Association between land cover, plant genera and pollinator dynamics in mixed-use landscapes

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Acknowledgements

1   **Abstract**

2   Context.

3   Land-use change threatens pollinators globally. However, pollinator-landscape studies tend to

4   focus on certain focal taxa and landscapes with intensive human activities. This limits the

5   implementation of targeted management policies for landscapes with different modifications

6   and pollinator groups.

7   Objectives.

8   This study aims to determine which habitat characteristics can predict abundance and

9   richness of multiple pollinator groups.

10   Methods.

11   We collected field data on the relative abundance and observed richness of nectivorous birds,

12   bees, beetles, butterflies across a mixed-use landscape in the Tasman Peninsula, Tasmania,

13   Australia; and determined if they could be predicted using land use, land cover at different

14   radii (100 m to 5000 m), plant genera and floral morphologies.

15   Results.

16   Using feature selection, we found land use was an overall poor predictor, with land cover,

17   plant genera and floral morphologies being superior. Random forest was used for predictive

18   modelling and goodness of fit R^2 calculated was highest and lowest for butterfly abundance

19   (0.65) and butterfly richness (0.08) respectively. Variable importance was calculated, and

20   forest cover achieved the highest importance value for nectivorous birds and butterflies,

21   whereas open cover was most important for bees and the presence of the plant genus

22   *Leptospermum* for beetles.

23   Conclusions.

24   Our results emphasise the importance of considering multiple habitat factors to manage and

25   support a dynamic pollinator community. We demonstrate how predictive modelling can be

26   used to make informed decisions on how to have a dynamic pollinator community in a way

27   that can be applied to real-world scenarios to validate the models and further improve

28   decision making.

29

30   **Keywords**

31   Honey bees, native bees, honeyeaters, Exoneura, Lasioglossum

32   **Introduction**

33   Pollinators (animal vectors of pollen) are important ecosystem components, assisting in the

34   sexual reproduction of plants (Kevan and Viana 2003). They are estimated to pollinate 70%

35   of global crops (Klein et al. 2007) and 87% of wild plants (Ollerton et al. 2011). Flying

36   insects, such as bees, beetles, and butterflies, play a particularly important role in pollinating

37   crops (Rader et al. 2016) and wild plants (Winfree et al. 2011). Birds such as honeyeaters

38   also act as pollinators, particularly in the Austral and Oceanic regions, where they pollinate

39   more than 10% of the flora (Sekercioglu 2006).

40   Pollinators are declining globally (Maes and Van Dyck 2001; Ollerton et al. 2014; Regan et

41   al. 2015). The causes are many and include land-use change (LUC: habitat loss and

42   fragmentation), introduced and invasive species, agrochemicals, climate change, and the

43   interactions and synergies between these threats (Potts et al. 2010; Regan et al. 2015;

44   Vanbergen et al. 2013). Of these, LUC is considered the most important threat to pollinators

45   as it reduces plant abundance and diversity, which in turn reduces the availability of floral

46   resources (Baude et al. 2016; Nicolson and Wright 2017; Paton 2000).

47   Land-use change can have mixed effects on pollinators (Winfree et al. 2011), with its relative

48   impact depending on pollinator taxa (Montero-Castaño and Vilà 2012), geographic location

49   (Archer et al. 2014; De Palma et al. 2016), the amount of native vegetation present (Winfree

50   et al. 2009) and the intensity of disturbance (Herrera 2018; Senapathi et al. 2015). The

51   impacts of LUC on pollinators is also influenced by the availability of floral resources

52   (Winfree et al. 2011) which are known to be a limiting factor for pollinators such as bees

53   (Roulston and Goodell 2011), butterflies (Öckinger and Smith 2006), and birds (Paton 2000).

54   Pollinator-landscape studies have typically focused on landscapes with extreme LUC

55   (Winfree et al. 2011) or on impacts of LUC on focal taxa, like bees (Senapathi et al. 2017).

4

56   This is a limitation because landscapes with varying degrees of modification and different

57   suites of pollinator groups might require distinct management policies.

58   The Tasman Peninsula (Tasmania, southern-temperate Australia) provides an excellent case

59   study as it consists of a mixed-used landscape (see Methods) with multiple pollinator taxa,

60   including bees, beetles, butterflies, and birds (Hingston and Mc Quillan 2000). The large

61   island of Tasmania is also rich in plant diversity, with 2,726 vascular plant species, of which

62   70% are native and the remaining 30% have naturalised from elsewhere (Baker and Duretto

63   2019). This allows the additional assessment of the impacts of plant genera and floral

64   morphologies (shape and colour) on different pollinator communities.

65   In this study, we aim to assess the influence of land use (LU), land cover (LC), plant genera,

66   and floral morphologies on the relative abundance and observed richness of nectivorous

67   birds, bees, beetles, and butterflies. To do this, we collected field data on the relative

68   abundance and observed richness of these main pollinator groups across different LU classes,

69   and analysed them using feature selection (Guyon and Elisseeff 2003) for predictor selection,

70   and random forests (RF) (Breiman 2001) for predictive modelling. The advantage of using

71   machine learning and predictive modelling is its ability to handle data with non-normal

72   distribution and noise, and use robust training-and-testing analysis to make predictions for

73   informed decision making (Thessen 2016; Willcock et al. 2018). We discuss the associations

74   between predictors and pollinators and which predictors are best suited to management for

75   improving the diversity and resilience of pollinator communities.

76   **Methods**

77   *Study area*

78   The Tasman Peninsula, located on the south-eastern portion of Tasmania, Australia (Fig. 1),

79   covers an area of 660.4 km^2 with elevation from 0 to 582 m a.s.l. (meters above sea level). It

5

80   is characterised by a mix of dry and wet sclerophyll eucalypt forest and dry coastal vegetation

81   and supports a third of the vascular plants found in Tasmania (Brown and Duncan 1986). In

82   terms of human activity, it is a mixed-use landscape, dominated by grazing pasture, forest

83   plantations and protected areas (Department of Primary Industries Parks Water and

84   Environment 2015), with protected areas covering 26.7% of its surface (Australian Bureau of

85   Statistics 2020). The three LU (Table 1) were used as predictor variables for all pollinator

86   groups.

87   **Table 1.** Characteristics of the different sites within each LU

| Land-use	Sites	Characteristics
Protected areas	Lime Bay State reserve (LBR)	Coastal woodland, with pockets of dense tree but overall open canopy cover and dense ground vegetation.
	Tasman National park (TNP) (a)	Sclerophyll forest with dense canopy cover and dense ground vegetation.
	Tasman National park (TNP) (b)	Sclerophyll forest, with moderate canopy and open ground vegetation.
Plantations	Plantation (a)	Contains patches of eucalypt and pine forest plantations and non-plantation eucalypt forest where fieldwork was carried out. Sclerophyll forest with dense canopy and ground cover.
	Plantation (b)	Contains patches of eucalypt forest and pine plantations and non-plantation eucalypt forest where fieldwork was carried out. Sclerophyll forest with dense canopy and ground cover. We noticed more harvested coups in this site than in plantation (a)
Pasture	Pasture	Pasture areas with cattle, with few isolated trees within the pasture.

88

89   *Study design*

6

90 We established one observation site in a pasture, two in plantations and three in protected

91 areas (Fig. 1). The unequal number of sites per land use was due to lack of accessibility. Each

92 site consisted of two subsites 1-3 km apart and each subsite included three plots, with birds,

93 bees, and beetles sampled in each plot, and one transect for butterfly sampling. The plots

94 were at least 400 m apart and randomly distributed 80-100 m from a chosen walking track,

95 while the transects were placed along the walking track between the three plots. In total there

96 were 18 plots and six transects in protected areas, 12 plots and four transects in plantations

97 and six plots and two transects in pasture.

98 Observations took place between 07.00 – 11.00 h and 16.00 – 19.00 h for birds and 10.00 –

99 15.00 h for insects, under non-windy and non-rainy conditions. Sampling of all the

100 investigated pollinator groups was then repeated monthly from September to December 2018

101 to account for temporal changes in flowering vegetation.

102 Using the same methodology described above, a proof-of-concept pilot study was previously

103 carried out in protected areas consisting of three sites with 12 plots and 6 transects (Fig. 1)

104 from January to February 2018.
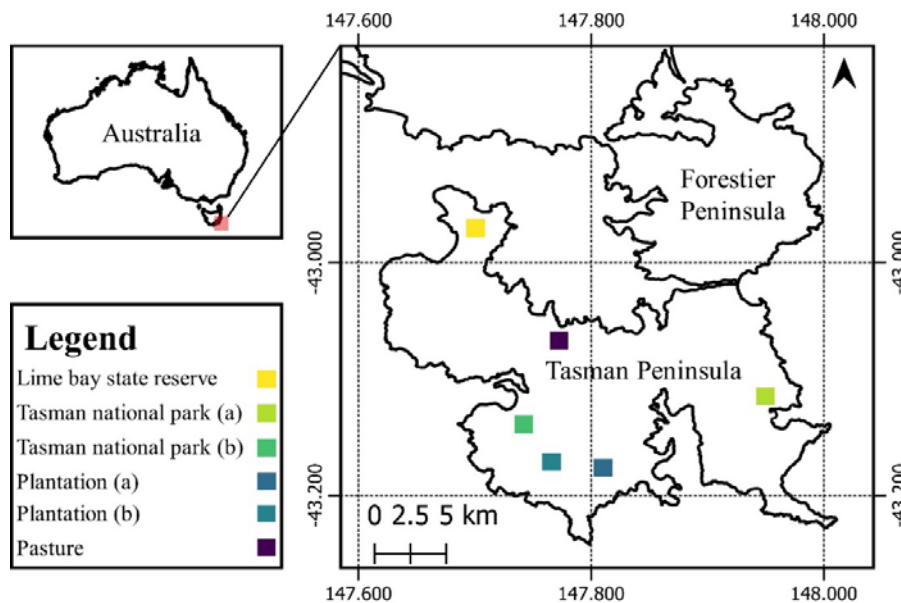
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106   **Fig. 1** Location of the sampling sites in the Tasman Peninsula, Tasmania, Australia.

107   *Pollinator sampling and plant identification*

108   Birds were visually observed using a standardised point-count method within a 2-ha plot for

109   20 minutes (BirdLife 2020). Honeyeaters (family *Meliphagidae*), were the only birds

110   considered for this study as they are dominant group of nectivorous birds in Australia (Ford

111   and Paton 1977). Honeyeater count and species were recorded with species grouped into

112   endemic (native to Australia but present only in Tasmania) and non-endemic (native to

113   Australia and present throughout Australia) honeyeaters.

114   *Eucalyptus* tree species within the 2-ha plots were recorded (presence/absence) and identified

115   using a field guide by Wiltshire and Potts (2007). They were grouped into *Symphyomyrtus*

116   and *Eucalyptus* (formerly *Monocalyptus*) sub-genera (Nicolle 2015) and used as predictors

117   for honeyeaters richness and abundance, as they have been shown to influence honeyeater

118   presence (Dunkerley et al. 1990; Woinarski and Cullen 1984).

119   Bees and beetles were recorded within the 2-ha plot by visually observing four ground-level

120   flowering plants for 10 minutes each, as observational sampling is a commonly used

121   technique to detect bee abundance (Prendergast et al. 2020). Both insects and plants were

122   photographed to allow for off-site identification (where required). Bees were grouped into

123   introduced bees and native bees; introduced bees included *Apis mellifera* (western honey bee)

124   and *Bombus terrestris* (buff-tailed bumble bee), the only introduced species found in

125   Tasmania (https://www.environment.gov.au/biodiversity/invasive-species/insects-and-other-

126   invertebrates/invasive-bees), while native bees included all other bee species. Beetles were

127   identified to family level using iNaturalist website (https://inaturalist.org/).

128   Where possible, four different species of flowering plant, separated by at least 5 m, were

129   chosen, with new species selected during the repeated visits. If no flowering plants were

130   present, that resulted in zero observations. Plants were identified to species or genus level

131   using the University of Tasmania key to Tasmanian vascular plants

132   (www.utas.edu.au/dicotkey/dicotkey/key.htm). The plants identified were grouped based on

133   their colour and shape using a classification adopted from Hingston and Mc Quillan (2000).

134   Colours were pale, yellow, and pink, while shapes were brush, tubular, actinomorphic, and

135   zygomorphic.

136   Butterflies were sampled along a 1000-m long and 5-m wide transect (Pollard 1977). An

137   insect net was used to catch butterflies and record the count and species. Species were

138   photographed and identified using the reference Common and Waterhouse (1972).

139   *Land-cover analysis*

140   Land Cover refers to the natural and artificial structures covering the land (Anderson et al.

141   1976); the LC classes considered in this study are 'forest' (areas dominated by trees,

142   including plantations), 'open' (areas with low-lying vegetation, including shrubs and

143   grasses), 'barren' (areas lacking vegetation) and 'water' (quantified as the percentage of total

144   cover at different spatial scales). The allocation of LC classes was inferred from Sentinel 2

145   imagery as it has a high spatial resolution of 10×10 m (Sentinel Online 2020).

146   The LC classification was done using machine learning algorithms – support vector machine

147   (Cortes and Vapnik 1995), random forest (Breiman 2001), k-nearest neighbour (Cover and

148   Hart 1967), and naïve Bayesian (Mitchell 1997) and averaging their results using an

149   unweighted ensemble (Diengdoh et al. 2020) in R v1.3 (RStudio Team 2020) and QGIS

150   v3.12 (QGIS Development Team 2020). Classification was implemented using the *caret* R

151   package (Kuhn 2020).

152   Accuracy was assessed by comparing it to external/independent/unseen data. The external

153   data consisted of 100 points/pixels per LC class, randomly selected from the classified image

154 and visually compared to imagery from Google Earth and from field data for accuracy

155 assessment. Output metrics we report include the overall accuracy (OA), the true-skill

156 statistic (TSS) for the classified image, and the sensitivity and specificity of each LC class,

157 where: OA is the number of correctly classified pixels divided by the total number of pixels

158 examined (Foody 2002); TSS is equal to the median of sensitivity plus specificity minus 1;

159 sensitivity is observed presences that are predicted as such; while specificity observed

160 absences that are predicted as such (Allouche et al. 2006). The method for LC classification

161 is detailed in the Supplementary Material.

162 The percentage of each LC class was calculated within buffers of varying size for each

163 pollinator group. For bees and beetles, we used buffers of 100 m radius from the centre of the

164 plots, as well as 500 m, 1000 m and 2000 m, corresponding to a range of foraging distances

165 of different bee species (Greenleaf et al. 2007). For honeyeaters, we used buffers of 100 m,

166 2000 m, and 5000 m radius, similar to Smith et al. (2011) and Lasky and Keitt (2010).

167 Buffers of 500 m, 1000 m, and 2000 m were used for butterflies, similar to Bergman et al.

168 (2004).

169 *Statistical analyses*

170 Feature selection was used to identify the best predictors among those chosen for each

171 pollinator group. Feature selection is a method used to find a subset of features with the

172 minimum possible (out-of-sample) generalization error (Granitto et al. 2006). It can

173 overcome high dimensionality (Guyon and Elisseeff 2003) and is important in datasets where

174 the number of available training samples is smaller compared to the possible combination of

175 features (Chen and Jeong 2007). Random-Forest-Recursive Feature Elimination (RF-RFE), a

176 backward feature selection or recursive feature elimination method, was implemented in this

177 study using the *caret* R package (Kuhn 2020). Feature ranking was based on a measure of

178   variable importance from the random forests fit. Leave-p-out cross validation was used,

179   where p was 70/30 % (training/testing) with 500 iterations; p was indexed based on the

180   number of plots (for honeyeater, bee, and beetle models) and sites (for butterfly models) to

181   ensure training and testing data had a unique set to account for repeated observations.

182   Random forest was used for predictive modelling once the best set of predictors was

183   identified, using the *randomForest* R package (Liaw and Wiener 2002). The goodness of fit

184   and cross-validated R^2 and root mean square error (RMSE) of each model were calculated.

185   Cross-validation was carried out by splitting the data into a training/testing set using a

186   random stratified method rather than a random percentage method. The stratification ensured

187   that, for each plot/site with repeated observations, there was at least one repeated observation

188   in the testing data that was not in the training data. Variable importance was calculated for

189   each predictor in a model using the *ggRandomForests* R package (Ehrlinger 2016).

190   **Results**

191   *Pollinator richness and abundance*

192   We observed a total of 405 honeyeaters belonging to eight different species, of which four are

193   endemic (186 individuals) and the remaining non-endemic (219 individuals). There was a

194   total of 509 bees consisting of 230 introduced bees (214 honey bees and 16 bumble bees) and

195   279 native bees (183 *Exoneura* genus, 48 *Lasioglossum* genus and 48 individuals classified as

196   others). There was also a total of 423 beetles, belonging to nine families and a total of 202

197   butterflies belonging to nine species. The observations for honeyeaters and butterflies were

198   from the main and pilot study while for bees and beetles were only from the main study due

199   to a lack of observations in the pilot. A list of species observed across the different LU and

200   LU sites is included in the Supplementary (Table S1).

201   The median of the log abundance and richness of different pollinator groups differed across

202   the three LU classes (Fig. 2) and the six LU sites (Fig. 3). Protected areas had an overall

203   higher abundance and richness of different pollinator groups (Fig. 2) particularly at Lime Bay

204   State Reserve (Fig. 3). Tasman National Park (b) had lower abundance of native bees,

205   beetles, and butterflies (Fig. 3f, h-k) and richness of beetles and butterflies (Fig. 3f, h-k).

206   Overall, plantations had a higher abundance of non-endemic honeyeaters than endemic

207   honeyeaters (Fig. 2b, c) and lower abundance and richness of beetles (Fig. 2h, i). Plantation

208   (a) supported both endemic and non-endemic honeyeaters (Fig. 3b, c) but had lower

209   abundance and richness of beetles (Fig. 3h, i); Plantation (b) supported only non-endemic

210   honeyeaters (Fig. 3b, c) but had higher abundance and richness of beetles (Fig. 3h, i). Sites in

211   pastures had the lowest abundance and richness of beetles (Fig. 2h, i; Fig. 3h, i;) and no

212   observed honeyeaters in either subsites (Fig. 2a-d; Fig. 3a-d) but had a high abundance of

213   native and introduced bees (Fig. 2f, g; Fig. 3f, g) as well as an abundance and richness of

214   butterflies (Fig. 2j, k; Fig. 3j, k).

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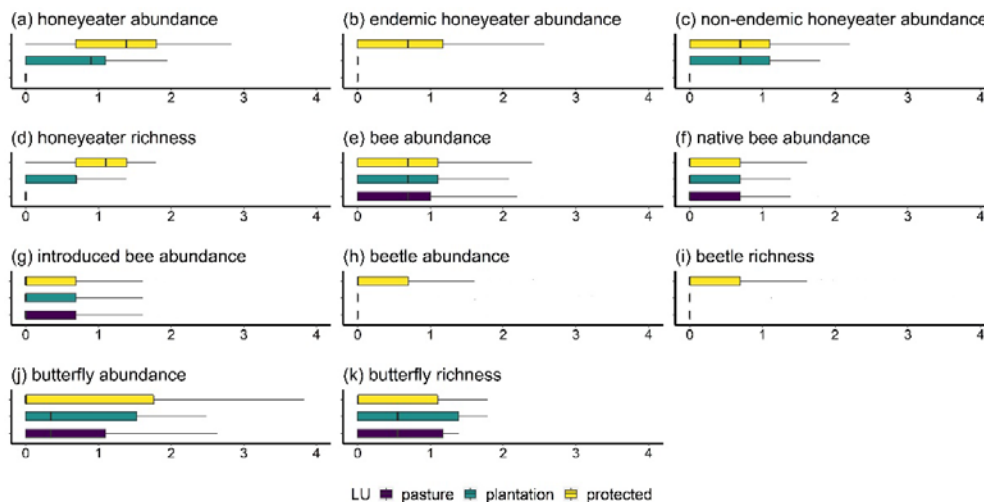
Fig. 2 Log of total abundance and richness of honeyeaters including endemic and non-

endemic honeyeaters (a-d), bees (e-g), beetles (h-i) and butterflies (j-k) in pastures,

plantations, and protected areas.

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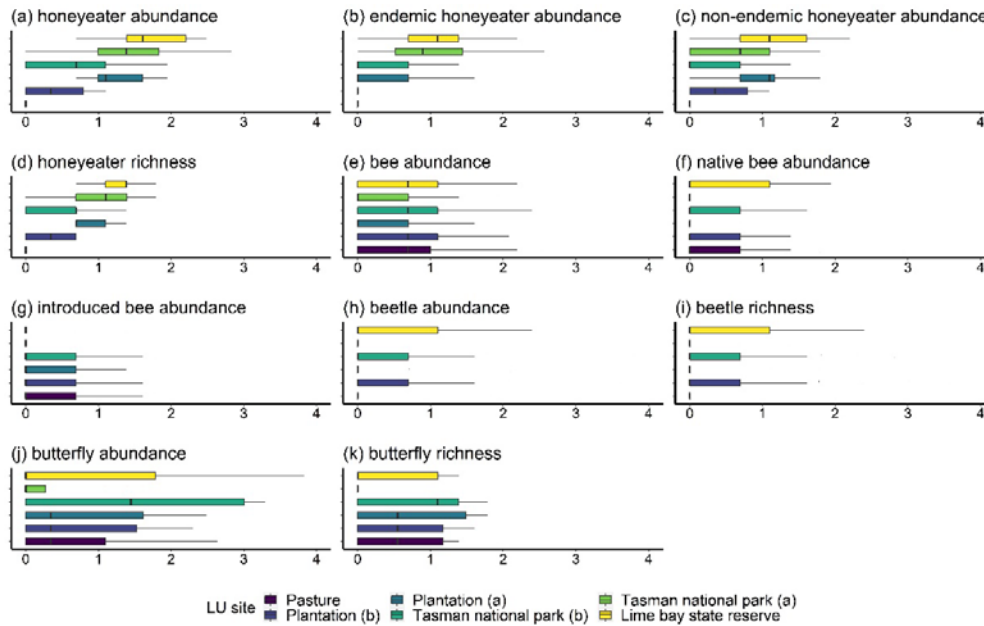
Fig. 3 Log of total abundance and richness of honeyeaters including endemic and non-endemic honeyeaters (a-d), bees (e-g), beetles (h-i) and butterflies (j-k) across pastures, plantations (plantation a and b) and protected areas (Tasman National Park a and b, Lime Bay State Reserve) LU sites.

Bees and beetles were observed visiting 24 plant genera, of which only three are exotic/naturalised, i.e., *Arctotheca, Taraxacum* and *Trifolim*, which were only found in pastures. The genera *Daviesia, Pultenaea,* and *Melaleuca* had the highest abundance of native bees (Fig. 4a), while *Anopterus, Pimelea, Pomaderris,* and *Trifolim* had the highest abundance of introduced bees (Fig. 4b) and *Leptospermum* the highest abundance of beetles (Fig. 4a). *Symphyomyrtus* presence was associated with an overall higher abundance and richness of honeyeaters (Fig. 5 e, h) compared to *Eucalyptus*. *Symphyomyrtus* also supported a higher abundance of endemic honeyeaters (Fig. 5f) than *Eucalyptus*.

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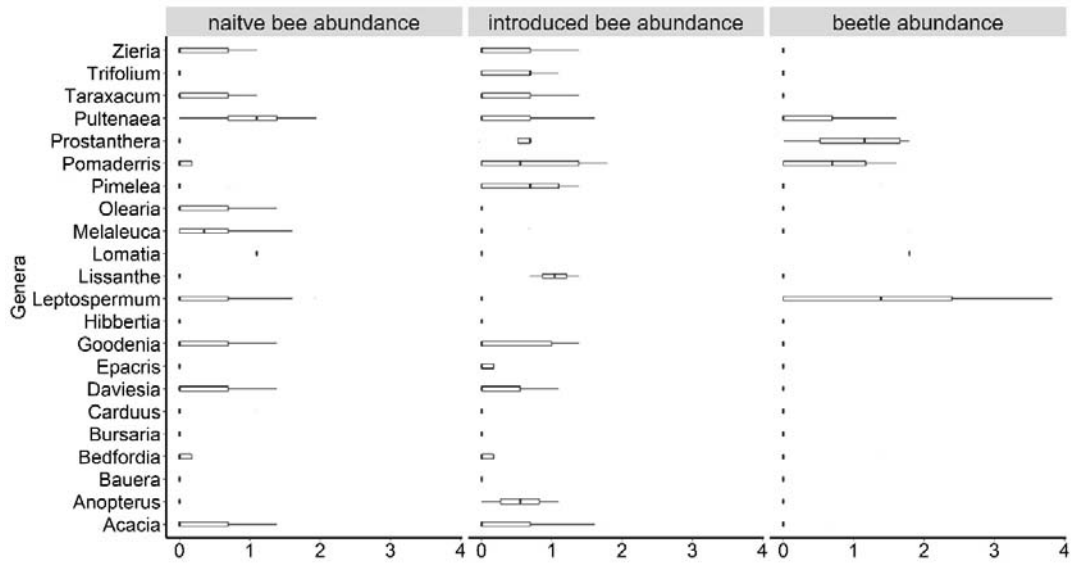
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233 **Fig. 4** Log of total abundance of native bees, introduced bees, and beetles per genus.
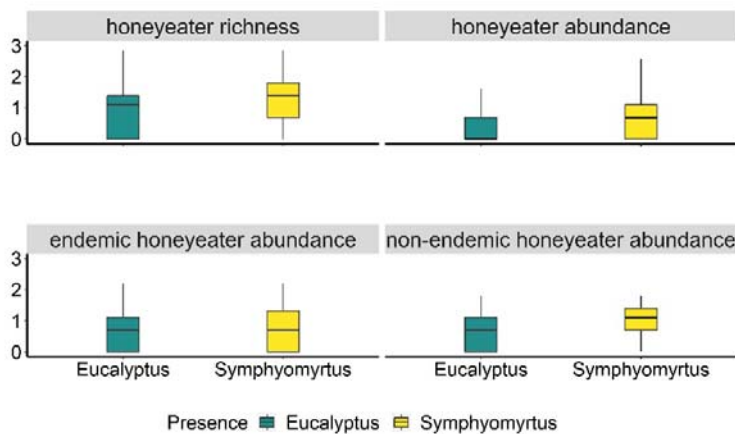
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235 **Fig. 5** Log of total abundance and richness of honeyeaters across in presence of *Eucalyptus*

236 and *Symphyomyrtus* plant genera.

237 *Land-cover analysis*

238 The classified image (Supplementary Fig. S1) had an OA of 79.5% with 95% CI [75.21,

239 83.35] and TSS score of 77.41%. The confusion matrix of the classification results with

240 sensitivity and specificity of the LC classes and the classified image, as well as the

241   percentage of forest and open cover within different buffers across the three LU, are included

242   in Supplementary (Table S2-S4).

243   *Predictors of pollinator richness and abundance*

244   Land use (i.e., human activities on the land) was not selected by RF-RFE as a predictor for

245   any of the models except for butterfly abundance (Fig. 6). Two land cover (i.e., structures

246   covering the land) classes—forest and open—were identified as important predictors in all

247   models, with buffering size selection differing between honeyeaters, bees and beetles, and

248   butterflies. Four plant genera, all native to Australia, were selected as predictors of bee and

249   beetle abundance and richness (Fig. 6e-i). Floral shape – zygomorphic and actinomorphic,

250   were selected for the native-bee and beetle models (Fig. 6f, h, i).

251   Structural goodness of fit (R^2) results showed that butterfly abundance and butterfly richness

252   had the highest and lowest R^2 values, respectively (Fig. 6j, k). R^2 values were highest in

253   beetle models (Fig. 6j, i) followed by honeyeater models (Fig. 6a-d) and lowest in bee models

254   (Fig. 6e-g).

255   Variable importance results from the random forests models show that, overall, LC had the

256   highest importance value for most models except for beetle abundance and richness models,

257   where *Leptospermum* was the most important (Fig. 6h, i). Buffers of 500 m, 1000 m, 2000 m

258   and 5000 m were all important for honeyeaters (Fig. 6a-d), while buffers of 100 m and 2000

259   m were important for bees and beetles (Fig. 6 e-i) and buffers of 500 m, 2000 m and 5000 m

260   were important for butterflies (Fig 6j, k).

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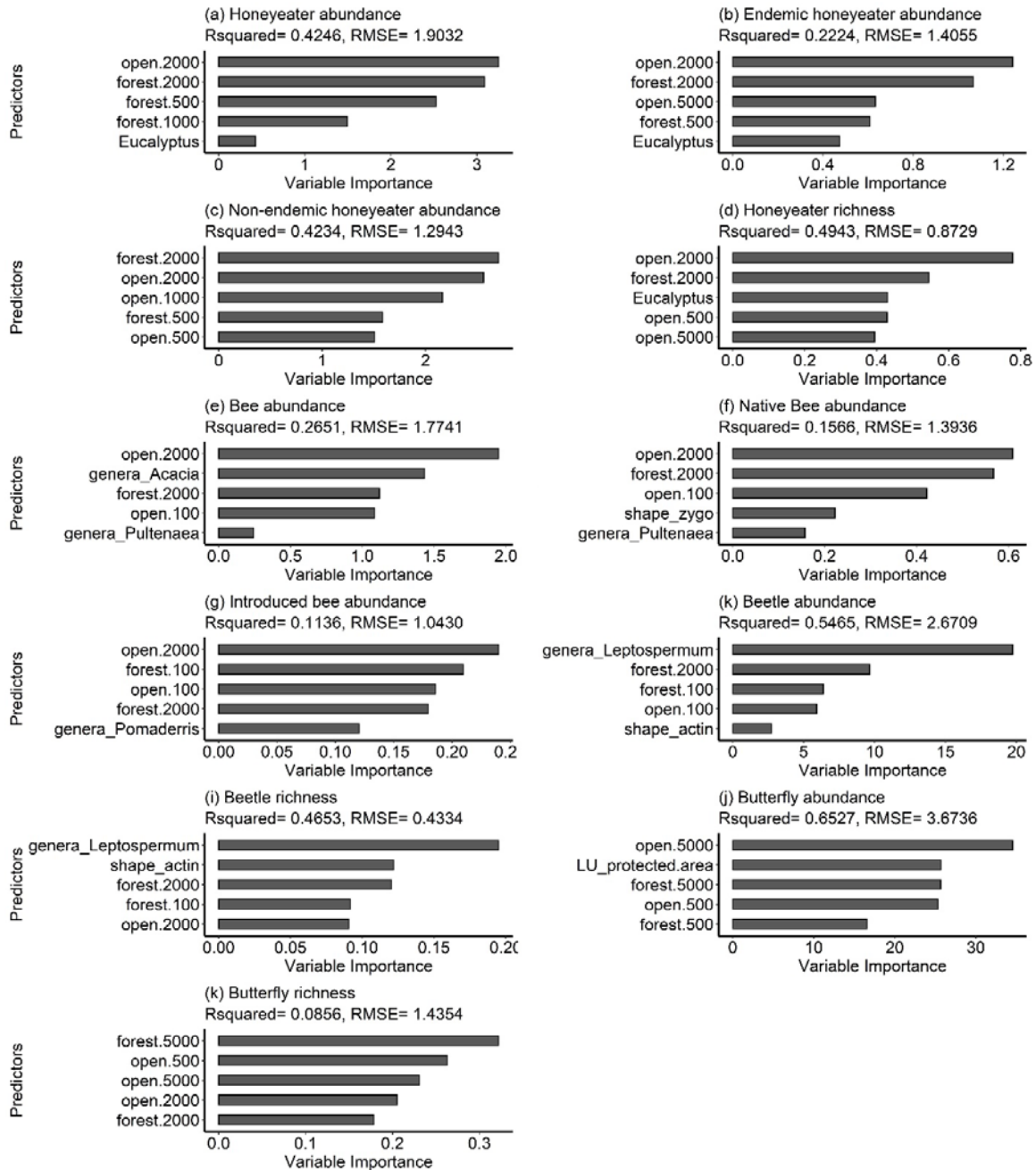
Fig. 6 Variable importance of the predictors along with goodness of fit R^2 and RMSE of the models. The predictors forest.n or open.n refers to forest or open cover within buffer of size n. Shape_actin and shape_zygo refers to actinomorphic and zygomorphic floral shapes.

Discussion

16

266   We assessed the richness and abundance of multiple pollinator groups across a mixed-use

267   landscape, combined with the influence of different floral resources and morphologies, and

268   found that pollinators were overall not affected by LU, whereas LC, plant genera, and floral

269   shape were all determinants. Forest cover was relevant to all pollinator groups while open

270   cover was important for bees, beetles, and butterflies, but not birds. Buffers of 2000 m and

271   below were important for all pollinators while 5000 m and below were important for

272   butterflies. The plant genera *Acacia*, *Pultenaea*, *Pomaderris* and *Leptospermum* were the

273   most important identified drivers of native bee and beetles, while *Eucalyptus* was a relevant

274   predictor for all honeyeater models except for non-endemic honeyeater abundance. In short,

275   land cover and the distribution of diverse floral resources are crucial determinants of the

276   health of pollinator communities.

277   Land use was generally a poor predictor even though pollinator abundance and richness

278   varied between and within the three LU types (Figs. 2, 3). We suspect the poor prediction is

279   because our study region does not include extremely modified land use types (e.g., pure

280   agriculture, or urban). Indeed, a meta-analysis by Winfree et al. (2009) found that habitat loss

281   and fragmentation severely impacted bees only in landscapes with little-to-no natural habitat

282   remaining. The variation in pollinator richness and abundance recorded between and within

283   the three LU types is thus likely to be predominantly driven by differences in forest cover and

284   availability of resources. For example, pastures with trees and high floral diversity have been

285   found to have higher abundance of nectivorous birds (Kavanagh et al. 2007) and beetles

286   (Harris and Burns 2000) than pastures that lack such resources. Human activities could also

287   influence pollinator presence. For example, the differences in endemic honeyeater abundance

288   between the two plantation sites could be at least partially associated with forestry activities

289   (e.g., harvesting) which have been shown to impact the diversity and abundance of endemic

290   birds including honeyeaters (MacDonald et al. 2005). Although LU was a good predictor of

17

291   butterfly abundance, the large differences between the protected sites points to an explanation

292   underpinned by habitat type, presence of host and nectar plants and micro-climatic

293   conditions, all of which are known to influence butterfly assemblages (see Curtis et al. 2015;

294   Eilers et al. 2013; Öckinger et al. 2012; Stefanescu et al. 2005).

295   Land Cover—specifically the presence of forest and open cover—were important predictors

296   for all the pollinator groups. We suspect forest and open cover types could contain a variety

297   of feeding and nesting resources essential for different pollinators (Kremen et al. 2007;

298   Öckinger et al. 2012). Moreover, the positive and negative impacts these cover types are

299   likely depend on the taxon; for example, open areas that lack floral resources—food and

300   shelter—are likely to have a negative impact on honeyeaters and beetles (Harris and Burns

301   2000; Kavanagh et al. 2007). Forest cover is known to influence birds presence in general

302   (Trzcinski et al. 1999) and honeyeaters specifically (Harrisson et al. 2014). Further, high

303   abundances of bees has been found in both forest (Taki et al. 2007, Ferreira et al. 2015) and

304   open areas (Winfree et al. 2007, Kaluza et al. 2016), and forest cover has been shown

305   elsewhere to be a good predictor of beetle assemblage (Sánchez-de-Jesús et al. 2016), with

306   high amount of forest cover associated with higher abundance and richness of beetles (Watts

307   and Larivière 2004). Although Posa and Sodhi (2006) found LC to have a weak correlation

308   with a butterfly assemblage, we hypothesise that this difference might be due to the higher

309   relative availability of resources in tropical (their study) versus temperate (our study) regions.

310   The buffers around forest and open land-cover types were important presumably because

311   these contain within them smaller patches of resources. Butterflies, being mobile organisms,

312   can use the resources from the surrounding landscape (Liivamägi et al. 2014) and we expect

313   the same for other flying insects like bees and beetles. The spatial distribution of resources

314   seems to drive buffer sizes, in general, as buffers for bees are known to vary (see Goulson et

315   al. 2010; Pisanty and Mandelik 2015; Taki et al. 2007). Forest cover within 2000 m, but not

18

316   5000 m, was most important for honeyeaters. This might be explained by their territorial

317   behaviour (Phillips et al. 2010), which allows them to monopolise patches of resources.

318   The presence of *Eucalyptus* was an important predictor for all honeyeater models except non-

319   endemics, and we suspect it to have a relatively negative effect compared to *Symphyomyrtus*

320   trees (Fig. 5). *Symphyomyrtus* trees are known to higher abundance of arthropods (Dunkerley

321   et al. 1990; Saunders and Burgin 2001) particularly in summer (when fieldwork was carried

322   out) which could explain why we observed a higher abundance and richness of honeyeaters

323   particularly endemics which included the more insectivorous Yellow-throated, Strong-billed,

324   and Black-headed honeyeaters (Thomas 1980).

325   *Acacia* and *Pultenaea* were relevant predictors for total bee abundance, *Pultenaea* and

326   *Pomaderris* for native and introduced bee abundance richness, respectively, and

327   *Leptospermum* for both beetle abundance and richness. All these relationships have plausible

328   biological underpinnings. *Acacia*, for example, produces copious pollen (Stone et al. 2003)

329   which is essential for larval provisions for almost all bees (Brosi et al. 2007), and *Pultenaea*

330   and *Pomaderris* contain nectar and pollen and have been found be pollinated by bees, beetles

331   and butterflies (Armstrong 1979; De Kok and West 2004; Ogilvie et al. 2009).

332   *Leptospermum*, in addition to providing nectar and pollen, is also a rich source of fruits and

333   grass-root material which beetles and their larvae feed upon (Andersen and New 1987;

334   Stephens et al. 2005).

335   Floral shape, but not colour, was also predictive, with zygomorphic and actinomorphic-

336   shaped plants relevant for native bees and beetles, respectively. The zygomorphic shape of

337   some flowers could be important for native bees as it includes native genera such as

338   *Pultenaea* and *Goodenia*. These taxa have been shown to exhibit bee-pollination syndrome

339   (i.e. flower features evolved in response to natural selection driven by bees) even though

340   pollinator syndromes have been found inadequate as an explanation for pollinator visitation

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341   in Tasmania (Hingston and Mc Quillan 2000). Actinomorphic shape could be important for

342   beetles as they find it easier to land on simple dish- and bowl-shaped blossoms (Armstrong

343   1979).

344   The goodness-of-fit statistics (R^2) of the models indicates that several other factors, not

345   measured in this study, might be required to improve the models. For honeyeater models, this

346   could include availability of other feeding resources such as mana (a type of resin),

347   honeydew and lerp (Paton 1980), and presence and abundance of other *Eucalyptus* species or

348   other genera, perhaps in distributed in complex communities (Phillips et al. 2010). For bee

349   models, this includes species-specific responses (Cariveau and Winfree 2015), ecological

350   traits such as flight seasons (De Palma et al. 2015) and nesting habitat (Kremen et al. 2007).

351   For beetle models, possible additional contributors are leaf litter, microclimate and soil

352   variables (Fountain-Jones et al. 2015). For butterfly models, host plants for larvae, nectar

353   plants for adults (Krämer et al. 2012), and micro-climatic conditions (Liivamägi et al. 2014),

354   and all plausible additional determinants, perhaps in a large suite of tapering effects.

355   Like most studies of the determinants of pollinator ecology, this research is limited by

356   considering LU and LC in their present conditions. Although a past-present comparison

357   would be more adequate to assess impacts of changes on pollinators this would require

358   baseline data on pollinators, which is lacking. The alternative—long-term monitoring—is a

359   resource intensive undertaking, making comparative space-for-time assessments a logical

360   substitute. One of the real-world constraints on this study was the frequent bad weather (wind

361   and rain, making sampling impossible on many days within the field season), and the choice

362   of a repeated sampling strategy (which yields higher precision within sites, at the cost of

363   spatial bias). Future studies could consider including a mix of human observations and

364   mechanised/automated methods such as acoustic recorders for birds (Wimmer et al. 2013)

365   and photographic recording of bees (Steen 2017). The visual sampling of bees and beetles

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366   allowed us to assess which plants they visited, but limited the taxonomic identification of

367   insects, and small samples sizes of rarer taxa, made the testing of species-specific responses

368   to the predictor variables infeasible.

369   A major advantage of the approach taken in this study, involving machine learning and

370   predictive modelling, is in its ability to subject available data to robust assessment and use it

371   to make informed decisions (Thessen 2016, Willcock et al. 2018). For example, what if a

372   land manager of a plantation or pasture wanted to clear forested areas to improve

373   production/yield, but still wanted to sustain a community of pollinators? Our results suggest

374   that the optimal approach would be to create a mosaic of LC in the surrounding landscape,

375   maintaining forest cover within a large spatial scale of 2000 m. The next best—or

376   complementary—option to sustain a community of pollinators would be to plant floral

377   resources with a brushed-shaped genus such as *Acacia*, the zygomorphic-shaped *Pultenaea*,

378   or the actinomorphic-shaped *Pomaderris* and *Leptospermum*, so as to sustain a richness and

379   abundance of bees and beetles which fall within a known a framework of choosing plants that

380   provide nectar and/or pollen resources for a long temporal span (Menz et al. 2011), with a

381   focus on native plants (M'Gonigle et al. 2015). Using trees consisting of a mix of the

382   *Symphyomyrtus* and *Eucalyptus* subgenera would promote honeyeaters. Applied

383   recommendations like this are based on evidence-based predictive results, which is valuable

384   for pollinator-management decisions. Further, the implementation of our recommendations

385   could then be used to validate our study's predictions, to improve future predictions in an

386   adaptive-management framework.

387   **Declarations**

388   *Funding*

390   *Conflicts of Interest*

391   None.

392   *Ethics approval*

393   Fieldwork was carried out in accordance with the ethics outlined by the Animal Ethics

394   Committee, University of Tasmania under Project No: A0016856 and Department of Primary

395   Industries, Parks, Water and Environment (DPIPWE) Tasmania, for fieldwork permits in

396   protected areas, under Authority No's. FA17315 and FA18185.

397   *Consent to participate*

398   Not applicable.

399   *Consent for publication*

400   All the authors have reviewed the manuscript and provided consent for publication.

401   *Availability of data and material*

402   Included in the supplementary material.

403   *Code availability*

404   Not included but available on request.

405   *Author Contributions*

406   VLD proposed and designed the study, carried out the fieldwork, analysed the data and wrote

407   the manuscript. BWB contributed significantly to the study design and writing of the

408   manuscript. MH contributed to the study design and writing of the manuscript. SO

409   contributed significantly to study design and writing of the manuscript.

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