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Environmental factors affecting the abundance of the threatened shrub *Tasmannia glaucifolia* (Winteraceae) in Barrington Tops National Park

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Abstract: *Tasmannia glaucifolia* (family Winteraceae) (Fragrant Pepperbush) is a rare and threatened shrub endemic to the Northern Tablelands of New South Wales. Reported to be a riparian species, this is the first study to examine the habitat, population structure, health, and potential environmental pressures relating to the Barrington Tops population, and will provide baseline data to increase our understanding of the species.

At four study locations in Barrington Tops National Park (one of the three known NSW populations), Polblue swamp, Beean Beean swamp, Edwards swamp and Upper Edwards swamp, 36 quadrats were surveyed across three different habitat types (riparian swamp, riparian woodland, and woodland). Counts, size and health of *Tasmannia glaucifolia* individuals were recorded, as well as selected environmental and disturbance variables. A total of 491 *Tasmannia glaucifolia* plants were recorded, lignotuber-style organs on mature individuals noted, and limited seed regeneration confirmed.

General linear mixed models (GLMM) showed greatest support for the abundance of *Tasmannia glaucifolia* depending on habitat type and aspect, and varying with swamp location. The highest numbers of *Tasmannia glaucifolia* were recorded in riparian woodland habitat (73%) followed by woodland habitat (26%); few individuals were recorded in riparian swamp habitat. An exploratory analysis leads us to hypothesise that aspect has an influence on *Tasmannia glaucifolia* abundance, with higher counts in this study tending towards southerly aspects. A purple discolouration observed on *Tasmannia glaucifolia* foliage appears to be more severe in northerly or westerly aspect sites.

Moderate support was shown for the GLMM model where *Tasmannia glaucifolia* abundance depended on habitat type and the cover of exotic Scotch Broom (*Cytisus scoparius*), with weaker support for *Tasmannia glaucifolia* abundance depending on habitat type and an indicator of feral horse activity. Scotch Broom and indicators of feral horse activity frequently occurred in the *Tasmannia glaucifolia* habitats investigated here. Management actions involving feral horse exclusion experiments and removal of Scotch Broom and monitoring over time is needed to evaluate impacts and refine the conservation strategies for this listed Vulnerable species.

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Introduction

Tasmannia glaucifolia J.B.Williams, family Winteraceae, commonly known as Fragrant Pepperbush, is a rare shrub, endemic to the Northern Tablelands of New South Wales (NPWS 2010; Sampson *et al.* 1988). Its three known populations are confined to altitudes of 1250m – 1530m, with population counts ranging from 100 to 300 plants (Sampson *et al.* 1988). It is currently listed as Vulnerable under the Commonwealth *Environmental Protection of Biodiversity and Conservation Act (1999)* and the *NSW Biodiversity Conservation Act (2016)* due to restricted population numbers and a localised and specific geographic range.

Our understanding of the environmental thresholds influencing *Tasmannia glaucifolia* distribution and population health, as well as the environmental pressures that the species faces is limited by a lack of research. Sampson *et al.* (1988), focusing on its taxonomic distinction described populations across NSW as occurring in cool-temperate rainforest communities and fringing scrub communities near defined streamlines, with occasional patches located up to 100 m away from watercourses. Floristic surveys in Barrington Tops found it occurred across four different vegetation communities, sub-alpine swamp and three *Eucalyptus* spp.-dominated communities (Zoete 2000). *Tasmannia glaucifolia* herbarium records for Barrington Tops describe associated habitats as sub-alpine grasslands, *Eucalyptus* spp.-dominated woodlands, swamp edges and areas containing shrubby or rocky creeklines (Atlas of Living Australia n.d.). The species phytomorphology is described as a spreading shrub with root-suckering attributes; observations of isolated seedlings indicated seed recruitment (Sampson *et al.* 1988). However, lack of quantitative studies of the distribution extent, growth patterns, and responses to environmental disturbances has hindered the ability to prepare an effective conservation management plan (NPWS 2010; Keith 2000; Sampson *et al*. 1988).

Assessing the status of a threatened species requires baseline information on the species population count and geographic range (IUCN 2001; Keith 2000), and the likely degree of impact of potential threats. The aim of this study was to survey populations of *Tasmannia glaucifolia* within the Barrington Tops National Park to provide baseline data on its distribution and health. This project collected population structure data and quantified the characteristics of its habitat for this part of its geographic range. Additionally, the potential impacts of competition by the invasive exotic shrub Scotch Broom (*Cytisus scoparius*) and disturbance caused by feral horses (*Equus caballus*), both significant threats identified in Barrington Tops National Park, were explored (NPWS 2010; Sampson *et al*. 1988).

Based on the available literature and preliminary site observations, it was hypothesised that the abundance of *Tasmannia glaucifolia* would be highest in riparian areas bordering streamlines adjacent to woodland communities. Two other habitat types were included for comparison, riparian areas of streamlines within swamp vegetation communities, and sites within woodland communities located at least 100 m away from streamlines. It was also hypothesised that sites exposed to high disturbance impacts from feral horses and sites with a high cover of Scotch Broom would contain a lower abundance of *Tasmannia glaucifolia*.

Methods

Study location

Barrington Tops National Park (74,567 ha as of 2010) is located approximately 100km north-west of Newcastle (NPWS 2010; Zoete 2000). The region contains a variety of significant environmental, cultural and economic values including: classification within the Gondwana Rainforests of Australia World Heritage listing; Aboriginal sites and declared Aboriginal places; extensive wilderness and sub-alpine regions; and recreational activities drawing an abundance of local and international tourists (NPWS 2010).

The study took place on the Barrington Tops Plateau at altitudes around 1500m above sea level. Temperatures and rainfall vary across the study location due to altitudinal and topographical variation (Nanson 2005; Zoete 2000; Story *et al.* 1963). At higher altitudes average temperatures range from 9°C to 23°C in January and -2°C to 9°C in July, and the area receives an average annual rainfall of 1524mm – 2000mm with snowfall events and frost known to occur in cold seasons (Zoete 2000; CMPS & F Environmental 1995; Story *et al.* 1963). Rugged, steep slopes form around the plateau, with soil formations ranging from acidic, stony, nutrient-poor compositions to friable, organic, strongly pedal compositions (Nanson 2005; Zoete 2000; Story *et al*. 1963). A diverse range of vegetation communities have developed in response to the varying conditions, including eucalypt subalpine woodlands, *Poa* spp.-dominated grasslands, *Nothofagus moorei* rainforests, *Montane Peatland and Swamps,* and *Sphagnum* moss hummocks (Nanson 2005; Zoete 2000; Story *et al*. 1963).

Sampling design

Study locations were chosen in proximity to the four swamp regions Polblue, Beean Beean, Edwards and Upper Edwards (Figure 1). Sampling sites were selected using stratified random sampling techniques. Concurrent threatened species survey data indicating the area of occupancy for *Tasmannia glaucifolia* was overlaid with aerial images of the swamp locations. At each of these four study locations, three study sites were randomly selected containing streamlines that intersected the swamp and bordered woodland vegetation. The three habitat types surveyed at each study site were riparian swamp (distance along a streamline in swamp community areas), riparian woodland (distance along a streamline where the stream abuts woodland habitat), and woodland (an area at least 100 metres away from a streamline that contained woodland-associated communities). A random number generator was used to determine the centre point of the quadrat to ensure unbiased sampling. For both riparian swamp and riparian woodland habitat a 10m x 40m quadrat was established, and for woodland habitat a 20m x 20m quadrat was used.

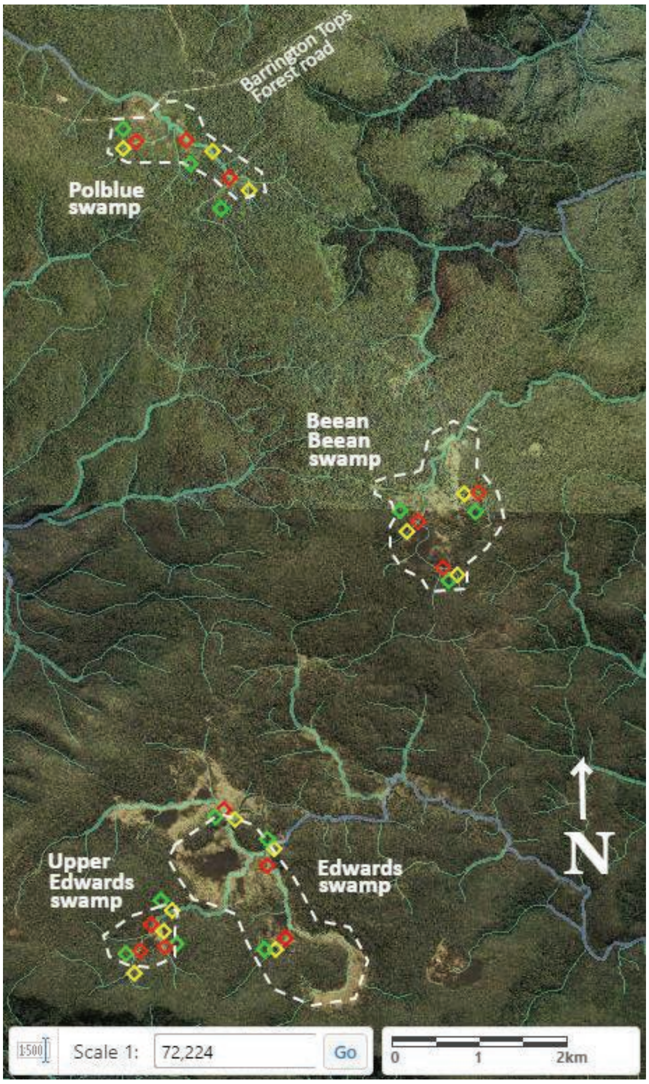

Figure 1. Map outlining the four study locations Polblue swamp, Beean Beean swamp, Edwards swamp and Upper Edwards swamp. Points indicate quadrat locations, coloured to reflect habitat type (red = riparian swamp; yellow = riparian woodland; green = woodland). Image source: DPIE Sharing and Enabling Environmental Data (SEED) – *DFSI - Spatial Services NSW Hydrography* (2022).

Tasmannia glaucifolia parameters

The number of individual plants were counted within each quadrat (parent plant defined by a 'clump' of stems originating from a central point) while isolated stems within one metre of a 'clump' were recorded as an additional stem count to the parent plant. Population structure data for *Tasmannia glaucifolia* included measuring the height of the tallest stem, the diameter of the largest stem at 10cm above ground level, and total stem count for the individual.

Depending on availability, 1 - 8 *Tasmannia glaucifolia* individuals were objectively selected (i.e. up to four plants located closest to each corner of the quadrat and four plants closest to the centre point) to assess foliage health. Average values were then calculated for each quadrat. Foliage assessments were recorded with reference to the Crown Damage Index criteria published by Stone *et al.* (2003). The incidence (the percentage of an indicator on the entire plant) and severity (the average percentage of an indicator per leaf) of three damage indicators (defoliation, necrosis, and discolouration) was assessed for each plant. Defoliation referred to whole or partial leaf missing (e.g. eaten), necrosis referred to dead leaf tissue, and discolouration was defined as any non-normal colouring of the leaf (Stone *et al.* 2003).

Environmental parameters

A range of environmental variables were measured in all quadrats. At the centre point of each quadrat, the slope (°), aspect, and elevation (m) were recorded. Canopy cover (%) using a spherical densiometer was recorded at each corner of the quadrat and averaged. Four subquadrats (1m x 1m) were placed in each corner of the quadrat to assess ground cover (% of bare ground, vegetated cover, water, or rock) and averaged to give total cover percentage. Soil drainage potential was visually assessed as Waterlogged (1), Poor (2), Intermediate (3), Good (4) or Excessive (5) following criteria published by Minchin (1989). Dominant species, defined as species that had high abundance relative to other species (Avolio *et al.* 2019), in each stratum layer (trees, shrubs, ground cover) were recorded in each quadrat to explore species associated with presence of *Tasmannia glaucifolia.*

Disturbance parameters

Four disturbance indicators were adapted from previous literature to measure feral horse activity (Cherubin *et al.* 2019; Robertson *et al.* 2015). Pugging, grazing, animal paths, and impact of animal paths were recorded in each quadrat and categorised from 1 (no impact) to 4 (severe impact). A Combined Horse Indicator Score (CHIS) was calculated by combining the four feral horse indicators as adapted from Cherubin *et al.* (2019). The CHIS score indicated low horse activity (4 - 8), moderate horse activity (9 - 10) and high horse activity (11 - 16). The percentage of total Scotch Broom cover (%) was assessed in each quarter of the quadrat then averaged. To reduce observer error, two observers assessed Scotch Broom cover.

Statistical analysis

Generalised linear mixed models (GLMM) were used to investigate whether *Tasmannia glaucifolia* counts depended on habitat type and varied with location using the R package 'glmmTMB' (Brooks *et al*. 2017). Models including the cover of Scotch Broom and the Combined Horse Indicator Score (CHIS) as explanatory variables were also tested. Scatterplot matrices showed that many of the environmental variables (e.g. bare ground, canopy cover, slope, drainage etc.) were correlated with habitat type, and therefore habitat type and these collinear variables were not included in candidate models at the same time. The exception was untransformed aspect, which was the only variable not showing collinearity with other variables (including habitat type) and also showed a potential relationship with *Tasmannia glaucifolia* count data. To avoid the problem of circular data, aspect was transformed according to Beers *et al.* (1966) with A_{max} set at 180° so that southerly aspects would be coded as higher values. As quadrats were nested within the four swamp locations, location was included as a random effect and the remaining explanatory variables (habitat, CHIS, Scotch Broom) as fixed effects (Brooks *et al.* 2017). Models were initially fitted assuming a Poisson error structure, but where over-dispersed the models were re-fitted using a negative binomial error structure (Zuur *et al.* 2009). Although zero *Tasmannia glaucifolia* counts were common, zero-inflation models did little to improve the Poisson or negative binomial models. Information-theoretic methods were used to estimate the relative difference in the expected predictive power of models (Burnham & Anderson 2004; Bolker *et al*. 2009) using the R package 'bbmle'. Akaike's Information Criterion (AIC) was calculated with the small-sample bias adjustment AIC_c and the magnitude of difference between models was assessed using the rules of thumb described in Burnham & Anderson (2004). Analysis excluding one outlier (Site 26 - *Tasmannia glaucifolia* count n = 118) had minor effects on ΔAIC_c and model rankings, and is not presented here.

An exploratory GLMM analysis, assuming a gaussian error structure, was also conducted to generate hypotheses about the relationship between environmental variables and foliage health indicators. To reduce the number of models examined, collinearity amongst explanatory variables and potential relationships with foliage health was first examined using bivariate scatterplots. Observed potential relationships between leaf discolouration and environmental variables were further analysed using GLMM. For the reasons described above, no candidate models included both habitat type and environmental variables (except aspect), and rules of thumb were used to interpret ΔAIC_c. All GLMM analyses were conducted using R version 4.0.2.

Kolmogorov Smirnov Two-Sample Test (using JMP Pro 14.2.0) was applied to population structure parameters to compare distribution shapes between habitat type. Size classes for the population structure were constructed based on available literature describing the species phytomorphology. Dominant species were analysed in PRIMER v7 to determine dominant species occurrence with the absence or presence of *Tasmannia glaucifolia*. Non-metric Multi-Dimensional Scaling (nMDS) ordinations were used with Bray-Curtis similarities to visualise sites with similar dominant species composition (points that are close together), and sites that held different vegetation compositions (points that are further apart) (Clarke & Gorley 2001). One-way SIMPER analysis with Bray-Curtis similarity index determined which dominant species occurred in sites with presence of *Tasmannia glaucifolia*.

Results

Tasmannia glaucifolia abundance

Of the 36 quadrats surveyed, a total of 491 *Tasmannia glaucifolia* individuals were recorded across 20 quadrats. Of the seven models tested, the most supported model confirmed that *Tasmannia glaucifolia* abundance depends on habitat (i.e. riparian swamp, riparian woodland and woodland) and aspect, and varies with swamp location (Table 1). The model with the additional co-variate of Scotch Broom cover received moderate support with $\Delta AIC_c = 2.9$ and the following three models (i.e. including habitat alone or in combination with CHIS or Scotch Broom) were less supported but not completely uninformative with $\Delta AIC_c < 10$. The final two models had essentially no support (Table 1).

Table 1. General linear mixed models with negative binomial distribution examining the relationship between hypothesised co-variates and *Tasmannia glaucifolia* count data. Models ranked by lowest AICc value. CHIS = Combined Horse Impact Score; Scotch Broom = *Cytisus scoparius*.

Candidate Models	AIC_c	ΔAIC_c
Tasmannia glaucifolia = (Habitat, Aspect) Location	194.9	0.0
Tasmannia glaucifolia = (Habitat, Scotch Broom, Aspect) Location	197.8	2.9
Tasmannia glaucifolia = (Habitat) Location	201.0	6.1
Tasmannia glaucifolia = (Habitat, CHIS) Location	202.9	8.0
Tasmannia glaucifolia = (Habitat, Scotch Broom) Location	203.2	8.3
Tasmannia glaucifolia = (Habitat, Scotch Broom, CHIS) Location	205.3	10.4
Tasmannia glaucifolia = Location	222.1	27.1

The abundance of *Tasmannia glaucifolia* varied across swamp locations; Edwards swamp contained 36% of overall count data (n = 176), followed by 34% in Beean Beean (n = 165) and 28% in Upper Edwards (n = 139). Polblue had the lowest count contributing only 2% (n = 11) of overall recordings (Figure 2). Patterns of *Tasmannia glaucifolia* abundance depended on habitat type (Table 1; Figure 3). Riparian woodland contained 73% of the overall count data (360 individuals) and woodland habitat contained 26% (130 individuals); *Tasmannia glaucifolia* was generally not found in riparian swamp areas with only one individual recorded (Figure 3). Models for *Tasmannia glaucifolia* abundance that included aspect had substantial or moderate support (Table 1) and more than half *Tasmannia glaucifolia* individuals recorded in this study were found in sites with a South-East aspect (255 individuals) (Figure 4). Of the 30 sites where aspect could be recorded (riparian swamp habitat generally had no aspect due to lack of topographical gradient), 15 sites had a predominantly southerly (S, SE, SW) facing aspect containing 72% of all *Tasmannia glaucifolia* count data (353 individuals), whilst sites with a northerly facing aspect (N, NE, NW) accounted for 10 sites and contained 25% of all *Tasmannia glaucifolia* counts (123 individuals).

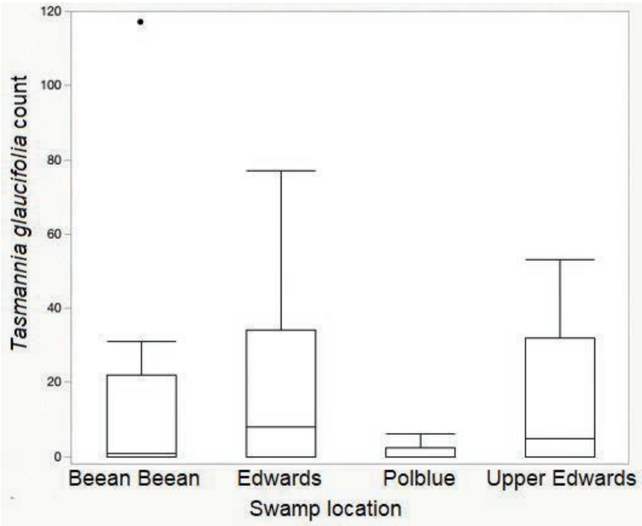

Figure 2. Total *Tasmannia glaucifolia* counts at each site (n = 36) across four swamps (Upper Edwards, Edwards, Beean Beean, and Polblue). Boxplots represent maximum, Q3, median, Q1 and minimum values. Dots represent outliers.

Figure 3. Total *Tasmannia glaucifolia* count recordings at each site (n = 36) across each habitat type (riparian swamp, riparian woodland, woodland). Boxplots represent maximum, Q3, median, Q1 and minimum values. Dots represent outliers.

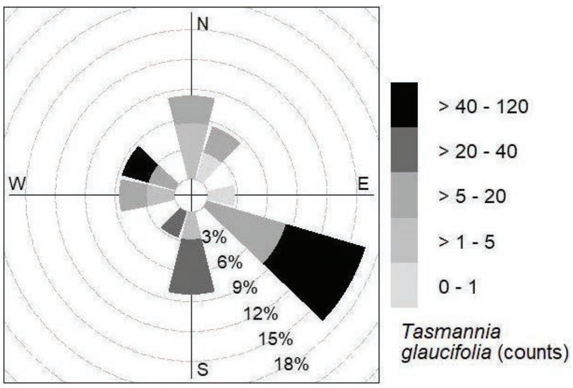

Figure 4. Windrose diagram showing the relative frequency (%) of *Tasmannia glaucifolia* abundance in sites with a particular aspect. Diagram generated using the openair R package (Carslaw & Ropkins 2012).

Tasmannia glaucifolia parameters

Population structure data was compared across riparian woodland and woodland habitat types; riparian swamp habitat type was excluded due to insufficient *Tasmannia glaucifolia* records (n = 1). Overall, population structure differed significantly between habitat type when applying the Kolmogorov Smirnov Two-Sample Test for height ($p < 0.0001$), diameter ($p < 0.001$) and stem count ($p = 0.0041$) data. Diameter measurements of the largest stem ranged from 0.1cm to 26.8cm, with average diameter in riparian woodland measuring 2.9cm compared to 3.4cm in woodland habitats. Riparian woodland patterns showed a reverse j-curve with the majority of records falling in the <1.9cm category (Figure 5). In contrast, a lower proportion of individuals in woodland had small stem diameter. Similar patterns, by habitat type, were evident for height measurements (data not shown). Height measurements of the largest stem ranged from 13cm – 402cm. Riparian woodland had an average height of 131cm with a peak in the 100cm-199cm size class, and a decline in numbers over 200cm. In contrast, individuals in woodland habitat averaged 171cm, and had an interrupted pattern with most records in the 200cm-299cm size class. Stem counts per parent plant ranged from 1 to 87, with larger *Tasmannia glaucifolia* found to have many stems emerging from a main point. Stem count in riparian woodland averaged 11 stems while individuals in woodland habitat averaged 15 stems. Both habitat types displayed reverse j-curves with highest frequencies in the 1-6 stem count class (data not shown).

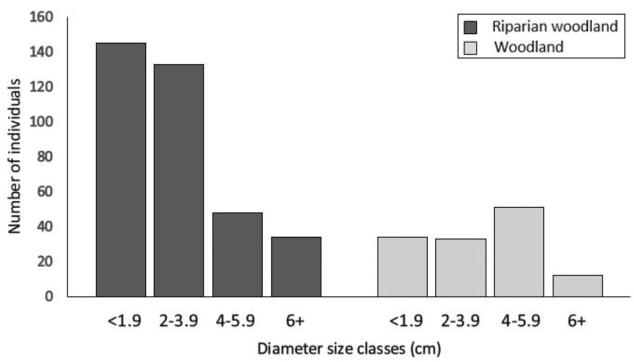

Figure 5. Population structure of *Tasmannia glaucifolia* based on diameter (cm) size classes for riparian woodland and woodland habitats. Diameter measurements were based on the largest stem of the individual measured 10cm above ground level.

The foliage health of 20 *Tasmannia glaucifolia* individuals was assessed, with 85% of the quadrats having had > 4 plants assessed (Figure 6). On average, the incidence of defoliation occurred across approximately one third of *Tasmannia glaucifolia* plants; however, it was observed that this was predominantly from insect attack and thus resulted in low severity per leaf. There was no observations indicative of herbivory from feral horses on the species. Necrosis incidence was less commonly observed on foliage but generally scored a much higher severity per leaf. On average, the incidence for discolouration occurred across 37% of *Tasmannia glaucifolia* plants with a severity of 35% per leaf; leaves usually showed a purple discolouration and less commonly the presence of an unknown black lichen-like biofilm (Figure 6).

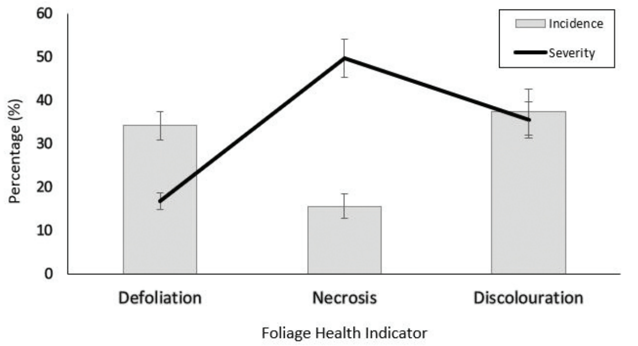

Figure 6. Mean incidence (percentage of individual plant) and severity (percentage of impact per leaf) for foliage health indicators (defoliation, necrosis and discolouration). Bars represent ± 1 standard error of the mean.

The GLMM with gaussian distribution showed that for *severity* of leaf discolouration for those *Tasmannia glaucifolia* individuals sampled, the first two models (i.e. including slope and aspect, or aspect alone, nested in location) had substantial support (Table 2). The remaining six models in Table 2 (i.e. with additional co-variates of canopy cover, percentage cover of Scotch Broom, drainage, and habitat type), were less supported but not completely uninformative with $2 < \Delta AIC_c < 10$. The first three models (aspect with and without slope or canopy cover, nested in location) for the *incidence* of leaf discolouration had substantial support with $\Delta AIC_c < 2$ (Table 3). The remaining six models in Table 3 (i.e. with additional co-variates of Scotch Broom, drainage or habitat type) had moderate to considerably less support with $3 < \Delta AIC_c < 6$.

Table 2. Exploratory generalised linear mixed models with gaussian distribution examining the influence of potential explanatory co-variates on the *severity* of leaf discolouration of *Tasmannia glaucifolia* individuals. Models are ranked by lowest AIC_c value. Scotch Broom = *Cytisus scoparius.**

Candidate Models	AIC_c	ΔAIC_c
Discolouration Severity = (Slope, Aspect) Location	174.5	0.0
Discolouration Severity = (Aspect) Location	176.5	2.0
Discolouration Severity = Location	179.2	4.7
Discolouration Severity = (Canopy cover, Aspect) Location	179.3	4.8
Discolouration Severity = (Scotch Broom, Aspect) Location	179.9	5.4
Discolouration Severity = (Canopy cover) Location	181.7	7.2
Discolouration Severity = (Drainage) Location	182.3	7.8
Discolouration Severity = (Habitat, Aspect) Location	182.5	8.0

Table 3. Exploratory generalised linear mixed models with gaussian distribution examining the influence of potential explanatory co-variates on the *incidence* of leaf discolouration of *Tasmannia glaucifolia* individuals. Models ranked by lowest AICc value. Scotch Broom = *Cytisus scoparius.**

Candidate Models	AIC_c	ΔAIC_c
Discolouration Incidence = (Aspect) Location	189.0	0.0
Discolouration Incidence = (Slope, Aspect) Location	189.6	0.6
Discolouration Incidence = (Canopy cover, Aspect) Location	190.7	1.7
Discolouration Incidence = Location	192.5	3.5
Discolouration Incidence = (Scotch Broom, Aspect) Location	192.6	3.6
Discolouration Incidence = (Habitat) Location	193.3	4.2
Discolouration Incidence = (Slope) Location	193.5	4.4
Discolouration Incidence = (Canopy cover) Location	194.2	5.2
Discolouration Incidence = (Drainage) Location	194.4	5.3

Dominant Species

The Non-metric Multi-Dimensional Scaling (nMDS) indicated that dominant species recorded in riparian swamp sites were similar in composition, forming a distinct cluster separate from riparian woodland and woodland sites (Figure 7). Indistinct clusters were formed for riparian woodland and woodland sites, with overlapping points indicating a greater similarity in dominant species composition between the two habitat types.

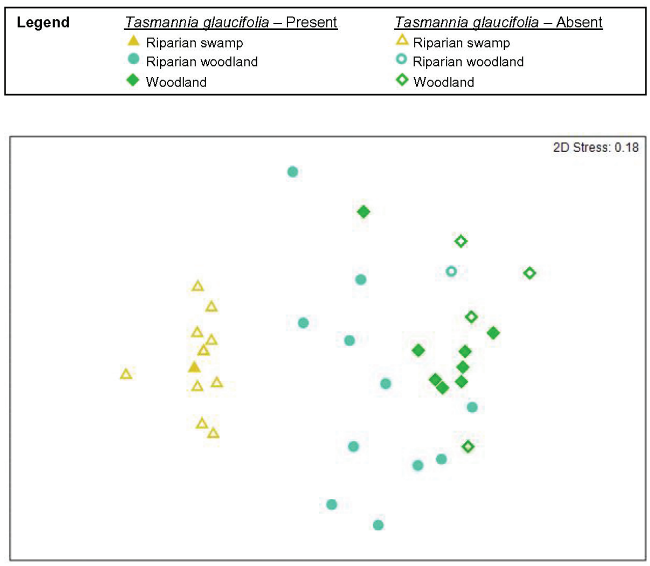

Figure 7. nMDS ordination of dominant species produced with Bray-Curtis similarities (2D stress value: 0.18). Sites are colour coded to habitat types: riparian woodland (yellow triangle), riparian woodland (aqua circle) and woodland (green diamond). Closed points indicate *Tasmannia glaucifolia* was present and hollow points indicate *Tasmannia glaucifolia* was absent.

One-way SIMPER analysis with Bray-Curtis similarities revealed four dominant species that made a cumulative 70% contribution to floristic similarity among both *Tasmannia* *glaucifolia* -present sites and *Tasmannia glaucifolia* -absent sites. At sites with *Tasmannia glaucifolia* present, the most frequent dominant species adding to the contribution level were *Poa sieberiana* (34%), *Eucalyptus pauciflora* (18%), *Eucalyptus stellulata* (15%), and the exotic shrub *Cytisus scoparius** (Scotch Broom) (12%). Both *Eucalyptus* species were common canopy species recorded in riparian woodland and woodland sites. Likewise, Scotch Broom was commonly found to occur in these habitat types and was generally absent in riparian swamp habitat. These species were also recorded in Zoete's (2000) vegetation communities that also contain *Tasmannia glaucifolia*: Community 9 (*Eucalyptus fastigata-Eucalyptus obliqua-Eucalyptus dalrympleana-Eucalyptus laevopinea-Eucalyptus pauciflora* open forest over *Poa sieberiana* grassland); Community 10 (*Eucalyptus stellulata* open forest over *Cytisus scoparius var. scoparius* shrubland over *Poa sieberian*a grassland); Community 11 (*Eucalyptus pauciflora* open forest over *Tasmannia purpurascens* shrubland over mixed herbland); and Community 12 (Sedgeland). In sites where *Tasmannia glaucifolia* was absent, the most frequent dominant species were *Poa sieberiana* (32%), *Baloskion stenocoleum* (22%), *Empodisma minus* (12%), and *Carex appressa* (11%). These graminoid species are strongly associated with swamp communities and were abundant in the majority of riparian swamp sites in this study. The highest contributing dominant species for both *Tasmannia glaucifolia* -present and -absent sites was *Poa sieberiana*, a common grass species that was recorded across almost all (92%) quadrats regardless of habitat type.

Discussion

This study found that *Tasmannia glaucifolia* abundance depends on habitat type (i.e. riparian swamp, riparian woodland and woodland) and aspect of sites, and varies across swamp location. When compared across habitat types, *Tasmannia glaucifolia* favours areas adjacent to streamlines where woodland vegetation communities dominate the riparian area supporting descriptions by Sampson *et al.* (1988). Observations by Sampson *et al.* (1988) of *Tasmannia glaucifolia* patches located away from defined streamlines was also supported with counts recorded in woodland quadrats up to 100m away from streams. Low counts of *Tasmannia glaucifolia* in riparian swamps however suggest unfavourable environmental factors, affecting its ability to establish and/or survive in any great number.

Tasmannia glaucifolia count data was strongly skewed towards southerly aspects, compared to northerly aspects. Southerly facing sites are well-documented to remain cooler and retain higher levels of moisture in comparison to northerly aspect sites, which are associated with lengthy periods of sunlight, reduced soil moisture and rainfall, and vulnerability to frost occurrence (Close *et al.* 2002; Kirkpatrick & Bridle 1999; Pook & Moore 1966). Aspect may influence environmental conditions that determine floristic composition as a result of species physiological requirements and tolerances (Kirkpatrick & Bridle 1999; Pook & Moore 1966). For example, Pook & Moore (1966) reported aspect as a primary environmental variable in determining the distribution and growth of *Eucalyptus macrorhyncha* and *Eucalyptus rossii*. Both species occur within the same geographic range, but *Eucalyptus macrorhyncha* was more frequent in southerly facing sites whilst *Eucalyptus rossii* exhibited greater frequencies in northerly facing sites.

Consistent with a physiological tolerance hypothesis, that the cooler, and potentially moister, southerly facing sites are favoured by *Tasmannia glaucifolia,* we found a purple leaf discolouration (Figure 8) was more severe on *Tasmannia glaucifolia* exposed to northerly or westerly aspects. Leaf pigments including anthocyanins, chlorophylls and carotenoids and their respective concentrations are responsible for the colouration of foliage (Landi *et al*. 2015; Stone *et al.* 2001). Red to purple leaf colour indicates increased concentration of anthocyanin pigments (Stone *et al.* 2001) which provide protective functions such as photoprotective qualities, metal-chelation and inhibition of leaf senescence associated with nutrient deficiency (Landi *et al*. 2015).

Figure 8. Purple discolouration evident on Tasmannia glaucifolia foliage.

Cold-induced photoinhibition refers to a chemical reduction in photosynthesis in plants subject to prolonged exposure of excessive light levels, particularly during cold weather (Close *et al.* 2002; Holly *et al.* 1994; Ball *et al.* 1991). Where the plant cannot use or waste the absorbed light energy, a red to purple discolouration caused by anthocyanins is commonly exhibited on foliage as a photoprotective function to protect leaves from molecular injury (Landi *et al*. 2015; Close *et al.* 2002). It has been widely reported that anthocyanins are upregulated in response to cold-induced photoinhibition (Landi *et al*. 2015; Stone *et al.* 2001).

In order to remain productive, species susceptible to cold-induced photoinhibition require protection from both excessive sun exposure during cold months as well as protection from frost (Close *et al.* 2002; Holly *et al.* 1994; Ball *et al.* 1991). During winter months *Eucalyptus* *pauciflora* (snow gum) seedlings in areas with high exposure radiation exhibited increased cold-induced photoinhibition and reduced productivity (Ball *et al.* 1991); the highest abundance of seedlings correlated with areas that provided protection to radiation exposure e.g. located on the southern aspect of mature trees (Ball *et al.* 1991). *Tasmannia glaucifolia* co-occurs with *Eucalyptus pauciflora* in the current study, so there may be potential in applying Ball *et al.'s* research approach to *Tasmannia glaucifolia*, though further testing the influence of aspect on *Tasmannia glaucifolia* is needed before effects on abundance, productivity and foliage discolouration can be accepted.

In the current study, the shape of the size frequency distributions of *Tasmannia glaucifolia* in riparian woodland was significantly different to that in woodland habitat suggesting that the drivers of the size distributions in the two habitats may differ in some way. In the riparian woodland habitat *Tasmannia glaucifolia* had a reverse j-shaped size distribution (interpreted for a fire-sensitive species by Woolfrey & Ladd (2001) as indicative of "continual recruitment or at least relatively short periods of episodic recruitment"). However *Tasmannia glaucifolia* is a known resprouter, confirmed in this study with stem counts ranging from 1-87, and evidence of lignotuber-style storage organs protruding from the soil on larger *Tasmannia glaucifolia* individuals (Figure 9). Seed recruitment was also confirmed; a *Tasmannia glaucifolia* juvenile found growing in the fork of a tree (approximately 2 metres DBH) suggesting seed dispersal via fauna species (Figure 10). The wildfire and prescribed burn history of the locations used was not conducive to an appropriately designed fire impact investigation; however the observations described above are relevant to future fire studies and we agree with Souza (2007) that monitoring species-specific reference distribution shapes is of some value but no substitute for directly monitoring the recruitment and mortality rates of a species.

Figure 9. Photo of a *Tasmannia glaucifolia* lignotuber protruding from the soil.

Figure 10. Juvenile *Tasmannia glaucifolia* growing in the fork of a tree.

Lower counts of *Tasmannia glaucifolia* were recorded in Polblue swamp compared to other swamp locations. Differences in the swamp morphology and channel form also exist in Polblue, with channels exhibiting an unusually constant width, low width-depth ratios, and bedforms that lack steepness, likely due to the moderate velocities received in streams (Nanson 2005). This is contrasted with channel forms in Barrington River and Edwards swamp that receive higher velocity flows and contain large bedforms. Further investigation into stream characteristics and dynamics may indicate relationships with the abundance of *Tasmannia glaucifolia.*

However Polblue has a landuse history of grazing and agricultural practices resulting in extensive modifications to the area (NPWS 2010; Nanson 2005). Although agricultural practices have now ceased, the highly visited Polblue Camp Area and adjacent walking track around the swamp margin have had increased soil damage and compaction, erosion, and damage to vegetation (NPWS 2010). Compared to the other locations examined in the current study, Polblue had the second highest median feral horse activity score.

The feral horse population in Australia is upwards of 400 000, with an estimated population of 100-200 residing in Barrington Tops National Park (Hunter pers. comm. 2019; Dawson *et al.* 2006). Impacts on native riparian and wetland ecosystems resulting from feral horse activity have been well reported elsewhere, including accelerated erosion, undercutting of banks, reduced species richness and abundance, and complete transitions in vegetation communities due to herbivory and trampling along streamlines (Cherubin *et al.* 2019; Schulz *et al.* 2019; Robertson *et al.* 2015; Dobbie *et al.* 1993; Dyring 1990). Support for *Tasmannia glaucifolia* abundance depending on habitat type and the feral horse impact indicator was weaker than for the model combining habitat and aspect. However, evidence of feral horses was recorded across all habitat types, particularly in open riparian swamp habitat consisting mainly of herbaceous and grass species, as well as more accessible (i.e. sparser layer of dense shrubs) riparian woodland. Dyring (1990) determined that streambank disturbance caused by feral horses was most severe in areas surrounded by herbaceous or *Sphagnum* vegetation, due to the increased accessibility of these more open landscapes. In the current study, feral horse impacts were highest in Beean Beean and Polblue (data not shown), and grazing was evident in one quadrat at Upper Edwards suggesting the movement of horse populations into areas hosting high counts of *Tasmannia glaucifolia*. Although observational, the findings suggest that *Tasmannia glaucifolia* populations in accessible riparian woodland areas may be vulnerable, and monitoring and managing feral horse movement may help conserve existing healthy populations in these locations. Exclusion experiments comparing fenced areas (restricting feral horse movement while allowing smaller herbivores to pass through) and unfenced areas (pre- and post-measurements) could confirm the impacts.

The exotic shrub Scotch Broom negatively impacts the growth and survival of Australian species once established in bushland areas, spreading rapidly and outcompeting native species (Sheppard *et al.* 2002; Hosking *et al.* 2000; Fogarty & Facelli 1999). Barrington Tops National Park has one of the highest infestations of Scotch Broom in Australia of at least 10, 000 ha (NPWS 2010). There was moderate support for *Tasmannia glaucifolia* abundance depending on habitat type and the cover of Scotch Broom. The SIMPER analysis indicated Scotch Broom was a dominant species occurring in sites containing *Tasmannia glaucifolia,* and that Scotch Broom cover was significantly higher in woodland and riparian woodland habitats indicating a preference for a similar habitat type and environmental conditions to *Tasmannia glaucifolia*. Management actions involving controlled experiments trialling the removal of Scotch Broom and monitoring these areas over time is needed to estimate impacts on *Tasmannia glaucifolia* populations.

Conclusion

A total of 491 *Tasmannia glaucifolia* plants were recorded across sites in the Barrington Tops National Park plateau, the majority occurring in riparian woodland habitat. Statistical modelling for inference showed most support for *Tasmannia glaucifolia* abundance depending on habitat type and aspect, and moderate support for the model where *Tasmannia glaucifolia* abundance depends on habitat type and the cover of Scotch Broom. There was weaker support for abundance depending on habitat type and feral horse activity, though the feral horse activity indicator provided evidence of disturbance in riparian woodland habitats that hosted the highest percentage of *Tasmannia glaucifolia* individuals; Scotch Broom was also found to grow in sites that contained *Tasmannia glaucifolia*.

Support for models tested in an exploratory analysis have led us to propose that southerly facing sites contain a greater proportion of *Tasmannia glaucifolia* individuals and a purple discolouration on the leaves of *Tasmannia glaucifolia* is more severe in northerly or westerly facing sites. However we emphasise that these two hypotheses need testing with independent data before being accepted. The study also noted lignotuber-style organs on mature *Tasmannia glaucifolia* and confirmed that seed regeneration does occur. This study provided baseline data on *Tasmannia glaucifolia* populations within Barrington Tops National Park and will aid in the implementation of future conservation management strategies for *Tasmannia glaucifolia* in Barrington Tops National Park.

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