Warrell Creek to Nambucca Heads Landscape Rehabilitation Monitoring Operational Phase Annual Report 2022/2023

Prepared by:

ECOS Environmental Pty Ltd

PO Box 641 Mullumbimby, NSW 2482

ph: 0487050005; email: andrewbenwell@bigpond.com

Prepared for:

Sandpiper Ecological Surveys, PO Box 401, Alstonville 2477, on behalf of

Transport for New South Wales, 21 Prince St Grafton, NSW 2460

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Contents

1 Introduction

Construction of the Warrell Creek to Nambucca Heads (WC2NH) Pacific Highway upgrade began in February 2015 and opened to traffic mid-2018. The project saw 19.6 km of the Pacific Highway between Warrell Creek and Nambucca Heads upgraded to a dual carriageway road.

To revegetate batters, verges and other bare ground along the new highway corridor, landscape rehabilitation treatments were carried out as described in the project's Urban Design and Landscape Plan (Roads and Maritime Services 2018a). The landscaping treatments were applied in 2016 as earthworks on different sections of the project were completed and diverted drainage lines reinstated.

To assess the results and effectiveness of the landscape rehabilitation treatments, 12 sites representing three different landscaping treatments were monitored for the first four years of highway operation, starting in Spring 2018, as required by the *Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief* (RMS 2018b) and the *Warrell Creek to Nambucca Heads Stage 2 Ecological Monitoring Program Revision C, June 2018* (RMS 2018c).

The 12 monitoring sites were first recorded during the construction phase by Geolink, as described in Geolink 2016 and Geolink 2017. Monitoring of the landscape rehabilitation sites during the first four years of highway operation was conducted by Ecos Environmental for Sandpiper on behalf of Transport for NSW (RMS).

This is the fourth and final annual monitoring report. Results are described, analysed and discussed for the whole four-year landscape rehabilitation monitoring project.

The contents of the report are set out as follows:

Section 2 describes the landscape rehabilitation treatments applied on the WC2NH project, monitoring site locations and data collection methods.

Section 3 presents the monitoring results and

Section 4 discusses the effectiveness of the landscaping treatments in achieving goals, any issues with implementation and outcome, and suggests measures to improve landscape rehabilitation outcomes in future.

The assessments and views presented in this report are those of the author Dr Andrew Benwell who has a horticultural background (Dip Hort, Burnley Vic) and a PhD in plant ecology (UNE, Armidale, NSW). Experience in the field of highway landscaping and revegetation includes reviews of draft landscaping plans and related advice for several Pacific Highway upgrade projects for RTA/RMS/TfNSW, and implementation of works including seed collection, propagation, and planting. A Discussion Paper on the use of soil seedbanks for revegetation and landscaping was prepared for the Glenugie Project in 2015 and WC2NH in 2018.

2 Methods

2.1 Landscape Monitoring Sites

Twelve locations sampling three landscape rehabilitation treatments were selected for monitoring by RMS/TfNSW (see Table 1 and Figure 1). These included five sites of the Hydromulching Seed Mix treatment, four of Bushland Reconstruction and three of Landscape Planting.

Bushland Reconstruction sites were located in the north of the road corridor (see Figure 1) adjoining forested areas where landscaping aimed to restore ecologically complementary vegetation and utilise salvaged bush topsoil containing seed of local species to assist landscaping (RMS 2018a).

The three landscaping treatments are explained in the next section (2.2)

Table 1 Monitoring locations and landscaping treatments (RMS 2018a).

No.	Location	Treatment
1	Fill 4 Embankment East – Southern Zone	Seed Mix 1 (hydroseeding)
2	Fill 4 Embankment West – Southern Zone	Seed Mix 2 (hydroseeding)
3	Cut 2 Embankment East – Southern Zone	Seed Mix 3 (hydroseeding)
4	Ancillary Area Fill 19 West – Northern Zone	Seed Mix 4 (direct seeding)
5	Fill 5 Vegetated Drainage Swale – Southern Zone	Seed Mix 5 (hydroseeding)
6	Cut 22 Embankment East – Northern Zone	Bushland Reconstruction (see note 1 below)
7	Cut 22 Embankment West – Northern Zone	Bushland Reconstruction
8	Fill 20 Embankment East – Northern Zone	Bushland Reconstruction
9	Cut 18 Embankment East – Northern Zone	Bushland Reconstruction
10	Williamson Creek	Landscape Planting (see note 2 below)
11	Stoney Creek	Landscape Planting
12	Butchers Creek	Landscape Planting

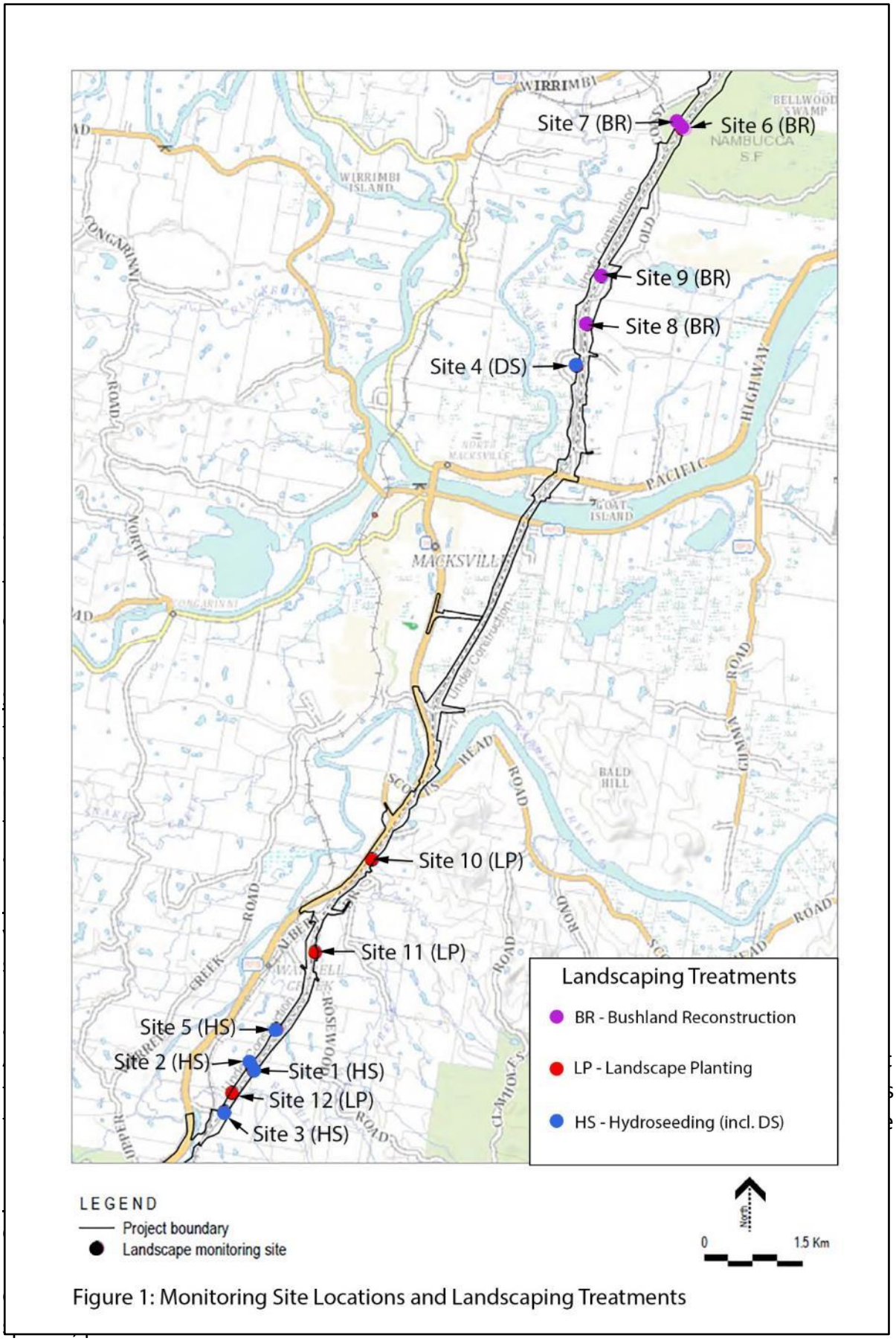


Figure 1: Monitoring Site Locations and Landscaping Treatments

2.2 Landscape Rehabilitation Treatments

Landscape rehabilitation works were implemented according to The *Warrell Creek to Nambucca Heads Upgrade Project Urban Design and Landscape Plan* (RMS 2018a), which sets out the landscaping treatments to be applied on the project as earthworks and drainage line construction were completed. Three main approaches to landscaping were applied, referred to as Seed Mix, Bushland Reconstruction and Landscape Planting (RMS 2018a), as described below.

2.2.1 Hydromulching Seed Mix

The Hydromulching Seed Mix method was the main landscaping treatment applied on the WC2NH project, accounting for more than 80% of landscaping along of the highway corridor. In this treatment, topsoil was spread over cut and fill batters and other bare ground, then a slurry of mulch and seed sprayed (hydromulched) over the ground using a high-pressure hose mounted on a tanker truck. This is the usual method of broadscale landscaping and revegetation used on highway construction projects, and varies according to soil conditions and seed mixes applied. Five different seed mixes consisting of different combinations of grass, shrub and grass species were included in the monitoring program, as indicated in Table 2.

Topsoil was salvaged and stockpiled near to where it would be reapplied to minimise haulage. It can be seen from Figure 1 that the Hydromulching Seed Mix treatment was applied in the southern three quarters of the road corridor, which traverses mainly cleared grazing land, so the topsoil salvaged would have had a high content of exotic pasture grass seed.

2.2.2 Bushland Reconstruction

Bushland Reconstruction aimed to restore vegetation consisting mainly of native species reflecting the surrounding vegetation and was implemented in the north of the road corridor closer to forested habitat and source areas of topsoil with a seedbank composed of indigenous species.

Topsoil was salvaged from bushland along the road corridor and combined with clearing mulch in the ratio of 3:2. The topsoil seedbank of native species was augmented with a seed mix consisting of Acacia species, the grasses Themeda australis and Cymbopogon refractus and pioneer natives such as Hardenbergia and Kennedia, as indicated at the bottom of Table 2. All the ingredients (i.e. topsoil, additional seed and clearing mulch) were applied over the ground surface after completion of earthworks. Topsoil and clearing mulch (i.e. course bark and wood chip material derived from trees and other vegetation put through the tub grinder during clearing) were blended prior to application and spread over the batters by

machine. The bushland seed mix was then applied to the batter via hydromulch application (i.e. a slurry of seed and mulch), with clearing mulch being used again.

Soil ameliorants were also added including Urea and Potassium (RMS 2018a), the Urea to counteract nutrient drawdown by the high C:N ratio of a 3:2 mixture of topsoil and clearing mulch.

Bushland Reconstruction aimed to reconstruct vegetation cover consisting of native species, whereas the Hydromulching Seed Mix approach aimed to establish vegetation cover appropriate to functions of highway revegetation such as landscaping aesthetics, erosion control, safety/frangibility, minimising weeds and utilising native species where possible. Key differences between the Bushland Reconstruction and Hydromulching Seed Mix methods of landscaping were the type of soil substrate formed at the treatment site and species composition of soil seedbanks in applied topsoil. Following the 'initial species composition' model of plant ecology theory, these factors determine the resultant type of vegetation established on the landscaping/revegetation sites.

2.2.3 Landscape Planting

The Landscape Planting sites were located on three drainage lines where the aim was to restore appropriate species in riparian areas along drainage lines that had been disturbed by construction works. After completion of construction, native species were planted in these areas. Although not part of the treatment, local topsoil was also present, often carrying a seedbank of exotic pasture species and weeds that strongly influenced the landscaping result.

Table 2. Landscaping treatments applied at monitoring sites – Seed Mix, Bushland Reconstruction and Landscape Planting.

(Note – Table 1 indicates the Seed Mix treatment as 'hydroseeding', although this is described below as 'hydromulching', as mulch was added to the slurry of water and seed applied, including clearing or tub-grinder mulch.)

Site	Treatment	Application	Date of application	Media	Species hydromulched/ planted
1	Seed Mix (Seed Mix 1)	Hydromulching	20/01/2016	Topsoil 100%	Indigenous grass species
2	Seed Mix (Seed Mix 2)	Hydromulching	7/04/2016	Topsoil 100%	Indigenous and exotic pasture grass species
3	Seed Mix (Seed Mix 3)	Hydromulching	20/01/2016	Topsoil 100%	Indigenous grass and shrub species
4	Seed Mix (Seed Mix 4)	Direct Seeding (tractor drawn)	7/11/2016	Topsoil 60%, mulch blend 40%	Indigenous and exotic pasture grass species
5	Seed Mix (Seed Mix 5)	Hydromulching	19/09/2016	Topsoil 100%	Indigenous grasses and sedges
6	Bushland Reconstruction	Hydromulching	2/04/2016	Bushland topsoil 60%, mulch blend 40%	BRC seed mix[1]
7	Bushland Reconstruction	Hydromulching	2/04/2016	Bushland topsoil 60%, mulch blend 40%	BRC seed mix[1]

8	Bushland Reconstruction	Hydromulching	16/09/2016	Bushland topsoil 60%, mulch blend 40%	BRC seed mix[1]
9	Bushland Reconstruction	Hydromulching	8/04/2016	Bushland topsoil 60%, mulch blend 40%	BRC seed mix[1]
10	Landscape Planting	Planting	14/11/2016	Topsoil 100%	Indigenous riparian and wetland species (planting mix code PM4C)[2]
11	Landscape Planting	Planting	12/09/2016	Topsoil 100%	Indigenous riparian and wetland species (planting mix code PM4A and PM4C)[2]
12	Landscape Planting	Planting	14/11/2016	Topsoil 100%	Indigenous riparian and wetland species (planting mix code PM4AA, PM4C, PM6 and PM7)[2]

[1]BRC seed mix made up of: Acacia longifolia @ 0.25 kg/ha, Acacia floribunda @ 0.25 kg/ha, Acacia fimbriata @ 0.25 kg/ha, Cymbopogon refractus @ 1 kg/ha, Hardenbergia violacea @ 1 kg/ha, Themeda australis @ 1 kg/ha.
[2]See GeoLINK (2017) for species list of each planting mix code.

2.3 Data Recording

To record the vegetation established by the landscape rehabilitation treatments, plant species composition was recorded on a fixed 50 m belt transect at each of the 12 monitoring locations. These transects had been set out in 2016 during the construction phase and monitoring of the transects was continued by Ecos Environmental during the operational phase, from Spring 2018.

The monitoring program (RMS 2018b) requires collection of the following data along each transect:

- Treatment percentage cover
- Braun-Blanquet cover class score
- Weed species present
- Details on plant species present (included or not included in seed mix)
- Signs of stress, predation or disease

All species on each transect were recorded and assigned a cover-abundance score according to the Braun-Blanquet scale:

1 – cover < 5% one or a few individuals;

2 - <5% more than a few individuals;

3 – 5-25%;

4 – 25-50%;

5 – 50-75%;

6 – 75-100%.

Crown cover was recorded within a 50 m long x 5 m belt transect. Photos were taken at both ends of the transect looking along the tape.

In Year 1 a slightly modified method was trialled where each 50 m transect was divided into five 10 m segments and species crown cover recorded in each segment, the objective being to increase sample number and apply statistical tests. However, the higher level of sampling did not make trends in species composition at each site any clearer, so this approach was dropped in favour of single measures of species abundance per site using Braun Blanquet cover class. The crown cover values per segment in year 1 were combined into an overall B-B cover class value per transect.

2.4 Data Analysis

Results of the three landscaping treatments were examined by comparing the species composition (species presence and abundance) and structure (height and crown cover) of landscaped vegetation established at the 12 monitoring sites and 3 treatments, at the start and end of the four year monitoring period. Species composition is compared in Summer 2018 an Autumn 2023, the first and last monitoring events when Braun-Blanquet cover-abundance was recorded. Species that increased noticeably in Braun-Blanquet cover-abundance in this period are indicated by '>' and those that decreased by '<'. The probable source/origin of seed of species showing these more marked changes in cover-abundance over the four year periods is indicated by HM, SS or S where HM is hydromulch, SS self-seeded/coloniser and S soil seedbank.

This analysis showed the dominant species resulting from each treatment and was also useful in indicating those native species with the potential to establish effectively (by rapid increase and coverage) on other highway or broadscale landscaping projects.

Ordination of site species lists was carried out for the first annual monitoring report to show how the treatments differed in species composition. Non-metric multidimensional scaling was performed on end of monitoring year species data and plotted in ordination space. This was performed in *R* version 3.6.1 (R Core Team 2019) using the *metaMDS* function of the *vegan* package (Oksanen et al. 2019). This was not repeated as species composition of the three treatments remained obviously different and the main species was the same as recorded in the first year of monitoring, although cover-abundance of these species often increased over time – see below.

3 RESULTS

3.1 SITE 1

3.1.1 Context, treatment and vegetation

Context

Fill batter; adjoins cleared grazing land.

Stake 1 coordinates	Stake 2 coordinates
490057, 6595205	490079, 6595238

Landscaping treatment

Hydromulching Seed Mix 1

Structure (vegetation height and density)

2018 – sparse shrubland 2-3 m high, canopy crown cover 30-50%, dense Setaria understory 1.5-2 m tall.

2023 – tall closed shrubland, 6-7 m high, canopy crown cover 90%, over moderately dense Setaria 1.5-2 m high

Floristics

2023 – canopy of Acacia fimbriata, understory dominated by Setaria plus other exotic herbs and grasses (see table below).

Species that increased noticeably between 2018 and 2023 included Acacia fimbriata, Cinnamomum camphora, Paspalum mandiocanum and Setaria sphacelata (see table below).

Setaria cover-abundance 6 (75-100%).

Comments

Dominance of Setaria due most likely to Setaria seed in salvaged topsoil spread onto the fill batter, sourced from, or next to, grazing land**.**

Seed mix 1 appears to have been composed of mainly Acacia species. No evidence of native grasses, shrubs or climbers in seed mix (see Table below).

Acacia longifolia and A. irrorata present in 2018, died out by 2023, while persisting at other sites (see Table below).

3.1.2 Species abundance data and photos 2018 & 2023

Site 1 – Hydromulching Seed Mix 1 treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn	Change
Acacia fimbriata	3	6	>
Acacia irrorata	2		<
Acacia longifolia	1	1	
Acacia melanoxylum			
Ageratum houstonianum			
Centella asiatica		1	
Cinnamomum camphora	1	2	>
Conyza bonariensis	1		
Kennedia rubicunda	1		
Lantana camara			
Parsonsia straminea		1	
Paspalum mandiocanum		3	>
Passiflora edulis			
Passiflora subpeltata			
Polygala multiflora		1	
Physalis peruviana		1	
Seeringia arborescens	1	1	
Senecio madagascariensis	1		
Setaria sphacelata	5	6	>
Sida rhombifolia	1		
Siratro atropurpureum			
Verbena bonariensis	1		

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - **Site 1** southern end

Autumn 2023 - Site 1 southern end

Spring 2018 - Site 1 northern end

Autumn 2023 - Site 1 northern end

3.2 SITE 2

3.2.1 Context, treatment and vegetation

Context

Fill batter; adjoins cleared grazing land.

Stake 1 coordinates	Stake 2 coordinates
490052, 6595299	490026, 6595259

Landscaping treatment

Hydromulching Seed Mix 2

Structure (vegetation height and density)

2018 – open shrubland 2-3 m high, dense Setaria understory 1.5-2 m tall.

2023 – tall shrubland to open shrubland, 4-8 m, canopy crown cover 60%; dense Setaria understory.

Floristics

2023 – canopy of Acacia fimbriata, A. irrorata and A. melanoxylon, understory dominated by Setaria plus other exotic herbs and grasses (see table below).

Species that increased substantially or noticeably between 2018 and 2023 included Acacia fimbriata, Cinnamomum camphora, Paspalum mandiocanum and Setaria sphacelata (see table below).

Setaria dominates ground layer/understory, 1.5-2 m high, cover-abundance 6 (75-100%).

Comments

Dominance of Setaria most likely due to presence of Setaria seed in salvaged topsoil spread onto batter, sourced from or next to grazing land**.**

Seed mix 2 appears to have been composed of Acacia species and a small amount of other native species (e.g. Kennedia and Pultenaea). No evidence of native grasses in seed mix (see Table below).

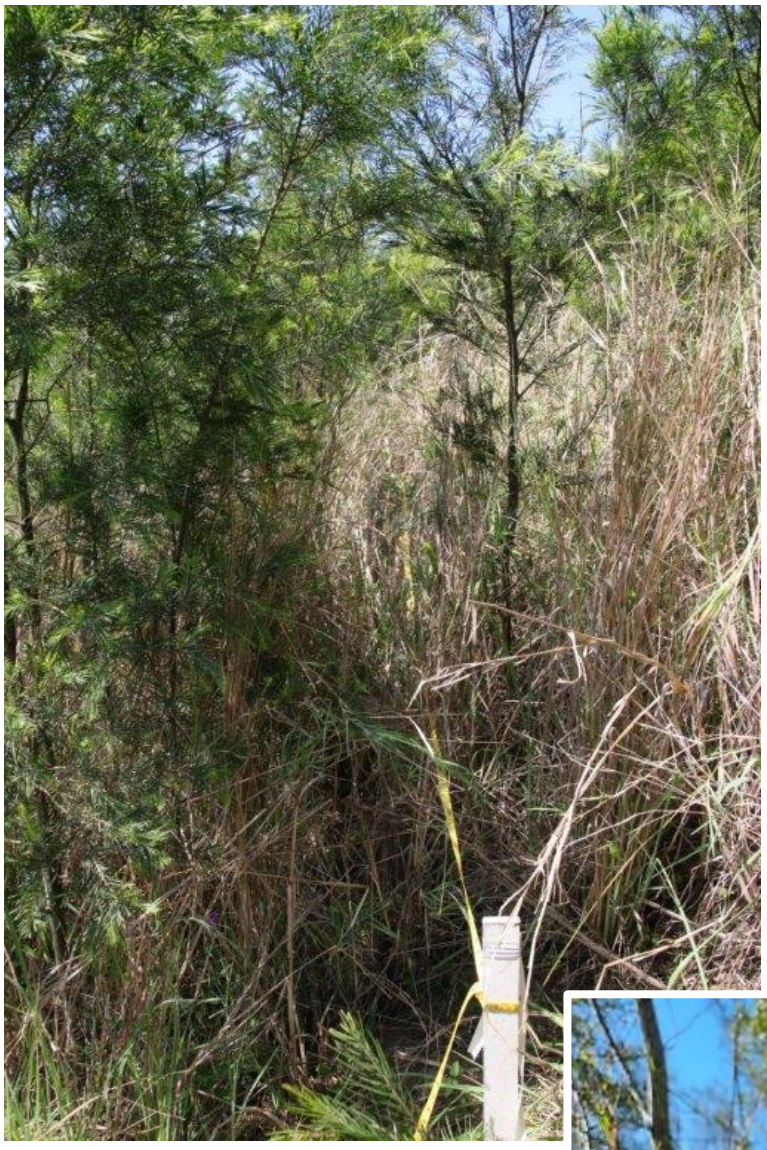
3.2.2 Species abundance data and photos 2018 & 2023

Site 2 – Hydromulching Seed Mix 2 treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn	Change
Acacia fimbriata	2	3	>
Acacia irrorata	2	3	>
Acacia melanoxylon	1	3	>
Ageratum houstonianum		2	
Alphitonia excelsa		1	
Anagallis arvensis	1		
Andropogon virginicus	1		
Billardiera scandens			
Centella asiatica	1	1	
Cinnamomum camphora		1	
Conyza bonariensis	1		
Glycine clandestina	1	1	
Grevillea banksii		1	
Kennedia rubicunda	1		
Lantana camara		1	
Paspalum mandiocanum	1	2	
Passiflora edulis	1	1	
Persoonia adenanthera		1	
Physalis peruviana			
Pultenaea villosa	1		
Setaria sphacelata	5	6	>
Senna floribunda			
Senecio madagascarensis	1		
Sida rhombifolia			
Stephania japonica		2	>
Verbena rigida			
Verbena bonariense	1		

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.



Spring 2018 - Site 2 southern end

Autumn 2023 - Site 2 southern end

Spring 2018 - Site 2 northern end

Autumn 2023 - Site 2 northern end

3.3 SITE 3

3.3.1 Context, treatment and vegetation

Context

Cut batter; adjoining mature open forest.

Stake 1 coordinates	Stake 2 coordinates
489722, 6594721	489686, 6594689

Landscaping treatment

Hydromulching Seed Mix 3; lower part of batter slashed by tractor in the second year of monitoring. (Transect runs along edge of slashed vegetation).

Structure (vegetation height and density)

2018 – sparse Acacia fimbriata 2-3 m, over dense Setaria.

2023 – unslashed - tall closed shrubland 6-8 m with emergent eucalypts.

slashed - dense Setaria grassland lower part of batter adjoining highway.

Floristics

2023 – canopy of Acacia fimbriata and A. melanoxylon, understory dominated by Setaria plus other native and exotic shrubs, herbs and grasses (see table below).

Species that increased substantially or noticeably between 2018 and 2023 included Acacia fimbriata, A. melanoxylon, Setaria sphacelata and Eucalyptus saligna (latter species self-seeded from adjoining forest).

Setaria dominates ground layer, 1.5-2 m high, cover-abundance 6 (75-100%).

Comments

Dominance of Setaria most likely due to presence of Setaria seed in salvaged topsoil spread onto batter, sourced from or next to grazing land**.**

Seed mix 3 appears to have been composed of Acacia species and a few other native species (e.g. Kennedia and Pultenaea). No evidence of native grasses in seed mix (see Table below).

3.3.2 Species abundance data and photos 2018 & 2023

Site 3 – Hydromulching/Seed Mix 3 treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn	Change
Acacia fimbriata	2	4	>
Acacia irrorata	1	2	
Acacia melanoxylon	1	3	>
Acacia longifolia	1	1	
Ageratum houstonianum		1	
Billardieria rubens		1	
Conyza bonariensis	1		
Dianella japonica		1	
Eucalyptus microcorys		1	
Eucalyptus saligna		2	>
Hakea sericea		2	
Kennedia rubicunda	1		
Lantana camara			
Macroptilium atropurpureum	1		
Paspalum mandiocanum	1	2	>
Polygala multiflora			
Pultenaea villosa		1	
Senecio madagascariensis	1		
Setaria sphacelata	5	6	>
Stephania japonica		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 3 southern end

Autumn 2023 - Site 3 southern end

Spring 2018 - Site 3 northern end

Autumn 2023 - Site 3 northern end

3.4 SITE 4

3.4.1 Context, treatment and vegetation

Context

Paddock outside highway fence on other side of a bund/sound barrier on edge of highway.

Landscaping treatment

Direct Seeding (tractor drawn) Seed Mix 4. Bare ground after construction, seeded with pasture grasses.

Structure (vegetation height and density)

Slashed grassland/paddock from first to fourth year of monitoring.

Setaria increased from a crown cover of 3 (5-25%) in 2018 to 6 (75-100%) in 2023.

Floristics

2023 - dominated by Setaria, with other common exotic weeds and herbs (see Table below). Few native landscaping trees at edge of transect.

Comment

Setaria probably grew from seed in soil disturbed by construction activities.

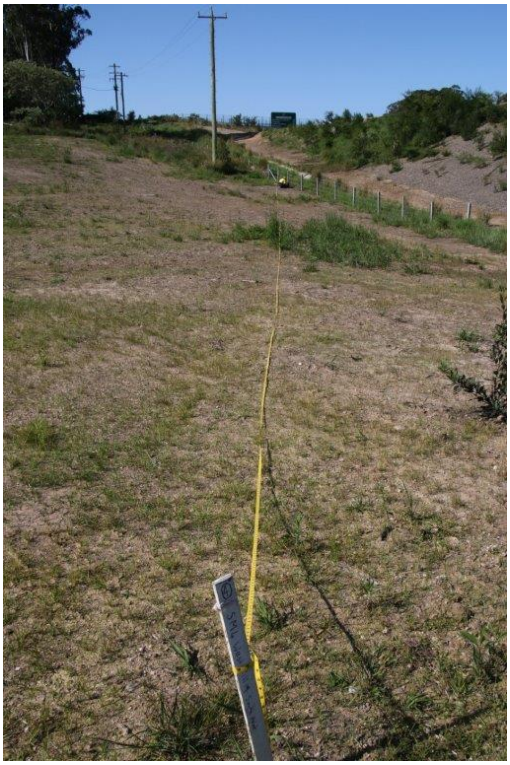
3.4.2 Species abundance data and photos 2018 & 2023

Site 4 – Direct Seeding mix 4 treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn
Acacia falcata		
Acacia fimbriata		2
Acacia irrorata		2
Acacia melanoxylon		
Ageratum houstonianum	1	2
Bidens pilosa		2
Centella asiatica	1	
Conyza bonariensis	1	
Cynodon dactylon	2	
Dodonaea triquetra	2	
Eucalyptus pilularis		1
Gomphocarpus fruticosus		
Hypochaeris radicata		
Kennedia rubicunda		
Paspalum mandiocanum	3	3
Senecio madagascariensis		
Plantago varia	1	
Setaria sphacelata	3	6
Sida rhombifolia	1	
Verbena bonariensis	1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.



Spring 2018 - Site 4 southern end

Autumn 2023 - Site 4 southern end

Spring 2018 - Site 4 northern end

Autumn 2023 - Site 4 northern end

3.5 SITE 5

3.5.1 Context, treatment and vegetation

Context

Deep drain cut into slope in cleared grazing land with scattered trees adjoining highway.

Stake 1 coordinates	Stake 2 coordinates
490383, 6595788	490359, 6595741

Landscaping treatment

Hydromulching Seed Mix 5.

Structure (vegetation height and density)

2018 - Dense closed grassland 2-3 m high.

2023 - Dense closed grassland 2-3 m high.

Floristics

Almost total Setaria, unchanged from start to end of monitoring, few established trees at start and end of transect.

Comment

Setaria probably grew from seed in soil disturbed by construction activities.

Unclear what was in Seed Mix 5. Little Acacia regeneration and no evidence of native grasses, shrubs.

3.5.2 Species abundance data and photos 2018 & 2023

Site 5 – Hydromulching/Seed Mix 5 treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn	Change
Acacia fimbriata	1	2	
Acacia irrorata	1	2	
Acacia melanoxylum	1	2	
Anagallis arvensis	1		
Centella asiatica	1		
Cinnamomum camphora		1	
Conyza bonariensis	1		
Cynodon dactylon	1		
Eucalyptus microcorys	1		
Euchiton sp.	1		
Glycine clandestina	1		
Kennedia rubicunda	1		
Lomandra longifola		1	
Paspalum dilatatum	1		
Paspalum mandiocanum	1		
Plantago varia	1		
Senecio madagascariensis	1		
Setaria sphacelata	5	6	>
Verbena bonariensis	1		

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 5 southern end.

Autumn 2023 - Site 5 southern end

Spring 2018 - Site 5 northern end

Autumn 2023 - Site 5 northern end

3.6 SITE 6

3.6.1 Context, treatment and vegetation

Context

Cut batter

Stake 1 coordinates	Stake 2 coordinates
495781, 6607729	495814, 6607767

Landscaping treatment

Bushland Reconstruction

Structure (vegetation height and density)

2018 – open shrubland, 1-1.5 m high

2023 – tall closed shrubland, 2-3 m high, emergent tall eucalypt saplings 6-8 m.

Floristics

No Setaria was recorded at this site.

High species diversity. Species that increased between 2018 and 2023 – Cymbopogon refractus (HM), Eragrostis sp. (?), Eucalyptus microcorys (SS), Ipomoea carica (SS), Lepidosperma laterale (S), Leptospermum polygalifolium (HM), Themeda australis (HM) (source/origin – HM hydromulch, SS self-seeded/coloniser, S soil seedbank).

Species that decreased between 2018 and 2013 – Acacia fimbriata (HM), Cassytha sp.(S), Dodonaea triquetra (S). These are all native species. Cassytha sp. is a parasitic vine and was very common in the second and third year of monitoring then had almost died out in 2023 (see table below).

Of five Acacia's only A. fimbriata and A. longifolia performed well.

Some native species appear to have been used in the seed mix that do not occur in local forests to the writers knowledge (e.g. Acacia elongata ssp., Callistemon sp.)

Comment

Bushland Reconstruction treatment was largely successful in establishing a diverse native plant cover. Native grasses performed well. Exotic species largely absent.

Setaria appears to be absent as only topsoil was used from weed free native forest.

Ipomoea carica (an exotic climber) is potentially a problem weed although it may not spread because of the very poor clay which is suited to natives but not exotics.

3.6.2 Species abundance data and photos 2018 & 2023

Site 6 – Bushland Reconstruction treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2020 autumn	2023 autumn	Change
Acacia fimbriata	1	2	1	<
Acacia irrorata		1		
Acacia longifolia	2	3	3	
Acacia elongata	1	1	1	
Acacia ulicifolia	1			
Ageratum houstonianum			1	
Allocasuarina litttoralis			1	
Allocasuarina torulosa				
Alphitonia excelsa				
Andropogon virginicus			1	
Babingtonia sp.		1		
Bidens pilosa			1	
Billardiera rubens	1	1	1	
Blechnum cartilageum	1	1	1	
Callistemon sp.		1	1	
Carex maculata			1	
Cassytha sp.	1	4	2	<
Conyza bonariensis		1		
Cymbopogon refractus		1	6	>
Cynodon dactylon				
Davesia ulicifolia	1			
Dianella caerulea		1	1	
Dodonaea triquetra	2	3	1	<
Doodia aspera		1		
Entolasia stricta		1	1	
Eragrostis sp.		1	2	>
Eucalyptus microcorys		1	2	>
Eucalyptus pilularis				
Eucalyptus resinifera			2	
Fimbrystylis dichotoma			1	
Gonocarpus tetragynus				
Goodenia heterophylla	1			
Hibbertia aspera			1	
Hypochaeris radicata			2	
Ipomea cairica		1	2	>
Lepidosperma laterale		1	2	>
Leptospermum polygalifolium	1	2	3	>
Lomandra longifolia		1		
Mitrasacme sp.				

Plant species	2018 summer	2020 autumn	2023 autumn	Change
Native Stipa sp.	1			
Ozothamnus diosmifolius		1		
Paspalum urvillei			1	
Persoonia stradbrokensis				
Polygala multiflora		1		
Pultenaea retusa				
Pultenaea villosa	1	1	1	
Senecio madagascarensis		1		
Sida rhombifolia		1		
Scleria levis			1	
Themeda australis	1	1	2	>

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 6 southern end

Autumn 2023 - Site 6 southern end

Spring 2018 - Site 6 northern end

Autumn 2023 - Site 6 northern end

Site 6 – Scleria levis (Winged Sedge). Site 6 near Macksville represents a new southern limit for this species according to Virtual Herbarium avh.chah.org.au/. The previous most southerly record is from Boambee (Coffs Harbour)

3.7 SITE 7

3.7.1 Context, treatment and vegetation

Context

Cut batter

Stake 1 coordinates	Stake 2 coordinates
495744, 6607783	495782, 6607824

Landscaping treatment

Bushland Reconstruction

Structure (vegetation height and density)

2018 – open shrubland, 1-1.5 m high

2023 – tall closed shrubland, 2-3 m high, emergent eucalypt saplings 6-8 m.

Floristics

No Setaria was recorded at this site.

High species diversity. Species that increased between 2018 and 2023 – Billardiera rubens (S), Andropogon virginicus (SS), Cymbopogon refractus (HM), Calochlaena dubia (SS), Eucalyptus pilularis (SS), Leptospermum sp. aff. polygalifolium (HM), Polygala multiflora (SS), Themeda australis (HM) (probable source/origin – HM hydromulch, SS self-seeded/coloniser, S soil seedbank).

Of three Acacia's only A. longifolia performed well.

Comment

Bushland Reconstruction treatment was largely successful in establishing a diverse native plant cover. Native grasses (Cymbopogon and Themeda) performed very well. Exotic species largely absent.

Setaria appears to be absent as only topsoil was used from weed free native forest.

Ipomoea carica (an exotic climber) is potentially a problem weed although it may not spread because of the very poor clay which is suited to natives but not exotics.

3.7.2 Species abundance data and photos 2018 & 2023

Site 7 – Bushland Reconstruction treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn	Change
Acacia fimbriata	1		
Acacia elongata	1		
Acacia longifolia	2	2	
Allocasuarina torulosa			
Anagallis arvensis	1		
Andropogon virginicus		2	>
Billardiera rubens	1	3	>
Briza maxima	1		
Callicoma serratifolia		1	
Callistemon sp.	1	2	
Calochlaena dubia		2	>
Carex maculata		1	
Cassytha pubescens	2	1	
Centaurium erythraea			
Centella asiatica		1	
Cheilanthes sieberi			
Conyza bonariensis	1	2	
Cordyline stricta	1		
Cymbopogon refractus	2	3	>
Daviesia ulicifolia	1		
Dianella caerulea		1	
Dodonaea triquetra	1	4	>
Eucalyptus microcorys		1	
Eucalyptus pilularis	1	3	>
Euchiton sp.	1	2	
Gahnia aspera			
Gonocarpus sp.	1		
Hakea gibbose/sericea	1	2	
Hibbertia aspera	1	2	
Gonocarpus tetragynus		1	
Goodenia heterophylla	1		
Hypocheirus radicata		2	
Lepidosperma laterale			
Leptospermum juniperinum	1		
Leptospermum sp. aff polygalifolium	2	3	>
Lomandra longifolia	1	2	
Melaleuca linariifolia	1	1	
Melaleuca sieberi			
Melastoma affine		1	

Plant species	2018 summer	2023 autumn	Change
Ottochloa gracillima		2	
Ozothamnus diosmifolius	1	2	
Paspalidium distans		2	
Paspalum mandiocanum		1	
Persoonia adenanthera	1	1	
Plantago varia	1		
Polygala multiflora	1	2	>
Pultenaea retusa	1		
Pultenaea villosa	1	1	
Pratia purpurascens			
Syncarpia glomulifera		1	
Themeda australis	1	4	>

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 7 southern end

Autumn 2023 - Site 7 southern end

Spring 2018 - Site 7 northern end

Autumn 2023 - Site 7 northern end

3.8 SITE 8

3.8.1 Context, treatment and vegetation

Context

Fill batter

Stake 1 coordinates	Stake 2 coordinates
494514, 6605138	494523, 6605177

Landscaping treatment

Bushland Reconstruction

Structure (vegetation height and density)

Open to sparse canopy of tall Acacia (4-5 m) with tall, dense understory of exotic grasses (tall open shrubland)

Floristics

Low species diversity. Dominated by exotic grasses (Setaria, Paspalum spp. and Panicum sp.). Low cover-abundance of Acacia's (see table below). Species that increased between 2018 and 2023 included Setaria sphacelate, Paspalum mandiocanum, Panicum sp. and Ageratum houstonianum, all exotic species.

Setaria (environmental weed)

Dominant – cover abundance 6 (75-100%)

Comment

This Bushland Reconstruction site was effective in establishing vegetation cover, but largely failed in establishing native (bushland) species. Even Acacia's failed to establish well and exotic grasses dominate the plot including Setaria, Broad-leaved Paspalum and a Panicum sp. These species were probably present in the soil seedbank spread on the batter. The topsoil may have come from a marginal forest area adjoining pasture.

Of six Acacias present at the start of monitoring, probably applied by hydromulching, four died out and two persisted in 2023 at low cover-abundance (A. fimbriata and A. longifolia). A few other native species were present at the start of monitoring and died out, such as Dodonaea triquetra, apparently due to competition from exotic grasses. The latter species indicates salvage of topsoil from 'bushland', which may have been mixed with soil from pasture containing Setaria.

3.8.2 Species abundance data and photos 2018 & 2023

Site 8 – Bushland Reconstruction treatment

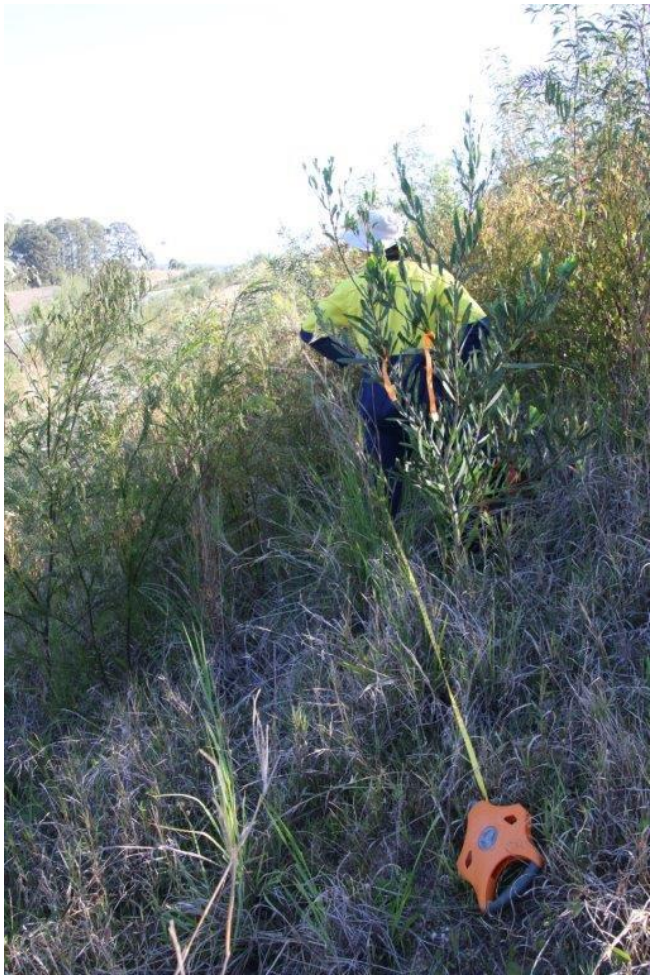
(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2020 autumn	2023 autumn	Change
Acacia binervata	1	1		
Acacia falcata	1	1		
Acacia fimbriata	2	2	2	
Acacia irrorata	1	1		
Acacia longifolia	1		1	
Acacia myrtifolia	2	3		<
Ageratina adenophorum	1		2	
Ageratum houstonianum		1	2	>
Axonopus affine	1			
Baccharis halimifolia				
Bidens pilosa	1	1		
Cassytha pubescens				
Centella asiatica				
Conyza bonariensis	1			
Crotalaria lanceolata	1			
Cymbopogon refractus				
Cynodon dactylon	1			
Dodonaea triquetra	1	1		
Euchiton sp.	2			
Glycine clandestina	1	1		
Kennedia rubicunda	1			
Lantana camara			1	
Lobelia alata				
Megathyrthus maximus				
Ozothamnus diosmifolius				
Panicum sp.			3	>
Paspaslum conjugatum				
Paspaslum dilatatum	1			
Paspalum mandiocanum	3	3	4	>
Paspalum urvillei				
Plantago lanceolata				
Pultenaea villosa	1			
Polygala multiflora	1		1	
Senecio madagascarensis	1			
Setaria sphacelata	3	3	6	>
Sida rhombifolia	1			
Themeda australis	1			

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 8 southern end

Autumn 2023 - Site 8 southern end



Spring 2018 - Site 8 northern end

Autumn 2023 - Site 8 northern end

3.9 SITE 9

3.9.1 Context, treatment and vegetation

Context

Cut batter

Stake 1 coordinates	Stake 2 coordinates
494703, 6605781	494721, 6605830

Landscaping treatment

Bushland Reconstruction then slashed by tractor on lower slope (lower half of plot) removing Acacia regrowth and allowing invasion by exotic grasses.

Structure (vegetation height and density)

2023 - unslashed (above) - tall closed shrubland 2-6 m

2023 – slashed (below) closed grassland dominated by exotic grasses

Floristics

High species diversity. Species that increased in the unslashed half of plot between 2018 and 2023 – Acacia fimbriata (HM), Capillipedium spicegerum (S)(in slashed), Cymbopogon refractus (HM), Eucalyptus microcorys (SS), Eucalyptus pilularis (SS), Paspalum mandiocanum (S), Themeda australis (HM) (probable source/origin – HM hydromulch, SS self-seeded/coloniser, S soil seedbank).

Comment

Bushland Reconstruction treatment (unslashed) was successful in establishing a diverse native plant cover. Native grasses (Cymbopogon and Themeda) performed very well. Exotic species largely absent.

Slashing produced a marked change in the landscaped vegetation on lower half of plot, killing Acacia's and allowing exotic grasses to invade and smother less common species regenerating from salvaged topsoil spread on batter.

3.9.2 Species abundance data and photos 2018 & 2023

Site 9 – Bushland Reconstruction treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 summer	2023 autumn	Change
Acacia fimbriata	3	4	>
Acacia irrorata	2	2	
Acacia longifolia	1	2	
Alphitonia excelsa	1	2	
Allocasuarina torulosa		1	
Andropogon virginicus		1	
Babingtonia sylvestris	1	1	
Billardiera rubens	1		
Callistemon salignus	1	1	
Capillipedium spicegerum		2	>
Seeringia arborescens			
Centalla asiatica	1		
Conyza bonariesis			
Cymbopogon refractus		4	>
Daviesia ulicifolia	1		
Desmodium rhytidophyllum			
Dodonaea triquetra		1	
Entolasia stricta			
Eragrostis sp.		2	
Eucalyptus microcorys	1	2	>
Eucalyptus pilularis	1	2	>
Fimbrystylis dichotoma			
Gahnia aspera		1	
Gonocarpus tetragynus	1		
Hardenbergia violacea	1		
Hibbertia aspera		1	
Kennedia rubicunda	1		
Lantana camara		1	
Lophostemon suaveolens			
Ozothamnus diosmifolius	1	1	
Passiflora eduls			
Paspaslum dilatatum	1	1	
Paspaslum mandiocanum	2	4	>
Paspalidium distans	1		
Paspalum urvillei			
Persoonia adenanthera	1	1	
Setaria sphacelata		3	>
Sida rhombifolia	1		
Themeda australis	1	3	>

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 9 southern end

Autumn 2023 - Site 9 southern end

Autumn 2023 - Site 8 northern end

Autumn 2023 - Site 9 northern end

3.10 SITE 10

3.10.1 Context, treatment and vegetation

Context

Drainage line diverted for bridge construction then reinstated.

Stake 1 coordinates	Stake 2 coordinates
491650, 6598045	491599, 6598037

Landscaping treatment

Landscape planting – riparian zone on reinstated drainage line (Williamson's Ck).

Structure (vegetation height and density)

2018 – bare rock-lined drainage line with a few planted shrubs and native and exotic grasses and herbs starting to colonise.

2023 – bare rock along drainage line covered by native and exotic grasses and herbs; floating and emergent aquatic species established.

Floristics

Species that increased substantially or noticeably between 2018 and 2023 – Hypolepis muelleri (SS), Nymphaea capensis (SS), Paspalum mandiocanum (SS), Persicaria strigosa (SS), Setaria sphacelata (SS) (probable source/origin – HM hydromulch, SS self-seeded/coloniser, S soil seedbank).

Comment

Threatened aquatic species Maundia triglochinoides re-introduced to drainage line. Declined between 2018 and 2021, increased in 2023. Scouring of the rock-lined bed of the drainage line during floods probably removed silt/mud needed by Maundia to grow in. Deposition of sediment may have increased in 2022 allowing Maundia to expand.

3.10.2 Species abundance data and photos 2018 & 2023

Site 10 – Riparian landscaping treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 Summer	2023 Autumn	Change
Acacia irrorata		1	
Aster subulatus			
Baumea articulata	2	2	
Carex appressa			
Conyza bonariensis			
Cirsium vulgare		1	
Cyperus polystachyos			
Convolvulaceae	1	1	
Cyclosorus interruptus			
Hypolepis muelleri		3	>
Juncus ursitatus	1	1	
Leptospermum polygalifolium		1	
Ludwigia peploides	1	2	
Maundia triglochinoides	1	2	
Nymphaea capensis	2	3	>
Panicum obseptum			
Paspalum distichum			
Paspalum mandicanum		3	>
Paspalum urvillei	1	2	
Persicaria lapathifolia			
Persicaria strigosa	2	4	>
Philydrum lanuginosum	1		
Schoenoplectus vallidus	1	1	
Setaria sphacelata	2	4	>
Sida rhombifolia	1		
Typha orientalis			
Verbena bonariensis	1		

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 10 eastern end

Autumn 2023 - Site 10 eastern end

Spring 2018 - Site 10 western end

Autumn 2023 - Site 10 western end

Site 10, Maundia triglochinoides (emergent aquatic plant with narrow, upright, sword shaped leaf), Autumn 2023. Lower photo includes in situ Maundia found 50 m downstream of the above photo under the new 4-lane twin bridge (i.e. not the one in photograph).

3.11 SITE 11

3.11.1 Context, treatment and vegetation

Context

Drainage line diverted for bridge construction then reinstated.

Stake 1 coordinates	Stake 2 coordinates
490895, 6596807	490897, 6596754

Landscaping treatment

Landscape planting – riparian zone on reinstated drainage line (Stoney Ck), topsoiled with salvaged material.

Structure (vegetation height and density)

2018 – drainage line planted with aquatic plants and bank surrounds with native shrubs.

2023 – drainage line densely covered by aquatic plants, mostly exotic but with some native species; surrounds dominated by exotic Setaria and occasional native shrubs and small trees.

Floristics

Species that increased substantially or noticeably between 2018 and 2023 – Ageratum houstonianum (S), Andropogon virginicus (S), Capillipedium spicegerum (S), Eleocharis acuta? (SS), Myriophyllum aquaticum (SS), Paspalum mandiocanum (SS), Persicaria strigosa (SS), Setaria sphacelata (SS)(probable source/origin – HM hydromulch, SS self-seeded/coloniser, S soil seedbank). These are mainly exotic species.

Comment

Drainage line and banks revegetated, but the species established are mainly exotics plus a few native species.

3.11.2 Species abundance data and photos 2018 & 2023

Site 11 – Riparian landscaping treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 Summer	2023 Autumn	Change
Acacia fimbriata	1	2	
Acacia irrorata	1		
Acacia longfolia		1	
Acacia melanoxylon	1		
Ageratum houstonianum	1	3	>
Anagallis arvensis	1		
Andropogon virginicus	1	3	>
Ambrosia psilostachya			
Aster subulatus	1		
Axonopus affinis	1		
Baccharis halimifolia			
Baumea articulata			
Capillipedium spicegerum	1	3	>
Carex appressa			
Casuarina cunninghamii	1		
Centaurium erythraea	2		
Centella asiatica	1		
Ciclospermum leptophyllum			
Conyza bonariensis			
Crassocephalum crepidoides			
Cynodon dactylon	1		
Cyperus polystachyos	1		
Dodonaea triquetra	1		
Eleocharis acuta	1	3	>
Eleocharis dulcis		1	
Euchiton sp.	1		
Gonocarpus tetragynus	1		
Isachne globosa		1	
Juncus prismatocarpus	2		
Juncus usitatus	2		
Kennedia rubicunda	1		
Lantana camara			
Leptospermum juniperinum	1	1	
Leptospermum polygalifolium	1		
Lomandra hysteryx		2	
Lomandra longifolia	1	1	
Ludwigia peploides	2		
Microlaena stipoides			
Myriophyllum aquaticum	2	3	>

Plant species	2018 Summer	2023 Autumn	Change
Nymphaea capensis			
Ozothamnus diosmifolius	1		
Paspalum mandiocanum	1	2	>
Paspalum urvillei	2		
Persicaria lapathifolia	2		
Persicaria strigosa	2	3	>
Plantago varia	1		
Polygala multiflora		1	
Rubus sp.			
Pultenaea villosa	1	2	
Ranunculus inundatus		1	
Sacciolepis indica			
Senecio madagascariensis	1		
Setaria sphacilata	1	5	>
Sisyrinchium sp.	1		
Tradescantia fluminensis			
Themeda australis	1		
Verbena bonariensis	1	1	
Verbena rigida	1		

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Spring 2018 - Site 11 southern end

Autumn 2023 - Site 11 southern end

Spring 2018 - Site 11 northern end

Autumn 2023 - Site 11 northern end

3.12 SITE 12

3.12.1 Context, treatment and vegetation

Context

Riparian zone next to bridge on reinstated drainage line (Butcher's Ck).

Stake 1 coordinates	Stake 2 coordinates
489789, 6594939	489789, 6594909

Landscaping treatment

Planting creek banks.

Structure (vegetation height and density)

2018 – open grassland 1-2 m on bed of creek, remnant and planted woody vegetation on banks.

2023 – grassland 1.5-2.5 m on bed of creek, remnant and planted woody vegetation on banks.

Floristics

2018 – bed of creek dominated by exotic herbs and grass, native species planted on banks

2023 – bed of creek disturbed by floods and dominated by exotic herbs and grass, native species planted on banks

Comment

Planting of the creek banks effective in establishing or augmenting existing woody species vegetation cover.

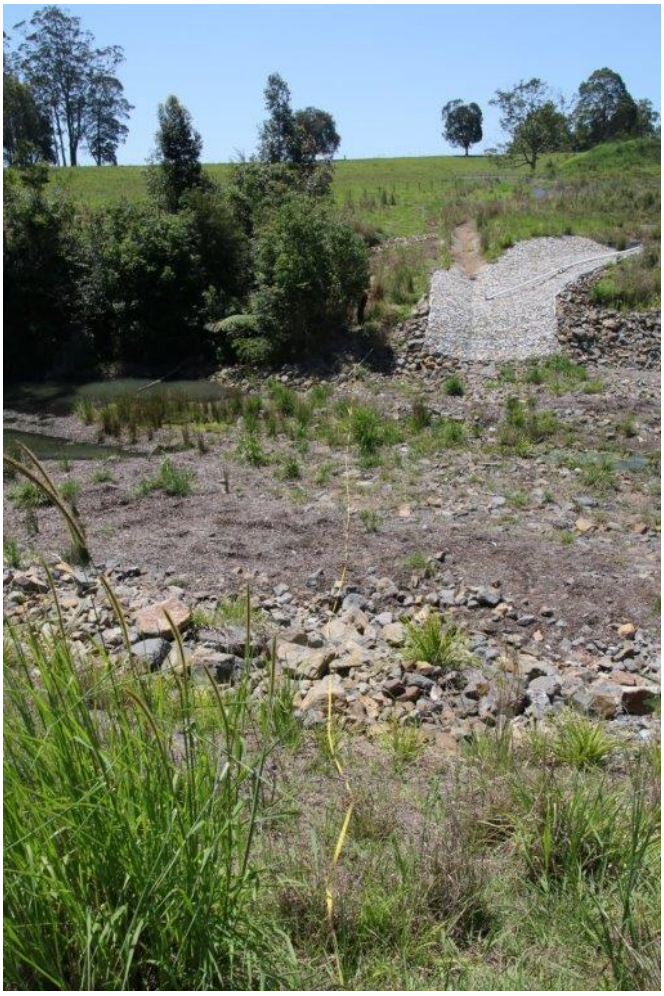
Site vegetation otherwise comprises exotic grasses and herbs.

3.12.2 Species abundance data and photos 2018 & 2023

Site 12 – Riparian landscaping treatment

(note – blanks are species recorded at other monitoring events)

Plant species	2018 Summer	2023 Autumn	Change
Acacia falcata		1	
Acacia fimbriata		2	
Acacia irrorata	1	3	>
Acacia melanoxylon		1	
Ageratina adenophorum		2	>
Ageratum houstonianum		2	>
Alphitonia excelsa	1		
Anagallis arvensis	1		
Billardieria rubens	1		
Bothriochloa sp.	1		
Capillipedium spicegerum		2	
Centaurium erythraea	2		
Cinnamomum camphora	1		
Cirsium vulgare		1	
Cissus antarctica	1		
Cymbopogon refractus	1		
Conyza bonariensis	1	1	
Cynodon dactylon	1		
Cyperus polystcahyos	2	1	
Gahnia aspera	1		
Geitonoplesium cymosum	1		
Hypocheirus radicata	1	1	
Hypolepis muelleri	1		
Imperata cylindrica		1	
Juncus ursitatus	1		
Kennedia rubicunda	1		
Lantana camara	1		
Lomandra hysteryx		1	
Lomandra longifolia	1		
Paspalum dilatatum	2		
Paspalum mandiocanum	2	2	>
Paspalum urvillei		2	
Phytolacca octandra			
Senecio madagascariensis	1	2	
Setaria sphacelata	2	6	>
Stephania japonica		1	
Themeda australis	1		
Trifolium repens	1		
Verbena bonariensis	1		



Spring 2018 - Site 11 southern end

Autumn 2023 - Site 11 southern end

Spring 2018 - Site 11 northern end

Autumn 2023 - Site 11 northern end

3.13 Results Summary

Landscaped vegetation on Hydromulching Seed Mix sites (1-5) was dominated by Acacia fimbriata and Setaria sphacelata with other exotic grasses and herbs such as Paspalum mandiocanum and Conyza bonariensis at mostly low abundance. The dominance of Setaria in the ground layer was already evident in the first year after application (Geolink 2017). During the four-year operational monitoring period, all sites had a high cover-abundance of Setaria (mostly >75%), forming a tall, dense ground layer, with an upper layer of Acacia fimbriata. The Setaria originated from topsoil salvaged from the works footprint and spread on the batters. Acacia fimbriata was added to the Hydromulching seed mix. It is important to note that Setaria is a common pasture grass in the local area and not a noxious weed. The Acacia-Setaria combination forms a dense vegetation cover on sloping batters and provides excellent soil cover to prevent erosion during heavy rain.

High native species diversity and cover persisted in the Bushland Reconstruction sites (6-9) during the four-year monitoring period. The Bushland Reconstruction sites were characterised by native grasses such as Cymbopogon refractus and Themeda australis, shrubs such as Acacia longifolia, A. fimbriata, Dodonaea triquetra, Leptospermum polygalifolium, Callistemon sp. and Hakea spp., and saplings of Eucalyptus pilularis, E. microcorys and other species that grew from seed dispersed from the adjoining forest.

The Landscape Planting sites (10-12) were located on drainage lines disturbed during construction and the vegetation established was characterised by a diverse mix of exotic and native species, including wetland species such as Juncus usitatus and Persicaria strigosa, and dryland species planted on creek banks, or regenerating from the in situ soil seedbank, including again Setaria sphacelata.

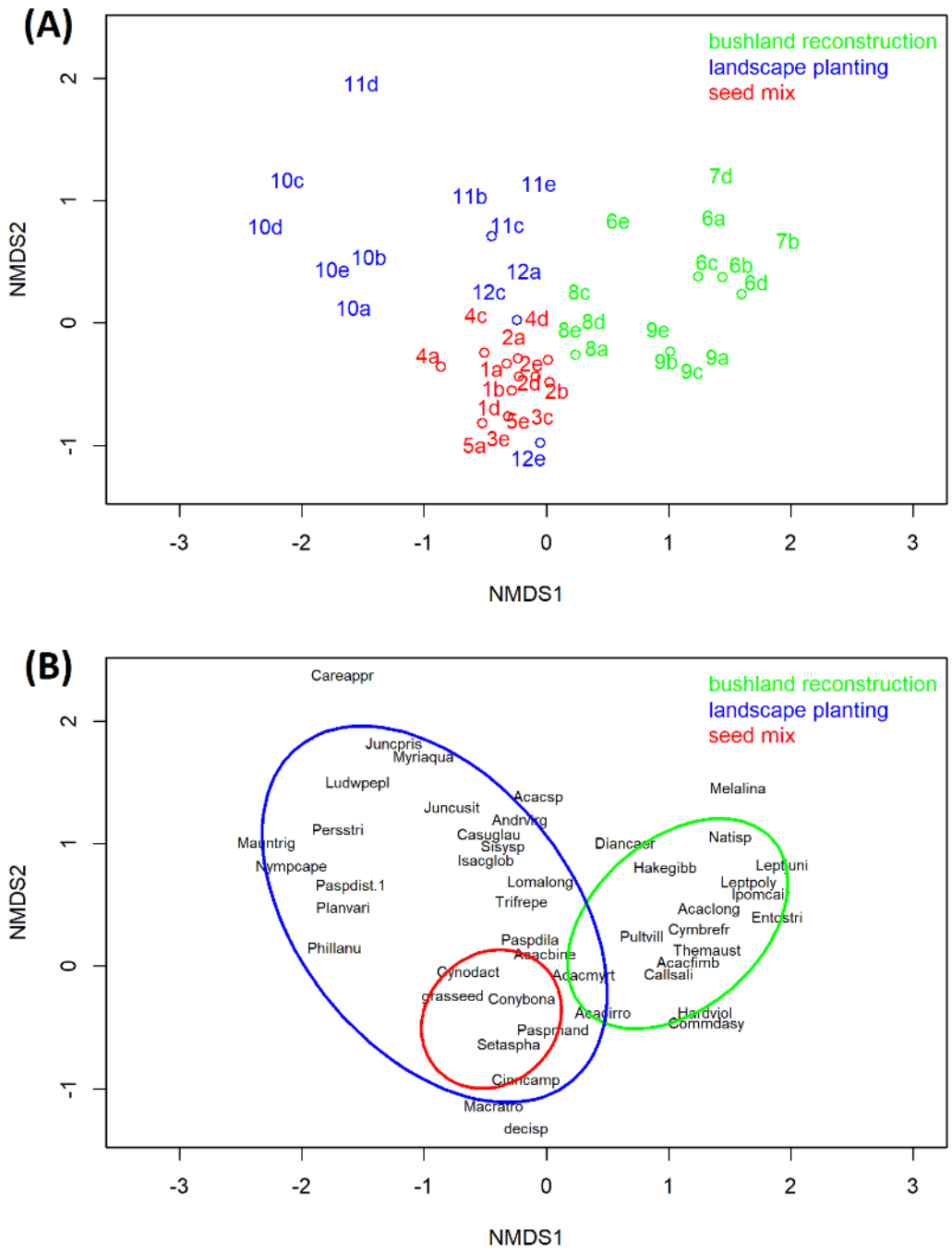


Figure 2. Non-metric multidimensional scaling of Transects of three landscape rehabilitation treatments. Stress = 0.15. Graph A shows the Transects in ordination space, where the closer Transects are in 2-d space, the more similar they are in terms of species composition. (a to e subscripts refer to the 10 m sub-transects). To reduce clutter, the *orditorp* function of the *vegan* package was used. Graph B shows species most characteristic of each treatment. Species names are abbreviated to the first four letters of genus and species. This analysis based on 2019 monitoring data, was carried out three years after the landscaping treatments were implemented in 2016 and highlights the difference in species composition of vegetation established by the three landscaping treatments.

4 Discussion

4.1 Hydromulching Seed Mix

Vegetation established by Hydromulching Seed Mix had a mostly dense canopy of Acacia and a ground layer dominated by Setaria sphacelata. Other exotic and native herbs and shrubs were present in low abundance. Acacia increased in height and density during the monitoring period despite intense periods of below average rainfall. Acacia fimbriata had the highest cover-abundance across the sites followed in decreasing order by A. irrorata, A. longifolia, A. falcata, A. binervata, A. myrtifolia and A. floribunda. The last three species had died out by 2021 and appear to be unsuitable for use for broad area landscaping.

In the information provided to Ecos Environmental, each site received a different seed mix. Acacias and indigenous grasses were listed as the main species in the seed mixes (GeoLINK 2017). Indigenous grass species were mostly absent or recorded in very low abundance by Ecos Environmental. GeoLINK (2017) did not record indigenous grasses in their 2016 and summer 2017 monitoring. It appears that this component of the seed mixes was either not included or unsuccessful, and that the understorey composition was instead a result of the seedbank in the topsoil applied to the sites. By contrast, Bushland Reconstruction results showed that hydromulched native grasses (i.e.Themeda and Cymbopogon) established well on gravelly clay batters with little bush topsoil and where Setaria was absent from the seedbank.

Setaria or South African Pigeon Grass is a vigorous and dominating pasture grass common in high rainfall coastal areas of the Mid and Far North Coast of NSW. In paddocks this tall tussock grass is kept under control by cattle grazing, but when cattle are removed, it rapidly increases in height and density, smothering other grasses, herbs and sedges, both exotic and native. Cattle assist the spread of Setaria by increasing levels of soil N and P in the soil through addition of excreta to soil. Setaria is a major ecological threat to native ground layer flora which may be completely displaced from grassy forest by Setaria.

Setaria is widespread in grazing land surrounding the WC2NH project, although often not obvious in grazed paddocks where controlled by cattle grazing. Topsoiling of batters and bare areas with soil from local paddocks results in dense Setaria, because of the Setaria seedbank present in the soil, the high growth potential of this species coming from Africa and absence of cattle from the road reserve. Setaria seed lacks a plume and is not adapted for wind dispersal. Instead, the seed falls to ground and is spread in soil sticking to cow hooves and on farm vehicles and machinery.

Seeds of Acacia species (particularly A. fimbriata probably collected/selected from existing revegetation) added to hydromulch were able to germinate and grow successfully in competition with Setaria due to their rapid growth rate. This resulted in batter vegetation consisting of tall Acacia shrubs over a tall, dense Setaria grass understorey. Other species added to the mixes established very little cover because of Setaria competition (i.e. dense overtopping and smothering).

Suggested measures for reducing the prevalence of Setaria established by highway landscaping:

- Avoid topsoiling batters with soil salvaged from paddocks, neglected cleared areas or other weedy vegetation, likely to contain Setaria seedbank. It is recognised that this may be impractical if weed-free bush topsoil is lacking on the construction footprint.

- Where practical and feasible, hydromulch with hardy native shrubs and grasses directly over subsoil material on cut and fill batters, which is free of weed seed. Native species such as wattles and casuarinas can fix nitrogen, are very hardy, and if species are selected appropriately will grow and establish on gravelly clay, avoiding importation of weed infested topsoil. This was demonstrated by the results of the Bushland Reconstruction treatment, where shrubs grew well on very shallow topsoil over cut batters of subsoil material, with a thin layer of clearing mulch.

- Use of topsoil for revegetation along highways requires advance planning before construction starts so that (i) adequate space is provided to store topsoil as it is stripped off, (ii) a tested and reliable means of storage is provided to ensure the topsoil seedbank remains viable, (iii) information on how species are likely to germinate from the seedbank, their rate of growth etc.

- Increase amount of Acacia fimbriata seed added to hydromulch to critical level required to suppress Setaria. An initial estimate of the density of A. fimbriata required to completely suppress Setaria in 6 year old landscaping based on field observations was 4-5 Acacia fimbriata (all size classes, not just canopy) per m^2 – see photo group on next page. Hydromulching Seed Mix typically resulted in 1 Acacia fimbriata per 2-3 m^2 and this had no effect on Setaria cover-abundance. Based on these estimates, increasing the quantity of Acacia seed applied in hydromulch by five would result in suppression of Setaria.

- Other measures that could be used as part of managing the topsoil during the construction stage include treating topsoil before stripping, during stockpiling and after placement to reduce the abundance and seed load of Setaria and other undesirable species. Whilst there are provisions for not using and burying weed infested topsoil, avoiding the use of topsoil from the construction footprint can sometimes result in a shortfall of the topsoil required for the landscape works and may require the importation of topsoil which can be expensive and possibly not as good for the overall sustainability rating for the project.

- Possibly early identification of areas that may have weed infested topsoil and some appropriate treatment or amelioration measures could be used. May also require more planting to allow more desirable species to establish.

Embankment between streamline and highway adjacent to Plot 11. Dense Acacia fimbriata, five years old, has suppressed Setaria sphacelata. Bottom of photo on lower right shows sparse Setaria under Acacia near slope base compared to dense Setaria on Site 11 in the open (see photos above). The ground is covered by brown Acacia leaf litter. Acacia density > one per 4 m².

4.2 Bushland Reconstruction

The Warrell Creek to Nambucca Heads Upgrade Project Urban Design and Landscape Plan notes that "Bushland reconstruction is an alternative revegetation methodology that is quickly becoming the Transport for NSW's preferred method of revegetation due to successful outcomes and environmental and project benefits. The methodology involves careful topsoil stripping and stockpiling, retention of existing seed within the topsoil, amelioration with the addition of nutrients and shredded mulch containing endemic seed and direct return of the topsoil to as near as possible to the location from where it was sourced. The methodology has been employed on other Transport for NSW projects, including the nearby Pacific Highway precedent of Glenugie Upgrade." (p. 72, Sec. 5.6.7). This approach to landscaping/ revegetation was applied at the northern end of the WC2NH project, closer to native forest and sources of topsoil containing native species seedbank.

However, Bushland Reconstruction may not be applicable to all landscapes/sites, depending on the availability within the road construction corridor of good quality forest with weed free, native seedbank

The Bushland Reconstruction sites on this project had much higher native plant cover and number of native species. Except for a few innocuous herbs, exotic species were largely absent from these sites. Bushland topsoil media, integrated shredded mulch (i.e. woody clearing mulch), seed and ameliorants were applied to the sites in 2016. The ratio of topsoil to mulch was 60:40. The seed mix contained the following species:

- Acacia longifolia @ 0.25 kg/ha
- Acacia floribunda @ 0.25 kg/ha
- Acacia fimbriata @ 0.25 kg/ha
- Cymbopogon refractus @ 1 kg/ha
- Hardenbergia violacea @ 1 kg/ha
- Themeda australis @ 1 kg/ha.

All sites had very low exotic plant cover, except for Site 8 which had a high abundance of Setaria sphacelata and Paspalum mandiocanum. A mistake may have been made with the classification of this site, as it is similar in species composition to Hydromulching Seed Mix sites.

All species applied as seed in the BRC seed mix (see six species listed above) were recorded by Ecos Environmental and these species dominated the vegetation at all the Bushland Reconstruction sites. In addition, 15 species most likely originating from bushland soil applied to the sites were also recorded (Table 5). However, most of these were in low abundance and contributed little to overall cover.

Several other species appear to have been added to the BRC seed mix, including four apparently non-indigenous native species (see Table 5). These are species native to NSW but probably not local ecosystems.

The Bushland Reconstruction (BRC) treatment was effective in establishing landscaped vegetation dominated by native species, and with a very low abundance of exotics. However, the sites were dominated by species applied in the BRC seed mix, not by local soil seedbank species, as was intended according to the quote from the Urban Design and Landscape Plan at the start of this section. Monitoring found that species from the local seedbank made up a small proportion of plant cover, with the exception of Hop Bush (Dodonaea triquetra), a soil seedbank species and probably the most common post-disturbance regenerator in native bushland in the local area.

The results indicate that there are aspects of how this treatment was applied that could be improved on. The local forest seedbank if properly salvaged, stored and reapplied should produce a dense cover of native plants, but the species that dominate the sites are mainly from the BRC seed mix. The main value of the BRC method applied was in excluding exotic species, especially Setaria.

Inspection of the soil at BRC sites during monitoring suggested minimal topsoil as only woody clearing mulch fragments and gravelly clay substrate were visible on the surface. Urea (soil ameliorant) was added to correct the soil C:N ratio, but soil chemistry and soil microflora could have been significantly altered by the inclusion of semi-decomposed mulch material, causing increased seed or seedling mortality. A subset of species may be able to tolerate these conditions. Further comment on this effect is provided in Benwell (2007) and revegetation literature. The weak contribution of native species from soil seedbank salvaged from forested areas to landscaped vegetation may have been due to:

- Shallow depth or quantity of bush topsoil applied.
- Storage of topsoil uncovered.
- Duration of topsoil storage.
- Adverse nutritional and pathogenic effects on seed germination and seedling survival of clearing mulch.

Advantages of using native species soil seedbanks include lower landscaping costs, increased native species diversity, guaranteed local species provenance, very low levels weeds and suitable frangible species for roadside, as pointed out in Transport for NSW (2018a, p. 72).

Table 3: Species composition of Bushland Reconstruction (BRC) sites including species abundance (i.e. relative establishment success) and whether the species originated from salvaged topsoil seedbank, added seed mix and seeded from adjoining forest. Origin (known or likely) is based on information provided and knowledge of the species population ecology. In some cases, interpretations may be wrong.

Species	Abundance	Origin	Comment
Acacia longifolia	Common	Seed Mix	Documented BRC seed mix
Acacia floribunda	Rare	Seed Mix	Documented BRC seed mix
Acacia fimbriata	Common	Seed Mix	Documented BRC seed mix
Cymbopogon refractus – Barb wire Grass	Common	Seed Mix	Documented BRC seed mix
Themeda Australia – Kangaroo Grass	Common	Seed Mix	Documented BRC seed mix
Acacia sp.? long leaf	Common	Seed Mix	Possibly a sub-species of A. elongata; may not be indigenous to region
Leptospermum polygalifolium var. ?	Common	Seed Mix	Leaf form unknown to author, may not be indigenous to region
Callistemon sp. ?	Common	Seed Mix	Unknown species to author, may not be indigenous to region
Melaleuca linariifolia	Rare	Seed Mix	Stores seed in capsules on branches, unlikely to be in soil seedbank
Hakea gibbosa	Occasional	Seed Mix	Stores seed in follicles, unlikely to be in soil seedbank, not in region?
Pultenaea villosa – Hairy Bush Pea	Occasional	Soil seedbank	Probably soil seedbank, also commonly used in hydroseeding
Pultenaea retusa – Bush Pea	Occasional	Soil seedbank	
Dodonaea triquetra – Hop Bush	Common	Soil seedbank	
Billardiera scandens – Apple Berry	Occasional	Soil seedbank	
Persoonia sp. – Geebung	Rare	Soil seedbank	
Davesia ulicifolia – Bitter Pea	Occasional	Soil seedbank	Probably soil seedbank, also used in hydroseeding
Kennedia rubicunda – Coral Vine	Occasional	Soil seedbank	
Acacia binervata	Occasional	Soil seedbank	
Gonocarpus tetragynus - Raspwort	Occasional	Soil seedbank	
Seeringia arborescens	Rare	Soil seedbank	
Glycine clandestina	Occasional	Soil seedbank	
Ozothamnus diosmifolius – Snow Bush	Rare	Wind dispersed	
Babingtonia sylvestris – A myrtle	Rare	Soil seedbank	
Lepidosperm laterale – Sword Sedge	Occasional	Soil seedbank	
Entolasia stricta – Forest Wire Grass	Occasional	Soil seedbank	
Cassytha pubescens – Dodder Laurel	Common	Soil seedbank	
Eucalpytus piluaris, microcorys, resinifera	Occasional	Adjoining Forest	Seed blown in from tall trees in adjoining forest, saplings up to 4 m high

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