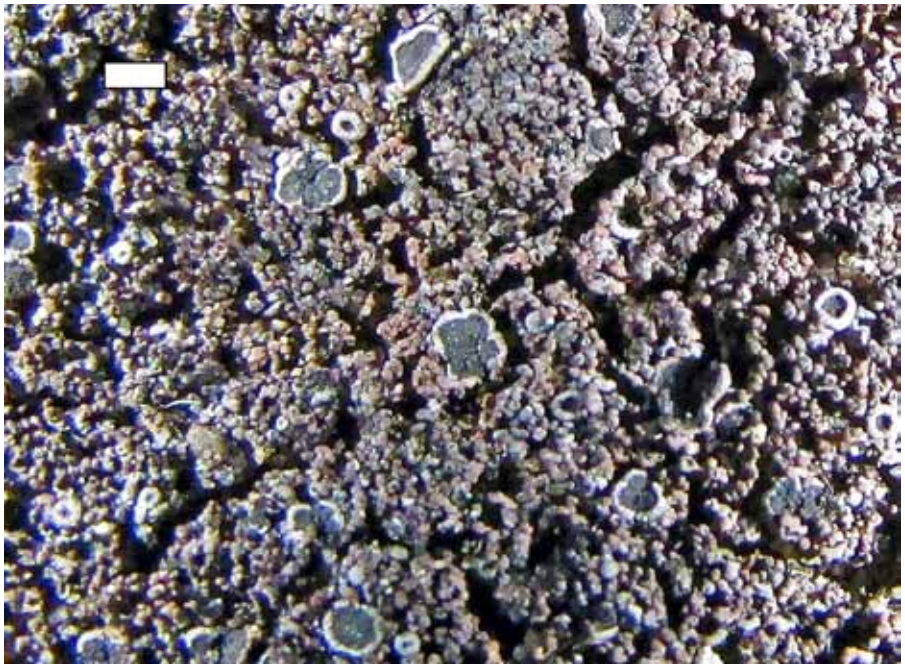

Figure 1. *Rinodina austroisidiata* (holotype in HO). Scale = 1 mm.

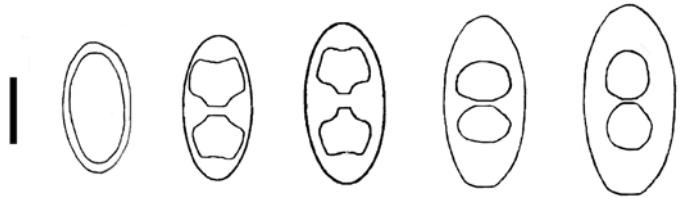

Figure 2. Ascospore ontogeny of *Rinodina austroisidiata*. Scale = 10 µm.



**Observations on the vertical distribution of lichens on a *Eucalyptus radiata* subsp. *radiata* tree in burnt lowland forest, Victoria, including a new State record**

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**Abstract**

A large, recently fallen branch presented an opportunity to record the previously undocumented vertical lichen distribution and canopy species on *Eucalyptus radiata* Sieber ex DC. subsp. *radiata* (narrow-leaf peppermint) in burnt lowland forest in Victoria, Australia. Ten species were detected from the canopy and eight were recorded from a shaded, unburnt part of the buttress. The heavily charred bark on the remainder of the lower trunk supported only *Hypocenomyce australis* and *Cladonia rigida* var. *rigida* squamules. Fifteen species were recorded overall, with the lignicolous *Xylographa isidiosa* a new record for Victoria. The zone near the base of the tree supported a Cladoniaceae-dominated community with *C. rigida* var. *rigida* extending higher up the trunk and into the lower canopy. *Pannoparmelia wilsonii* and *X. isidiosa* occurred only on canopy branches and attained the greatest coverage of all species observed. These observations provide a preliminary insight into the lichen flora of *Eucalyptus radiata* subsp. *radiata*, and the contribution this makes to biodiversity in a fire-affected, lowland forest by providing suitable lichen habitat.

**Introduction**

Differences in light intensity, humidity and nature of the bark are evident between the base of the tree and canopy branches (McCune 1993; Fritz 2009; Li *et al.* 2017) and, accordingly, spatial heterogeneity appears to be a critical factor influencing the height at which different lichen communities develop (Pirintsos *et al.* 1993; Morley & Gibson 2010; Kobylinski & Fredeen 2014; Li *et al.* 2017). For practical reasons most lichen studies consider the flora up to a height of 2 m with incidental evidence of canopy species derived from recently fallen twigs and debris on the forest floor. However, surveying only the base of the tree can underestimate species of conservation concern as well as their population size (Fritz 2009). Hence, weather events leading to large, wind-thrown branches (such as reported on in this study) and/or entire trees (e.g. Jarman & Kantvilas 1995; Milne & Louwhoff 1995; Aptroot 1997; Fritz 2009; Li *et al.* 2017), present an invaluable opportunity to scrutinize the canopy lichens more systematically.

Fire is increasingly a part of our landscape, and literature on post-fire recovery of lichens indicates a link to the intensity of the blaze and time since fire (Pharo & Beattie 1997; Kantvilas & Jarman 2006; Cranfield *et al.* 2011; Kantvilas *et al.* 2015). Some lichen species are host specific and/or restricted to particular forest types. McMullin & Wiersma (2019) suggest that lichen richness and abundance can be effective indicators of forest continuity and can be used as tools to prioritise forest areas in terms of management.

While lichens are frequently overlooked, they can play an important ecological role in eucalypt forests (Pharo & Beattie 1997; Cranfield *et al.* 2011). Cranfield *et al.* (2011) documented the canopy lichens of *Eucalyptus marginata* Sm. in jarrah silviculture forest in Western Australia, and Jarman & Kantvilas (unpublished data) referred to observations on canopy lichens for *E. obliqua* in wet forest in Tasmania. No studies have investigated the canopy lichens of narrow-leaf peppermint (*E. radiata* subsp. *radiata*, hereafter referred to as *E. radiata*), a common tree species in lowland forest in Victoria. *Eucalyptus radiata* is a small woodland or tall forest tree and can grow to a height of *c.* 45 metres in mountainous forest, although in more open sites it tends to be much smaller (EUCLID 2015). The subfibrous bark is finely fissured and persistent to the smaller canopy branches, creating the potential for suitable lichen habitat into the crown.

This study provides initial observations on the canopy lichens of *E. radiata*, including evidence of continuity between the lower trunk flora and that along canopy branches, and the suitability of this tree species as a partially charred host in a previously burnt lowland forest.

## Methods

### Nature of the site

Traralgon South Flora and Fauna Reserve (TSFF Res) is situated in the Gippsland Plains Bioregion [Department of Environment, Land, Water & Planning (DELWP) 2019] of Victoria, Australia, where Damp Forest (EVC 29) and Lowland Forest (EVC 16) are the dominant Ecological Vegetation Classes (EVCs) [Department of Sustainability and Environment (DSE) 2007]. *Eucalyptus radiata* is a typical canopy cover species in Lowland Forest, which has a vulnerable Bioregional Conservation status (DSE 2007). The last fires to occur in the reserve (February 2009) significantly burned parts of the forest and resulted in charred *Eucalyptus* trunks and a dense regrowth of *Acacia* species. In June 2019 a weather event caused a large *E. radiata* branch at approximately 8 m height to fall. This branch, prior to detachment, would have reached roughly 16 m into the canopy. The age of the tree, based upon dbh of *c.* 70 cm, was estimated at 70 years. The tree had a fire-affected trunk, being blackened up to detachment of the large canopy branch, with some mild charring on the underside of the branch.

### Sampling Method

The tree (38°17.56.4'S, 146°33.34.7'E) was divided into 10 sampling sections in order to observe any changes in the lichen flora along the length of the canopy branch, and to compare these with lichens on the charred lower trunk and unburnt part of the buttress. The first two sampling sections (ground to 99 cm, 100–200 cm) were on the upright tree trunk, and sampling sections 3–10 were *c.* 1 m apart on the fallen canopy branch. The average diameter of the canopy branch was 24 cm, being close to 32 cm at the widest point and 19.1 cm at the narrowest. An additional section (sampling section 11) comprised fallen debris such as bark, outer canopy branches and twigs, which were dislodged by the fall. Presence of lichens was recorded, and separate observations were made on their habit, maturity and abundance (based on a visual assessment). The major fallen branch had two side branches (19 and 24 cm in diameter, respectively), and the lichen flora on those was recorded (sampling sections 9 and 10) as part of the assessment to determine continuity in the canopy lichens.

### Lichen identification

Lichens were identified in the field, and small samples were analysed by means of thin-layer chromatography (TLC) (Orange *et al.* 2001; Elix 2014), or by further microscopic examinations. The investigations were made under a DELWP research permit No. 10008741. Nomenclature follows that of McCarthy (2018), and Bendiksby & Timdal (2013) for *Xylographa isidiosa*. *Cladonia* squamules were collected along the various sampling sections, and their identity confirmed using TLC. Juvenile specimens of *Usnea* and *Hypogymnia* were presumed to be recruiting individuals of the same species present in greater maturity and abundance along other sections of the fallen canopy branch. One crustose specimen with a leprose habit and fumarprotocetraric acid (and two faster moving TLC spots) was tentatively identified as a species of *Placynthiella* (to be confirmed and as yet not reported for Victoria).

## Results

### *Lichen richness in sampling sections*

Fifteen lichens in 12 genera and 8 families were identified, and their habit and vertical distribution on the tree presented in Table 1. The family Cladoniaceae was best represented with 5 species, followed by Parmeliaceae with 3 and Trapeliaceae with 2. All other families had only 1 species.

Lichen richness was greatest on the lower metre of the upright trunk (8 species), with individuals almost entirely restricted to a shaded, unburnt part of the buttress, although coverage was minimal. These lichens were all fruticose, with the exception of the foliose *Hypogymnia subphysodes* var. *subphysodes* (hereafter referred to as *H. subphysodes*). The charred bark on the remainder of the lower trunk did not support any lichens, apart from a few individuals of *Hypocenomyce australis* and *C. rigida* var. *rigida* (hereafter referred to as *C. rigida*) squamules (juvenile specimens only). Although species richness was lower on the main fallen canopy branch, including the two side-branches (6 species), overall a greater number of individuals covered large parts of the bark. Apart from *X. isidiosa*, which is crustose to subsquamulose with densely isidiate clusters (but see also brief description below) at times entirely obscuring the primary thallus, all the species were macro chlorolichens with fruticose habit most common (6 species) whilst only 2 were foliose. This included established mature specimens as well as juvenile recruitments, particularly of *P. wilsonii*, *H. subphysodes* and *U. inermis*.

Five species occurred on the canopy twigs and debris surrounding the fallen branch and, apart from *H. subphysodes*, all were crustose lichens, bringing the total number of species from the canopy to 10. *Ochrolechia pallescens* occurred on the main branch, but was not seen on the secondary branches. Conversely, *Chrysothrix candelaris* was recorded from the side branches but not the main branch. Neither species was seen on the trunk nor on the debris and smaller canopy branches on the ground surrounding the main fallen branch. In all 7 crustose, 6 fruticose and 2 foliose lichens were recorded from the *E. radiata* tree.

### *E. radiata subsp. radiata as a lichen host and charred bark as a substratum*

There is an observable zonation of trunk, lower branch canopy and upper branch canopy lichen communities with some species showing overlap. *Cladonia rigida* was very well represented by primary squamules which occurred on the trunk (including the burnt bark) and along the entire length of the fallen branch (including side branches) but not on the upper canopy twigs or fallen debris. However, fertile *C. rigida* podetia were, for the most part, observed only from the unburnt bark of the shaded buttress, as were all *Cladia* and other *Cladonia* species. *Hypocenomyce australis* was the only other lichen to occur on the charred bark of the trunk, but only juvenile individuals were observed. Two other lichens that were seen on the lower trunk were juvenile individuals of *Hypogymnia subphysodes* and *Usnea inermis.*

*Pannoparmelia wilsonii* and *X. isidiosa* were present along all sections of the main fallen lower branch, including side branches, but not from the upper canopy. *Usnea inermis*, *Chrysothrix candelaris* and *Ochrolechia pallescens* were not consistently present along its entire length. *Hypogymnia subphysodes* was common along the main fallen branch where it attained a healthy presence of mature and recruiting specimens, whilst only juvenile individuals were observed in the upper canopy.

The very upper canopy branches, which had only thin bark, acted as the substratum for the crustose species *Megalaria grossa, Pertusaria pertractata* and ?*Placynthiella*, and recruiting juveniles of *H. subphysodes*.

## Discussion

### *Lichen community zonation*

The lichen zone on the buttress of *E. radiata* was distinctly compromised by fire in the landscape 10 years prior. Only the protected, unburnt parts supported a "*Cladoniaceae* community" together with juvenile individuals of *H. subphysodes* and *Usnea inermis*. However, observations on a nearby eucalypt suggests that, when not affected by fire, this association becomes well developed. Kantvilas & Jarman (2004) reported a similar band at the base of messmate stringybark (*Eucalyptus obliqua* L'Hér.) in wet forest in Tasmania where *Cladia aggregata* and *Cladonia* species were most common and interspersed with crustose lichens. The latter were not observed in the Cladoniaceae community on *E. radiata* and, apart from *Hypocenomyce australis*, crustose lichens were present only higher up on the tree. Here, *Megalaria grossa, P. pertractata* and ?*Placynthiella* appeared to have a preference for the thinner bark on the outer branches, whilst *Chrysothrix candelaris, O. pallescens* and *X. isidiosa* were observed on only the fibrous bark on the main canopy branch.

*Pannoparmelia wilsonii* and *Hypogymnia subphysodes* were common along the main canopy branch, and Cranfield *et al.* (2011) associated those species with mature forest trees (*E. marginata*), which they considered to be imperative in retaining habitat.

***Eucalyptus radiata as a lichen host***

*Xylographa* reportedly displays strong substratum specificity for wood (Spribille *et al.* 2008), and the distinctly "isidiate" thallus of *X. isidiosa* has so far been described from only charred bark of eucalypts in western W.A., where it is considered to be a rare species although locally common (Elix 2005). It is a new record for Victoria.

These preliminary observations confirm that *E. radiata* in lowland forest is a suitable host for 15 species with lichens extending far into the canopy. Many eucalypts are poor lichen hosts due to their continuously flaking and shedding bark. However, species such as *E. radiata*, which retain their finely textured bark almost to the outer canopy branches, provide suitable habitats for a number of different lichens, including the rare *X. isidiosa*.

No lichens appeared restricted to *E. radiata*, but some degree of specificity with eucalypts in general has been observed. The bright yellow, leprose lichen *Chrysothrix candelaris* is much more conspicuous on the fibrous bark of eucalypts in damp forest in Victoria than on *Acacia* species (*A. melanoxylon* and *A. dealbata*) occurring nearby (Hunt 2019, unpublished data; Louwhoff pers. observation).

Other large trees comprising the overstorey in lowland forest (*E. obliqua* and *E. considenana*), also had bark persistent into the canopy branches, although their suitability as a lichen host was not investigated here.

***Xylographa isidiosa*** (Elix) Bendiksby & Timdal, *Taxon* **65**, 952 (2013)

This lichen is characterised by dense black-tipped granular, globose to subglobose goniocysts (Ryan 2004; Spribille *et al.* 2008), referred to as isidia by Elix (2005), which often obscure the crustose thallus. No fertile material has been found (Elix 2005), and it is easily overlooked. The species contains the rare depsidodepsones friesiic and confriesiic acids (Timdal 1984; Elix *et al.* 2004). In Victoria, it was collected from previously burnt (in February 2009) lowland forest on a large, fallen, partly charred canopy branch of *Eucalyptus radiata* subsp. *radiata* where it was common, forming a distinct branch community with *Pannaparmelia wilsonii*.

SPECIMEN EXAMINED

*Victoria*. ● Traralgon South Flora and Fauna Reserve, Gippsland, behind township fire break, along Centre Track, approx. 400 m from North South Track turnoff, 38°17.56.4'S, 146°33.34.7'E, 165 m alt., *S.H. Louwhoff SL2177*, 19.vi.2019 [MEL 2476633].

***Impact of fire***

These initial observations of a partially burnt *E. radiata* confirm that epiphytic lichen recovery after fires is slow, with only juveniles of *C. rigida* and *Hypocenomyce australis* present on the heavily scorched bark of the trunk, most likely recolonizing from nearby trees. Indeed, other studies suggest that, while low severity fire had little effect on lichens, under moderate to high severity fires very little post-fire recolonization occurred on burnt substratum even after 15 years (Miller *et al.* 2018). Furthermore, Ivanova *et al.* (2017) indicate that lichens (and mosses) did not recover 20 years post-fire in pine forest.

The fallen canopy branch had only minor scorching on the lower reaches; indeed Ray *et al.* (2015) suggest that the canopy could potentially provide some refuge from fire for lichens. While a "fire response" lichen community, including *P. wilsonii*, *X. isidiosa* and *H. subphysodes*, occurred on the partly charred bark of *E. radiata*, with the exception of *X. isidiosa*, those species were also observed on blackened trunks in other areas with a longer fire history (30+ years) (Louwhoff & Harris 2014; Louwhoff pers. observations). It appears that the change in chemical or water-repelling properties of the bark following fire make it more conducive to the establishment of certain species, whilst acting as an inhibitor to others, but that possibility requires thorough investigation.



**Conclusions**

The lichen richness of a single *E. radiata* (15 species) in lowland forest in Victoria was similar to that of a single *E. obliqua* (18 species) in wet forest in Tasmania (Kantvilas & Jarman 2004). However, only three species were common to both studies, most likely due to differences in microclimate between the different forest types. Indeed, there was more overlap (9 species) with lichens found on *E. marginata* in silviculture forest in W.A.

These preliminary observations confirm that *E. radiata* makes a valuable contribution to the biodiversity of lowland forest in Victoria by providing suitable substratum, including for *X. isidiosa*, previously thought to be endemic to eucalypt forest in W.A. The observations, based on the examination of the upright trunk and a large, fallen canopy branch, indicate there is a recognizable lichen zone on buttress, main canopy branch and outer canopy branch, in addition to a "fire response" lichen community. Additional sampling of fire-affected eucalypt trunks in lowland forest will provide further insight into sensitivity of lichens to charred bark and their recovery period following fire.

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Table 1. Lichen species and their growth form (FRU = fruticose, FOL = foliose, CRT = crustose) in each of the sampling sections (ss), where ss 1 & 2 are on the upright tree trunk (up to 200 cm height), ss 3–10 are on the main fallen branch (9 & 10 on narrower, side branches from main branch) and ss 11 is the debris surrounding the fallen branch, consisting mainly of outer canopy branches.

| Form | Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FRU | *Cladia aggregata* (Sw.) Nyl.# | * | | | | | | | | | | |
| FRU | *Cladia schizopora* (Nyl.) Nyl.# | * | | | | | | | | | | |
| FRU | *Cladonia scabriuscula* (Delise) Nyl. # | * | | | | | | | | | | |
| FRU | *Cladonia merochlorophaea* Asahina # | * | | | | | | | | | | |
| FRU | *Cladonia rigida* (Hook.f. & Taylor) Hampe var. *rigida* # | * | * | * | * | * | * | * | * | * | * | |
| CRT | *Hypocenomyce australis* Timdal * | | * | | | | | | | | | |
| FOL | *Pamoparmelia wilsonii* (Räsänen) D.J.Galloway ∞ | | | * | * | * | * | * | * | * | * | |
| CRT | *Xylography isidiosa* (Elix) Bendiksby & Timdal> | | | * | * | * | * | * | * | * | * | |
| FOL | *Hypogymnia subphysodes* (Kremp.) Filson var. *subphysodes* ∞ | * | | * | * | * | | | | | * | * |
| FRU | *Usnea inermis* Motyka ∞ | * | | | * | * | * | | * | * | * | |
| CRT | *Ochrolechia pallescens* (L.) A.Massal ^ | | | | | * | * | * | | | | |
| CRT | *Chrysothrix candelaris* (L.) J.R.Laundon ° | | | | | | | | | * | | |
| CRT | *Megalaria grossa* (Pers. ex Nyl.) Hafellner ~ | | | | | | | | | | | * |
| CRT | *Pertusaria pertractata* Stirt. + | | | | | | | | | | | * |
| CRT | ?*Placynthiella* sp. Elenkin > | | | | | | | | | | | * |
| | TOTAL | 7 | 2 | 4 | 5 | 6 | 5 | 4 | 4 | 5 | 5 | 4 |
| | Position of section | Upright tree | | | Main fallen branch | | | Side branches | | Other | | |
| | Total species/category | 8 | | | 6 | | | 6 | | 4 | | |

Shaded columns denote fallen branches. Lichen families: #Cladoniaceae, *Ophioparmaceae, ∞Parmeliaceae, ^Ochrolechiaceae, °Chrysotrichaceae, ~Megalariaceae, +Pertusariaceae, >Trapeliaceae.