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1 **The importance of Travelling Stock Reserves for maintaining high-quality**
2 **threatened temperate woodlands**

3

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15 *Running head:* Vegetation attributes of Travelling Stock Reserves

16

17 **Additional keywords:** box-gum grassy woodland, grazing, habitat quality, plant species
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19

20 **Summary text for Table of Contents:**

21 Travelling Stock Reserves (TSRs) are critically important for the conservation of temperate
22 woodland communities that have otherwise been extensively cleared and degraded for
23 agriculture. We compared the vegetation attributes of TSRs with remnants managed for
24 agricultural production and found they supported higher native plant species richness, more
25 native ground cover, and fewer exotic plants. Our results indicate that, in general, land
26 tenure status of remnant woodlands influenced several vegetation attributes that are also
27 important for native biodiversity.

28

29 **Conflict of Interest Statement**

30 The authors declare no conflicts of interest

31

32

33 **Abstract.** Travelling Stock Reserves are thought to represent some of the highest-quality
34 and least degraded remnants of threatened temperate woodland in south-eastern Australia.
35 These public reserves have not had the same high levels of grazing pressure and other
36 disturbances as woodland remnants on private land. Thus, Travelling Stock Reserves are
37 expected to be important for the protection of biodiversity in heavily cleared and modified
38 landscapes. We tested the hypothesis that land tenure had significant effects on the quality
39 of woodlands by comparing vegetation structural attributes between Travelling Stock
40 Reserves and remnant vegetation used for primary production purposes. Vegetation
41 attributes were monitored in 155 permanent plots over five years in remnant temperate
42 woodland sites in the Riverina bioregion of New South Wales. Overall, Travelling Stock
43 Reserves supported higher native plant species richness and were characterized by higher
44 ground cover of native shrubs and less cover of exotic plant species when compared to
45 agricultural production areas. We found land tenure had significant effects on some
46 vegetation attributes demonstrated to be important for threatened fauna. We attribute
47 these results to Travelling Stock Reserves having a history of lower grazing pressure
48 compared to remnants managed for agricultural production. Our study provides empirical
49 evidence to support the high conservation value of Travelling Stock Reserves in formerly
50 woodland-dominated, but now extensively cleared, agricultural landscapes.

51

52 **Introduction**

53

54 Temperate woodlands of south-eastern Australia have been extensively cleared and
55 degraded for agricultural production (Yates and Hobbs 1997; Lindenmayer *et al.* 2010a).
56 Clearing of up to 90% of these woodlands has highly modified the ecosystem, mostly leaving
57 small remnant patches (Yates and Hobbs 1997; Burrows 1999). Most woodland remnants
58 that remain occur on private land and are used primarily for agricultural and pastoral
59 production – being subjected to livestock grazing as well as pressures from cropping and
60 fertilizer use on adjacent land. Biodiversity has changed significantly in these areas because
61 of the decreased amount and quality of these woodlands, including declines in native plants
62 (McIntyre *et al.* 1993; Prober *et al.* 2005), reductions in populations of many species of
63 mammals, birds and reptiles (Ford *et al.* 2009; Lindenmayer *et al.* 2012; Dorrrough *et al.*

64 2012; Michael *et al.* 2014) and increases in exotic plant species (Burrows 1999; Spooner *et*
65 *al.* 2002).

66

67 Presently, most intact examples of the pre-European condition of endangered woodland
68 communities exist in Travelling Stock Reserves (TSRs) (Lindenmayer *et al.* 2010b; Lentini *et*
69 *al.* 2011b; Davidson and O'Shannassy 2017). TSRs are often regarded as the 'reference
70 condition' for these temperate woodlands (Prober *et al.* 2002; Lindenmayer *et al.* 2012,
71 2013; Michael *et al.* 2014) and are of high value for biodiversity conservation (Yates and
72 Hobbs 1997; Lindenmayer *et al.* 2010a; Smiles *et al.* 2011; Lentini *et al.* 2011b). These linear
73 strips and small blocks of remnant vegetation are public reserves originally established to
74 facilitate movement of livestock to major city markets and around the landscape (Spooner
75 2005; Lentini *et al.* 2011b). Relative to other remnants, TSRs have historically experienced
76 less vegetation clearing, lower grazing pressure, no cultivation, and no pasture
77 improvement (Spooner 2005; Davidson *et al.* 2005). Use of TSRs for livestock grazing has
78 decreased since the 1950s following the advent of modern transport (Davidson *et al.* 2005;
79 Lentini *et al.* 2011b).

80

81 Vegetation structural attributes that are important properties of temperate woodlands,
82 such as high levels of plant species richness and understory cover, tend to be associated
83 with TSRs (Davidson *et al.* 2005; Montague-Drake *et al.* 2009; Gibbons *et al.* 2010;
84 Lindenmayer *et al.* 2010b). When grazing pressure is reduced or excluded from these
85 woodlands, understory complexity increases via regenerating trees and shrubs, cover of
86 native grasses and native plant species richness increases, and exotic species and bare
87 ground tends to decrease (Prober *et al.* 2001; Spooner *et al.* 2002; Briggs *et al.* 2008;
88 Dorrrough and Scroggie 2008). Threatened woodland birds, arboreal mammals and reptiles
89 respond positively to these vegetation attributes, and most studies consistently find a
90 significant positive relationship between TSRs and the occurrence of these groups of
91 animals (Montague-Drake *et al.* 2009; Lindenmayer *et al.* 2010b; Lentini *et al.* 2011a;
92 Lindenmayer *et al.* 2012; Michael *et al.* 2014).

93

94 Monitoring changes in the vegetation attributes of TSRs is critical given their significance for
95 biodiversity (Lindenmayer *et al.* 2010b), their susceptibility to grazing (Briggs *et al.* 2008),

96 the substantial time it takes for some vegetation attributes to develop (Vesk *et al.* 2008),
97 and their value as reference sites of pre-European conditions (Gibbons *et al.* 2010). Key
98 vegetation attributes, such as ground and overstory cover, are frequently monitored as
99 explanatory variables for other measures of interest (e.g. species richness of birds), but are
100 less frequently the core focus of research. Additionally, most previous studies have been
101 snapshot comparisons, with limited long-term monitoring. Understanding the overall
102 influence that TSR tenure has on monitored vegetation attributes is useful for habitat
103 quality assessments and informing management decisions.

104

105 This study aimed to answer three key questions: (1) Do TSRs support higher native plant
106 species richness, native ground cover, above-ground cover, measures of growth, and
107 structural attributes compared to sites managed for agricultural production? (2) How do
108 vegetation attributes change over time and are any temporal changes different between
109 TSRs and production sites? And, (3) do different woodland community types support higher
110 or lower values of vegetation attributes irrespective of land tenure? Our study focused on
111 broad tenure effects to generalize the significance of TSRs. We hypothesized that land-use
112 history would have a significant influence on vegetation attributes leading to TSRs
113 supporting higher quality vegetation than remnant woodland managed for production.

114

115 **Materials and Methods**

116

117 *Study area and sites*

118

119 This study was completed in the Riverina bioregion of southern New South Wales, Australia
120 (Fig. 1). The study area covers approximately 3,000 km² and extends from the townships of
121 Coleambally in the north (34°48'19" S, 145°52'58" E), Walbundrie in the east (35°41'40" S,
122 146°44'30" E), Moolpa in the west (35°00'01" S, 143°40'11" E) and is bordered by the
123 Murray River in the south. The area receives an annual average rainfall of 400 mm that is
124 uniformly distributed throughout the year. The dominant native vegetation in the study
125 region is temperate eucalypt woodland, and primarily Box Gum Grassy Woodland
126 dominated by grey box (*Eucalyptus microcarpa*), black box (*E. largiflorens*), white box (*E.*
127 *albens*), yellow box (*E. melliodora*) or Blakely's red gum (*E. blakelyi*).

128

129 Extensive land-clearing of the region for agriculture (cropping, grazing and horticulture) has
130 reduced native vegetation by up to 85% (Hobbs and Yates 2000), leading to the classification
131 of these woodlands as Endangered communities under the *Environment Protection and
132 Biodiversity Conservation Act 1999*. Some areas of remnant vegetation of varying quality
133 exist throughout the study area on private land. These remnants are typically used for
134 agricultural production and subject to intensive grazing pressure from livestock. The
135 landscape also includes publically owned remnant vegetation that has not been subject to
136 the same production pressures as woodlands on private land. These are typically
137 cemeteries, railway corridors and TSRs that have rarely been cleared, typically experienced
138 periodic grazing with long rest periods, have not been subject to fertilizer application, and
139 rarely been ploughed for cropping (Davidson *et al.* 2005). Cemeteries and railway corridors
140 are usually spatially limited or linear strips of vegetation, whereas TSRs represent the most
141 extensive and largest examples of remnant woodland in the landscape (Lentini *et al.* 2011b).

142

143 >> Location of **Fig. 1** >>

144

145 We stratified our study based on land tenure and woodland type. We selected 40 temperate
146 woodland sites on private land used for agricultural production (production sites), and 25
147 TSR sites nearest to the sites on private land (Fig. 1). Annual grazing permits ceased on TSRs
148 from 2008, subjecting those sites to only rare travelling stock grazing (1-2 days) or very short
149 term grazing contracts (<1 month). By comparison, private land sites were not subject to
150 grazing restrictions and were set stocked 12 months of the year. This difference provided a
151 strong grazing contrast between sites based on land tenure during our study. We
152 interviewed landholders to verify production sites were representative of historical land-use
153 practices (i.e. intensively grazed, primarily by sheep, with no strategic rest periods). We also
154 interviewed land managers from the Local Land Services (formally the Livestock Health and
155 Protection Authority) to verify our TSR sites were representative of historical land-use
156 practices (i.e. periodically grazed, primarily by cattle, with long rest periods) and that all
157 TSRs were not subject to annual grazing permits throughout the duration of the study. We
158 concluded from these interviews that the sites we monitored were broadly representative
159 of how woodland under different land tenure have been typically grazed in this landscape,

160 and were not biased towards selecting only high or only low impacted sites. No sites that
161 had been subjected to cropping were included in this study.

162

163 TSRs ranged in size from 4 to 262 ha (median = 33 ha). Vegetation in each TSR was mapped
164 and classified according to Keith Class vegetation community (Keith 2004). Permanent
165 monitoring plots were established and consisted of one 50 x 20 m quadrat (central 50 m
166 transect \pm 10 m) with a 20 x 20 m quadrat nested within it (starting at the zero point of the
167 transect). The number of monitoring plots per site varied for TSRs based on size and
168 presence of multiple vegetation communities (minimum of two and a maximum of five plots
169 per site). Production sites were typically smaller than TSRs (median = 5 ha), contained only
170 one vegetation community, and each site typically included two monitoring plots. Plots in
171 production sites were placed towards the middle of the patch and away from the edge,
172 whereas plots in the larger TSRs were randomly selected, while also avoiding edges.

173

174 Monitoring plots were established in four threatened vegetation communities: (1)
175 floodplain transition woodland, which is located on the edge of the semi-arid zone and
176 typically dominated by grey box (hereafter Grey Box Woodland), (2) inland floodplain
177 woodland, which is dominated by black box and occasionally inundated (hereafter Black Box
178 Woodland), (3) Riverine plain woodland, which is dominated by boree (*Acacia pendula*) and
179 occurs on grey clay soils on flats and shallow depressions (hereafter Boree Woodland), and
180 (4) Riverine sandhill woodland, which is dominated by yellow box and white cypress pine
181 (*Callitris glaucophylla*) on prior streams and alluvial sediments (hereafter Sandhill
182 Woodland). Overall, we established 75 monitoring plots in TSRs, and 80 plots in production
183 sites (Table 1).

184

185 >> Location of **Table 1** >>

186

187 *Vegetation attributes sampling*

188

189 Monitoring of vegetation attributes was undertaken at each plot during spring 2008, 2010
190 and 2012 using the BioMetric assessment method (Gibbons *et al.* 2009). Plots were
191 permanently marked with star pickets at 0 m and 10 m along the 50 m transect. Native plant

192 species richness was determined for each plot as the number of native species present in a
193 20 x 20 m quadrat. Species were classified as either native or exotic and either grass, forb,
194 shrub or tree. Individual plant species identity is not a component of the BioMetric
195 assessment method (Gibbons *et al.* 2009) and therefore this level of detail was not captured
196 across years. Consequently, floristic composition was not assessed in this investigation as
197 the focus of our study was on vegetation structure. Ground cover variables were measured
198 at each 1 m interval (starting at 1 m) along the 50 m transect. The ground cover variables
199 were the amount of bare ground, and the cover of cryptogams (lichens and mosses), exotic
200 plants, native grasses, native forbs, native shrubs, organic litter and rock. More than one
201 variable could intersect a single point (e.g. native grass and organic litter could be recorded
202 for the same interval of the tape). Percentage cover for each variable was calculated by
203 multiplying the sum of recorded presences by two. The above-ground variables of native
204 midstory and overstory cover also were determined along the transect. At each 5 m interval,
205 percentage cover of these variables was visually estimated (to the nearest 10%) and
206 averaged for a single value for each plot. Vegetation growth and other structural variables
207 were determined in the 50 x 20 m quadrat. These variables included tree and shrub
208 recruitment (total count), proportion of overstory and midstory regeneration (visual
209 percentage estimation), number of hollow-bearing trees (total count) and total length of
210 logs > 10 cm diameter (measured to the nearest meter).

211

212 *Data analysis*

213

214 We used hierarchical generalized linear mixed models (Lee *et al.* 2006) to test the effect of
215 land tenure, time and woodland type on vegetation attributes. We completed two sets of
216 analyses. First, data were fitted for the fixed effects of land tenure (production site vs TSR),
217 time (year) and woodland type (Keith Class). Second, data for each woodland type were
218 fitted separately for the main effects of land tenure and time. Each response variable was
219 fitted for two models in each analysis: one in which the interaction of land tenure and time
220 was included in the model, and one where it was not. This was done as we were equally
221 interested in the interactive and non-interactive effects of land tenure and time, and
222 interpreting the singular effects from an interactive model may be misleading (Zuur *et al.*
223 2009). For response variables that were percentages (ground cover, above-ground cover

224 and regeneration), we fitted proportional response data ($0 \leq y \leq 1$) using a quasi-binomial
225 distribution with a logit function. For counts (native species richness, tree and shrub
226 recruits, and habitat variables), we modeled the response variables with quasi-Poisson
227 distributions and logit link functions. The effects of spatial autocorrelation were controlled
228 for in each model with site, and plots within a site included as random effects. All analyses
229 were performed using the 'hglm' package (Ronnegard *et al.* 2010) in R version 3.3.2 (R Core
230 Team 2016).

231

232 **Results**

233

234 *Effect of land tenure*

235

236 We found significant land tenure differences in several vegetation attributes (Table 2; Fig. 2-
237 4). TSRs were characterized by significantly higher native plant species richness (Table 2; Fig.
238 2), cover of cryptogams (Table 2; Fig. 3), cover of native shrubs (Table 2; Fig. 3), overstory
239 regeneration (Table 2; Fig. 4), and significantly lower cover of exotic plants (Table 2; Fig. 3).
240 No land tenure differences were observed for above-ground cover attributes, recruitment of
241 trees or shrubs, number of hollow bearing trees or total length of logs (Table 2).

242

243 >> Location of **Table 2** >>

244 >> Location of **Fig. 2** >>

245 >> Location of **Fig. 3** >>

246

247 *Effect of time and interaction with land tenure*

248

249 A number of vegetation attributes significantly changed over time, irrespective of land
250 tenure (Table 2; Fig. 2-4). From 2008 to 2012, native plant species richness almost doubled
251 (Table 2; Fig. 2), the cover of bare ground decreased by approximately 75% (Table 2; Fig. 3),
252 and native grass cover increased two-fold (Table 2; Fig. 3). Recruitment of shrubs and trees
253 was low across all sites, with both higher in 2012 compared to 2008 (Table 2). There was a
254 significant interaction of land tenure and year for organic litter cover, which was higher in
255 TSRs in 2008, but lower than production sites in 2012 (Table 2; Fig. 3).

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>> Location of **Fig. 4** >>

Effect of woodland type

Several vegetation attributes differed significantly among woodland types (Table 2; Fig. 5, 6). Compared to most other woodland types, Boree Woodland had significantly higher native plant species richness (Table 2), cover of bare ground (Table 2; Fig. 5), native shrub cover (Table 2; Fig. 5), mid and overstory cover (Table 2; Fig. 6a), number of shrubs recruits (Table 2; Fig. 6b), and significantly lower exotic plant cover (Table 2; Fig 5), number of hollow-bearing trees (Table 2; Fig. 6c), and total length of logs (Table 2; 6d). Black Box Woodland had higher native shrub cover (Table 2; Fig. 5), and supported significantly more hollow-bearing trees and logs than other woodland types (Table 2; Fig. 6).

>> Location of **Fig. 5** >>

>> Location of **Fig. 6** >>

Discussion

We found a significant tenure effect for some important vegetation attributes in remnant temperate woodlands. Travelling Stock Reserves were characterised by higher native species richness, greater cover of native shrubs and cryptogams, more mid- and overstory regeneration and less exotic ground cover compared to remnant woodlands on private property used for agricultural production. Some vegetation attributes that did not differ between TSRs and production sites were significantly influenced by time (e.g. the amount of bare ground and native grass cover) and woodland type (e.g. midstory regeneration and habitat attributes). The key results of our comparative study were that: (1) TSRs are important for supporting vegetation attributes significant for the conservation of these woodlands, (2) there is a need to monitor sites on a regular basis to quantify how vegetation attributes change through time, and (3) some important vegetation attributes differ among woodland communities, irrespective of land tenure.

288 *Effect of land tenure*

289

290 The average number of native plant species was highest in TSRs compared with production
291 sites and this pattern was consistent over time (Fig. 2). Many native plants in southern
292 Australia are highly-sensitive to livestock grazing and our finding is consistent with other
293 studies showing high species richness where grazing pressure is low (McIntyre *et al.* 2004,
294 2014; Dorrough and Scroggie 2008; Michael *et al.* 2016). Native plant species richness is also
295 associated with greater reptile species richness (Michael *et al.* 2014), is known to influence
296 the composition of woodland bird assemblages (Montague-Drake *et al.* 2009; Lindenmayer
297 *et al.* 2012), and is an indicator of high vegetation quality (Briggs *et al.* 2008; Gibbons *et al.*
298 2008). While plant species richness increased on production sites from 2008 – 2012, it never
299 reached the same values as on TSRs (which also increased), confirming the importance of
300 land tenure in maintaining this floristic attribute. However, quantifying changes in plant
301 community composition is also important, as different species respond differently to grazing
302 pressure (Dorrough and Scroggie 2008). Further research is needed to determine whether
303 other plant community responses, such as diversity, abundance and composition, are also
304 positively influenced by land tenure of these woodlands.

305

306 We observed significant land tenure effects for many ground cover attributes, with TSRs
307 having higher cover of native shrubs and cryptogams, and lower vegetation cover of exotic
308 plants compared to production sites. Understory structural complexity is beneficial to
309 threatened birds in temperate woodlands (Ford *et al.* 2009; Lentini *et al.* 2011a;
310 Lindenmayer *et al.* 2012; Dorrough *et al.* 2012), with higher ground cover of native shrubs in
311 TSRs suggesting that those sites are providing, and potentially increasing the levels of, this
312 important habitat attribute. Cryptogams can alter microenvironment conditions and affect
313 vascular plant establishment (Briggs and Morgan 2011) meaning that TSRs may be less
314 susceptible to weed invasion while the cover of lichens and mosses remains relatively high.
315 This may explain, in part, why TSRs supported less exotic plant cover than sites in
316 production areas. However, lower exotic plant cover on TSRs was more likely related to less
317 livestock grazing pressure over time, meaning fewer seeds of weed species were
318 transported into sites (Hogan and Phillips 2011). In addition, less soil disturbance may have

319 created fewer establishment opportunities for weeds (Hobbs and Huenneke 1992; Driscoll
320 *et al.* 2014).

321

322 *Effect of time*

323

324 Some vegetation attributes changed over time, but were not influenced by land tenure.
325 Bare ground decreased and native grass cover increased from 2008 to 2012 and did not
326 differ between TSRs and production sites. Recruitment of shrubs and trees was low across
327 all sites, but had increased by 2012, and organic litter cover was much more dynamic at
328 production sites during our study. These changes were almost certainly related to increased
329 rainfall following an extended drought, which ended in 2010 (Leblanc *et al.* 2012). The
330 prolonged dry period was associated with significant reductions in many groups of animals –
331 in particular threatened woodland birds – but the dramatic shift to above-average wet
332 conditions was not consistently associated with recovery of those groups (Bennett *et al.*
333 2014; Nimmo *et al.* 2015; Selwood *et al.* 2015). Similarly, these kinds of dramatic shifts in
334 rainfall are predicted to significantly alter vegetation communities and promote exotic plant
335 species (Hammill *et al.* 2016; Prober *et al.* 2016). In our study, we did not record increased
336 exotic plant species over time and observed a positive response only from a native
337 component of the flora. It is significant for the overall conservation value of the woodland
338 remnants in our landscape that several key vegetation attributes responded almost
339 immediately to increased rainfall following the drought.

340

341 *Effect of woodland type*

342

343 Vegetation attributes differed among woodland type irrespective of whether remnants
344 were in TSRs or on production sites. These attributes included the ground cover of exotic
345 plants, native shrub and bare ground, extent of mid- and overstory regeneration, amount of
346 tree and shrub recruitment, and the important structural attributes of length of fallen logs
347 and number of hollow-bearing trees. Some of these effects represent inherent structural
348 differences associated with particular vegetation communities (Keith 2004). For example,
349 Boree woodland occurs on clay soils and is not typically dominated by eucalypt species,
350 meaning it is less likely to have a densely vegetated ground layer or large trees providing

351 fallen logs. However, it is important to note differences in vegetation attributes among
352 woodland types as such differences can influence their value as habitat for some animal
353 species. For example, many reptile species are dependent on woody debris (Michael *et al.*
354 2014, 2015) and hollow-bearing trees are a critical habitat requirement for some mammals
355 and birds (Lindenmayer *et al.* 2013). Thus, Boree Woodland will support a different faunal
356 assemblage relative to Black Box Woodlands where logs and hollow-bearing trees are
357 intrinsically more abundant.

358

359 *Implications for management*

360

361 Our results indicate that TSRs are important for supporting high values of a number of
362 vegetation attributes deemed important for threatened biodiversity. Despite TSRs having
363 high conservation values (see Lentini *et al.* 2011b), they continue to be threatened by both
364 current forms of use as well as pressure to change their tenure status (and in turn how they
365 are managed) (Possingham and Nix 2008; Smiles *et al.* 2011; Local Land Services and
366 Department of Industry - Lands 2017). Despite livestock grazing pressure on TSRs being
367 considerably lower than the set-stocking grazing regimes which typically occurs in remnants
368 on adjacent private land, TSRs are not free of this kind of disturbance and many are far from
369 'pristine' (Davidson *et al.* 2005; Davidson and O'Shannassy 2017). Manipulating the timing
370 of livestock grazing may reduce its negative impacts (Davidson and O'Shannassy 2017). In
371 our study, TSRs were grazed periodically under short-term contracts that were issued for
372 travelling stock, drought or flood relief, or fire hazard reduction. Systematically collating
373 details of grazing pressures on TSRs (timing, frequency and intensity) would provide
374 valuable insight into the effect of livestock on vegetation attributes of these remnant
375 woodlands.

376

377 The land tenure status of woodland remnants in our study significantly influenced many
378 vegetation attributes important for explaining biodiversity patterns in the landscape. Over
379 the last 10 years, there have been multiple attempts to change the tenure status of TSRs
380 and potentially move ownership to private landholders (Possingham and Nix 2008; Smiles *et al.*
381 *et al.* 2011; Local Land Services and Department of Industry - Lands 2017). Such a change
382 would almost certainly shift the primary management of those sites to agricultural

383 production, likely leading to increased grazing pressure, set-stocking, pasture improvement,
384 and limited control of weeds and pests. Most vegetation attributes would likely change
385 rapidly in response to grazing intensification (Dorrrough and Scroggie 2008) with TSRs
386 becoming more like production sites. Many of these attributes are slow to recover once
387 grazing pressure is reduced (Vesk *et al.* 2008). Given the significant modification of the
388 landscape and paucity of large ecological reserves in the Riverina bioregion (Pressey *et al.*
389 2000), any policy changes that results in the degradation of TSRs would be a significant
390 threat to the conservation efforts and values of these woodlands and the region.

391

392 *Conclusion*

393

394 Our study provides empirical evidence of the significant biodiversity value of TSRs for the
395 conservation of temperate woodlands in south-eastern Australia. Our study also shows
396 that, relative to remnants used for intensive livestock production, TSRs are characterized by
397 higher values for many vegetation attributes that are important for threatened fauna
398 species. However, TSRs should not be viewed as the exclusive resource for biodiversity
399 conservation in this landscape, with all remnants across different land tenures providing
400 complementary value to the overall protection of these threatened woodland communities
401 (Lindenmayer *et al.* 2013). Further research is needed to determine how changes in these
402 important vegetation attributes relates to vegetation 'quality' (as measured against a
403 benchmark (Keith 2004; Gibbons *et al.* 2008)) and what effect different management
404 approaches have on improving the condition of what little remains of the temperate grassy
405 woodlands of south-eastern Australia.

406

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408

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419

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575 **Tables and Figures**

576

577 **Table 1.** Total number of sites and plots monitored in this study stratified by land tenure
 578 and vegetation (Keith Class). Keith Classes include floodplain transition woodland (Grey
 579 Box), inland floodplain woodland (Black Box), Riverine plain woodland (Boree) and Riverine
 580 Sandhill Woodland (Sandhill). Asterisk denotes where there are less sites than the sum of
 581 the column because some sites contained plots in multiple communities.

Keith Class	Travelling Stock Reserve		Production site	
	Sites	Plots	Sites	Plots
Grey Box Woodland	10	28	9	18
Black Box Woodland	10	23	9	18
Boree Woodland	5	14	12	24
Sandhill Woodland	5	10	10	20
Total	*25	75	40	80

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584 **Table 2.** Parameter estimates of all vegetation attribute response variables as calculated by
 585 hierarchical generalized linear mixed models. The main effects of land tenure (Travelling
 586 Stock Reserve (TSR) compared to production sites) and year are presented for all variables.
 587 Only significant interactive effects of Tenure and Year and main effects of woodland type
 588 are presented. Woodland type are based on the Keith Classes: Inland Floodplain Woodland
 589 (Black Box), Riverine Plain Woodland (Boree) and Riverine Sandhill Woodland (Sandhill).
 590 Woodland parameter estimates are relative to the baseline of Floodplain Transition
 591 Woodland (Grey Box).

Response variable	Parameter	Estimate	SE	<i>t</i>	<i>P</i>
Native species richness					
Native species per plot	Tenure	215.51	38.06	5.66	<0.001
	Year	0.20	0.01	13.22	<0.001
	Tenure x Year	-0.11	0.02	-5.65	<0.001
	Black Box	0.23	0.04	5.88	<0.001
	Boree	0.45	0.04	10.96	<0.001
Ground cover (%)					
Bare ground	Tenure	-0.49	0.27	-1.80	0.07
	Year	-0.46	0.11	-4.203	<0.001

	Black Box	1.00	0.36	2.78	0.01
Organic litter	Tenure	658.18	246.68	2.67	0.01
	Year	0.35	0.09	4.00	<0.001
	Tenure x Year	-0.33	0.12	-2.67	0.01
Cryptogam	Tenure	1.02	0.44	2.31	0.02
	Year	0.09	0.12	0.78	0.43
Exotic plants	Tenure	-0.93	0.26	-3.52	<0.001
	Year	0.07	0.07	0.92	0.36
	Boree	-1.29	0.38	-3.32	<0.001
Native grass	Tenure	0.34	0.26	1.32	0.19
	Year	0.30	0.08	3.95	<0.001
Native shrub	Black Box	-1.38	0.37	-3.77	<0.001
	Tenure	1.58	0.52	3.05	<0.01
	Year	0.27	0.13	1.95	0.05
	Black Box	1.88	0.71	2.63	0.01
Native forb cover	Sandhill	1.84	0.75	1.13	0.01
	Tenure	0.22	0.35	0.63	0.53
	Year	0.13	0.10	1.31	0.19
Above-ground cover (%)					
Native midstory	Tenure	0.28	1.72	0.17	0.87
	Year	0.37	0.24	1.54	0.13
Native overstory	Tenure	0.48	0.37	1.30	0.19
	Year	0.05	0.10	0.50	0.62
Vegetation growth					
Midstory regeneration	Tenure	620.19	300.28	2.07	0.04
	Year	0.03	0.10	0.26	0.80
	Tenure x Year	-0.31	0.15	-2.06	0.04
	Black Box	2.36	0.49	4.80	<0.001
	Boree	3.17	0.50	6.35	<0.001
	Sandhill	1.76	0.54	3.24	<0.01
Overstory regeneration	Tenure	2.29	0.71	3.23	<0.01
	Year	-0.05	0.05	-0.75	0.45
	Boree	0.69	0.31	2.20	0.03
	Sandhill	-0.79	0.37	-2.14	0.03
Revegetated shrubs	Tenure	-3.56	0.69	-0.51	0.61
	Year	1.27	0.12	16.02	<0.001

	Black Box	2.36	0.28	8.44	<0.001
	Boree	3.18	0.27	11.69	<0.001
	Sandhill	1.89	0.28	6.64	<0.001
Revegetated trees	Tenure	-1.96	7.69	-0.26	0.80
	Year	0.43	0.04	11.18	<0.001
	Black Box	0.42	0.15	2.85	<0.01
	Boree	0.73	0.14	5.24	<0.001
	Sandhill	0.59	0.14	4.30	<0.001
Habitat attributes					
Hollow bearing trees	Tenure	0.03	0.10	0.31	0.75
	Year	-0.07	-0.01	-1.08	0.28
	Black Box	0.66	0.10	6.78	<0.001
	Boree	-2.19	0.29	-7.59	<0.001
	Sandhill	-1.41	0.24	-5.79	<0.001
Length of logs	Tenure	-0.49	0.37	-1.32	0.19
	Year	-0.15	0.01	-1.73	0.08
	Black Box	0.32	0.03	11.88	<0.001
	Boree	-0.75	0.04	-19.97	<0.001
	Sandhill	-0.32	0.04	-8.64	<0.001

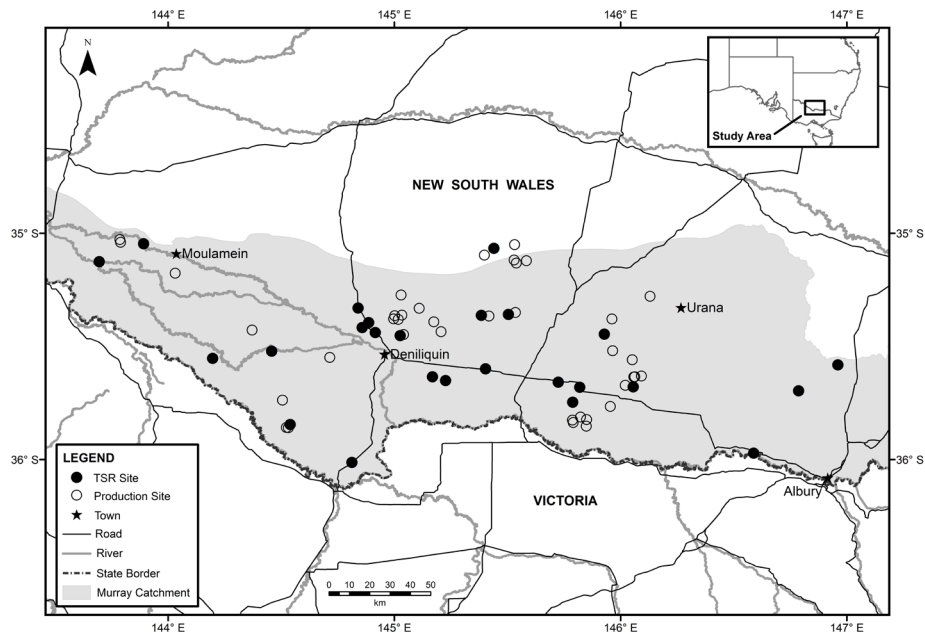
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598 **Fig. 1.** Location of woodland remnants in Travelling Stock Reserves (●) and production sites
 599 (○) within the Riverina bioregion of the Murray Catchment, south-western New South
 600 Wales, Australia.

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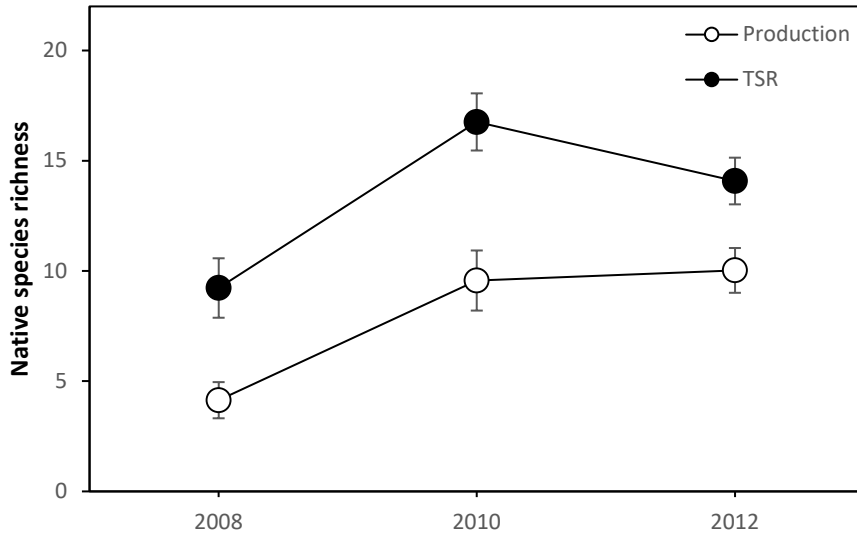
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Fig. 2. Mean number of native species per 400 m² plot in Travelling Stock Reserves and production site woodland remnants for three monitoring years. Error bars denote 95% confidence intervals.

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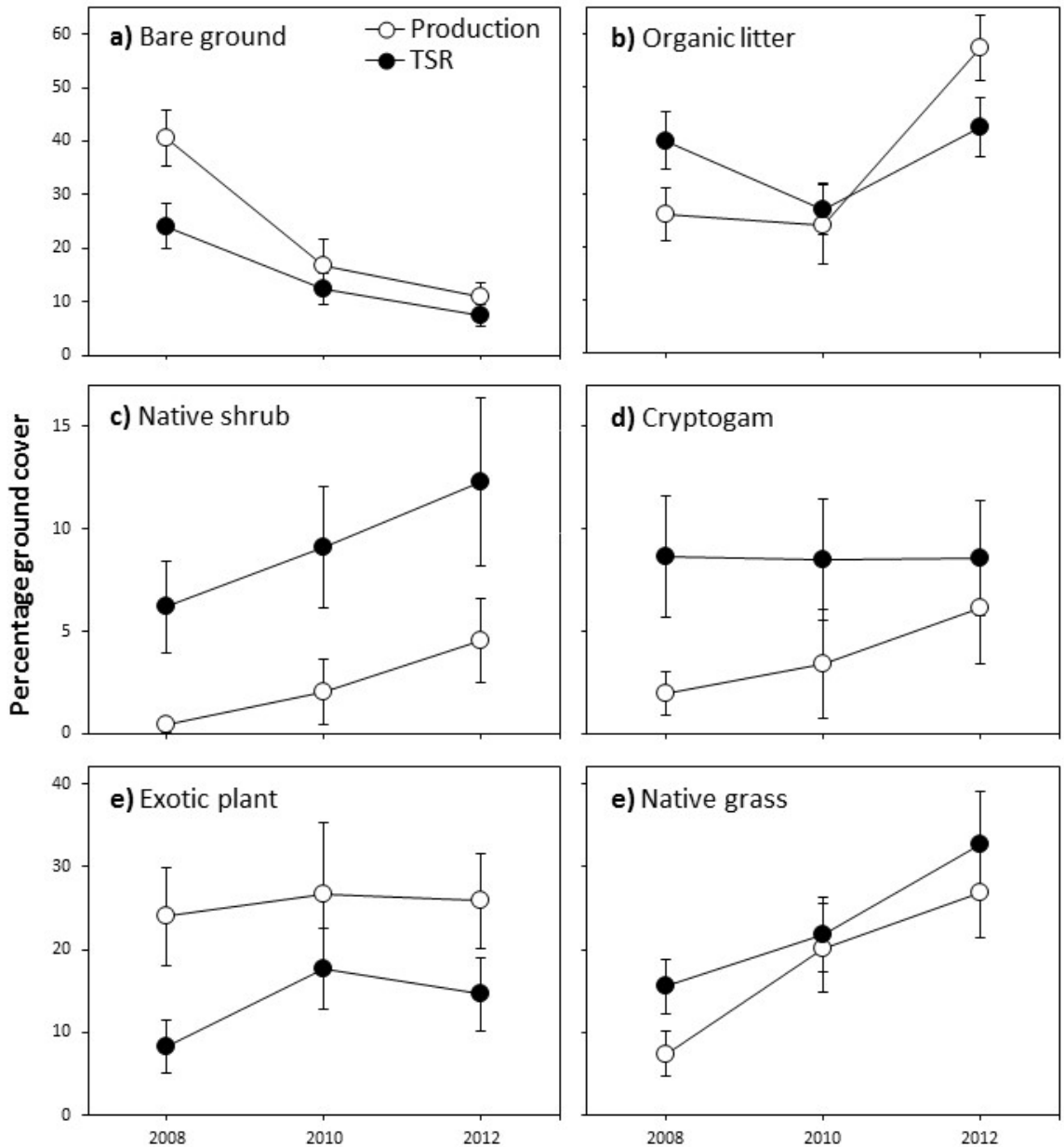
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625 **Fig. 3.** Mean percentage cover of ground cover variables in Travelling Stock Reserves (black
 626 circles) and production site (white circles) woodland remnants for three monitoring years.
 627 Error bars denote 95% confidence intervals.

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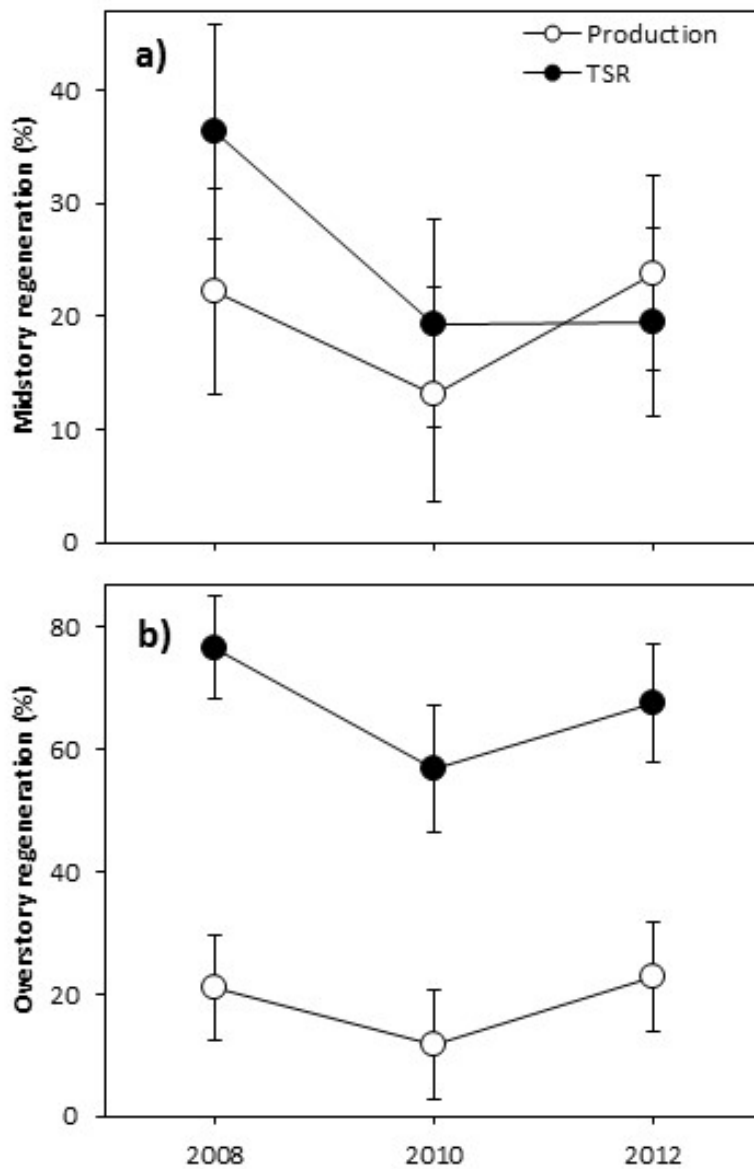
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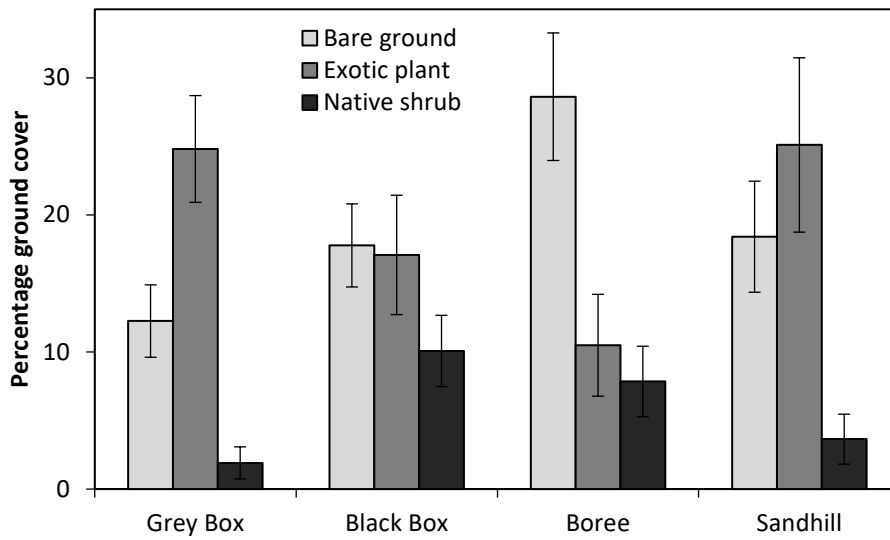
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 635 **Fig. 4.** Mean percentage cover of the growth variables **a)** mid- and **b)** overstory regeneration
 636 in Travelling Stock Reserves (black circles) and production site (white circles) woodland
 637 remnants for three monitoring years. Error bars denote 95% confidence intervals.

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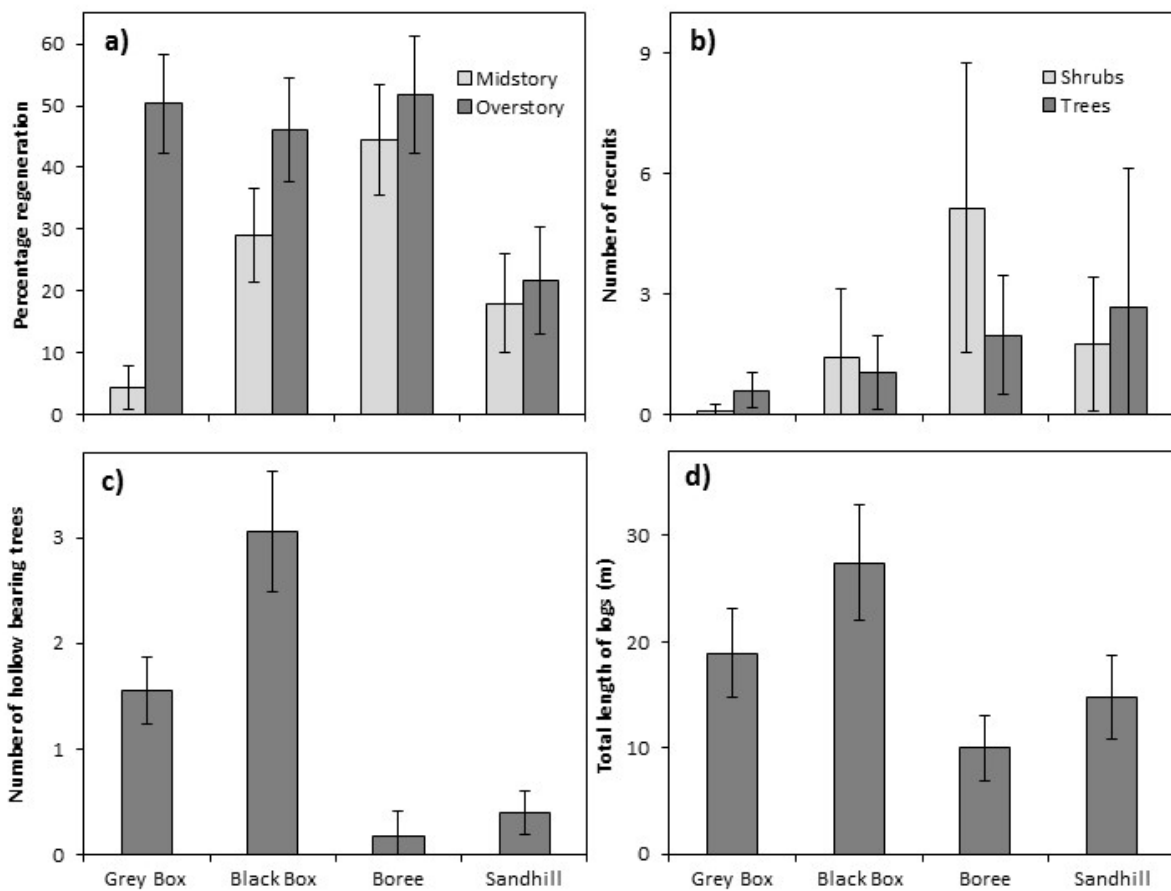
647 **Fig. 5.** Mean percentage cover of ground cover variables for the different woodland types.

648 Keith Class vegetation communities are floodplain transition woodland (Grey Box), inland

649 floodplain woodland (Black Box), Riverine plain woodland (Boree) and Riverine sandhill

650 woodland (Sandhill). Error bars denote 95% confidence intervals.

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653 **Fig. 6** Mean **a)** percentage of regeneration, **b)** number of shrub and tree recruits, **c)** number
 654 of hollow-bearing trees and **d)** total length of logs (> 10 cm diameter) for each of the four
 655 woodland types (based on Keith Classes floodplain transition woodland (Grey Box), inland
 656 floodplain woodland (Black Box), Riverine plain woodland (Boree) and Riverine sandhill
 657 woodland (Sandhill)). Error bars denote 95% confidence intervals.

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