First report of native vegetation recovery at the Roe 8 corridor

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Dr Jane Chambers and Murdoch University ecology students monitoring vegetation recovery in September 2017. Staff and students were required to wear fluoro vests because at the time, the site was under management of Main Roads Western Australia. Photo by RJ Standish.

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Executive summary

Murdoch University staff and students have tracked the recovery of native vegetation at the Roe 8 corridor 7 to 25 months after the clearing disturbance. Density, species richness and percentage cover of native perennial species was monitored in 20 m × 20 m plots across seven ecosystem types. Data on vegetation recovery were benchmarked to reference woodlands to assess progress against Restoration Goals 9, 10, 11.4 and 12 of the Rehabilitation Management Plan. These data suggest recovery is on-track for most ecosystem types, and particularly banksia-woodypear and banksia-jarrah ecosystem types. We found no evidence of mulch, soil compaction and soil pH influencing recovery. However, corridor soils are compacted compared with reference soils, which may impact root growth. Intervention may be necessary to return trees to banksia-blackbutt and holly-leaved banksia woodlands. Ongoing weed control is likely to be required especially in the banksia woodland ecosystem type, which is one of the most degraded of the target ecosystems. Density of resprouters was reduced in corridor compared with benchmark reference plots. Resprouters with concomitant low seed output characterise these banksia woodland ecosystems; sourcing their seeds for restoration could be problematic. Future student-led monitoring of these permanent plots would be complemented by expert monitoring of random unmarked plots and remote sensing data.

Dr Phil Ladd helping Murdoch University ecology student identify a native seedling at Roe 8 in Spring 2017. Photo by Jaimee Smith.

Introduction

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER 2004). At best, the practice of restoration is informed by ecological science, and actioned by the stakeholders with vested interests in the ecosystem requiring restoration. Stakeholders include conservation land managers, ecologists, local community, and industry. One of the first steps in the restoration process is to assess the level of intervention required to achieve restoration goals. Intervention can range from doing nothing (i.e., unassisted recovery) to moderate intervention (e.g., installing fences to protect seedling recruits from herbivores; Prober et al. 2011) right through to high levels of intervention that include multiple activities (e.g., topsoil application, seeding, planting and fertiliser application; Daws et al. 2015). In some cases, the ecosystem will recover certain attributes without intervention. In these cases, restoration interventions would be designed to return attributes that the ecosystem has not recovered on its own. Measuring recovery prior to restoration is particularly important where the goal is the restoration of the historic native ecosystem (i.e., the native ecosystem that grew at the site prior to its being degraded, damaged or destroyed; the 'reference').

Theory predicts unassisted recovery will occur in the absence of abiotic (non-living) and biotic (living) thresholds (Whisenant 1999). Thresholds are essentially barriers that prevent ecosystem recovery. For example, an abiotic barrier might be compact soils that limit growth of plant roots whereas a biotic barrier might be the presence of competitive weeds that negatively effects growth of native plants. Restoration would focus on interventions to overcome these barriers, so intervention to reduce soil compaction (e.g., through soil ripping) and interventions to reduce the abundance of the competitive weed (e.g., through herbicide application or hand-weeding). More than one barrier can be present at any one site and so the effort involved can be significant, particularly for large areas requiring restoration (Menz et al. 2013). For this reason, the absence of abiotic and biotic thresholds is particularly fortunate because it means the ecosystem itself will help with the process of recovery.

The Roe 8 corridor was cleared of native vegetation in February 2017 (Save Beeliar Wetlands 2017). Impetus to restore the Roe 8 corridor emerged in the aftermath of the clearing and was supported by the then newly elected State Labor Government. These key ingredients, coupled with strong engagement by scientists and the local community, resulted in the development of a ten-year rehabilitation plan for the corridor (Flint 2017; Emerge Associates 2018). Murdoch University academics have been engaged with restoration and educational activities at Roe 8 since April 2017. Beginning in September 2017, Dr Rachel Standish has led a vegetation monitoring effort throughout the Roe 8 corridor to capture vegetation recovery benchmarked against reference plots (Manning 2017). Plots have been monitored twice; Sept 2017 (i.e., 7 months after impact) and Sept 2018 (i.e., 19 months after impact). Additional data were collected in April–May 2019. These data and their analysis, led by Dr Joe Fontaine, form the basis of this report. Specifically, we report vegetation recovery against Goals 9, 10, 11.4 and 12 of the rehabilitation management plan (Emerge Associates 2018; Table 1). These data can be used to assess the level of additional intervention required to overcome barriers to recovery and to achieve the restoration goals.

Table 1. Data available from the Permanent Monitoring Plots established by Murdoch University in 2017 and 2018 to address restoration goals detailed in the Rehabilitation Management Plan. Goals copied from Table 4 on page 10 of plan. #Important native species are highlighted in Appendix 1.

Goal	Primary Objective	Minimum Objective	Data to address Objective
9. Re-establish native vegetation in cleared areas	9.1a. Density (stems/unit area) of each important# native species ± 25% of that recorded in reference sites	9.1b Density (stems/unit area) of each important# native species ± 50% of that recorded in reference sites	Average density of native perennial species in corridor and benchmark reference plots per target ecosystem. Spatial scale: subplot (5 m × 5 m).
	9.2a Count of native flora ≥90% mean species richness identified for target ecosystem	9.2b Count of native flora ≥60% mean species richness identified for target ecosystem	Average species-counts (native perennial richness per subplot) in corridor and benchmark reference plots per target ecosystem. Spatial scale: subplot.
	9.3a Cover (%) native understorey flora species ≥95% of total understorey cover (%)	9.3b Cover (%) native understorey flora species ≥80% of total understorey cover (%)	Percentage cover of ALL native perennial plant species in corridor and benchmark reference plots per target ecosystem. (See also Goal 10). Spatial scale: subplot.
	9.4a Understorey cover (%) ±25% mean understorey cover (%) recorded in reference sites.	9.4b Understorey cover (%) ≥50% mean understorey cover (%) recorded in reference sites.	Percentage cover of weed species in corridor and benchmark reference plots per target ecosystem. Spatial scale: subplot.
10. Re-establish fauna habitat in cleared areas	*We inferred that density of differing growth forms would estimate recovery of fauna habitat. Further research is required to test our inference.*		Density of native species per plant growth form in corridor plots relative to benchmark reference plots per target ecosystem. Spatial scale: plot (20 m × 20 m), subplot.
11. Re-establish ecosystem function in cleared areas	11.4a Count of native flora species recorded as recruited from seed ±50% that recorded in reference sites.	11.4b Count of native flora species recorded as recruited from seed in the corridor.	Density of native perennial plant species split by resprouting capacity in corridor plots relative to degraded reference and benchmark reference plots. Spatial scale: subplot.
12. Manage native vegetation in uncleared areas within 20 m of cleared areas	12.1a Cover (%) native understorey flora species ≥95% of total understorey cover (%) (*reference sites*).	12.1a Cover (%) native understorey flora species ≥80% of total understorey cover (%) (*reference sites*).	Density, richness, and percentage cover of native perennial plant species in degraded reference relative to benchmark reference plots for jarrah-banksia woodland. Spatial scale: subplot.

Methods

Monitoring design

At total of 63 20 m × 20 m monitoring plots were established throughout the Roe 8 corridor and adjacent remnant vegetation (Figure 1). Fifty-two plots were established in Spring 2017 and a further 11 plots were established in Spring 2018. Plot locations were selected to represent the spatial extent of the seven ecosystem types that occur within the site boundary (Figure 1; Table 2). Most plots surveyed in 2017 were re-surveyed in 2018. Vandals removed plot markers in some Management Areas making re-survey difficult and, in these cases, new plots were established in 2018.

Figure 1. Map of monitoring plots established by Murdoch University in Spring 2017 and Spring 2018. Invasive weeds were abundant in Degraded Reference plots whereas Benchmark Reference plots were in good condition at the time of monitoring. Four degraded reference and ten benchmark reference plots were within a 20 m buffer of the corridor; two degraded reference and four benchmark reference plots were outside the 20 m buffer.

Table 2. Permanent Monitoring Plots (20 m × 20 m) established by Murdoch University staff and students in 2017 and 2018 by ecosystem type and listed from most to least common ecosystem type within the site boundary. Dune soils after McArthur and Bettenay (1974); the older Bassendean dune soils are east of the younger Spearwood dune soils. The number of Benchmark Reference (i.e., good condition) plots are indicated in brackets; invasive weeds were abundant in Degraded Reference plots (Figure 1). Management Areas within the corridor are indicated in brackets. In addition to the impact of vegetation clearing, power-lines and a limestone track run through Hope Road North and there is road construction at Bibra Drive. Note that for Hope Road North, the target ecosystem is banksia woodland rather than the reference banksia–jarrah woodland, owing to the need to restore short-statured vegetation beneath the power lines.

Ecosystem type	Dune soils	Corridor	Reference (Benchmark)
Banksia–jarrah woodland	Spearwood	19 (Forrest Road North & South, North Lake Road West & East)	8 (4) (Forrest Road South, North Lake Road West & East)
Banksia–coastal blackbutt woodland	Bassendean	3 (Hope Road North, Bibra Drive)	2 (1) (Hope Road North, Bibra Drive)
Banksia–woody pear woodland	Spearwood	10 (North Lake Road West)	1 (1) (North Lake Road West)
Banksia–tuart woodland	Spearwood	3 (Stock Road West)	3 (3) (Stock Road West)
Holly-leaved banksia woodland	Bassendean	4 (Hope Road North, Bibra Drive)	3 (3) (Hope Road North, Bibra Drive)
Wet forest and woodland	Bassendean	2 (Hope Road North)	2 (1) (Hope Road North)
Banksia woodland	Bassendean	2 (Hope Road North)	1 (1) (Hope Road North)
TOTAL	**2**	**43**	**20 (14)**

Data collection

Undergraduate students worked in groups with staff to record vegetation recovery in plots, and subplots and quadrats nested within plots (Figure 2). Here, we report data collected in plots and subplots. Plots were surveyed in spring of 2017 (25–29 Sept) and 2018 (24–28 Sept) to capture annual plants and to help with plant species identification (i.e., using flowers). Students counted the number of trees, grass trees and macrozamias within plots and the number of shrubs and understorey species within subplots. In subplots, students also visually estimated the percentage cover of shrub and understory species. Staff helped students to identify plant species. Students subsequently entered the data on spreadsheets. It is important to note that the vegetation data presented here are not exhaustive; some annual species may be active at different times of the year and other species may grow outside the plots. Plant species richness in the entire corridor will likely be higher than what we report here.

In 2017, students collected additional plot-level data on percentage cover of mulch, soil compaction and soil pH, to determine the effects of these variables on vegetation recovery. Areas of the corridor were under piles of mulch between February and May 2017, and in September 2017, the footprint of these piles was evident as a thin layer of mulch cover. The percentage cover of this footprint was visually estimated for plots (i.e., 0 to 100% cover).

Soil compaction was measured as penetration resistance in megapascals, up to a depth of 80 cm, and these data were collected using a Penetrologger (ver. 6, Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands; using a 10 mm probing rod and Cone 3 with a base area of 3.33 cm^2). Soil samples were collected to a depth of 10 cm in the centre of each plot and soil pH was measured in a laboratory using 1:5 ratio of soil to water. We predicted that mulch cover and soil compaction would negatively impact vegetation recovery and that soil pH would have no impact except perhaps where lime from limestone paths had leached into the soils elevating the pH.

Finally, in April 2019, Murdoch University undergraduate student Sam Hovard collected data on density of native perennial plant species in a subset of degraded reference, benchmark reference and corridor plots (n = 2, 3 and 20 plots respectively). For each plant he recorded whether it had regenerated from seed or resprouted after the 2016-2017 clearing. Some native species regenerate solely from seed (nonsprouters; Appendix 1) while others may regenerate from seed or via resprouting (resprouters; Appendix 1). In May 2019, Sam measured soil penetration resistance in these plots using the Penetrologger as before but up to a depth of 40 cm to specifically target the rooting zone of the young native plants. He used the 8 mm probing rod and Cone 1. These data will differ to the round of measurements collected in 2017 because of the two depths at which data were collected, the two cone sizes and the physical strength and leverage of the different operators (Herrick and Jones 2002).

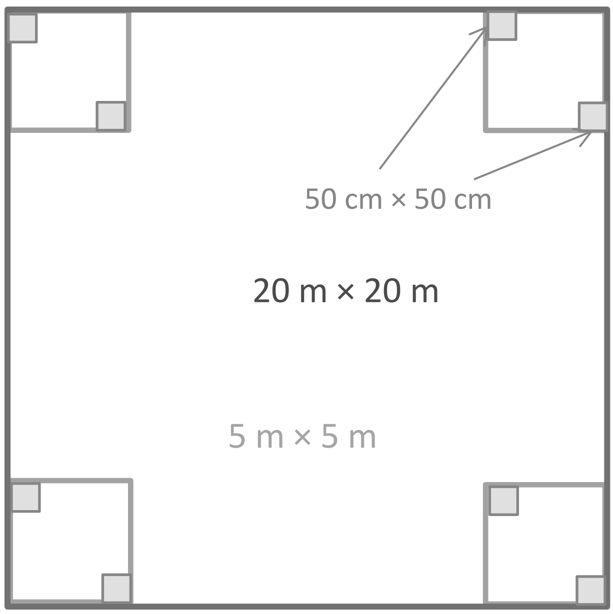
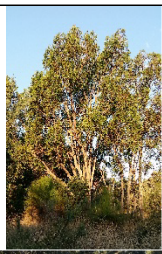
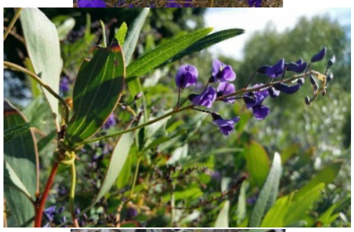
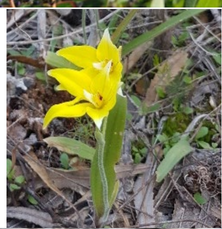
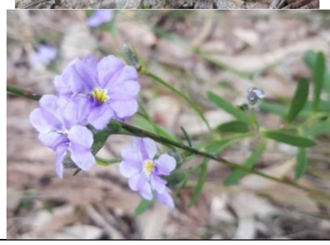


Figure 2. Size and configuration of plots (20 m × 20 m), subplots (5 m × 5 m) and quadrats (50 cm × 50 cm). Data reported here were collected from plots and subplots.

Data management and synthesis

Staff checked the data and created a relational database to store and manage the dataset. Relational databases are fit-for-purpose because they help enforce data structure and prevent errors with data entry. The data from the monitoring plots were combined with species-level data on species origin: native or weed; growth form: bulb, grass and herb for non-woody species and climber, dwarf shrub and shrub for woody species, and palmoid (i.e., grass trees and macrozamias) and tree for large woody species (Table 3). Splitting plant species into groups based on their origin, growth form and other traits is a long-standing tradition in plant ecology because these traits tend to predict species' responses to disturbance events such as vegetation clearing. In the restoration context, the trait-based approach helps ecologists to identify patterns in the data that help to inform management (i.e., to identify groups of species that need intervention to assist their recovery). The obvious example is weeds—known disturbance specialists, but there are likely to be other differences in disturbance responses too, say between trees and herbs. Another pertinent example in the restoration context is capacity to resprout from rootstock (e.g., lignotuber, rhizomes, stem base) because this trait helps to predict species' responses to disturbance, usually fire but also clearing, and tends to be associated with other life history characteristics including reduced seed output (Clarke et al. 2015). Sourcing and growing native resprouters from seeds is difficult and these species can be 'recalcitrant' to restoration (Koch 2017). On the other hand, some problem weeds are resprouters! We compared recovery of resprouters and nonsprouters for the subset of native perennial plant species captured in the April 2019 dataset. The species within each growth form and resprouting capacity are listed in Appendix 1. We created figures of data to address Goals 9, 10, 11.4 and 12 of the Rehabilitation Management Plan (Table 1).

Table 3. Plant growth forms. All photos by Joe Fontaine

Growth form	Description	Scale of monitoring	Example species	Photograph
Tree	Large woody species forming the canopy of a benchmark site	Plot	*Eucalyptus todtiana*	
Palmoid	Large statured but non-woody species with apical growth	Plot	*Macrozamia fraseri*	
Shrub	Tall woody species in the understory	Subplot	*Calytrix fraseriana*	
Dwarf Shrub	Small woody species in the understory	Subplot	*Hovea pungens*	
Climber	Woody or semi-woody species that use other plants for support	Plot	*Hardenbergia comptiana*	
Bulb	A species whose leaves are present in winter-spring but not in summer	Subplot	*Caladenia flava*	
Grass-like	Grasses and grass-like species with a tussock or similar growth form	Subplot	*Schoenus clandistinus*	
Herb	A non-woody perennial species in the understory	Subplot	*Dampiera linearis*	

Results

This section includes a series of figures of data matched to Restoration Goals and organised by ecosystem type (Table 1). For each goal, data are means + 95% confidence intervals (CIs). If CIs overlap, then means are not statistically different from one another. If CIs do not overlap, then means are statistically different from one another. For Goal 10, we organised the data by plant growth form (Table 3). For Goal 11.4, we organised the data by resprouting capacity (Appendix 1). For Goal 12, we focused on the banksia-jarrah woodland because replicate plots were available to compare degraded and benchmark reference plots across years. To assess impacts of mulch, soil compaction and soil pH we used means + 95% CIs or scatter plots (i.e., to check for correlation between variables).

Goals 9.1 and 9.2

Vegetation recovery along the Roe 8 corridor was evident from data on density and species richness of native perennial plants (Figures 3 and 4). The density of native perennials was comparable between corridor and reference plots for banksia-woodypear, banksia-jarrah, banksia-tuart and wet forest in one or both years (Figure 3). The density of native perennials in the corridor increased between 2017 and 2018 for banksia-blackbutt, banksia and holly-leaved banksia ecosystems (Figure 3).

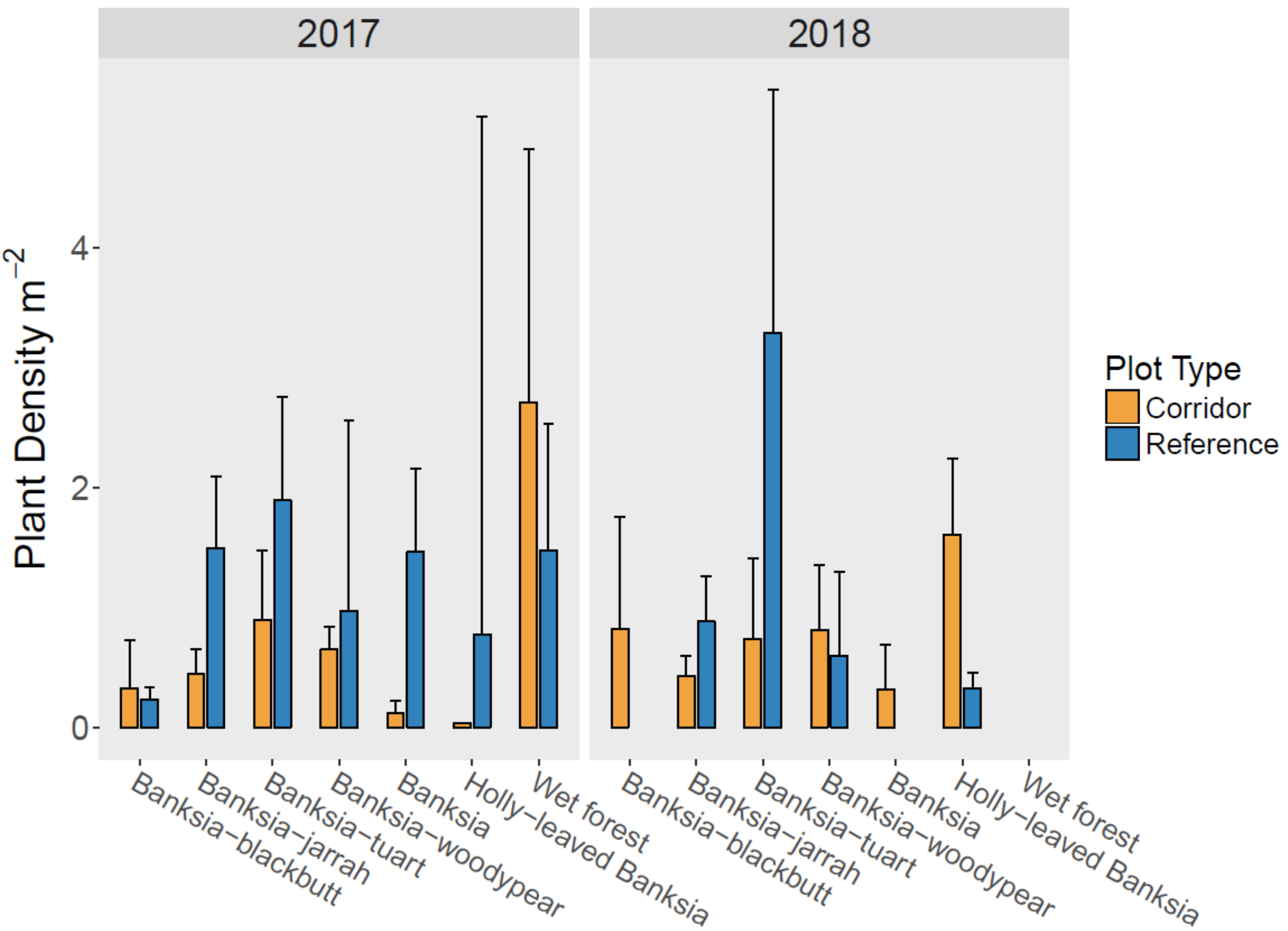


Figure 3. Native perennial plant density by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 2–52 subplots. Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018.

Counts of native perennial plant species were similar between corridor and benchmark reference plots for banksia-blackbutt, banksia-jarrah, banksia-woodypear in one or both years (Figure 4). The large CIs indicate high variation in species richness among plots, particularly among benchmark reference plots, which could reflect variation in vegetation condition. Counts of native perennials in corridor plots were similar between years for all ecosystem types, except holly-leaved banksia woodland, where more species were counted in 2018 compared with 2017 (Figure 4).

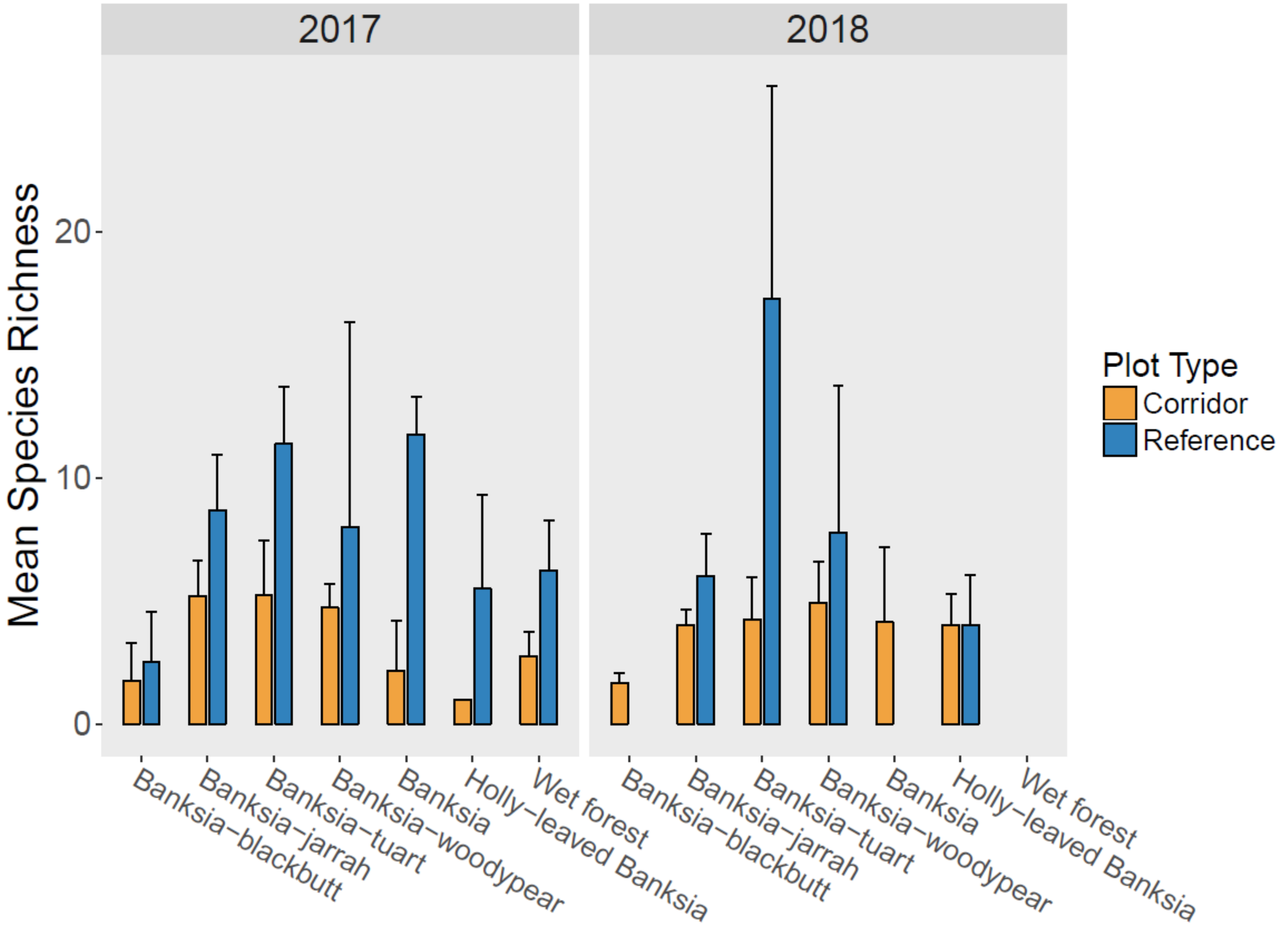


Figure 4. Counts of native perennial plant species by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 2–64 subplots. Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018.

Goals 9.3 and 9.4

Percentage cover of native perennial species were similar between corridor and benchmark reference plots for banksia-jarrah in 2017 and 2018, and banksia in 2017 (Figure 5). Percentage cover of native perennials was lower in corridor compared with benchmark reference plots for banksia-blackbutt, banksia-tuart, banksia-woodypear, holly-leaved banksia and wet forest (in 2017) ecosystem types (Figure 5). Percentage cover of native perennials was variable among corridor and especially benchmark reference plots (Figure 5). These data include all native perennial species; please see next section (Goal 10) for specific data on recovery of understorey species (Goal 9.3). Percentage cover of weed species were consistently lower than percentage cover of native species in corridor and benchmark reference plots (Figures 5 and 6).

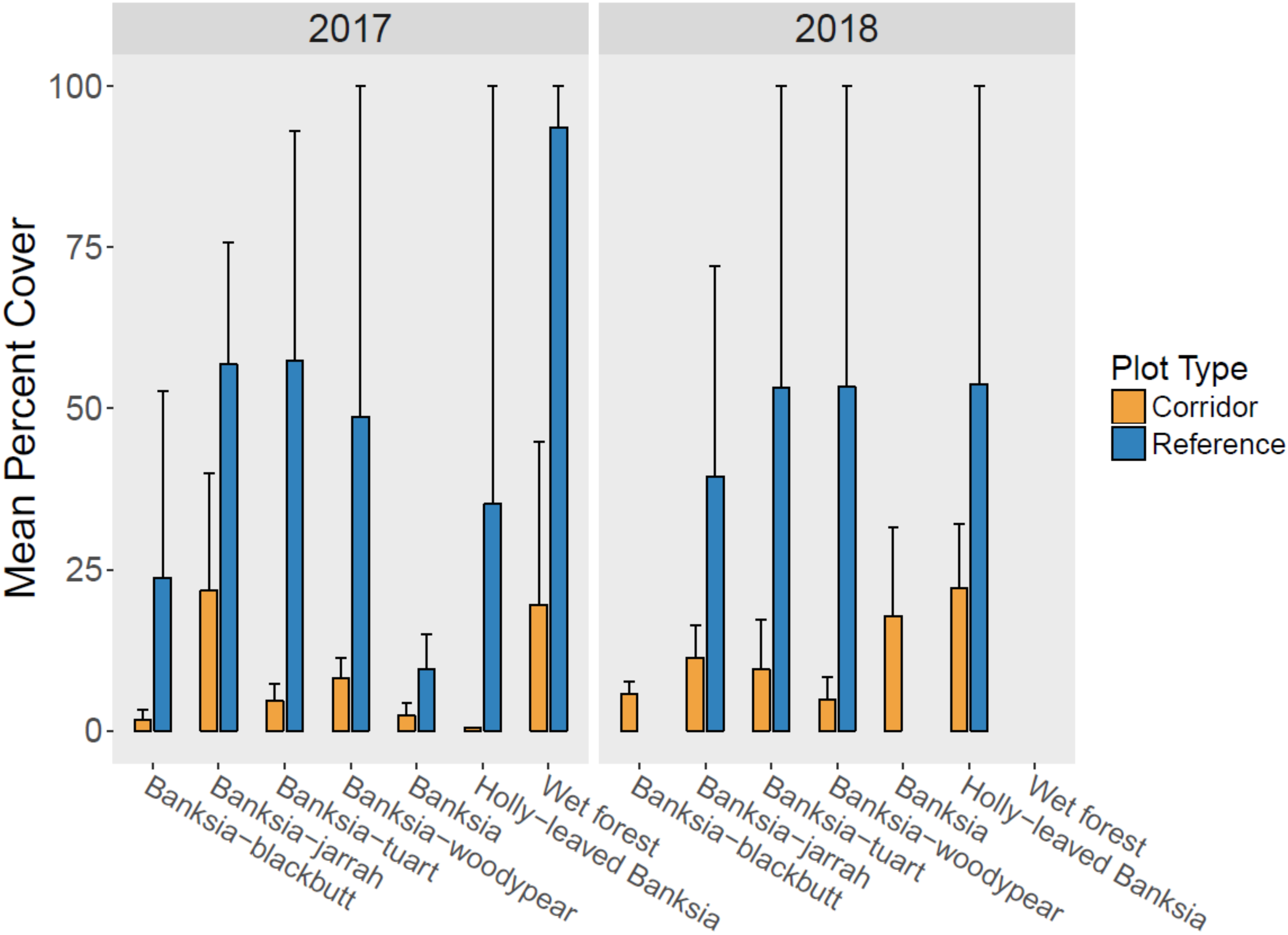


Figure 5. Percentage cover of native perennial plants by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 2–31 subplots. Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018.

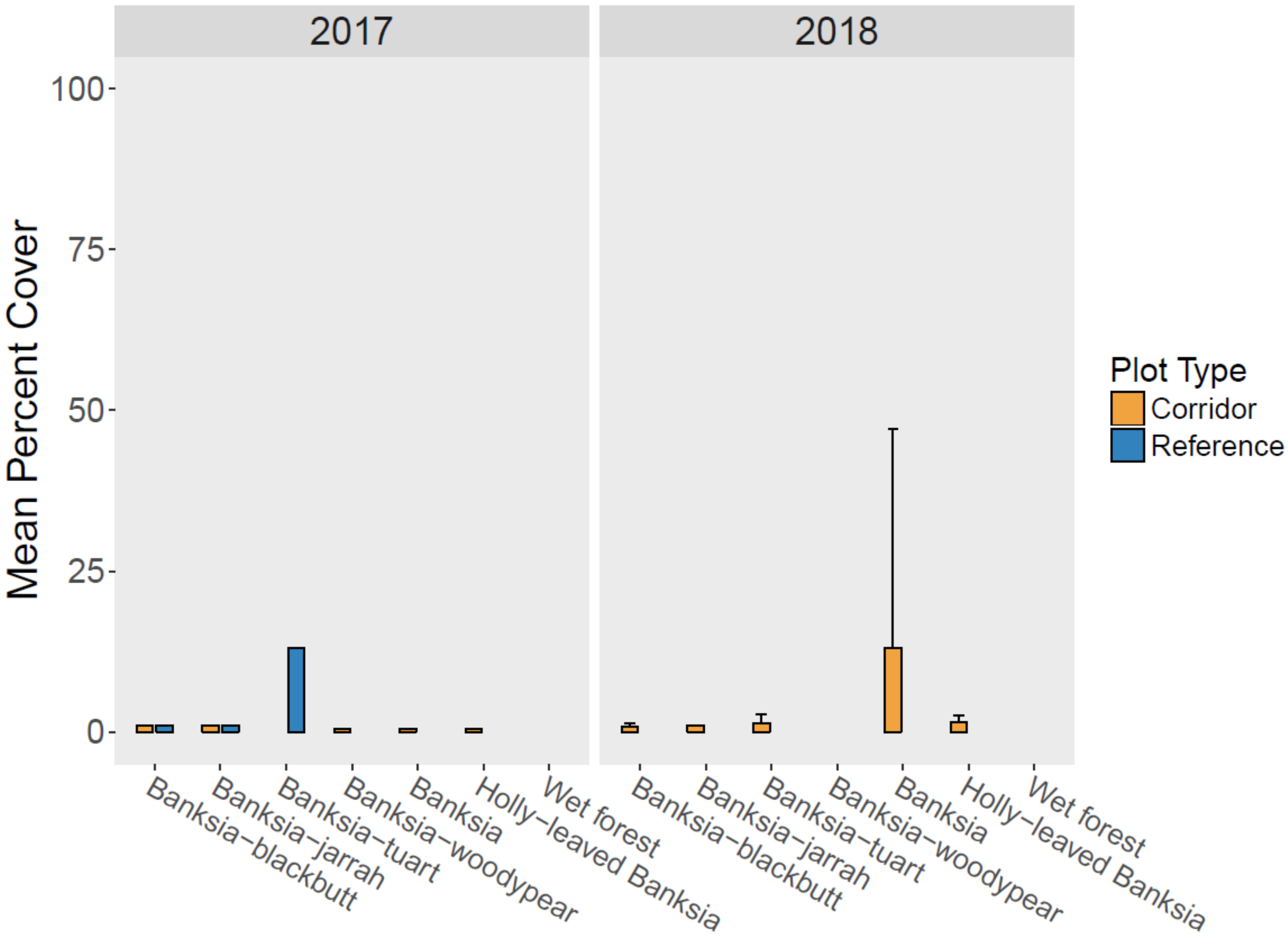


Figure 6. Percentage cover of weeds by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 1–12 subplots. Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018, and data are missing for some ecosystem types because some groups did not record weeds in subplots.

Goal 10

Recovery of palmoid and tree growth forms was evident in corridor plots especially for banksia-jarrah and banksia-woodypear ecosystems (Figure 7). No palmoids or trees were recorded in corridor plots in banksia-blackbutt and holly-leaved banksia ecosystem types (Figure 7). Recovery of woody understorey plants in corridor plots was also evident, particularly for dwarf shrubs (Figure 8). Recovery of all three plant growth forms was evident in banksia-woodypear corridor plots. Density of dwarf shrubs and shrubs increased between 2017 and 2018 in corridor plots in holly-leaved banksia woodland (note change in y-axis values for shrubs from 2017 to 2018). In 2017, the density of shrubs was similar for corridor and benchmark reference plots across ecosystem types, and similarly for 2018, except shrubs were denser in corridor plots compared with benchmark reference plots for banksia-blackbutt and holly-leaved banksia woodland (Figure 8). Non-woody perennial natives showed mixed dynamics over 2017 and 2018 (Figure 9; axis values of grasses changed markedly due to wet forest not being sampled in 2018). Bulb densities tended to be higher in 2017 than 2018, likely owing to the stimulation of flowering by the clearing disturbance. For example, *Drosera* species tended to be more abundant in 2017 versus 2018. Grass-like species and herbs persisted at low densities over both years with abundance varying across vegetation types more than between corridor and reference plots (Figure 9).

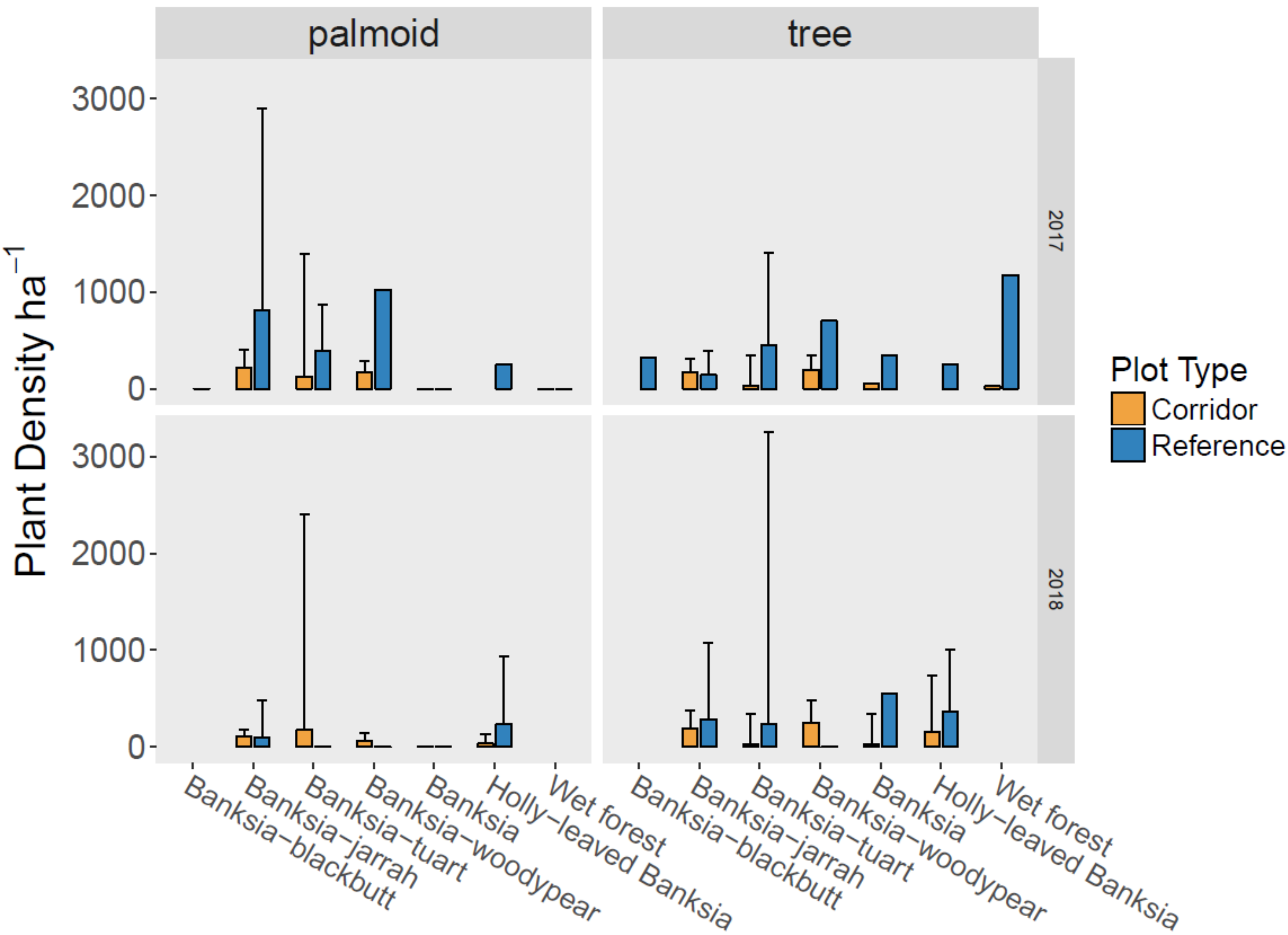


Figure 7. Density of overstorey plants by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Palmoid includes grasstrees and macrozamias. Data are means + 95% confidence intervals (CIs); n = 1–15 plots.

Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018.

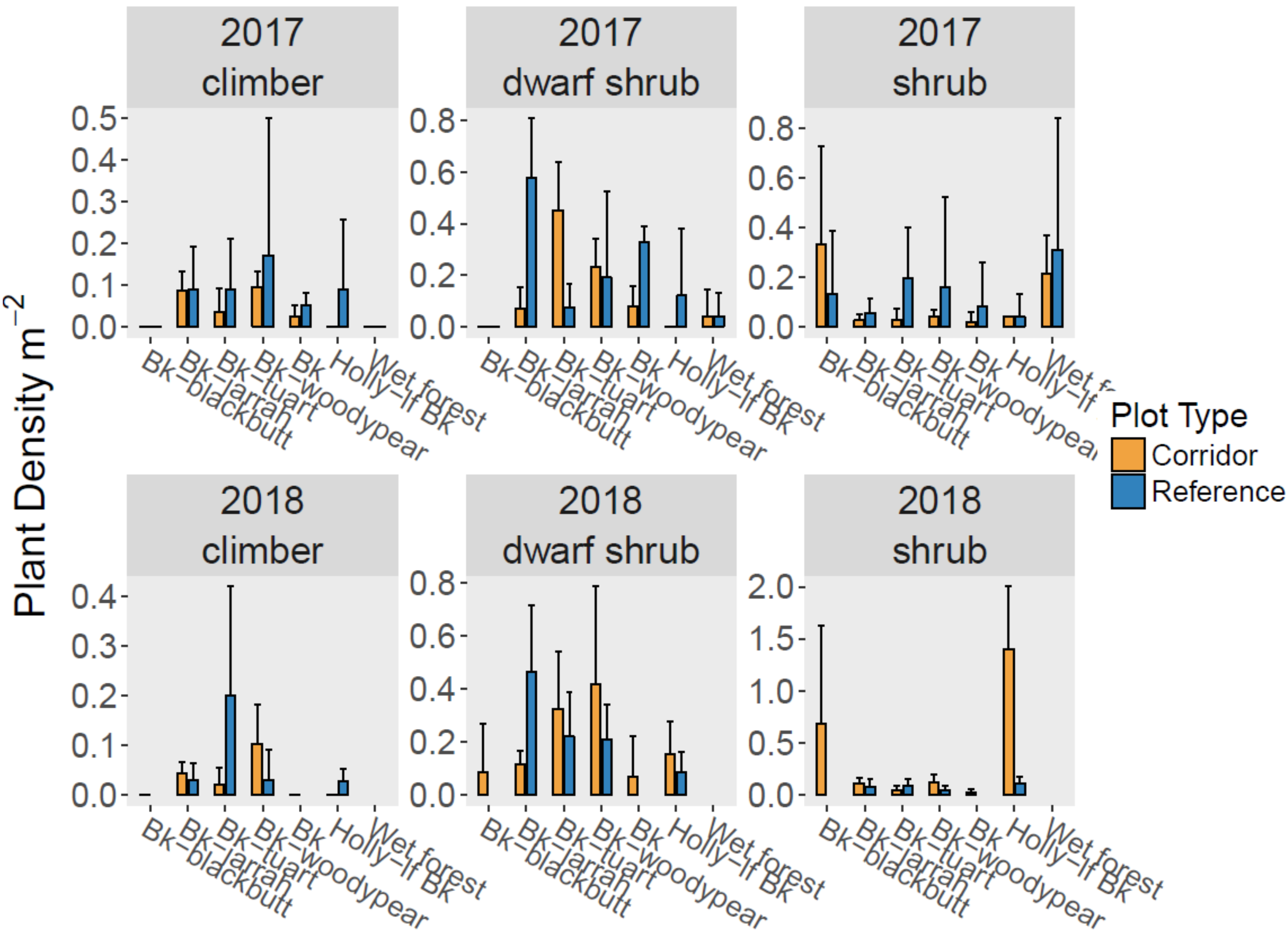


Figure 8. Density of woody understory plants by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 3–57 subplots. Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018.

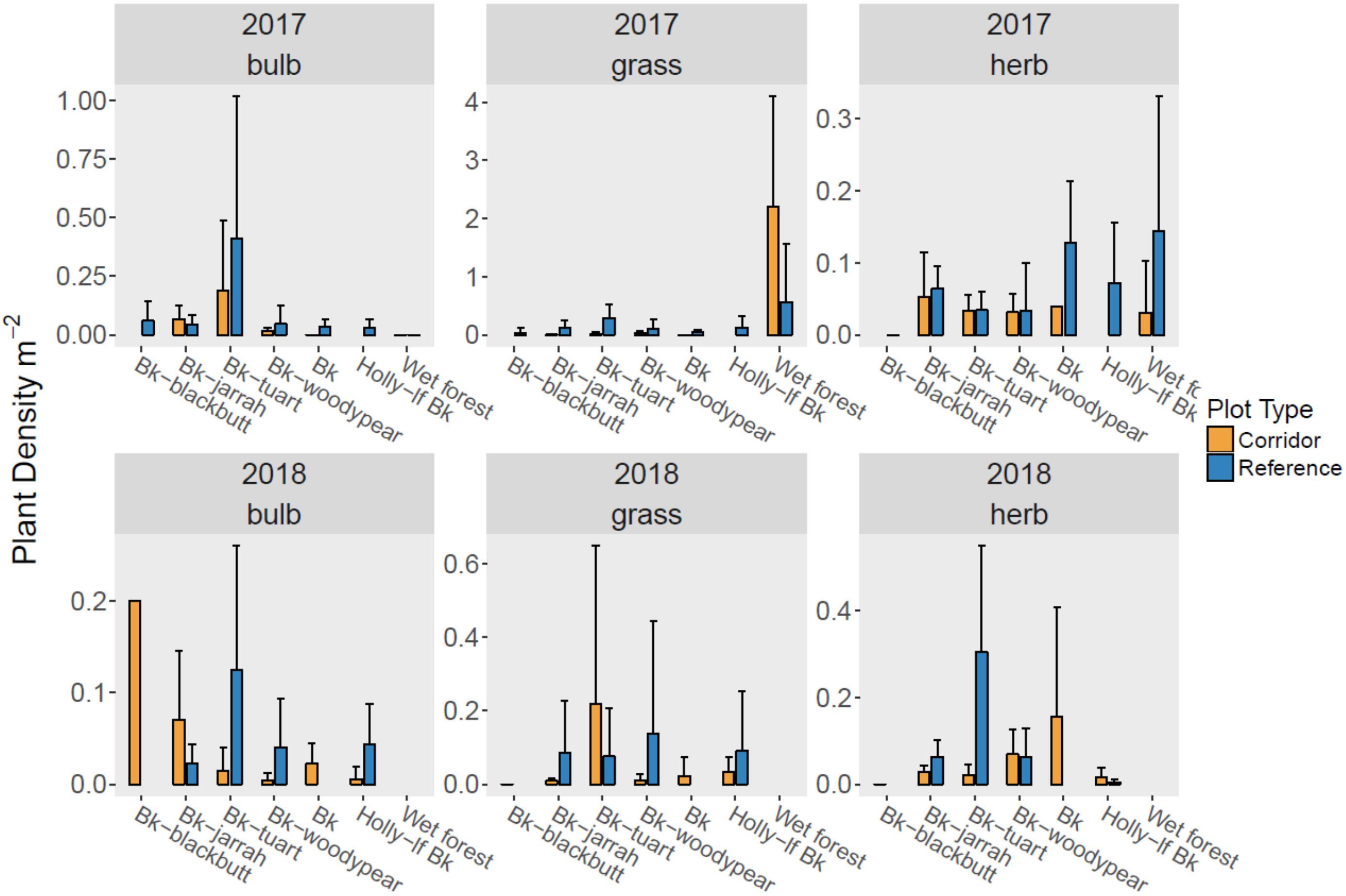


Figure 9. Density of non-woody understory plants by ecosystem types for corridor and benchmark reference plots in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 4–31 subplots. Labels for some ecosystem types have been shortened to fit on the figure (Table 2). Wet forest, reference banksia and reference banksia-blackbutt were not monitored in 2018.

Goal 11.4

Density of resprouters and nonsprouters was similar in corridor plots (Figure 10). Density of nonsprouters was lower in degraded reference compared with their density in corridor and benchmark reference plots (left-hand panel, Figure 10). Density of resprouters in corridor plots was similar to their density in degraded reference but lower than their density in benchmark reference plots (right-hand panel, Figure 10).

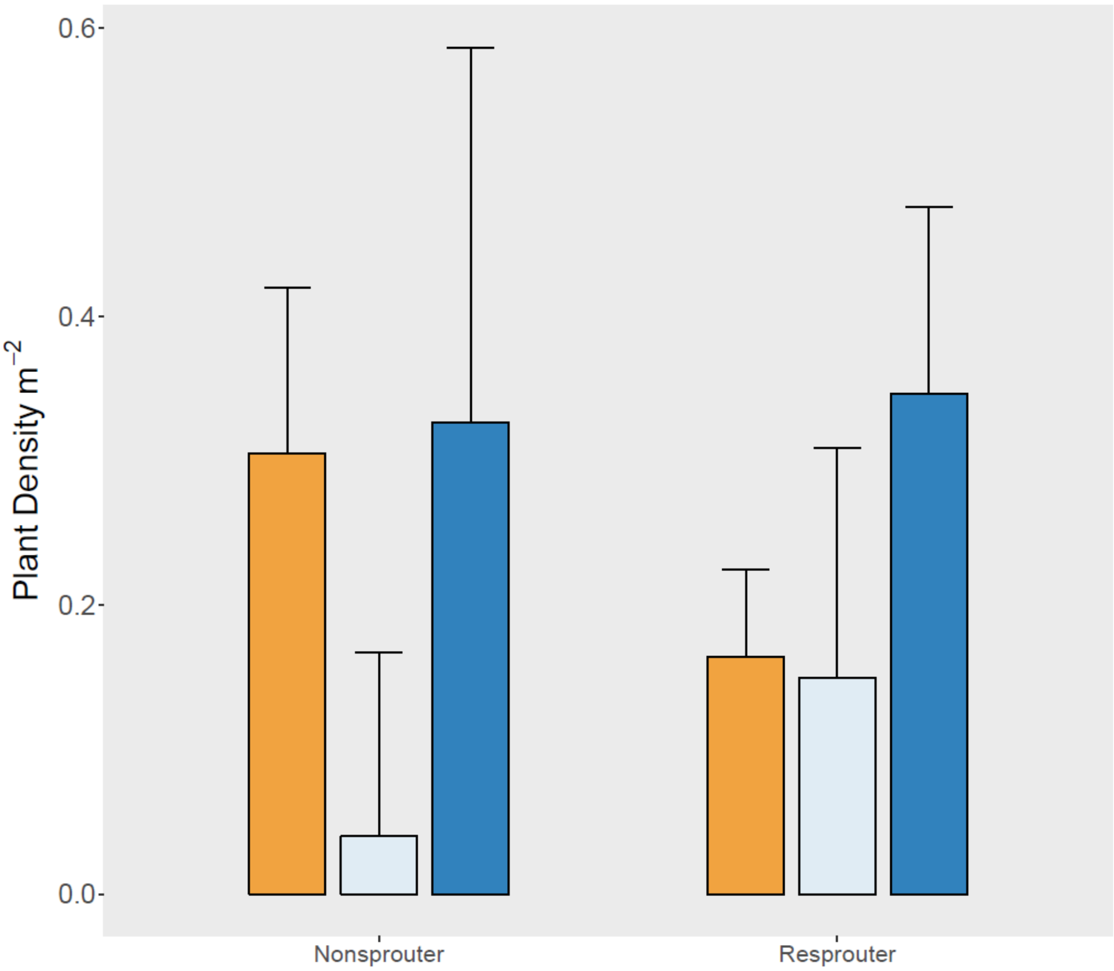


Figure 10. Density of nonsprouter (6 species) and resprouter (17 species) native perennial plant species in corridor (orange bars), degraded reference (pale blue bars) and benchmark reference (French blue bars) plots in April 2019. Data are means + 95% confidence intervals (CIs); n = 4–40 subplots. Species details are included in Appendix 1.

Goal 12

The banksia-jarrah woodland had sufficient numbers of degraded reference plots to contrast with benchmark reference plots (Figures 11–13). In all cases of native perennial plant density, species richness, and percentage cover, the degraded reference plots overlapped with the benchmark reference plots (Figures 11–13). Percentage cover of native perennials were lower in degraded compared with benchmark reference plots, but the difference was not statistically significant (Figure 13).

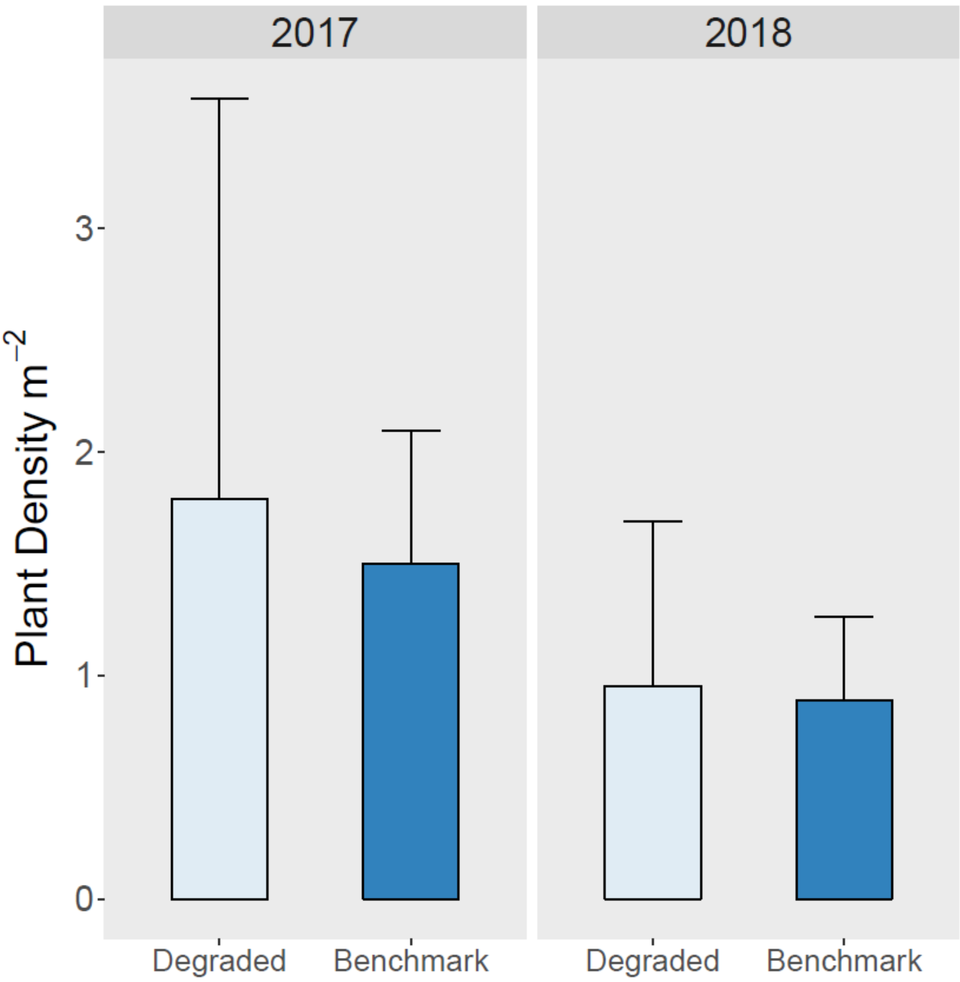


Figure 11. Density of native plant species in degraded reference and benchmark reference plots in banksia-jarrah woodland in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 6–9 subplots.

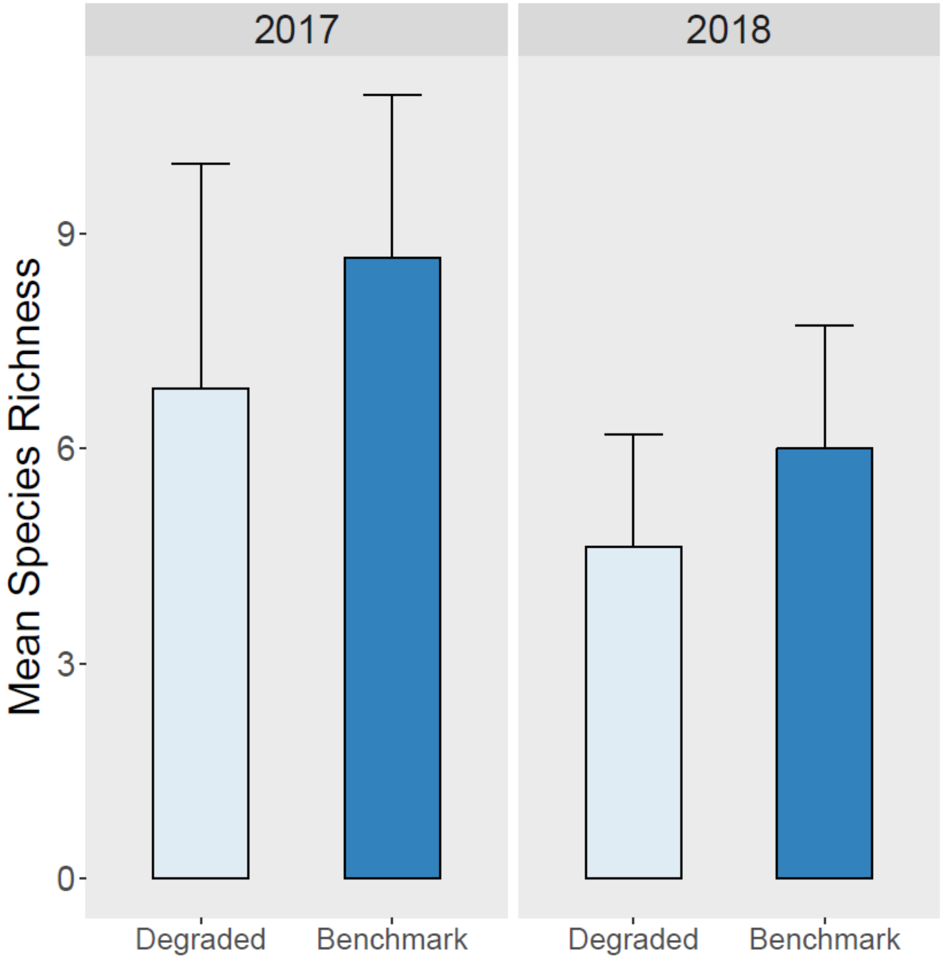


Figure 12. Counts of native plant species in degraded reference and benchmark reference plots in banksia-jarrah woodland in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 6–12 subplots.

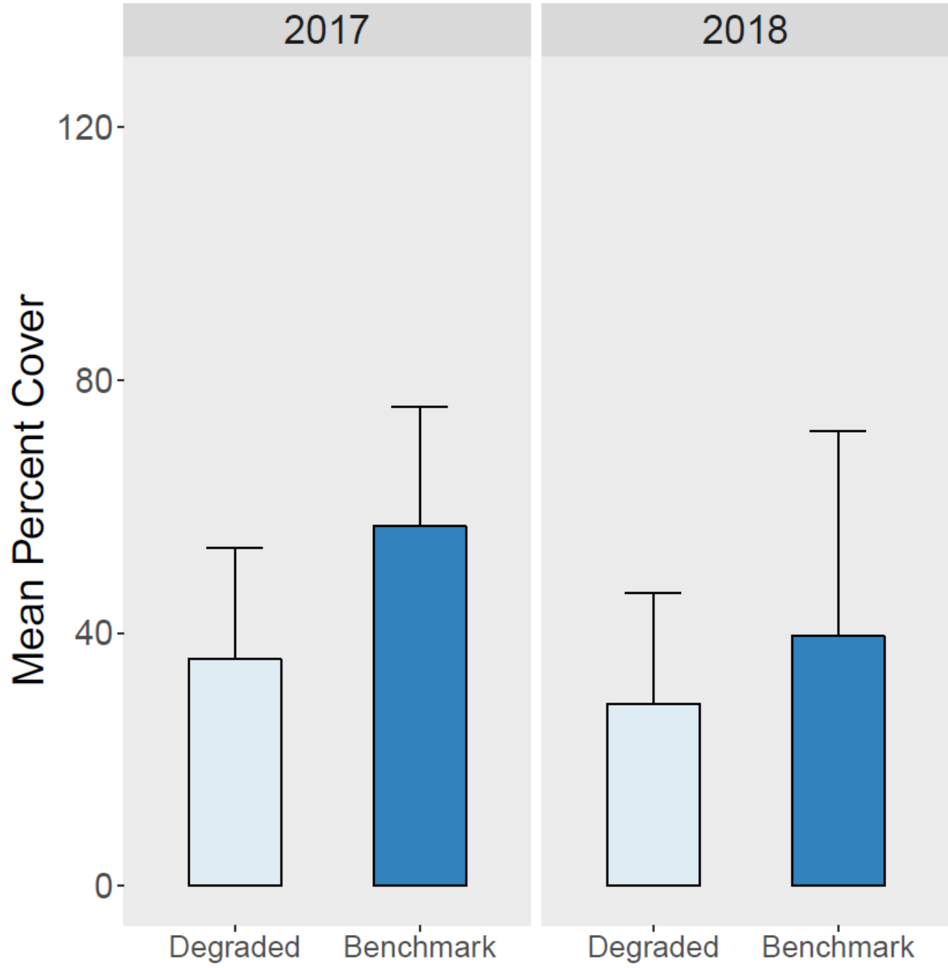


Figure 13. Percentage cover of native plant species in degraded reference and benchmark reference plots in banksia-jarrah woodland in 2017 and 2018. Data are means + 95% confidence intervals (CIs); n = 5–10 subplots.

Impacts of mulch, soil compaction and soil pH

Recovery of native vegetation was not impacted by mulch cover despite covering up to 80% of some corridor plots (Figure 14). Soil penetration resistance to 80 cm depth was similar between corridor and benchmark reference plots and had no impact on density of native perennial plants (Figure 15). Soil penetration resistance to 40 cm depth was higher in corridor plots compared with degraded reference and benchmark reference plots (Figure 16). There was no relationship between soil pH and density of native perennial plants (Figure 17). Soil pH was relatively high for the plot with a limestone track running through it (Figure 17) but within the range reported for banksia woodland soils nearby (Standish et al. 2012). Aside from the banksia-jarrah plot with a soil pH of 8, soil pH for the *terrestrial* woodland plots were within the range of soil pH recorded for banksia woodland soils at three nearby sites at Murdoch University and Piney Lakes (Standish et al. 2012). Soil pH for the wetland plots are within the range reported for wetland sites on the Swan Coastal Plain (Brody Loneragan, unpublished data, November 2018).

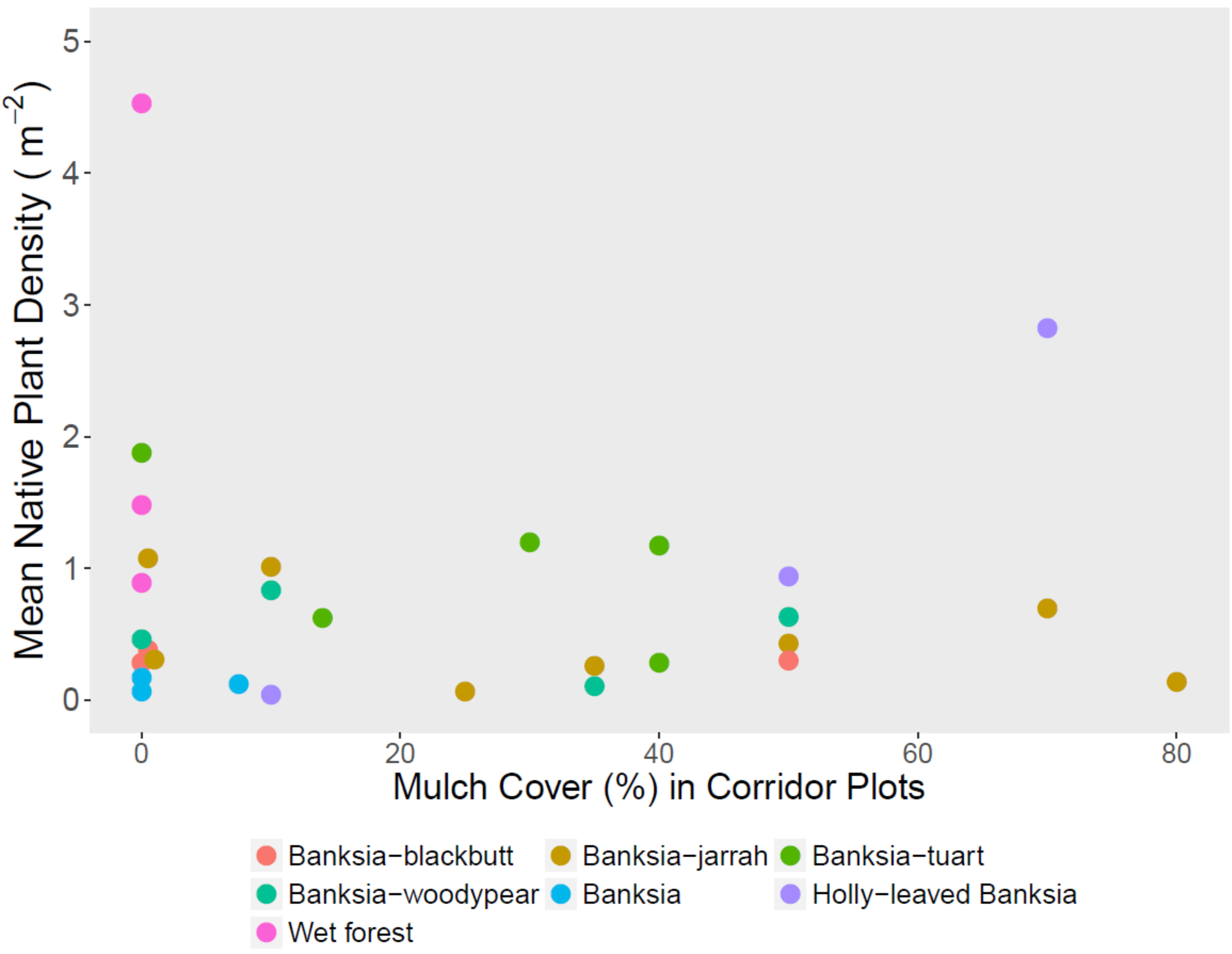


Figure 14. Percentage mulch cover versus mean native perennial plant density in corridor plots in September 2017 by ecosystem types; n = 29 plots.

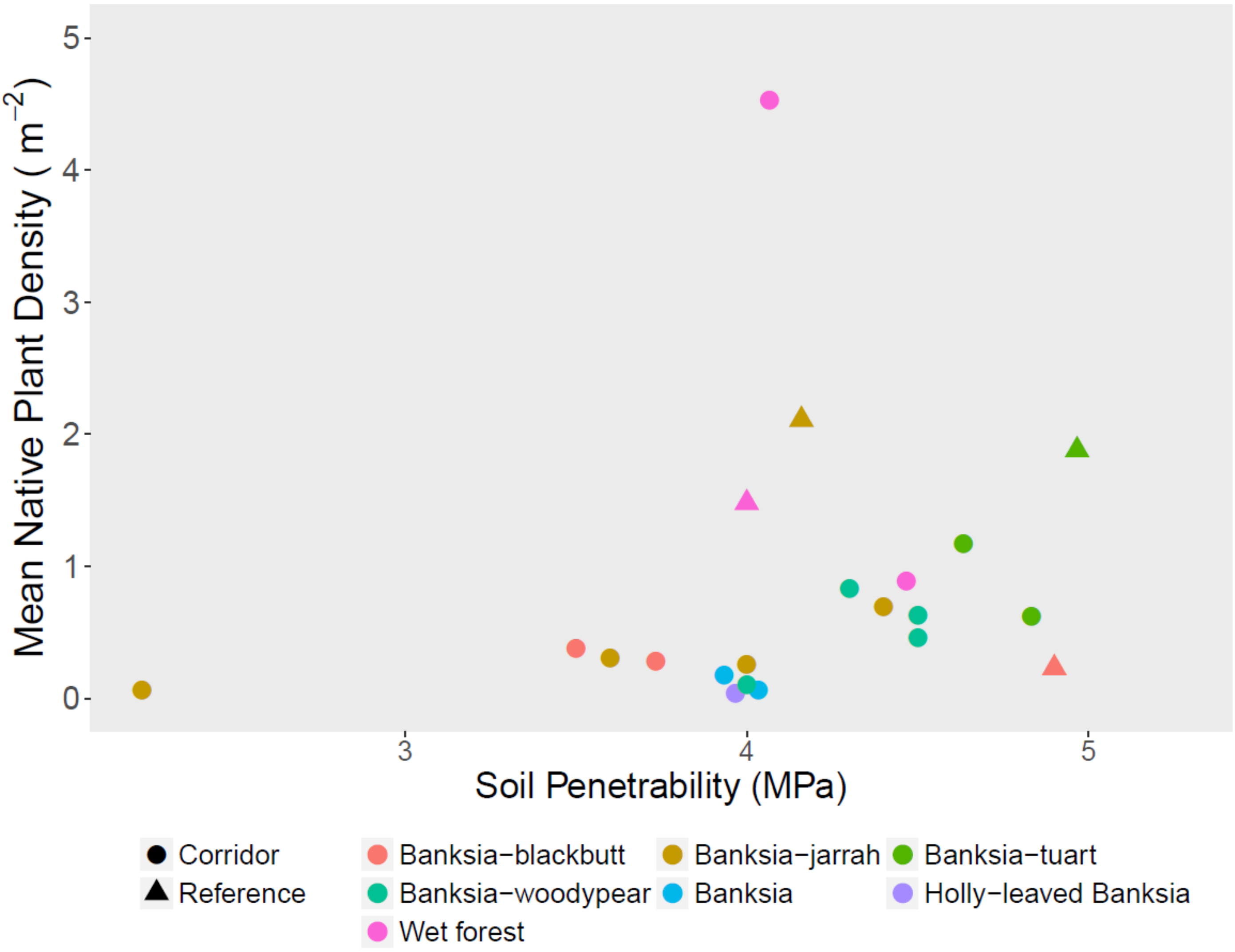


Figure 15. Soil penetration resistance (penetrability) up to 80 cm depth versus mean native perennial plant density in benchmark reference and corridor plots in September 2017 by ecosystem types; n= 4 and 17 respectively.

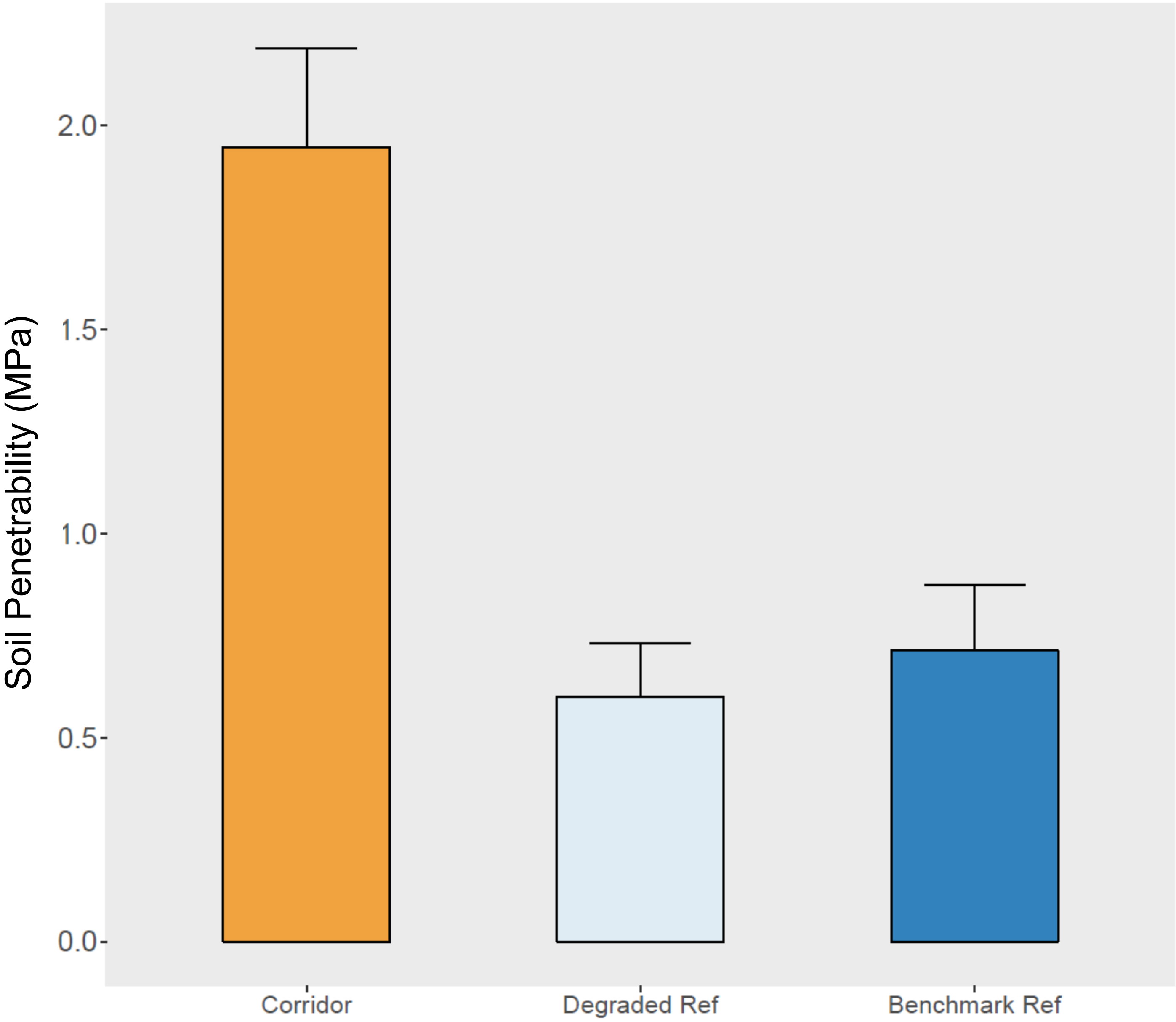


Figure 16. Soil penetration resistance (penetrability) up to 40 cm depth in corridor, degraded reference and benchmark reference plots in May 2019; n= 20, 2 and 3 respectively. Data are means + 95% confidence intervals (CIs).

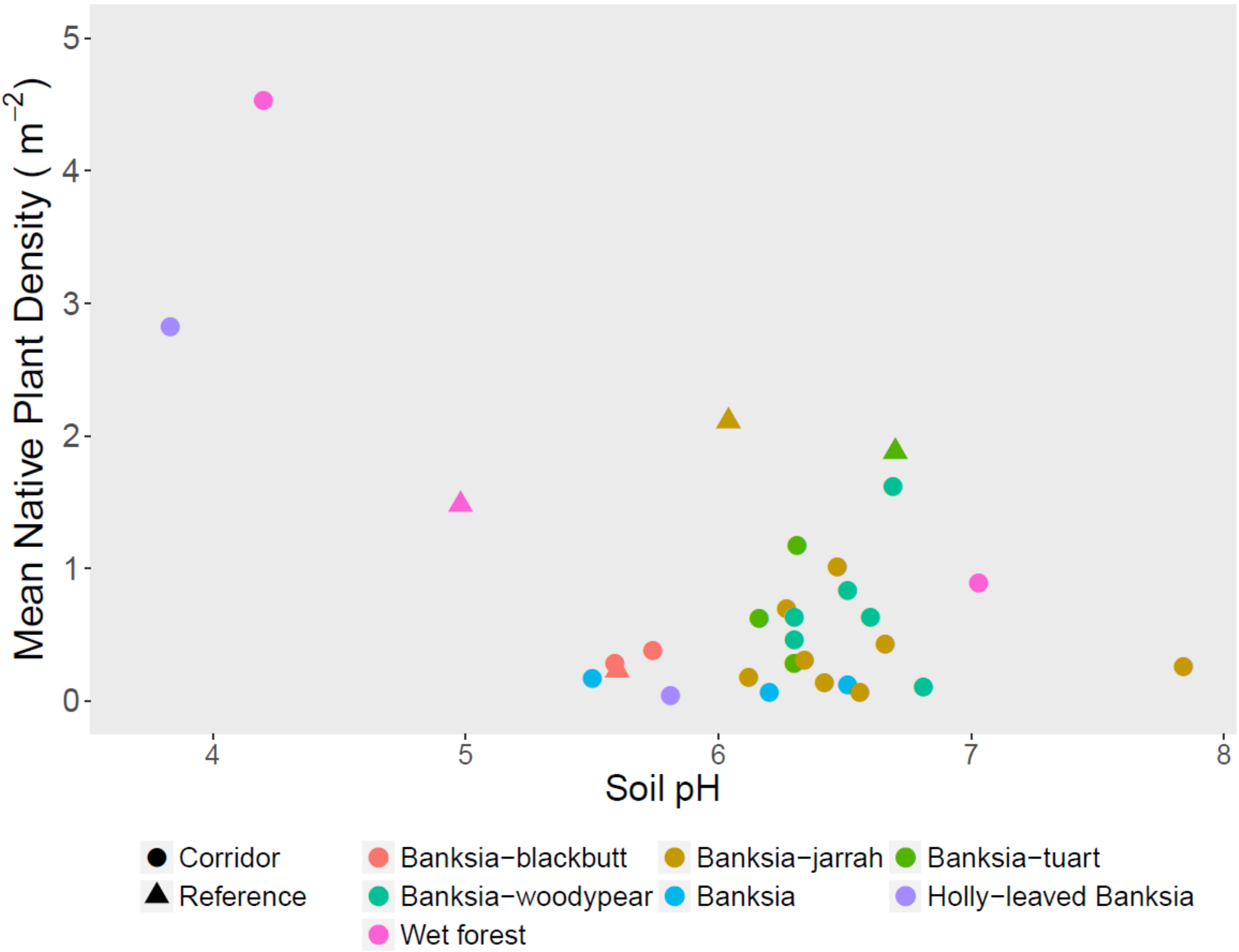


Figure 17. Soil pH versus mean native plant density in benchmark reference and corridor plots in September 2017 by ecosystem types; n= 4 and 26 respectively. The wet forest plot with a soil pH of 7 was near to the limestone track.

Discussion

Recovery of native plant communities from human-mediated disturbances can be limited by barriers such as competition with weeds and land-use legacies. Indeed, in south-western Australia, barriers can prevent return of native plant communities to abandoned farmlands (Standish et al. 2007), even with restoration interventions to assist recovery (Waryszak 2017). The ancient soils, remarkable species diversity, and complex plant-soil interactions, are difficult to replace once modified by human activity (Standish and Hobbs 2010). Moreover, the drying climate and persistent weeds means that active restoration is often needed to fully recover native plant communities (Ruthrof et al. 2018, Standish and Hobbs 2010). Despite these misgivings, there is evidence of native vegetation recovery at the Roe 8 corridor.

There are several factors likely contributing to vegetation recovery at Roe 8. One, the clearing disturbance was rapid—ecologists call these types of disturbance 'pulse' disturbance, and research suggests unassisted recovery from pulse disturbances is generally more rapid than unassisted recovery from longer-term 'press' type disturbances (e.g., mining activity; Moreno-Mateos et al. 2017). In the case of Roe 8, the availability of rootstock and viable seeds in the soil seedbank would have contributed to vegetation recovery. Two, the rainfall for 2017 and 2018 was higher than average: 830.6 mm in 2017 and 844 mm in 2018 compared with 824.2 mm for the long-term (1972–2018) average recorded at Jandakot Airport (BOM 2019). Establishment of newly emerging resprouters and nonsprouters (from seeds) would have been assisted by the rain. Three, despite concerns about mulch piles, soil compaction, and limestone paths impacting native plants, these factors do not appear to have had a negative effect on their recovery. However, corridor soils are compacted compared with reference soils and this could impact future recovery if plant roots systems are not able to access soil water needed to support plant growth aboveground (Waryszak 2017). Weed control may also have assisted vegetation recovery; our data suggest weed cover was low across the corridor except for the banksia woodland ecosystem type. Ongoing weed control is likely to be necessary, both in the corridor and in the degraded reference sites, given the presence of weeds in the surrounding urban landscape and the ability of weeds to disperse. Finally, fences may have helped to limit plant herbivory by rabbits and kangaroos in some parts of the corridor (e.g., Hope Road North) and community planting (in 2018) may have contributed to vegetation recovery in North Lake Road East.

Vegetation recovery was variable throughout the Roe 8 corridor, reflecting both the likely condition of the vegetation prior to clearing, as evidenced by the adjacent reference vegetation, and the patchy nature of the clearing. Data are variable for reference plots too, reflecting vegetation condition and the variation inherent in these woodland and wet forest systems. Species turnover is very high—in a narrow 4.2 km section of the landscape there are seven different ecosystem types! Selection of reference plots based on proximity was logical given high species turnover in the landscape and the likelihood that adjacent reference was a good predictor of vegetation recovery in the corridor. However, future monitoring could target good-condition sections of reference woodland to better benchmark recovery. The availability of good-condition reference woodland will be limited given effects of urbanisation (i.e., habitat fragmentation, weed invasion). These modifications to the design will improve the ability to track vegetation recovery though will not necessarily reduce variation in the data.

Across ecosystem types, the banksia-woodypear ecosystem showed good recovery in terms of density and species richness of native plants (Goals 9.1 and 9.2), as did the banksia-jarrah ecosystem (Table 4). Holly-leaved banksia woodland showed limited recovery in 2017 but good recovery in 2018. Both this ecosystem and the banksia-jarrah ecosystem also showed good recovery in the percentage cover of native plants (Goal 9.3). Arguably, species richness is the best indicator of vegetation recovery at this early stage of succession as we would predict early successional communities to have similar numbers of species, but not necessarily similar densities and percentage cover of native plants, to mature plant communities (i.e., the benchmark reference). Data on species composition of recovering versus reference vegetation would complement the measures of recovery, particularly in the early stages, as most species should be present in the community as rootstock or seeds in the soil seed bank (Table 1). More data are needed to assess recovery of banksia-blackbutt, banksia and wet forest ecosystem types (Table 4).

Table 4. Summary scorecard of Roe 8 recovery against Goals 9.1 to 9.4 for the seven target ecosystems in 2017 and 2018 respectively. *Note we have used 95% confidence intervals to score recovery* (Figure 3) where OT = on-track; corridor averages within range of averages for benchmark reference, and XX = corridor averages below range of averages for benchmark reference measured in same year, and ND = not determined here but to be targeted in future monitoring. For Goal 9.1, we have inserted mean densities (m^2) below each score; banksia has a mean for corridor plots but not reference plots in 2018 hence score of 'ND'. Refer to figures in results for details and specifically Figures 8 and 9 for recovery of understorey species.

Goal	Metric	Banksia-blackbutt	Banksia-jarrah	Banksia-tuart	Banksia-woodypear	Banksia	Holly-leaved banksia	Wet forest
Year		2017 2018	2017 2018	2017 2018	2017 2018	2017 2018	2017 2018	2017 2018
9.1	Density	OT ND	XX OT	OT XX	OT OT	XX ND	XX OT	OT ND
	Corridor	0.33 0.82	0.45 0.43	0.90 0.74	0.65 0.81	0.12 0.32	0.04 1.61	2.71 --
	Reference	0.23 ND	1.49 0.88	1.90 3.29	0.97 0.60	1.47 ND	0.78 0.33	1.48 ND
9.2	Species richness	OT ND	OT OT	XX XX	OT OT	XX ND	XX OT	XX ND
9.3	%Cover ALL native perennials	XX ND	OT OT	XX XX	XX XX	XX ND	XX OT	XX ND
9.4	%Cover weeds	OT ND	OT OT	ND OT	OT ND	OT ND	OT OT	ND ND

We observed different responses in recovery of plant functional groups over time (Goals 10 and 11.4). The first year was dominated by resprouters (e.g., jarrah, marri, grass trees, *Macrozamia*) with some recruitment from seeds (e.g., *Jacksonia* and *Acacia* species), and low overall percentage cover of native perennial species. In the second year, percentage cover of native perennials was higher, largely due to growth of resprouters and some peas. In April 2019, density of native perennial resprouters and nonsprouters was similar in corridor plots. Resprouters were represented by more species in the corridor (17 of 23 species were resprouters: 74%) than predicted by their representation in the greater species pool of native woody perennial species (39 of 66 species were resprouters: 59%; Appendix 1). However, the reduced density of resprouters in corridor and degraded reference plots compared with benchmark reference plots could be a future management issue given the difficulty in sourcing and growing native resprouters from seeds. Twenty-four of the 33 Important Species (73%) are resprouters (Appendix 1).

The reduced density of native perennial nonsprouters in degraded reference plots, compared with both their density in benchmark reference plots and density of native perennial resprouters in degraded reference plots, highlights the sensitivity of nonsprouters to degradation. Native nonsprouters are often outcompeted by weedy nonsprouters because weeds germinate more quickly in response to cues (Standish et al. 2007). This situation is evident in degraded reference ecosystems dominated by veldt grass (*Ehrharta calycina*) disturbed by fire: after fire, veldt grass returns or native resprouters do, but not nonsprouters. Perhaps a strategy for restoring native nonsprouters in highly degraded areas (i.e., where there is a low density of native resprouters too) is to seed these species after scraping and removing the topsoil thereby removing weedy bulbs and the seedbank of the nonsprouting weeds including veldt grass.

The open environment of the corridor was likely stressful for non-woody native species that prefer partial shade and indeed, some have not persisted to the re-establishment phase. Many of these non-woody species are resprouters (Appendix 1). In a post-fire environment, the more typical, historic disturbance for these ecosystems, the environment is closed relative to the corridor owing to the presence of standing burnt trees, providing some shade, and increased nutrients from ash. Thus, native non-woody species may require intervention to ensure their recovery at the Roe 8 corridor. They include orchids, sedges and rushes that are typically recalcitrant to restoration without significant intervention (Koch 2007). Yet their recovery is essential for restoration of ecosystem integrity and function. The Important Native Species listed in the Rehabilitation Management Plan are mostly woody natives (Appendix 1) whose recovery is underway. Although the lack of trees in banksia-blackbutt and holly-leaved banksia woodlands is concerning.

Recommendations for future monitoring led by Murdoch University

- Capture Goals 11.1, 11.2 and 11.3 (i.e., data on percentage leaf and woody litter cover, percentage leaf and woody litter depth, and percentage bare ground) in future monitoring efforts. Leaf and woody litter was negligible in the corridor in 2017 and 2018 but will increase as the recovering vegetation matures.
- Maintain database of community planting efforts with assistance from City of Cockburn. These data will be particularly important to track recovery of plants that recruit from rootstock and seeds versus planted seedlings (Goal 11.4).
- Expert monitoring of random unmarked plots to complement data collected by students.
- Target good-condition sections of reference woodland to benchmark recovery.
- Simplify data set to be collected by future students. Gaps in data collection indicated that some groups were confused about what data to collect and/or were not able to collect all the data in the time available to them.
- Prioritise monitoring of ecosystems with limited data, including but not limited to banksia and wet forest. Some replicate plots in other ecosystem types (e.g., banksia-jarrah) may have to be dropped as a result given time constraints.
- In addition to Important Plant Species, report recovery of non-woody species that are critical for restoration of ecosystem integrity and function.
- Track response of vegetation to management within 20 m buffer of corridor: there are four degraded reference and ten benchmark reference plots in the buffer zone. Plots can be added to this set or we can assess this goal with monitoring of random unmarked plots.
- Compute compositional similarity of corridor and reference vegetation as an additional measure of recovery.
- Integrate ground-based monitoring with remote sensing to provide a comprehensive set of indices reflecting vegetation recovery and condition over time and space. While remote sensing cannot replace ground-based

monitoring for indices such as plant species richness, species composition and recovery of important native species, it does enable greater spatial and temporal coverage. The two-pronged approach (ground + remote) could enable more targeted and cost-effective management interventions.

Recommendations for managers and policymakers

- Designate the corridor as a nature reserve using federal listing of banksia woodlands as a Threatened Ecological Community to drive the designation through government planning.
- Increase public awareness of monitoring efforts to reduce vandalism of plot markers.

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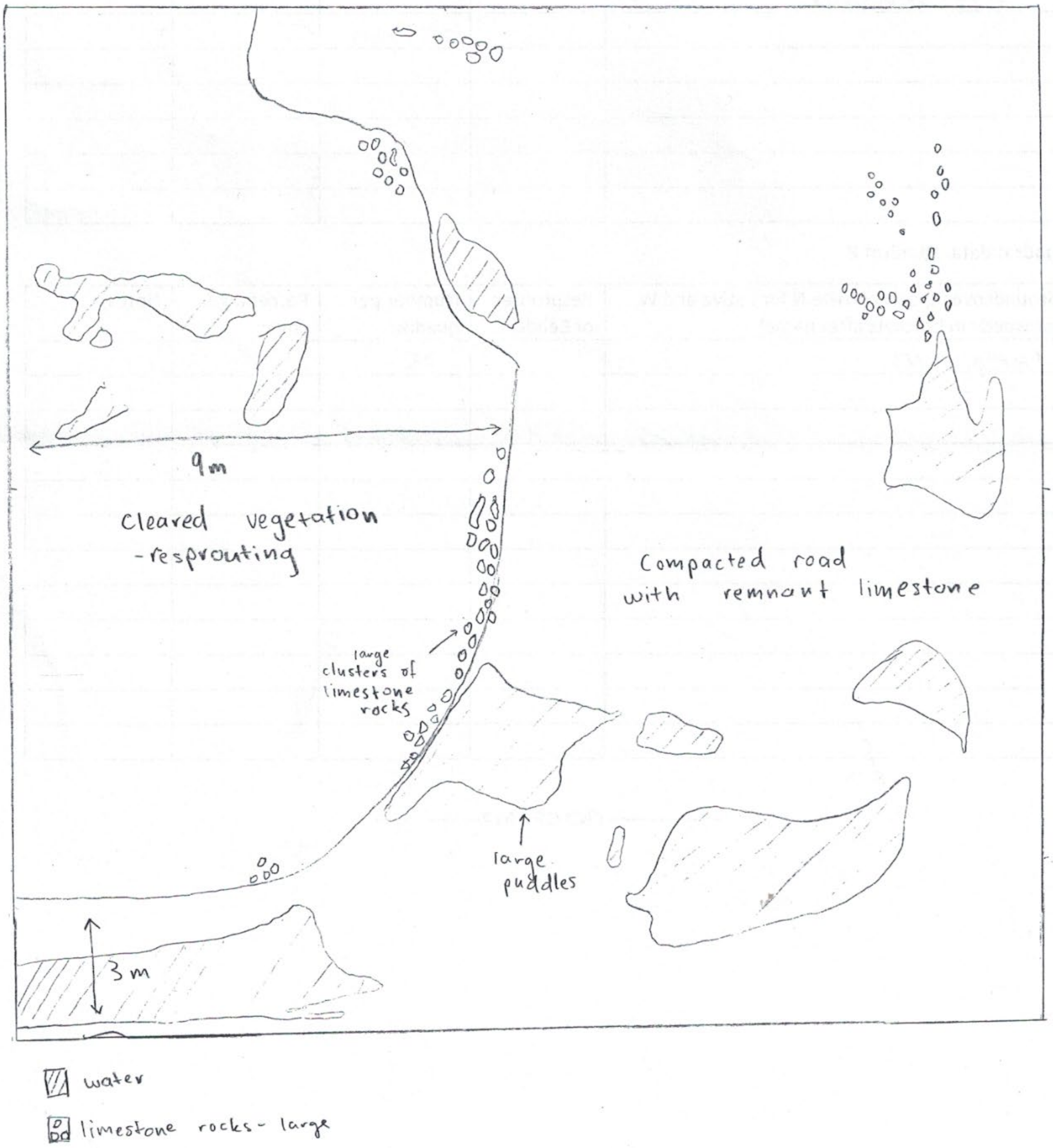

Sketch of corridor wetland plot with remnant limestone track by ecology student Rochelle Sweeney, class of 2017, Murdoch University.

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Resprouting jarrah in spring 2017. Photo by Mark Brundrett.

Appendix 1. Native species list categorised by plant growth form and resprouting capacity where RS = resprouters and NS = nonsprouters. Important Native Species (Emerge Associates 2018) are indicated by a cross. Resprouters and nonsprouters observed in the subset of plots resurveyed in April 2019 to assess Goal 11.4 are indicated by an asterisk. Overall, 78% of the plants listed here are resprouters (107 species) and 22% are nonsprouters (31 species).

Growth Form	Family	Genus species	Important Species	RS/NS	Count of taxa
Tree	Casuarinaceae	*Allocasuarina fraseriana*	X	RS	2
		Allocasuarina humilis (*)		RS	2
	Myrtaceae	*Corymbia calophylla* (*)	X	RS	79
		Eucalyptus gomphocephala	X	RS	4
		Eucalyptus marginata (*)	X	RS	57
		Eucalyptus rudis	X	RS	10
		Eucalyptus todtiana	X	RS	5
		Melaleuca preissiana	X	RS	5
		Melaleuca rhaphiophylla	X	RS	3
		Melaleuca thymoides (*)		RS	2
	Proteaceae	*Banksia attenuata* (*)	X	RS	47
		Banksia grandis	X	RS	2
		Banksia ilicifolia	X	RS	1
		Banksia littoralis	X	RS	2
		Banksia menziesii (*)	X	RS	23
		Xylomelum occidentale (*)	X	RS	8
Palmoid	Xanthorrhoeaceae	*Xanthorrhoea brunonis* (*)	X	RS	9
		Xanthorrhoea preissii (*)	X	RS	108
	Zamiaceae	*Macrozamia fraseri* (*)	X	RS	78
Shrub	Casuarinaceae	*Allocasuarina humilis*	X	RS	8
	Dilleniaceae	*Hibbertia cuneiformis*		RS	19
	Ericaceae	*Leucopogon australis*		NS	2
	Fabaceae	*Acacia cyclops*	X	NS	3
		Acacia pulchella (*)	X	NS	47
		Acacia saligna		NS	10
		Acacia stenoptera (*)		RS	4
		Daviesia chapmanii (*)		NS	1
		Daviesia divaricata		RS	9
		Daviesia horrida		RS	1
		Daviesia nudiflora		RS	3
		Gastrolobium ebracteolatum		NS	4
		Jacksonia furcellata (*)	X	NS	57
		Jacksonia sericea		NS	1
		Jacksonia sternbergiana (*)		NS	3
	Myrtaceae	*Astartea fascicularis*		RS	8
		Chamelaucium uncinatum		NS	1
		Hypocalymma angustifolium		NS	7
		Hypocalymma robustum	X	NS	31
		Kunzea glabrescens (*)	X	NS	57
		Melaleuca seriata		RS	1
		Taxandria linearifolia	X	RS	6
	Proteaceae	*Banksia sessilis*		NS	5
		Hakea prostrata (*)	X	RS	4
Dwarf Shrub	Dilleniaceae	*Hibbertia hypericoides* (*)	X	RS	106
		Hibbertia subvaginata	X	NS	1

Growth Form	Family	Genus species	Important Species	RS/NS	Count of taxa
	Ericaceae	*Conostephium pendulum*		RS	2
		Leucopogon conostephioides		NS	9
		Leucopogon propinquus		NS	4
	Euphorbiaceae	*Monotaxis occidentalis*		RS	2
	Fabaceae	*Acacia huegelii*		NS	1
		Acacia stenoptera		RS	9
		Bossiaea eriocarpa (*)	X	NS	42
		Gastrolobium capitatum		NS	1
		Gompholobium tomentosum (*)	X	NS	84
		Hovea pungens		NS	4
		Hovea trisperma		NS	5
		Mirbelia sp.		NS	2
		Pultenaea reticulata	X	NS	4
	Goodeniaceae	*Scaevola canescens* (*)		RS	4
	Lamiaceae	*Hemiandra pungens*		RS	2
	Myrtaceae	*Eremaea pauciflora*	X	RS	2
		Scholtzia involucrata (*)		RS	6
	Proteaceae	*Banksia dallanneyi*	X	RS	2
		Petrophile linearis (*)		RS	4
		Petrophile macrostachya		RS	2
		Stirlingia latifolia	X	RS	4
	Rutaceae	*Boronia ramosa*		NS	1
		Philotheca spicata		NS	3
	Thymelaeaceae	*Pimelea rosea*		RS	42
Climber	Fabaceae	*Hardenbergia comptoniana*		RS	139
		Kennedia prostrata		NS	43
Bulb	Asparagaceae	*Sowerbaea laxiflora*		RS	47
	Commelinaceae	*Cartonema philydroides*		RS	2
	Droseraceae	*Drosera erythrorhiza*		RS	10
		Drosera macrantha		RS	5
		Drosera menziesii		RS	14
		Drosera pallida		RS	2
		Drosera stolonifera		RS	26
	Haemodoraceae	*Anigozanthos humilis*		RS	9
		Haemodorum brevisepalum		RS	2
	Orchidaceae	*Caladenia flava*		RS	18
		Caladenia georgei		RS	2
		Caladenia latifolia		RS	7
		Diuris corymbosa		RS	1
		Microtis media		RS	1
		Pterostylis sp.		RS	1
		Pyrorchis nigricans		RS	1
Grass-like	Anarthriaceae	*Lyginia barbata*		RS	1
	Asparagaceae	*Dichopogon capillipes*		RS	8
		Laxmannia squarrosa		RS	3
		Lomandra caespitosa		RS	2
		Lomandra hermaphrodita		RS	1
		Lomandra maritima		RS	1
		Lomandra micrantha		RS	4

Growth Form	Family	Genus species	Important Species	RS/NS	Count of taxa
		Lomandra preissii		RS	2
		Lomandra suaveolens		RS	1
	Cyperaceae	*Cyathochaeta* sp.		RS	1
		Cyperus sp.		RS	2
		Lepidosperma leptostachyum		RS	9
		Lepidosperma longitudinale		RS	8
		Lepidosperma squamatum		RS	4
		Mesomelaena pseudostygia		RS	11
		Mesomelaena tetragona		RS	1
		Schoenus clandestinus		RS	2
		Schoenus curvifolius		RS	4
		Tetraria octandra		RS	1
	Dasypogonaceae	*Dasypogon bromeliifolius*		RS	7
	Haemodoraceae	*Conostylis aculeata*		RS	15
		Conostylis candicans		RS	25
		Conostylis setigera		RS	1
	Hemerocallidaceae	*Dianella revoluta*		RS	16
	Iridaceae	*Patersonia occidentalis*		RS	9
	Juncaceae	*Juncus pallidus*		RS	3
	Poaceae	*Austrostipa semibarbata*		RS	7
Herb	Amaranthaceae	*Ptilotus drummondii*		NS	1
		Ptilotus polystachyus		NS	2
	Apiaceae	*Eryngium pinnatifidum*		RS	25
		Xanthosia huegelii		RS	4
	Asparagaceae	*Laxmannia* sp.		RS	2
		Thysanotus multiflorus		RS	1
		Thysanotus patersonii		RS	18
		Thysanotus sparteus		RS	4
		Thysanotus triandrus		RS	2
	Colchicaceae	*Burchardia congesta*		RS	48
	Dennstaedtiaceae	*Pteridium esculentum*		RS	1
	Fabaceae	*Isotropis cuneifolia*		RS	24
	Goodeniaceae	*Dampiera linearis*		RS	3
		Scaevola canescens		RS	10
	Haemodoraceae	*Anigozanthos manglesii*		RS	9
	Hemerocallidaceae	*Caesia micrantha*		RS	3
		Tricoryne elatior		RS	3
		Tricoryne tenella		RS	3
	Juncaceae	*Juncus* sp.		RS	6
		Luzula meridionalis		RS	1
	Lauraceae	*Cassytha* sp.		NS	1
	Restionaceae	*Desmocladus flexuosus*		RS	24
	Rubiaceae	*Opercularia vaginata*		RS	1
	Stylidiaceae	*Stylidium brunonianum*		RS	1