival of transplanted native plants, however, did not seem to be effected by the presence of *Atriplex* as it appeared to provide physical protection that reduced detection and subsequent impacts from mammalian grazing.

ii) Control regenerating aliens by (iii) re-introducing biological control Adair and Bruzzese (2006) observed the greatest impact of *P. violaceum* upon

Table 1. Herbicide (metsulfuron-methyl) application at the various post-blackberry decline restoration sites. (Spot spraying = only target weed sprayed; cover spraying = general area containing predominantly the target weed sprayed).

Species	Spot (S) or Cover (C) sprayed				
	CRC	LBC	RRB	ATR	BS
Atriplex prostrata DC.	–	–	–	S/C	S/C
Cyperus congestus Vahl	S/C	–	–	–	–
Cyperus eragrostis Lam.	S/C	–	–	–	–
Dysphania ambrosioides (L.) Mosyakin & Clemants	–	–	–	S	–
Rubus anglocandicans	S	S	S	S	S
Rumex conglomeratus Murray	S/C	S	S	C	S/C
Rumex crispus L.	S/C	S	S	C	S/C
Setaria parviflora (Poir.) Kerguelen	S/C	–	–	–	–

plants growing in large infestations and receiving full-sun, whilst blackberry in shaded habitats and those experiencing temperature or moisture stress during summer appear to be only weakly affected. Our observations on impacted blackberry populations suggest the reduction in biomass due to the decline complex complements the control expected by the introduced leaf rust biocontrol. That is, plants showing symptoms in the declining populations were usually growing in the shade whereas healthier plants were usually overhanging the water and growing in the sun, where the leaf rust usually thrives. More recently, some of the blackberry populations impacted by the decline in 2008-13 have begun to show signs of the blackberry population recovering (Yeoh, unpublished data).

iv) Manipulate disturbance regime Motion detecting cameras have been used to monitor for the presence of exotic mammals in the study areas, with rabbits, foxes, cats, pigs, and sheep being observed. Based on observations, only rabbits were in sufficient numbers to be providing grazing pressure and they have been subjected to control measures. It was not feasible to fence restoration areas due to the presence of native herbivores such as quokkas, possums and kangaroos that also graze the same areas.

v) Seeding or planting: is it needed? Blackberry infestations are known to negatively impact upon native plant species with a 46% reduction in the richness of native plant species in areas where blackberry had invaded when comparisons were made between areas ahead and behind of invading blackberry fronts at five bushland sites within the south-west of Western Australia (Yeoh *et al.* 2006). Subsequent surveys from 10 sites found the reduction in native plant diversity remained at 46% and was associated with an average 79% decrease in native plant cover. The blackberry populations averaged 59% cover in the survey areas classed as 'post-blackberry invasion' and 1% cover in the 'pre-blackberry invasion' areas (Yeoh *et al.* 2006, unpublished data). The locations surveyed in this study were at the leading edge of the blackberry population, where the weed had probably been present for the shortest period of time (relative to other blackberry at the site but further from the edge). It could be anticipated that the weed's impact upon native plants would be even greater in parts of the infestations further in from the invading fronts.

It was hypothesized that soil seed banks of both native species and blackberry could be stimulated to germinate by cultivation and the addition of smoke water. This would deplete the weed's seed bank whilst possibly removing the need to plant/sow native species. A pilot trial (16 plots each 2.5 × 2.5 m) was set up within a blackberry decline area to test this with half the plots cultivated to a depth of approximately 10 cm (Ryobi 2 stroke cultivator) and either 0, 10, 20 or 100% strength Regen 2000 smoked vermiculite (7.5 g m^{-2}) applied to each plot.

Based on careful consideration of positive and negative outcomes for the community overall, the method was considered unsuitable because 1) the surface roots of the existing overstore plants could be excessively damaged, 2) any existing ground cover (mainly native grasses) could be disturbed/potentially injured and, therefore, the risk of erosion increased, 3) the cultivator posed a fire risk and was slow due to roots/sticks jamming the blades, 4) a significant amount of Regen 2000 smoked vermiculite would be needed to treat the whole restoration area creating logistical challenges, and most importantly, 5) there did not appear to be any significant increase in the germination of either blackberry seedlings (six total seen) or native tree/shrub seedlings. Numerous annual plants (especially chenopods) did germinate but it was not clear if this was beneficial or not to the restoration efforts (see spraying section).

The results (or lack thereof) from the smoke water pilot study supports the alternative hypothesis that the long term dominance of blackberry in understorey has suppressed native species, depleting their seed banks. The potentially low benefits from physically disturbing the soil surface does not seem to warrant the associated high costs/risks and so the idea was not pursued further. It was therefore decided that planting/sowing of native species into the areas of decline is essential.

vi) Selection process for species to plant Our aim was to maximize the resilience of the restored ecosystems by replanting multiple species in multiple height and vegetation type stratifications.

Our logistical restrictions for the restoration included 1) a general lack of knowledge of historical pre-blackberry species composition, 2) only local provenance seed required to be used for plantings, 3) unknown methods of propagation/germination for some species, 4) unavailable seed/propagules for some species ranked as high restoration priorities, 5) the susceptibility of some species to *Phytophthora cinnamomi,* which was known to be in some restoration areas, and 6) the cost of acquiring plants of suitable size/condition to confer resilient to transplant shock.

The definition of local provenance is highly variable (see Carr 2008). We relied on advice from project collaborators Drs. M. Byrne, T. Hopley and T. Macfarlane (Department of Parks and Wildlife, WA) who used the principle of planting within areas where gene flow from natural dispersal was probable. This meant plantings could occur within the same vegetation complex for several kilometres downstream of collection sites but it may be more restricted in an upstream direction. Plantings at our sites utilized 15 native species (three over-storey and three mid-storey trees/shrubs, five sedges/rushes, two grasses and two herbs) and we are currently 85% towards the anticipated final project totals (Table 2).

vii) Lessons learned a) Access problems to sites (requiring the use of a flying fox, canoes, waders, bush treks) slows planting rates and makes it difficult to use volunteers. This can significantly increase planting costs. b) Planting out required at least a season's pre-preparation (to allow for seed collection, after-ripening, germination and growing to transplant size). Local disasters (storms/disease etc) at the nursery stage can be catastrophic. We mitigated against such disasters by using several suppliers. c) Herbivores can also be disastrous. We had to trim the upper foliage off grasses just prior to planting to prevent them all being pulled out of the ground by kangaroos! d) Similarly abiotic factors (heat waves/floods) caused problems. Long range weather forecasts potentially can help planning when and where to plant so as to avoid plants being washed away or dehydrating before they have established adequate root systems, but in reality the long range forecasts are often unreliable. Again, we recommend spreading the risks by planting cohorts across years/sites.

CONCLUSIONS

When a weed species dominates habitats to such an extent that it is beyond chemical/physical control then normally biological control is seen as the most obvious viable option of control.

What is not so obvious is that within natural environments, the same issues that made the weed control difficult with chemicals/physical methods are likely to also make restoration as difficult. Furthermore, the severity of previous infestations make the need for restoration more likely. Forward planning is therefore needed to protect affected susceptible/sensitive habitats.

Table 2. Current plantings at the various post-blackberry decline restoration sites.

Species	Life form	# Individuals planted per sites					Total
		CRC	LBC	RRB	ATR	BS	
Eucalyptus rudis Endl.	*Tree (5–20 m)	100	2,900	3,630	240	1,040	**7,910**
Agonis flexuosa (Willd.) Sweet	Tree/shrub (to 10 m)	600	2,800	1,240	2,660	3,660	**10,960**
Paraserianthes lophantha (Willd.) I.C.Nielsen	Tree/shrub (1–10 m)	8,300	4,700	1,050	1,690	3,750	**19,490**
Astartea leptophylla Schauer	Tree/shrub (to 5 m)	–	–	–	–	320	**320**
Taxandria linearifolia (DC.) J.R.Wheeler & N.G.Marchant	Tree/shrub (to 5 m)	1,250	1,720	–	–	120	**3,090**
Callistachys lanceolata Vent.	Tree/shrub (1.5–7 m)	–	380	–	–	–	**380**
Carex appressa R.Br.	Sedge (0.5–2 m)	1,130	46,970	6,540	10,650	17,200	**82,490**
Carex tereticaulis F.Muell.	Sedge (0.7 m)	1,370	1,920	610	570	2,670	**7,140**
Lepidosperma persecans S.T.Blake	Sedge (0.5–2 m)	1,040	14,080	–	4,290	6,160	**25,570**
Juncus amabilis Edgar	Rush (0.3–1 m)	920	6,580	5,750	1,700	2,360	**17,310**
Juncus pauciflorus R.Br.	Rush (0.45–1 m)	6,200	23,690	3,550	7,860	10,030	**51,330**
Microlaena stipoides (Labill.) R.Br.	Grass (0.3–0.75 m)	770	3,260	–	1,860	4,950	**10,840**
Poa porphyroclados Nees	Grass (0.4–1.0 m)	–	1,450	1,360	–	–	**2,810**
Alternanthera nodiflora R.Br.	Herb (0.02–1 m)	60	250	1,390	–	1,130	**2,830**
Persicaria prostrata (R.Br.) Sojak	Herb (0.05–0.1 m)	70	–	–	–	2,100	**2,170**
Total		**21,810**	**110,700**	**25,120**	**31,520**	**55,490**	**244,640**

*Life Forms are as described Florabase https://florabase.dpaw.wa.gov.au

ACKNOWLEDGMENTS

The Australian Government's Clean Energy Future Biodiversity Fund, Warren Catchments Council and CSIRO financially supported this work. Jody Quinn and many volunteers have also helped.

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