How the severe fires of 2019-2020 promoted regeneration of the rare Bendethera Shrublands

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The Bendethera Shrublands are a unique and fascinating ecological community restricted to less than 100 hectares on a series of steep limestone outcrops in the Deua River valley. The community is characterised by a dense shrub layer to around 7.5 metres height and dominated by *Acacia covenyi,* a locally endemic species, whose blue foliage forms a striking contrast with adjacent *Eucalyptus* forests (Figure 1a). Scattered eucalypts and kurrajongs emerge above the shrub thicket in places, the latter, according to conventional wisdom, indicating the location of dolines (a shallow, funnel-shaped depression of the ground surface, typically found in karst/limestone regions) in the underlying bedrock. The shrublands were located within the epicentre of some of the most severely burnt areas of the south coast. The fires were preceded by prolonged drought and followed by intense rainfall. We evaluated the impacts of these factors when we returned to our established monitoring sites in November 2020.

Ecological characteristics of Acacia shrublands

The Bendethera shrublands are a form of Dry Acacia Shrublands, a type of vegetation unusual in temperate humid south east Australia being dominated by Acacias rather than Eucalypts, and distinctly different from more open Acacia shrublands of Australia's semi-arid and arid climates (Keith 2004). Acacia shrublands of temperate humid climates occupy small isolated patches in rugged mountainous country, usually on exposed rocky slopes with shallow or skeletal soils. These sites are thought to retain too little moisture to support Eucalypt forests, drawing comparisons with Acacia- dominated communities west of the divide (Costin 1954) – semi-arid oases in otherwise temperate climes. Like their western counterparts, Dry Acacia Shrublands are moderately tall (5-20 m) and establish dense canopies with a relatively sparse ground cover. One major point of distinction is the dependence of the eastern Dry Acacia Shrublands on fire for regeneration. The dominant Acacia species are killed by fire and recruit seedlings *en masse* in response to soil heat fluxes during fire which break seed dormancy. Dense, even-aged stands establish following fire, gradually thinning over the course of their lifespan, estimated to be up to 100 years (Clayton-Green and Wimbush 1988, Hunter 2005). Paradoxically, the paucity of ground cover and small shrubs is not conducive to either the spread of fire or the generation of soil heat-fluxes sufficient to break dormancy (Bradstock and Auld 1995). In fact, anecdotal evidence suggests wildfires of low to moderate intensity tend not to penetrate the Eucalypt-Acacia boundary at all and attempts to ignite the shrublands using aerial incendiary have so-far proved unsuccessful (Clayton-Green and Wimbush 1988).

History of fire in the Bendethera shrublands

Prior to 2020, the last known fire in the Bendethera shrublands occurred in the summer of 1968-69 under circumstances strikingly similar to those of 2019-20. That fire was preceded by a prolonged drought, culminating in rainfall less than half the annual average recorded in 1968. Severe fire weather prevailed over a season extending from early September to late March and, as in the recent fires, extensive areas of the southern coast and ranges were burnt, including forest and rainforest communities which rarely burn under normal conditions (Duggin 1976). Fire history prior to 1969 is uncertain. Wallis (1965) commented that, at the time of his visit, the caves were difficult to access due to dense post-fire regrowth, so it is possible the shrublands burnt in fires which occurred in the area over the summers of 1938-39 or 1953-54 (Duggin 1976). A number of fires have occurred in the area since 1968, most notably a major wild-fire in the summer of 2001-02 which self-extinguished at the boundary of the shrublands.

Pre-fire conditions

Aerial photographs combined with the present structure of the heathland indicate Acacias re-established at high densities following the 1968 fire and have undergone self-thinning over an extended period. From 2006 up until the time of the fire, significant senescence, augmented by lightning strikes and wind damage, initiated a gradual transformation of the shrublands. Parts of the upper slopes became bare or supported only scattered shrub cover with little or no groundcover (Figure 1b). On the mid-slopes Acacias were gradually replaced by shrub species able to establish in the absence of fire, such as *Beyeria lasiocarpa* and *Myoporum acuminatum*. Acacias disappeared from the lower slopes almost

Figure 1. A) Characteristic blue foliage of *Acacia covenyi* (seedlings) contrasting with burnt eucalypt forests in the background; B) Prior to the fire, senescence of *Acacias* created gaps in the shrub canopy; C) Flora monitoring plot in dense shrubland prior to the fire; D) The same plot after the fire. *Scaevola albida* has colonised the site while *A. covenyi* seedlings are too small to see (cf Figure 2), the first cohort having been washed away ; E) *Melaleuca armillaris* seedbanks only survived on plants growing within rock outcrops; F) Seedlings of *M. armillaris* re-establishing within a rock outcrop. Photos: Mark Tozer (A, C, D, E, F); Chris Simpson (B)

entirely, replaced by a dense herbaceous groundcover undoubtably sustained by groundwater seepage. These changes were not necessarily irreversible because other *Acacia* species typically establish dormant, long-lived seedbanks. However, because of the lack of ground-fuel on the upper-slopes and the fact that Acacia shrublands are notoriously non-flammable, the fate of the community was uncertain.

Impacts of the fire

High intensity fire typically precipitates a stunning transformation in heath and shrublands, turning impenetrable thickets of green to a sea of blackened, skeletal remains. What we observed in our plots was extraordinary for the almost complete absence of woody remains (Figures 1c,1d). This is testimony to the exceptional intensity of the fire, but also a particular feature of the shrublands. While the canopy foliage in our plots was generally continuous, the structure of the population suggested this was maintained by ever-decreasing numbers of live plants which were progressively increasing in size. Smaller plants remained standing following death to the extent that in 2015, the ratio of dead to live plants ranged from 1.2–2.6 and may have been higher at the time of the fire following three years of drought. We suggest this created conditions for a fire of exceptionally high severity and long residence-times as the canopy collapsed and continued to burn on the ground. The very high densities of *Acacia* seedlings that emerged following the fire are consistent with a significant soil heat flux (Figures 2, 3). Surprisingly, we even recorded reasonable seedling densities in areas bare of fuel prior to the fire. The heating required to drive this may have come from movement of coarse woody debris during the fire storm, the 'attachment' of flames to the steep slopes due to strong up-slope wind driving convective heating (Zylstra in review) or by solar insolation in the weeks following fire (Santana *et al*. 2010).

Kill thy Neighbour?

One interesting outcome of the fire was declines in populations of species with serotinous seedbanks. No seed capsules remained on any *Hakea eriantha* (an obligate seeder) marked prior to the fire (in fact the plants themselves were wholly consumed) and we conclude the species is likely to have been eliminated from the site. A similar fate befell individuals of *Melaleuca armillaris* (facultative resprouter), which neither resprouted nor retained a seedbank except when they were surrounded by extensive rock outcrops which afforded some protection (Figures 1e, 1f). It seems that dense, prolifically branching stands of *Acacia covenyi*

Figure 2. Dense seedling recruitment of *Acacia covenyi* with *Brachychiton populneus* resprouting in the background. Although *Brachychiton* individuals show extensive fire-damage and have been slow to recover, we recorded mortality of only 2% in the first year post-fire. Photo: Mark Tozer

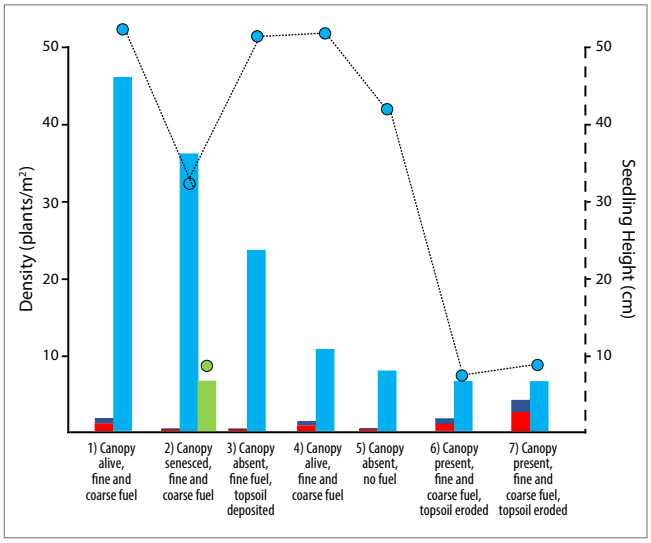

Figure 3. Densities (bars, left axis) of *Acacia covenyi* adults (live – dark blue, dead – red) prior to the 2019-2020 fires and density of seedlings (*A. covenyi* – light blue, *Beyeria lasiocarpa* – green) following the fires. Average seedling heights are represented as circles (right axis).

can, under the right conditions, support fires of sufficient intensity to reduce populations of potential competitors. Bond and Midgley (1995) proposed this mechanism of neighbour mortality as a means by which some pyrogenic species might maintain occupancy, despite presence of superior competitors represented in the regional species pool. Replacement by *Beyeria lasiocarpa* and *Myoporum acuminatum* was also reversed following the fire, although while the latter species has almost entirely disappeared, the former has persisted, albeit at much lower densities than *A. covenyi* and with less vigorous growth rates (Figure 3).

….of flooding rains

On February 10, coastal settlements on the NSW south coast recorded up to 150 mm of rainfall in the preceding 24 hours. While the exact figures for Bendethera are unknown, we recorded evidence of significant erosion within the shrublands. The stripping of topsoil from the steep upper slopes had several consequences. First, it appears erosion removed much of the seedbank which supported such prolific seedling establishment on more gently sloping areas. Cohorts of seedlings in eroded areas are at significantly lower densities and heights (Figure 3), suggesting seed previously buried deep beneath the surface has only recently germinated, presumably having had dormancy broken by solar insolation during spring (Santana *et al*. 2010). Conversely, the lower slopes of the mountain from which *Acacia covenyi* had disappeared prior to the fire now support dense stands of Acacia on deep colluvium, potentially originating from seed transported from upslope.

Conclusions

While undeniably traumatic, the evidence suggests that the summer of 2019-2020 witnessed a set of circumstances which have maintained the Bendethera Shrublands throughout their history. We suspect that, historically, such events could be cyclical on a multi-decadal scale. Our observations suggest that severe fires must be regular, if infrequent, events in these ecosystems, and it is difficult to imagine how the Bendethera Shrublands could persist in their absence for extended periods. While the palatability of *A. covenyi* seedlings is unknown, severe and extensive fires also reduce herbivore densities in the period when seedlings and juveniles are most vulnerable, which is potentially critical for a species restricted to such a small area.
The main threats to the Bendethera shrublands are twofold. In the aftermath of the fires, erosion of the steep slopes provides opportunities for invasion by exotic species in areas with low levels of recruitment. This is a particular problem in the sub-catchment in which the main cave is located, and so careful management of visitation must be a priority as recovery continues. More broadly, while our investigations commenced in response to concerns about the long-term absence of fire, the events of 2019-2020 serve as a reminder that extreme fire events are projected to become more frequent as a consequence of climate change (Stephens *et al.* 2014; Bowman *et al.* 2017). Further research is required to determine minimum fire-free intervals required to permit persistence of the Bendethera shrublands in their current state.

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