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Reconstruction of the pre-European vegetation of Wolgan Valley, western Blue Mountains, NSW

Julia Green, Scott Mooney and Frank Hemmings*

School of Biological, Earth and Environmental Sciences, UNSW Sydney, NSW 2052 AUSTRALIA
*Correspondence: s.mooney@unsw.edu.au

***Abstract*:** Historical sources and the field description of extant remnants were used to reconstruct the distribution and characteristics of the pre-European vegetation of Wolgan Valley resort, in the western Blue Mountains on the western edge of the Sydney Basin. Like many of the agricultural landscapes of Australia the vegetation of this valley has changed dramatically since European settlement, however an understanding of the original state may facilitate effective management and potentially facilitate restoration.

Investigation of remnants suggests that the pre-disturbance vegetation of the now cleared valley floor can be described with four plant communities. Grassy Woodland is likely to have occupied most of the valley floor and was part of the Grassy *White Box – Yellow Box – Blakely's Red Gum Woodland* listed as an Endangered Ecological Community under the NSW *Biodiversity Conservation Act 2016* and as Critically Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Grassy woodland would have graded into a shrubby woodland extending up the drier footslopes, eventually merging with the existing Talus Slope Woodland. Riparian Forest is likely to have occupied the major drainage lines of the valley and where the water-table was consistently higher, Closed Herbfield and Shrub swamp in swampy meadows/fens was likely in a chains of ponds landscape.

The characterisation of the pre-disturbance vegetation allows the identification of a suite of species appropriate for planting in relevant landforms. Significantly, the luxury resort has the space to experiment with the various techniques needed to restore some of this Endangered Ecological Community, and in so doing make a significant contribution to its broader regional survival.

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Introduction

Changes since European colonisation have resulted in a growing concern for the conservation and management of Australia's native vegetation (Adamson and Fox, 1982; Benson, 1991; Kirkpatrick, 1999). Ecological restoration is one option for the management of some Australian ecosystems and this requires data at local scales to guide decision making (Jackson and Hobbs, 2009; Tongway and Ludwig, 2011).

This research aimed to document the pre-European vegetation of a section of the Wolgan Valley in the western Blue Mountains, 35 km north of Lithgow, NSW. This valley was taken up by European pastoralists in the 1820-1830 period, placing it amongst the oldest agricultural landscapes in Australia; the historic significance of the valley is also enhanced by a visit from Charles Darwin in 1836. The pre-disturbance vegetation of the valley was researched using a combination of field work and historical sources including parish maps, Crown plans, surveyor's field books, and other observations through time including aerial photography. This resulted in a suite of predicted pre-European vegetation communities and description of their floristic composition, community structure and approximate extent. That information was then used to consider the conservation and management of the extant remnants, and to suggest information and potential approaches for restoration and revegetation projects.

Site Description

Wolgan Valley is located in the western Blue Mountains, approximately 190 km north-west of Sydney and 35 km north of Lithgow, at the western edge of the Sydney Basin Bioregion (Figure 1). The Wolgan River (catchment area 238 km^2 -Breckwoldt, 1977) is approximately 45 km long and flows eastward to join the Colo and Hawkesbury Rivers (Benson and Keith, 1990). The Wolgan Valley, formed by past stream incision through the Triassic sandstone plateau has a broad undulating valley floor, virtually walled by near vertical sandstone cliffs with steep talus slopes described as a 'bottle neck valley' (Breckwoldt 1977; Benson and Keith, 1990). The valley floor sits at approximately 600 m above sea level with two residual mesas – Donkey Mountain (995 m elevation) and Mount Wolgan (877m). The surrounding sandstone plateaus are 900-1100 m high.

The geology and soils of the area have a strong control over the vegetation communities (Benson and Keith, 1990). The physiography of the study area includes the Triassic Narrabeen Sandstone plateaus and cliffs, Permian Illawarra Coal Measures exposed on the lower slopes and valley floor, and Quaternary Alluvium along the major drainage lines. The Triassic Narrabeen Sandstone produces sandy, low nutrient, acidic soils which are shallow and well drained, but the Permian sediments form more clayey loam soils with higher organic matter resulting in better fertility, structure and water retention (Benson and Keith, 1990; DEC, 2006).

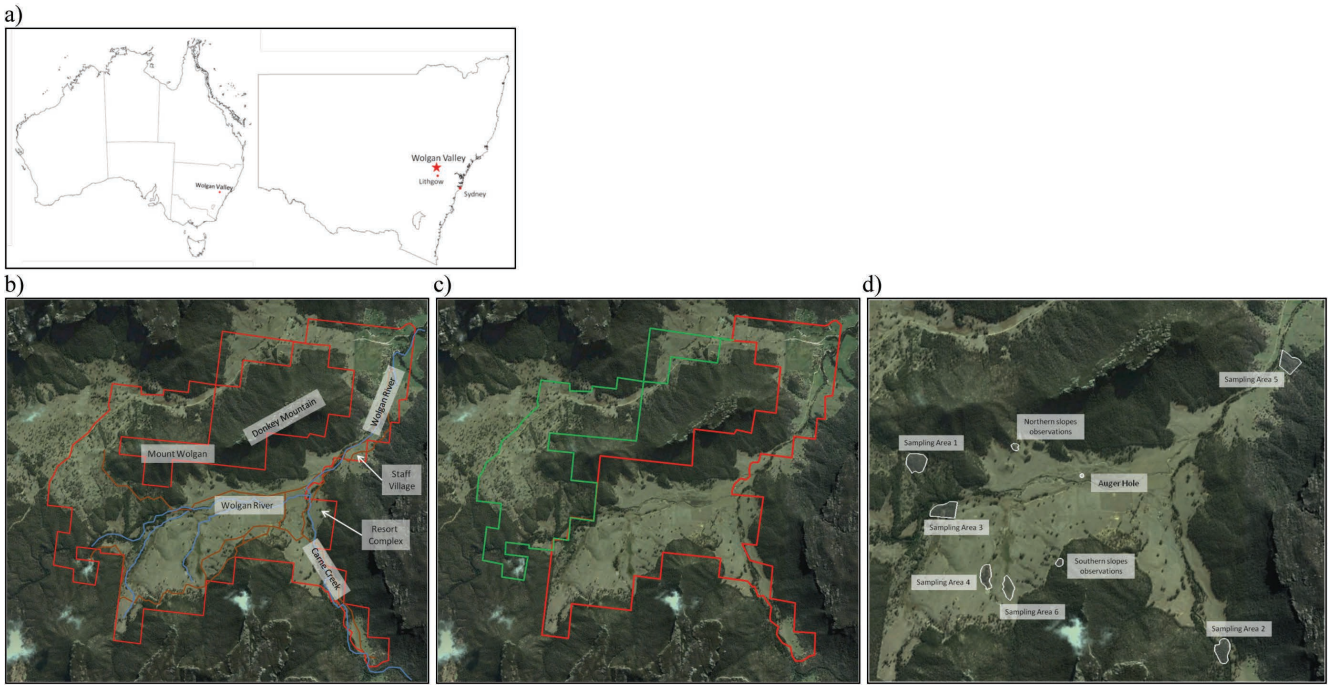

Figure 1. a) The location of Wolgan Valley; b) Significant features of Wolgan Valley including major drainage lines (blue), four-wheel drive tracks (brown) and mountains and the red line indicates the Wolgan Valley resort property boundary; c) The red line indicates the land previously owned by the Webb family and the green indicates the land owned by the Stammer family; d) The location and approximate extent of areas where the extant vegetation was surveyed in Wolgan Valley.

The climate is strongly influenced by topography, in general, the lower elevation valley floors experience warm, dry climates while the higher elevation plateaus experience cooler, wetter climates (DEC, 2006). The average annual rainfall of the region is 750-900 mm, with summer being the wettest season and winter the driest (BOM, 1967). Wolgan Valley and the Capertee Valley have the lowest average rainfall of the broader region, while Newnes Plateau is the wettest (Benson and Keith, 1990; DEC, 2006). Winter temperatures are more variable and generally warmer in the valleys than on the plateaus (BOM records for Glen Davis and Newnes SF).

Wolgan Valley is surrounded by natural areas, Gardens of Stone National Park to the north-west and south, and Wollemi National Park to the north-east (both part of the Greater Blue Mountains World Heritage Area), and Ben Bullen, Wolgan and Newnes State Forests to the west and south. The study area includes areas (1600 ha) of Wolgan Valley owned by Emirates One&Only Wolgan Valley (formerly Emirates Wolgan Valley Resort and Spa) (Figure 1). The extensively cleared valley floor forms the focus of this study.

Current vegetation of Wolgan Valley and surrounding slopes

Two major vegetation surveys cover Wolgan Valley; Benson and Keith (1990) and DEC (2006). Benson and Keith (1990) described three vegetation units (at 1.100 000 scale) within Wolgan Valley, 'Cleared', 'Talus Slope Woodland' and 'Pagoda Rock Complex', the latter restricted to the very top of Donkey Mountain. The DEC (2006) vegetation (at 1:25,000 scale) shows a number of mapping units within the valley including Capertee Grassy Woodland, Capertee-Wolgan Riparian Open Forest, Capertee-Wolgan Slopes Grassy Woodland, Tableland Gully Forest, Tableland Shrubby Open Forest and Wolgan Riparian Scrub Complex.

The valley floor vegetation is on the most fertile soils and has been significantly impacted by European settlement through extensive clearing for grazing (Figure 2). The current vegetation is dominated by both introduced pastures species and some native grass species. Native species include *Microlaena stipoides, Austrostipa verticillata* and *Chloris ventricosa*; common exotic grass species include *Bromus catharticus* (previously *B. uniolides*)*, Paspalum dilatatum* and *Phalaris minor*. Exotic weed species including *Echium plantagineum* (Patterson's Curse), *Verbena bonariensis* (Purple Top), *Rubus fruticosus* (Blackberry) and *Nasella trichotoma* (Serrated Tussock) are also prevalent on the valley floor and some of the other more disturbed areas of the slopes (Cumberland Ecology, 2007).

Small remnants in the valley on the drainage lines, gullies and depressions of the southern facing slopes, south of Mount Wolgan, are mapped by DEC (2006) as Capertee Grassy Woodland and dominated by *Angophora floribunda, Eucalyptus blakelyi* and *E. melliodora*. Tableland Shrubby Open Forest intergrades with the Grassy Woodland on the south facing slopes below Mount Wolgan, with dominant species *E. rossii, E. sparsifolia, E. mannifera* and *E. punctata* (DEC 2006). Sampling Area 1 fell within this unit (Figure 1d).

There is a discontinuous riparian zone along the banks of the Wolgan River and Carne Creek, with more mature trees than the adjacent open valley floor, and mapped as Capertee-Wolgan Riparian Open Forest (DEC 2006). The dominant canopy species are *Eucalyptus viminalis, Angophora floribunda* and less commonly *Eucallyptus eugenioides* and *Eucalyptus blakelyi* as well as *Casuarina cunninghamiana* (Benson and Keith, 1990). DEC (2006) also describes patches of Tableland Gully Forest along Carne Creek, again dominated by *E. viminalis* and *Angophora floribunda* but with *Acacia melanoxylon*. *Acacia filifolia* is common elsewhere on the river flats (Breckwoldt, 1977). Ground cover and small shrubs include *Dodonaea, Indigofera, Breynia, Pteridium esculentum* and *Viola*. Similar vegetation is also found along the Capertee River just below Glen Davis (Benson and Keith 1990). Wolgan Riparian Scrub Complex, occurs as a small patch on the Wolgan River just south of Mount Wolgan Sampling Area 3 (Figure 1d). It includes *E. viminalis* and occasional *E. melliodora* with a small tree layer of *Leptospermum* and *Acacia* and is distinguished from Riparian Forest by absence of *Casuarina cunninghamiana* (DEC 2006).

Benson and Keith (1990) classified the vegetation of the slopes of the Wolgan Valley as 'Talus Slope Woodland' grading to open forest in the more sheltered, lower slopes; DEC (2006) mapped it as Capertee-Wolgan Slopes Grassy Woodland. Canopy species on the slopes include *Eucalyptus melliodora, E. cypellocarpa, E. eugeniodies, E. punctata* and *E. rossii,* and less commonly *E. crebra, E. blakelyi, E. tereticornis and Angophora floribunda* (Benson and Keith, 1990). The understorey is shrubby with a herbaceous ground cover – the relative proportions depending on exposure and nutrients (DEC, 2006). Northwest slopes are more exposed to wind and sun and have a more open and stunted structure (Breckwoldt, 1977). *Eucalyptus polyanthemos, E. punctata* and *E. macrorhyncha* are the dominant canopy species on the slopes of Mount Wolgan and Donkey Mountain (DEC, 2006).

Figure 2. A view of Wolgan Valley, depicting the cleared valley floor, remnant paddock trees, and Donkey Mountain and vegetated talus slopes in the background.

The higher elevation sandstone Newnes Plateau vegetation is Blue Mountains Sandstone Complex, dominated by *Eucalyptus blaxlandii, E. agglomerata, E. radiata, E. fastigata, E. oreades, E. piperata, E. dalrympleana* and *E. cypellocarpa* with a shrubby sclerophyllous understorey (Benson and Keith, 1990). It occurs more widely in the adjacent National Park areas, and is outside the scope of this study.

Aboriginal prehistory, European settlement, history and land use

Wolgan Valley has been linked to various Aboriginal groups including the Wiradjuri, Daruk and Gundangarra people (Breckwoldt, 1977; DEC, 2006). Evidence of their occupation includes rock artefacts including axes, camp sites, rock engravings and burial sites; artefacts are particularly found near watercourses, swamps and creeks (Breckwoldt, 1977; DEC, 2006).

The first recorded European discovery of Wolgan Valley was by surveyor Robert Hoddle in 1823, seeking a route from the Bells Line of Road to the Hunter Valley; his work included identifying areas of arable land (Breckwoldt, 1977; Conybeare Morrison, 2006). In 1832 James Walker of 'Wallerawang' established an outstation 'Wolgan' in the valley (Breckwoldt, 1977). Grazing and agriculture expanded to an estimated 8000 ha being devoted to grazing (Breckwoldt, 1977). In 1836 Charles Darwin visited Wolgan Valley and commented on the greater number of cattle and horses rather than sheep "owing to some of the valleys being swampy and producing coarse pastures" He also described its shape "When cattle are driven into the valley of the Wolgan by a path (which I descended) partly cut by the colonists, they cannot escape; for this valley is in every other part surrounded by perpendicular cliffs, and eight miles lower down, it contracts, from an average width of half a mile, to a mere chasm impassable to man or beast." (Darwin, 1838).

The construction of the Western Railway to Wallerawang in 1870 increased development in the area; Large scale shale oil mining in the Permian Illawarra Coal Measures began in the early 1900s at Newnes and resulted in ~30 years of industrial mining activity in the Wolgan Valley (Macleod, 1959).

The Webb family acquired a large portion of the Wolgan Valley in 1935 (Figure 1c) and managed it for cattle (Conybeare Morrison, 2006) until Emirates purchased the eastern side of the property in 2008 (Cumberland Ecology, 2009). The western half of the property previously owned by the Stammer family was also managed for cattle farm for much of its history, but livestock were removed in 1999 and has been conserved as Wollemi Nature Reserve since then (Cumberland Ecology, 2009).

Wolgan Valley Resort and Spa (now Emirates One&Only Wolgan Valley) owns approximately 1600 ha of Wolgan Valley (Emirates Group, 2012) at the junction of Carne Creek and the Wolgan River. The six-star eco-tourism resort which opened in October 2009, occupies less than 2% of the land owned and is the only luxury resort in the world to achieve "carboNZero" certification, as well as being certified through an internationally recognised greenhouse gas programme (Emirates Group, 2012). The design, construction and ongoing operation of the resort has aimed to minimise environmental impacts.

Methods

Aerial photographs dating from 1950 to 2006 together with geological maps were used to identify patches of vegetation within the valley floor which potentially represented remnants of the original vegetation. This resulted in six sampling areas across the variety of landscapes still present within the valley (Figure 1d). Between five and ten random (20 m x 20 m) quadrats were surveyed within each of these sampling areas. to record site characteristics and vegetation structure. All species within the quadrat were identified and approximate average height and cover recorded. For larger species the number of individuals was also recorded. In addition, informal observations and species lists were also created for both the north facing and south facing slopes to compare with the broader descriptions in the literature.

The current extent of the freshwater wetlands in the valley was examined with observations from a number of vantage points around the valley, walking their perimeters and using probes (and an auger hole) to consider presence of peat and substrate wetness.

An investigation of large, probably remnant trees remaining within the cleared sections of the valley floor was also undertaken. Each 'paddock tree' was identified, given a unique number, photographed and located using a GPS. The diameter at breast height was measured of all paddock trees (and if trees were multi-stemmed and the branching began below breast height, each stem was measured separately).

The use of historical sources was a significant component of the project. Parish maps and Crown plans are a useful yet under-utilised resource in reconstructive investigations (Jeans, 1978). The parish map (Parish of Wolgan, County of Cook, 1884) shows the portion and Crown plan numbers for each parcel of land (Figure 3a). Crown plans covering the area of interest within Wolgan Valley were obtained from the NSW Land and Property Information office. Historic Surveyors Field Books were another source of historic information. These are available through the NSW State Government's "Baseline" website (State Records Authority, 2010) and are indexed by the Parish name. These surveys were largely used to develop the more formalised Crown Plans.

The area examined through Crown plans and surveyor's field books extended over a range of environmental contexts and landscape types within the valley including the slopes, flats and riparian areas. Figure 3b is an example of the type of information included on the Crown plans, including the boundary of the property, trees marked at each corner and other landscape features. The use of these sources is also described in Fensham and Fairfax (1997; 2002) and Franco and Morgan (2007).

Information from the parish maps, Crown plans and field books was combined with images from the NSW State Government map website *Six Viewer* which has a cadastral layer showing the boundaries of the land parcels on the most recent available Google Earth image. Each of the Crown plans corresponded to a box on the cadastral layer of Six Viewer and this was used to create a polygon layer over a Google Earth image. The corner trees and other written notes from these plans and the surveyor's field notes were also recorded on separate maps. In addition, the parish map showed the historic extent of freshwater wetlands within the area and this was also recorded on the base map.

To bring together the information from the various sources, a map was created to represent the likely distribution of pre-European vegetation communities. This involved synthesising the results into the likely vegetation communities present, describing them and mapping their likely pre-European extent. The field work components provided information regarding the nature of the extant vegetation which, in combination with other environmental information, was extrapolated to the probable pre-disturbance vegetation. A list of plant species encountered in the field work is provided in Appendix 1.

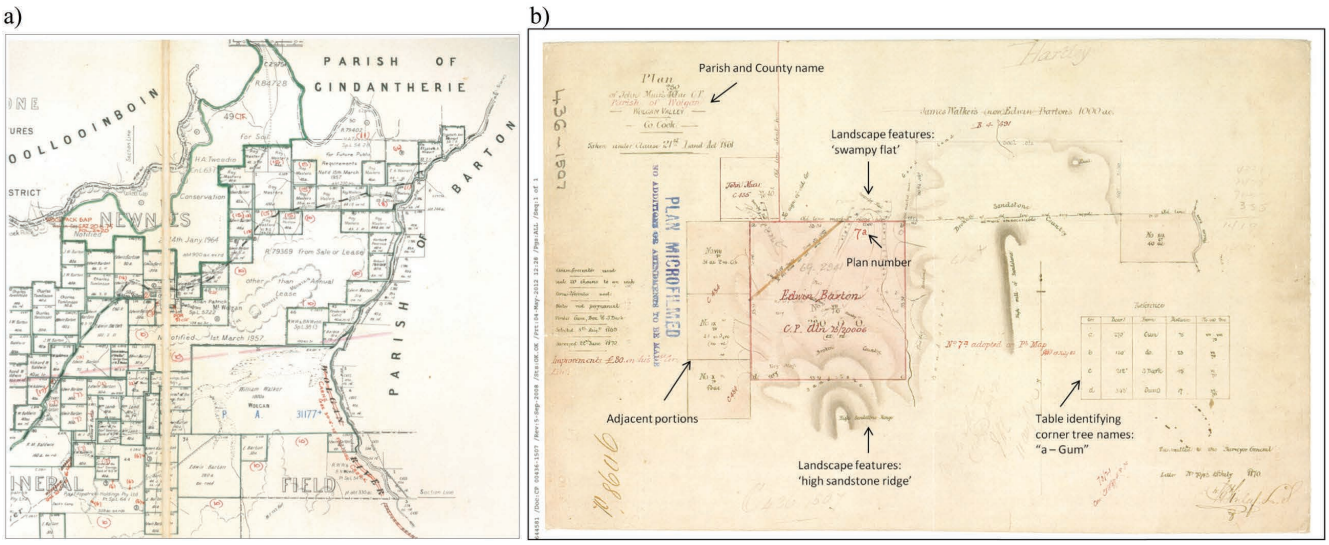

Figure 3. Some of the historic sources used in this research. a) The parish map for the Parish of Wolgan, County of Cook, 1884. b) An example of a Crown plan (Number 7a) with key features including the parish and county name, location and extent of adjacent portions, plan number, descriptions of significant landscape features, corner trees with their corresponding taxa.

Results- current vegetation of the Wolgan Valley Resort site

Surrounding Slopes

The valley floor, which formed the major focus of this study, is surrounded by relatively steep, sandstone-dominated slopes with a generally shallow sandy and rocky substrate. Our observations on the southern slopes (with a northern aspect) found a relatively open canopy with a variety of eucalypts including *Eucalyptus blakelyi, E. cannonii* and *E. punctata* as well as a scattering of *Callitris endlicheri* of different sizes. DEC (2006) suggested red stringybark in the valley was *E. macrorhyncha,* but we recorded the closely related species *Eucalyptus cannonii,* which is listed as Vulnerable. There was a large shrubs stratum of *Dodonaea triquetra* and *Exocarpos cupressiformis* and many typical smaller sandstone sclerophyllous species including *Acacia eucolobia, Acacia longifolia, Cassinia sifton, Leptomeria acida, Lissanthe strigosa* and *Podolobium ilicifolium*. Ground cover was patchy and fairly sparse with a high amount of leaf litter and exposed rock with herbaceous species including *Dichondra repens*, *Asperula conferta* and *Gahnia clarkei*.

The northern, south-facing slopes had a high diversity of canopy tree species including *Eucalyptus blakelyi, E. eugenioides, E. cannonii, E. mannifera, E. punctata* and *E. rossii* and a diverse layer of tall (1.5-2.5m) *Acacia* and a patchy, shrubby understorey. The understorey was slightly more open and grassier than the southern slopes, probably because of the cooler, southerly aspect. Nonetheless, ground cover was still patchy with large proportions of leaf litter and exposed rock. Additional species found were *Acacia paradoxa, Bursaria spinosa* var. *spinosa* and *Cassinia arcuata*.

Valley Floor

The relatively undisturbed nature of Carne Creek means that it is likely to be a relatively faithful remnant of the Riparian Forest community on alluvial substrates. *Eucalyptus viminalis* was the dominant canopy species along with *Casuarina cunninghamiana, Eucalyptus melliodora* and *E. cannonii*. The mid-storey was composed of trees of *Acacia filifolia, Hakea salicifolia, Leptospermum* and *Callistemon*, which are typical riparian species. Dominant understorey species included *Pteridium esculentum, Hydrocotyle laxiflora, Digitaria diffusa* and *Lomandra longifolia*. This mix of species is likely to have existed along both Wolgan River and Carne Creek.

The sampling area adjacent to the western end of Wolgan River was strongly influenced by nearby watercourses but included a slightly different suite of species providing an indication of variation within the Riparian Forest vegetation community of the valley. It was dominated by *Eucalyptus viminalis* to 23 m tall and trees of *Acacia implexa* and *A. filifolia*. There were very few mid-storey species and a dense, herbaceous ground cover dominated by exotic species, reflecting rural disturbance. There were some dense patches of *Pteridium esculentum* scattered throughout the sampling area but the most abundant ground species included *Microlaena stipoides, Geranium solanderi, Dichondra repens, Urtica incisa,* and exotics *Phalaris minor, Dactylis glomerata, Echium vulgare* and *Cirsium vulgare*.

At the south-western corner of the valley floor, adjacent to an extant swamp, the soils were sandy with a large proportion of cobbles and pebbles and generally drier than the other riparian areas appeared to indicate a former once-active channel that has since dried. The canopy was again dominated by *Eucalyptus viminalis* (~20 m height) and the dominant understorey species were *Austrostipa verticillata* and *Urtica incisa*. The groundcover was patchy with significant areas of bare ground and leaf litter; numerous *Eucalyptus viminalis* saplings were found in the area.

The northern arm of the Wolgan River was quite saturated at the time of sampling (mid-2012). *Eucalyptus viminalis* was again the dominant canopy species with some *E. blakelyi, Angophora floribunda* and tall *Acacia filifolia* also present. The dominant understorey species included *Microlaena stipoides, Hydrocotyle peduncularis, Poa labillardierei, Entolasia marginata, Carex* sp., *Themeda australis* and *Austrostipa scabra*. Dense thickets of *Leptospermum polygalifolium* and *L. juniperinum* over an understorey of *Juncus sarophorus* and *Isachne globosa* were evident in small saturated drainage depressions.

The very wettest areas included freshwater wetlands ('swamps'; Figure 4) dominated by tall (average 1.5 m high) *Juncus* species (*Juncus sarophorus, J. continuus*, *J. usitatus*), *Phragmites australis, Poa labillardierei* and exotic *Holcus lanatus*. *Carex appressa* was dominant on the drier edges of the swamp. Ground cover was characterised by herbaceous species such as *Ranunculus inundatus* and *Rumex brownii* as well as exotics *Hypochaeris glabra, Hypochaeris radicata, Rubus fruticosus* and *Cirsium vulgare*. There were also occasional shrubs of *Leptospermum polygalifolium* and *Callistemon citrinus* within the area.

The saturated area was restricted to the southern side of the Wolgan River. A 70 cm auger hole on the northern banks of the Wolgan River showed no evidence of peat. Local scale topographic variation also suggested that small 'islands' of slightly higher elevation were surrounded by elements of the freshwater wetland vegetation community, following the low-lying drainage lines. This information was used to map the current extent of wetland (Figure 5).

Figure 4. Views of the present freshwater wetlands ('swamps) of Wolgan valley. a) a small un-named wetland on a tributary of the Wolgan River, taken from the southern slopes of the valley (photo by Len Martin); b) A view from within the wetland on the valley floor, near Wolgan River; c) Taken from the northern slopes, facing south, with the banks of Wolgan River in the foreground.

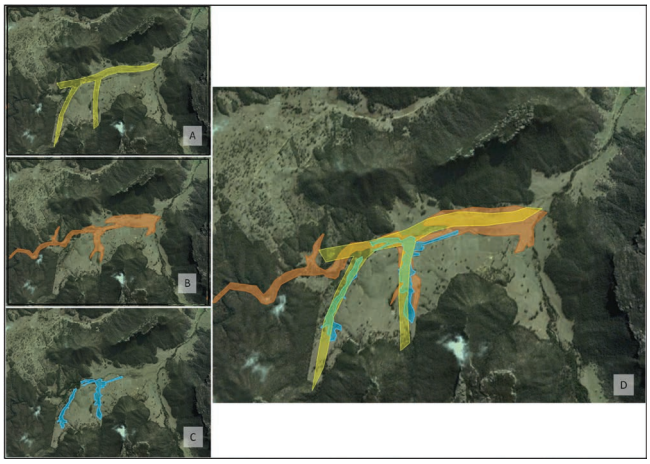

Figure 5. The freshwater wetlands ('swamps') of the Wolgan Valley. a) The extent of the swamp (shaded in yellow) from the 1831 Crown plan (number 26); b) The extent of the swamp (shaded in orange) from the 1884 parish map; c) The contemporary (mid-2012) extent of the swamp (in blue) from field observations of this study; d) A combination of all three area, emphasising considerable similarity in their extent. The images are draped on a 2012 Google Earth image.

Results- Historical Sources

Historical plans

Crown Plan 26 covers the oldest Portion and a large part of the present day cleared valley floor (Figure 3a), but unfortunately had very little vegetation information and no corner trees or other site-specific detail. This (1831) plan did show the extent of the freshwater wetland at that time (Figure 5b). The 1884 Parish of Wolgan map also indicated that the freshwater wetland extended along most of the

Wolgan River, as well as along a relatively large section of the valley floor, north of Wolgan River Resort but our observations make it likely that this was an exaggeration.

'Gums' were the most prevalent corner tree on the Crown plans on the valley floor areas, particularly close to the river. 'Boxes' and 'Stringybarks' were more commonly annotated on the slopes and 'Ironbark' was restricted to the far western edge of the valley. Although these are generic common names, the surveys of the extant vegetation can be used to speculate as to what species these names may have been referring to.

The surveyor's written comments also provided some more general landscape characteristics which were also overlayed over the area. These descriptions document the undulating hills of the valley floor, interspersed with flats of good soil and swampy areas. The 'swampy flat' of 'good soil' indicated that portion of the valley suitable for grazing and agriculture, and presumably guided rural activity in the following decades.

Analysis of aerial photos

The aerial photos showed no major changes to the extent of valley floor vegetation over the 56-year record (1950-2006) indicating the majority of clearing and landscape modification occurred between initial occupation of the valley in the 1820s and 1950.

Some smaller-scale changes were evident in the aerial photo compilation. As an example, the 1950 photos show less vegetation around the Wolgan River head-cut than today suggesting some natural regrowth has occurred and this appears to have reached its current extent by 1998. In 1950 there was more vegetation surrounding Carne Creek than today but this was lost by 1961. There has been some regrowth around the southern foot slopes between 1950 and 1998 but this has been relatively stable since that time. The majority of the remnant paddock trees on the valley floor have remained unchanged since 1950.

Paddock Trees

The species and spatial distribution of the paddock trees surveyed (Figure 6), show *Eucalyptus melliodora* was the most common species over the whole valley floor, but its distribution displays a tendency towards low ridges. This is a common grassy woodland species elsewhere (David Keith, pers. comm.). *Eucalyptus bridgesiana* was found in slightly drier areas, mostly on eastern facing slopes. *Eucalyptus viminalis* was usually located close to the river lines and on flatter ground. *Eucalytpus blakelyi* also tended to be proximal to the watercourses but on slightly more elevated and probably slightly drier substrates than *Eucalylptus viminalis*. A few *Angophora floribunda* were found on the swampier soils near the wetland area.

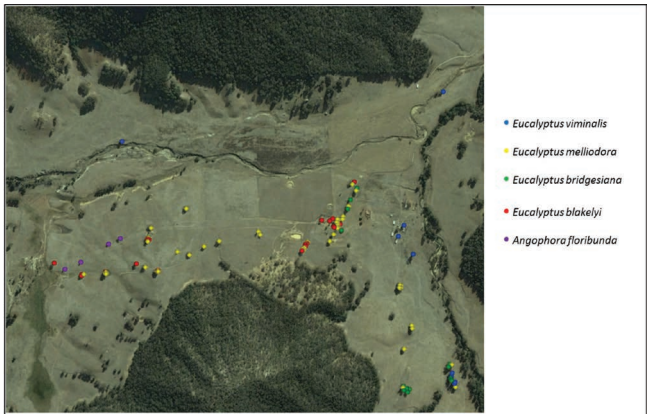

Figure 6. The results of the survey of the paddock trees in the Wolgan Valley. These trees were all extant in the 1950s aerial photographs, and could represent remnants of the pre-disturbance vegetation.

Discussion

Results from the field surveys and historical sources allows consideration of the pre-European vegetation communities of Wolgan Valley Resort area, best described using four vegetation communities or map units (Figure 7): Riparian Forest, Closed Herbfield and Shrub Swamps, Grassy Woodland and Shrubby Woodland (Table 1). These predicted vegetation communities are centred on the largely cleared valley floor; the talus slopes and upper plateau vegetation is still intact and well documented by other studies.

Riparian Forest

A Riparian Forest community would have dominated the major drainage lines of Wolgan Valley before European settlement and is likely to have been similar to the extant vegetation sampled along Carne Creek. There is however some uncertainty about how far this community extended along Wolgan River above the Carne Creek confluence as some wet swampy areas along parts of the river may not have supported a forest structure.

The Riparian Forest is likely to have been characterised by a tall open canopy of *Casuarina cunninghamiana* close to the drainage lines, with the surrounding floodplains dominated by *Eucalyptus viminalis, Angophora floribunda* and *Eucalyptus blakelyi*. The mid-storey is likely to have included smaller trees and some shrubs such as *Acacia filifolia, Hakea salicifolia* and *Leptospermum polygalifolium*. The understorey is likely to have been grassy with a diversity of herbaceous plants tolerant of sporadic flooding including *Poa labillardierei, Microlaena stipoides, Hydrocotyle peduncularis, Entolasia marginata, Themeda australis*, *Hydrocotyle laxiflora, Phragmites australis, Lomandra longifolia, Dichondra repens, Echinopogon caespitosus* and *Gahnia aspera*. This community is likely to closely resemble the DEC (2006) map unit "54: Capertee – Wolgan Riparian Rough-Barked Apple – River Oak Open Forest".

Table 1. The summary of the major features of the likely pre-disturbance vegetation communities of the Wolgan Valley.

	Riparian Forest	**Closed Herbfield and Shrub Swamp**	**Grassy Woodland**	**Shrubby Woodland**
Specht structure (1970)	Tall open forest	Herbfield to Shrubland	Woodland	Woodland
Location/ topography	Along major river lines, particularly Carne Creek. Extent along western branching arm of Wolgan Creek unknown.	Lowest topography surrounding and extending further than current swamp position. Extent along the river unsure.	The flatter but non-swampy sections of valley floor and some of the wetter drainage lines of the slopes.	Low slopes of the valley floor, grading up into talus slopes
Geology/ soils/ substrates	Alluvial sediments	Accumulated organic-rich sediments	Permian Illawarra Coal Measures (Nile sub-group)	Permian Illawarra Coal Measures (Charbon sub-group)
Canopy species	*Angophora floribunda* *Casuarina cunninghamiana* *Eucalyptus viminalis*		*Angophora floribunda* *Eucalyptus melliodora* *Eucalyptus blakelyi* *Eucalyptus bridgesiana*	*Eucalyptus mannifera* *Eucalyptus punctata* *Eucalyptus sparsifolia* *Eucalyptus cannonii*
Midstorey species	*Acacia filicifolia* *Hakea salicifolia* *Leptospermum polygalifolium* *Callistemon citrinus* *Persoonia linearis*	*Imperata cylindrica var. major* *Isachne globosa* *Juncus sarophorous Juncus usitatus* *Phragmites australis* *Carex appressa* *Poa labillarieri*	*Acacia filicifolia* *Acacia eucolobia* *Exocarpus cupressiformis*	*Acacia eucolobia* *Acacia longifolia* *Cassinia arcuata* *Leptomeria acida* *Lissanthe strigosa* *Podolobium ilicifolium*
Ground- cover	*Microlaena stipoides* *Hydrocotyle peduncularis* *Entolasia marginata* *Themeda australis* *Lomandra longifolia*	*Ranunculus inundatus* *Rumex brownii*	*Austrostipa scabra* *Cymbopogon refractus* *Themeda australis* *Poa sieberiana* *Microlaena stipoides*	*Dichondra repens Gahnia clarkei*
Previously mapped as	Capertee – Wolgan Riparian Rough-Barked Apple – River Oak Open Forest (DEC, 2006)	Cox's River Swamp (Benson and Keith, 1990)	Capertee Box Grassy Woodland (DEC. 2006) Threatened Ecological Community - Grassy Box Woodland (DEH, 2002/ DSEWPC, 2012)	Capertee – Wolgan Slopes Grassy Woodland & Tableland Shrubby Open Forest (DEC, 2006) Talus slope woodland (Benson and Keith, 1990)

Closed Herbfield and Shrub Swamp

The extent of Closed Herbfield and Shrub Swamp in Wolgan Valley is uncertain. The Parish Map, Crown Plan 26 and field observations all support freshwater wetland extending over part of the western branch of Wolgan River, with two sections branching south (Figure 5). These same sources suggest that it is unlikely that the wetland extended to the northern side of the valley. The area of freshwater wetland mapped (Figure 7) takes these uncertainties into account and represents the most likely extent of the original freshwater wetlands in the valley. There is no evidence (e.g. of drainage ditches) to indicate that pastoralists diverted river flows or drained wetlands, but it is likely that clearing, grazing, trampling and eutrophication by stock, and possibly altered fire regimes, resulted in considerable changes in species composition and/or dominance, and particularly the loss of sensitive species (Mactaggart *et al*. 2007).

It is also difficult to describe with certainty the original freshwater wetlands species composition as the only source of information comes from the field observations of the extant swamp. This suggests that it is likely that it was dominated by rushes, reeds and grasses such as *Juncus sarophorous, Juncus usitatus*, *Juncus continuus*, *Carex appressa, Poa labillardierei* and *Imperata cylindrica* var *major.* There may also have been patches, perhaps dense in places, of shrubs including *Leptospermum* and *Callistemon citrinus*. Searches in Wolgan Valley for the rare *Callistemon megalongensis* and *Callistemon purpuracen*s, only known in similar wetland habitat in Megalong Valley, were unsuccessful (D. Benson pers. comm. 2020). In the contemporary Wolgan Valley environment *Leptospermum juniperinum* only occurs as isolated shrubs on drainage lines but may have previously been a part of the more extensive swamp community. A variety of herbs or small shrubs tolerant of inundation have probably been lost due to their sensitivity to grazing, clearing, eutrophication or other aspects of this disturbance but likely included *Ranunculus inundatus* and *Rumex brownii*. The prevalence of *Phragmites australis* before the introduction of pastoral activity is uncertain: it is grazed on by stock (Roberts, 2000) but can also be advantaged by disturbance, particularly associated with any increasing groundwater salinity.

It is also clear that the Wolgan Valley includes extensive peat, with over 3 metres (in depth) exposed, for example, as a head cut has extended to the west along the Wolgan River. The

age of this peat is unknown, but it is likely an extensive mire occupied the valley when Europeans first entered the valley. Darwin (1838) described "the valleys being swampy and producing coarse pastures" (in reference to 1836). It is likely the original wetland was similar to the nearby Coxs River Swamps such as Long Swamp, which are dominated by a dense ground cover of sedges and grasses, *Carex, Juncus* and *Poa* species on waterlogged sites, where soils are clayey and organic, and derived from the Illawarra Coal Measures as in the Wolgan Valley (Keith & Benson 1988; Benson & Keith 1990). Long Swamp forms part of the Montane Peatlands and Swamps EEC (NSW *Biodiversity Conservation Act*).

Comparison of species lists across analogous valley fen vegetation communities, including *Carex-Poa* fen (e.g. Hunter and Bell, 2009), Tableland Swamp Meadow or more broadly swampy meadows/chains of ponds (e.g. Mactaggart *et al*. 2008) may be instructive in better characterising them. The Wolgan Valley swamps do not share much in common with the low nutrient and more sandy Newnes Plateau Shrub Swamps (e.g. Benson and Baird, 2012), a State and federal listed Endangered Ecological Community.

Grassy Woodland

Grassy Woodland is likely to have been the dominant valley floor vegetation surrounding the Swamp and Riparian communities. This community is likely to have existed on the flatter sections of the floodplains and concave slopes, as well as potentially extending further up the slopes along moist drainage lines, as an ecotone with the Shrubby Woodland (discussed below). The valley floor is likely to have supported a grassy and herbaceous understorey as the soils have better moisture-holding capacity than the sandstone soils of the surrounding slopes.

The dominant canopy species in the Grassy Woodlands were likely to have included *Eucalyptus melliodora, E. blakelyi, E. bridgesiana* and *Angophora floribunda*. The mid-storey was probably relatively sparse but scattered shrubs could have included *Acacia filicifolia, A. leucolobia,* members of the Ericaceae family, *Exocarpos cupressiformis* and *Leptospermum polygalifolium*, depending on small scale variations in drainage and soil type. The grassy and herbaceous ground cover is likely to have included species such as *Austrostipa scabra, Cymbopogon refractus, Themeda australis, Poa sieberiana* and *Microlaena stipoides*.

The Grassy Woodland identified in the Wolgan Valley is likely to share many similarities with the widespread *White Box Yellow Box Blakely's Red Gum Woodland* of the tablelands and western slopes of NSW and listed as an Endangered Ecological Community (NSW *Biodiversity Conservation Act 2016*) and as the Critically EEC *White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland* (Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*)). These grassy box woodland formations tend to occur on relatively fertile soils and are characterised by an overstorey of one or more of *Eucalyptus albens, E. melliodora* and *E. blakelyi* with a grassy and herbaceous ground layer and few shrubs in the understorey (DEH, 2002). This community has been highly fragmented because of clearing for cropping, pasture and agriculture and this fragmentation and their poor representation in our reservation system means that they have been described as some of the most critically endangered vegetation communities in Australia (Department of Sustainability, Environment, Water, Population and Communities, 2012).

Shrubby Woodland

A Shrubby Woodland is likely to have intergraded with the Grassy Woodland in places with a greater sandstone influence, such as the drier convex slopes and could be considered as an ecotone between Grassy Woodland and Talus Slope Woodland communities. The dominant canopy species was likely to have included some of those more commonly found on the talus slopes including *Eucalyptus mannifera, E. punctata, E. cannonii with E. blakelyi* and *E. melliodora* scattered throughout. The mid-storey was probably shrubbier and more sclerophyllous than the Grassy Woodland given sandier soils and reduced moisture availability. Common shrub species were likely to include *Acacia leucolobia, Acacia longifolia, Cassinia sifton, Leptomeria acida, Lissanthe strigosa* and *Podolobium ilicifolium*. A greater cover of small tree species than the Grassy Woodland was also likely these might have included *Acacia filicifolia, Acacia falciformis, Dodonaea triquetra* and *Exocarpos cupressiformis*. The lowermost stratum was probably less continuous with more exposed ground, rocks and litter cover. There was likely to be some slight differences within this community depending on aspect, with the north facing slopes being slightly drier and therefore more open. This vegetation community probably has elements of the DEC (2006) units 32 (Capertee – Wolgan Slopes Red Box – Grey Gum – Stringybark Grassy Woodland) and 21 (Tableland Scribbly Gum – Narrow-Leaved Stringybark Shrubby Open Forest).

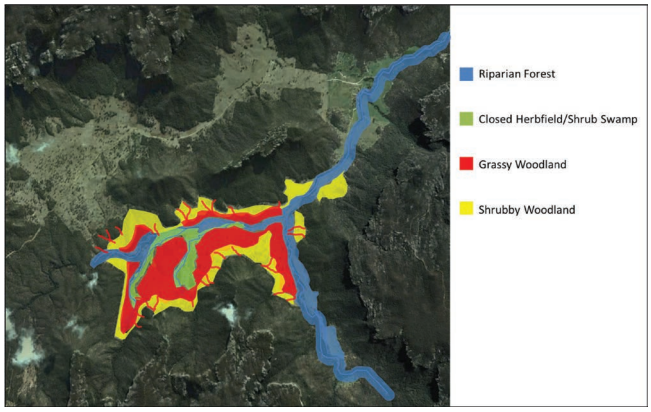

Figure 7. A map of the predicted pre-disturbance vegetation communities of the Wolgan Valley.

Restoration Ecology at Wolgan Valley Resort

Wolgan Valley Resort is a luxury tourist resort marketed by the land-owners (Emirates One&Only Wolgan Valley) as a

"conservation-based resort" that occupies one percent of a "2,800-hectare conservancy" (EO&OWV 2019). Previous management plans have emphasised protection, revegetation and the sustainable management of the ecological communities within the Wolgan Valley (Cumberland Ecology, 2007) and tree-planting and habitat restoration are listed as potential family activities for guests of the resort. This land-use and management focus adds to an impetus for restoration in comparison to alternative potential land uses such as agriculture.

Although restoration can encompass a variety of activities (e.g. McLoughlin, 1990), it is centred on the concept of recovery; revegetation efforts aimed at improving the quantity, quality and connectivity of remnant patches (Kimber *et al.* 1999). The Wolgan Valley resort's Ten-Year Plan (WVRS, 2012: p. 3) has stated that their "intention is to restore the former grazing property to a condition as close as possible to that existing at the time of pre-European settlement". The management of the study site has included plans for both regeneration and restoration (e.g. Cumberland Ecology, 2007). The former involves activities to encourage the *natural* regeneration of the vegetation, but this has largely been limited to weed control. Restoration, encompassing more intensive management action, has included the planting of a limited number of species of tube-stock or the direct seeding of local indigenous species, particularly in the riparian zone (Cumberland Ecology, 2007). This restoration has had limited success to date, although the restoration of previously cleared and grazed grassy woodlands and riparian vegetation typically face various and persistent challenges (e.g. Hobbs & Yates, 2000).

Our study provides the best picture of the pre-European landscape and vegetation now available, and a strategy of selecting species for planting in the restoration zones more closely associated with the original communities will have better long-term outcomes. It is clear that the original vegetation structure and floristic composition was influenced by localised physiographic conditions, and with variations in aspect, soil and hydrology. It is particularly important that species being chosen for planting should match the landform and context (Bennett *et al.* 2000). Other considerations beyond species selection and provenance, including design (i.e. density, arrangement or planting), the establishment of appropriate structural layers and the natural patchiness are all potentially facilitated with consideration of these results.

A considerable portion of the Wolgan Valley floor is likely to have originally been Grassy Woodland (Figure 7), and part of the listed Critically Endangered *White Box Yellow Box Blakely's Red Gum Woodland* EEC of the tablelands and western slopes of NSW. Management plans for the Wolgan Valley have not previously identified this EEC, perhaps because, in comparison to the other identified pre-European communities in Wolgan Valley, there is no intact remnant of the Grassy Woodland community perhaps not unexpectedly, as this area bore the brunt of agriculture and grazing. This is a common observation in eastern New South Wales where grassy woodlands have been severely degraded by agriculture (McIntyre *et al*., 2002; Keith, 2004). Nonetheless, arguably, isolated paddock trees and native herbs and grasses are extant remnants of this vegetation community. Robust and dense introduced pasture grasses (e.g. *Paspalum dilatatum*), likely significant exotic seed banks in the soil and potential changes to the physical or chemical characteristics of the soil (e.g. increased nutrient levels) (Fitzgerald 2009; Hobbs & Yates 2000) are all significant barriers to both regeneration and more active restoration in the valley (e.g. Wilkins *et al*. 2003; Nichols *et al*. 2010). Nonetheless, the Grassy Woodlands should be a priority for future efforts.

Finally, the imposed agricultural landscape arguably also has historic significance in the Wolgan Valley, as an extremely early pastoral landscape for Australia (early 1830s), with associated historic buildings, and documented visit by Charles Darwin in 1836. There is some potential for conflict between the regeneration or restoration of the pre-disturbance vegetation in the valley and this significance, and indeed the current luxury resort currently enjoys significant views of the surrounding sandstone cliffs and a pastoral 'idyll'. It is entirely possible that successful restoration could impinge on these values, but given the size and variation of areas suitable for different restoration techniques (forest, woodland, wetland etc), and the timescales involved, both natural and historical heritage values should be able to coexist and be appreciated within the spectacular landscape of the Wolgan Valley.

Conclusions

It is clear that the current landowner, Emirates One&Only Wolgan Valley is committed to the sustainable management and the regeneration and restoration of the ecological communities within their estate. It is less clear as to whether they are trying to restore the species composition and community structure to its pre-European state, or are simply aiming to restore the functional capacity of the landscape. Given the conservation status of the Grassy Woodland community, management should further consider their options regarding this Critically Endangered Ecological Community. Significantly, the luxury resort has the space, and seemingly the inclination, to experiment with the various techniques needed to restore some of this Endangered Ecological Community, and in so doing make a significant contribution to its broader regional survival.

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Appendix 1. Species encountered in this research in Wolgan Valley.

The locations of the sampling areas are indicated in Figure 1d. * exotic species. [a] only new species were recorded for the North Slopes.

	Presence of species in Sampling Areas								Planted in Conservation Zone
	1	2	3	4	5	6	S	N[a]	
Canopy species									
Angophora floribunda	✓				✓				✓
Brachychiton populneus	✓								
Callitris endlicheri							✓		
Casuarina cunninghamiana		✓					✓		✓
Eucalyptus albens									✓
Eucalyptus blakelyi	✓				✓		✓	✓	✓
Eucalyptus cannonii	✓	✓					✓	✓	
Eucalyptus cypellocarpa	✓								✓
Eucalyptus eugenioides	✓							✓	✓
Eucalyptus mannifera	✓							✓	✓
Eucalyptus melliodora		✓							
Eucalyptus punctata	✓						✓	✓	✓
Eucalyptus rossii	✓							✓	
Eucalyptus tereticornis	✓								✓
Eucalyptus viminalis		✓	✓	✓	✓				✓
Small trees									
Acacia dealbata							✓		✓
Acacia filifolia	✓	✓	✓		✓				✓
Acacia implexa	✓		✓						
Acacia leucolobia	✓								
Acacia maidenii									✓
Acacia obtusifolia									✓
Acacia verniciflua	✓								
Brachychiton populneus				✓					
Dodonaea triquetra							✓		
Exocarpos cupressiformis							✓		
Exocarpos strictus							✓		
Hakea salicifolia		✓							
Myoporum montanum							✓		
Persoonia linearis							✓		
Shrubs									
Acacia brownii									✓
Acacia leucolobia							✓		
Acacia longifolia							✓		
Acacia paradoxa								✓	
Asperula conferta							✓		
Breynia oblongifolia	✓								✓
Brachyloma daphnoides	✓								
Bursaria spinosa var. spinosa								✓	
Callistemon citrinus		✓							✓
Cassinia sifton							✓		
Gonocarpus teucroides					✓				
Leptomeria acida							✓		
Leptospermum juniperinum					✓				
Leptospermum polygalifolium subsp. *polygalifolium*		✓	✓		✓				
Leucopogon lanceolatus		✓							
Lissanthe strigosa	✓						✓		
Ozothamnus diosmifolius	✓								
Podolobium ilicifolium	✓						✓		
Polyscias sambucifolia		✓							

	Presence of species in Sampling Areas								Planted in Conservation Zone
	1	2	3	4	5	6	S	N[a]	
Pomadarris prunifolia var. *prunifolia*			✓						
Pteridium esculentum		✓							
Rubus anglocandicans		✓							
Rubus parvifolius		✓							
Solanum nigrum *		✓							
Grasses, Herbs and Groundcovers									
*Acetosella vulgaris**				✓					
Adiantum aethiopicum		✓							
*Anagallis arvensis**					✓				
Asperula conferta							✓		
Austrostipa scabra					✓				
Austrostipa verticillata				✓	✓				✓
Billardiera sp.			✓						
Blechnum nudum					✓				
*Bromus catharticus**				✓	✓				
Carex appressa					✓	✓			
Cheilanthes sieberi					✓				
Chloris ventricosa				✓	✓				
*Cirsium vulgare**		✓	✓	✓	✓	✓			
Clematis aristata					✓				
*Conyza bonariensis**		✓							
*Conyza sumatrensis**			✓						
Cotula australis			✓						
Cymbonotus lawsonianus			✓		✓				
Cymbopogon refractas					✓				
*Dactylis glomerata**			✓	✓					
Dianella revoluta					✓				
Dichondra repens			✓	✓	✓		✓		
Digitaria diffusa		✓			✓				
Echinopogon caespitosus		✓			✓				
Echinopogon ovatus		✓							
*Echium plantagineum**				✓	✓				
*Echium vulgare**			✓		✓				
Einadia nutans			✓						
Einadia trigonos			✓						
Entolasia marginata		✓			✓				
Entolasia stricta				✓					
Eragostus brownii				✓					
Eragrostis leptostachya					✓				
Gahnia aspera			✓		✓				
Gahnia clarkei							✓		
*Gamochaeta coarctatum**			✓						
Geitonoplesium cymosum					✓				
Geranium solanderi		✓	✓		✓				
Glossocardia bidens			✓						
Glycine tabacina					✓				
Gonocarpus teucrioides		✓							
Hardenbergia violacea							✓		
*Holcus lanatus**					✓	✓			
Hydrocotyle laxiflora		✓			✓				
*Hypochaeris glabra**						✓			
*Hypochaeris radicata**			✓	✓	✓	✓			
Imperata cylindrica var *major*		✓				✓			
Isachne globosa					✓	✓			
Juncus australis					✓				

	Presence of species in Sampling Areas								Planted in Conservation Zone
	1	**2**	**3**	**4**	**5**	**6**	**S**	**N[a]**	
Juncus sarophorus					✓	✓			
Juncus usitatus						✓			
Lagenifera stipitata		✓							
*Lepidium africanum**			✓	✓					
Leptomeria acida							✓		
Lissanthe strigosa					✓		✓		
Lomandra filiformis subsp. *coriacea*					✓				
Lomandra longifolia		✓	✓						
*Lotus uliginosus**						✓			
Luzula sp.					✓				
Lythrum salicaria						✓			
*Marrubium vulgare**								✓	
Microlaena stipoides			✓		✓				
*Modiola caroliniana **			✓						
*Nassella trichotoma**				✓	✓				
Oplismenus aemulus		✓	✓		✓				
Oxalis corniculata			✓						
*Panicum capillare**				✓					
*Paronychia brasiliana**			✓						
*Paspalum dilatatum**						✓			
*Phalaris minor**			✓						
Phragmites australis		✓	✓			✓			
*Plantago lanceolata **					✓				
Poa labillardierei					✓	✓			
Poa sp.						✓			
Podolobium ilicifolium							✓		
Poranthera microphylla					✓				
Pseudognaphalium luteoalbum			✓						
Pteridium esculentum			✓	✓	✓				
Ranunculus inundatus						✓			
*Rubus fruticosus**						✓			
Rumex brownii						✓			
Scleranthus sp.						✓			
Senecio diaschides		✓	✓		✓				
Senecio hispidulus			✓						
Senecio minimus			✓						
Senecio quadridentatus			✓						
*Silybum marianum**			✓						
*Solanum nigrum **			✓	✓					
Solenogyne gunnii					✓				
*Sonchus oleraceus **			✓	✓					
*Stellaria media**			✓						
Stypandra glauca	✓								
*Taraxacum officinale **				✓					
Themeda australis					✓				
*Trifolium repens **			✓						
Urtica incisa			✓	✓					
*Verbascum virgatum**			✓						
*Verbena bonariensis**			✓		✓				
Veronica plebeia		✓	✓		✓				
Viola hederacea					✓				
Vittadinia cuneata var. *cuneata*			✓						
Wahlenbergia gracilis		✓			✓				