Surveying and promoting better management of endangered Granite Belt boronias

Final report for the Stanthorpe Rare Wildflower Consortium

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Stanthorpe Rare Wildflower Consortium

Contents

1. About the project

In late 2019, the Stanthorpe Rare Wildflower Consortium received a Community Sustainability Action Grant from the Queensland Department of Environment and Science to survey and promote better management of 2 boronia species, both listed as endangered by the Queensland and Australian governments – *Boronia granitica* (granite boronia) and *Boronia repanda* (repand boronia). The project concluded at the end of 2022.

1.1 Project aims

1. Assess the current population size and distribution of the most important subpopulations of *Boronia granitica* (endangered) and *Boronia repanda* (endangered) on the Granite Belt.

2. As a basis for future management, during the surveys document any threats observed – particularly signs of browsing and likely sources (eg goats, deer, macropods), damage from feral pigs, weed invasion, drought impacts, inappropriate fire regimes, clearing.

3. Assess recent recruitment rates – document numbers of seedlings and juveniles, and determine whether recruitment, where found, is occurring in response to fire or in its absence.

4. Set up fire monitoring sites through mapping and photo monitoring as a basis for assessing the response of the boronias to future prescribed burning and wildfires in the Passchendaele and Broadwater state forests.

5. Assess the impacts of fire by monitoring subpopulations of *B. granitica* and *B. repanda* in Passchendaele and Broadwater State Forests, if and when the forest managers do prescribed burning or wildfires occur (including subsequent to the project period).

6. Encourage land managers to mitigate threats – e.g. by fire management and fencing or pest control for browsing impacts (including subsequent to the project period).

1.2 Project conditions – drought, rain and fire

The project took place during extreme weather conditions. It started in a severe drought, which lasted from 2018 to 2020, which was followed by extreme wet weather (Table 1).

The drought was one of the worst on record for the Granite Belt. The 2019 rainfall total for Stanthorpe was just 257 mm, the lowest since records began in 1873. In contrast, the rain received in 2021 was the highest for 6 decades and included the highest ever daily rainfalls recorded for November and December. It was quadruple the rainfall received in 2019.

In September 2019, the northern part of the range of repand boronia was subject to a severe wildfire and some was subject to a controlled burn (for a backburn). However, during the project period, apart from minor patch burning on one nature refuge property, there has been no prescribed burning on properties known to have granite boronia or repand boronias due to the winters and springs mostly being too wet for burning.

Table 1. Stanthorpe rainfall totals, 2018–2022

	2018[1]	2019	2020	2021	2022	Mean since 1873
Rainfall (mm)	568	257	733	1092	927	765
% mean annual rainfall	74	34	96	143	121	

Source: Bureau of Meteorology. Rainfall records for Stanthorpe have been kept since 1873

1.3 Acknowledgements

Thank you to the Stanthorpe Rare Wildflower Consortium for the opportunity to undertake this project and the support provided.

Thank you to the volunteers who worked with us and provided data, with special mention of the assiduous work by Liz Bourne, John and Ursula Gardner, Teresa Clifford and Jayn Hobba. Others who participated in surveys included Ian Milanovich, Andrew Pengelly, Peter Pemberton, Jeanette Davis, Dell Baldwin, Cec Van Heumen, and Alex and Colleen Harslett.

Thank you to the landholders and land managers who welcomed us to their properties and provided valuable information. All care deeply about their places and strive to be responsible stewards of their boronia plants.

Thank you to the Queensland Department of Environment and Science for the funding to undertake this project.

[1] http://www.bom.gov.au/climate/current/annual/qld/archive/2018.summary.shtml
[2] http://www.bom.gov.au/climate/averages/tables/cw_041095.shtml

2. About the species, including some project observations

The natural history of both boronia species is very poorly known, including of basic life history parameters such as longevity and pollinators. Addressing these gaps wasn't the focus of our project, but we have added some information. There is much yet to be learned about these species.

2.1 Taxonomy

Genus *Boronia* (family Rutaceae) has 134 known species, all endemic to Australia except for 4 species in New Caledonia [1,2]. The genus is classified into 7 sections (lineages). *Cyanothamnus*, formerly a boronia section, has recently been classified as its own genus due to substantial genetic differences [3].

B. granitica and *B. repanda* – near relatives of each other – belong to section Valvatae, named after their characteristic valvate petals (meeting at the edges with no overlap) [4]. Valvatae species are widespread but concentrated in south-east Australia [4]. Other species closely related to *B. granitica* and *B. repanda*, also with small ranges and found only on the New England Tableland, are *B. boliviensis, B. warrumbunglensis* and *B. ruppii*. The New England Tableland harbours many such plant species with small distributions, reflecting their role as a refuge from Tertiary climate change and Australia's increasing flammability. The rocky summits attract rain and provide a wide range of microclimates, and the granite expanses impede fires.

2.2 Distribution and habitat

Granite Boronia

Granite boronia occurs in the New England Tablelands and Nandewar IBRA bioregions. In Queensland it has been recorded only in the Granite Belt. In NSW it is known from several scattered locations from near Armidale to the Torrington district [5,6]. The extent of occurrence is an estimated 8,000 km^2 [6].

Granite boronia is mostly found in shallow soils associated with granite and occasionally rhyolitic outcrops [5]. Growing among rocky outcrops would help buffer it from too-frequent fires, allowing it the time to mature and set seed [7]. In most locations in the Granite Belt, the plants grow near the base of rocky slopes, where they would benefit from runoff water. They sometimes grow in sites highly exposed to the sun.

Just one forest population has been reported away from rock outcrops – in narrow-leaved ironbark forest on deep lateritic soils in Severn Nature Reserve, NSW [5,6]. We have recorded some in the Granite Belt growing in dappled light in woodland sites, and some seedlings have appeared in densely shaded areas below rocky outcrops (from where seeds may have washed down from a colony above). The seedlings in shaded areas grow more slowly than those in sunlight and, where they are frequently browsed (probably by macropods and maybe goats), many do not last.

Most granite boronias grow in colonies, in which they are sometimes the dominant shrub across small areas. Some are in dense, even-aged stands that have emerged after fire. Others are more scattered with multi-aged plants.

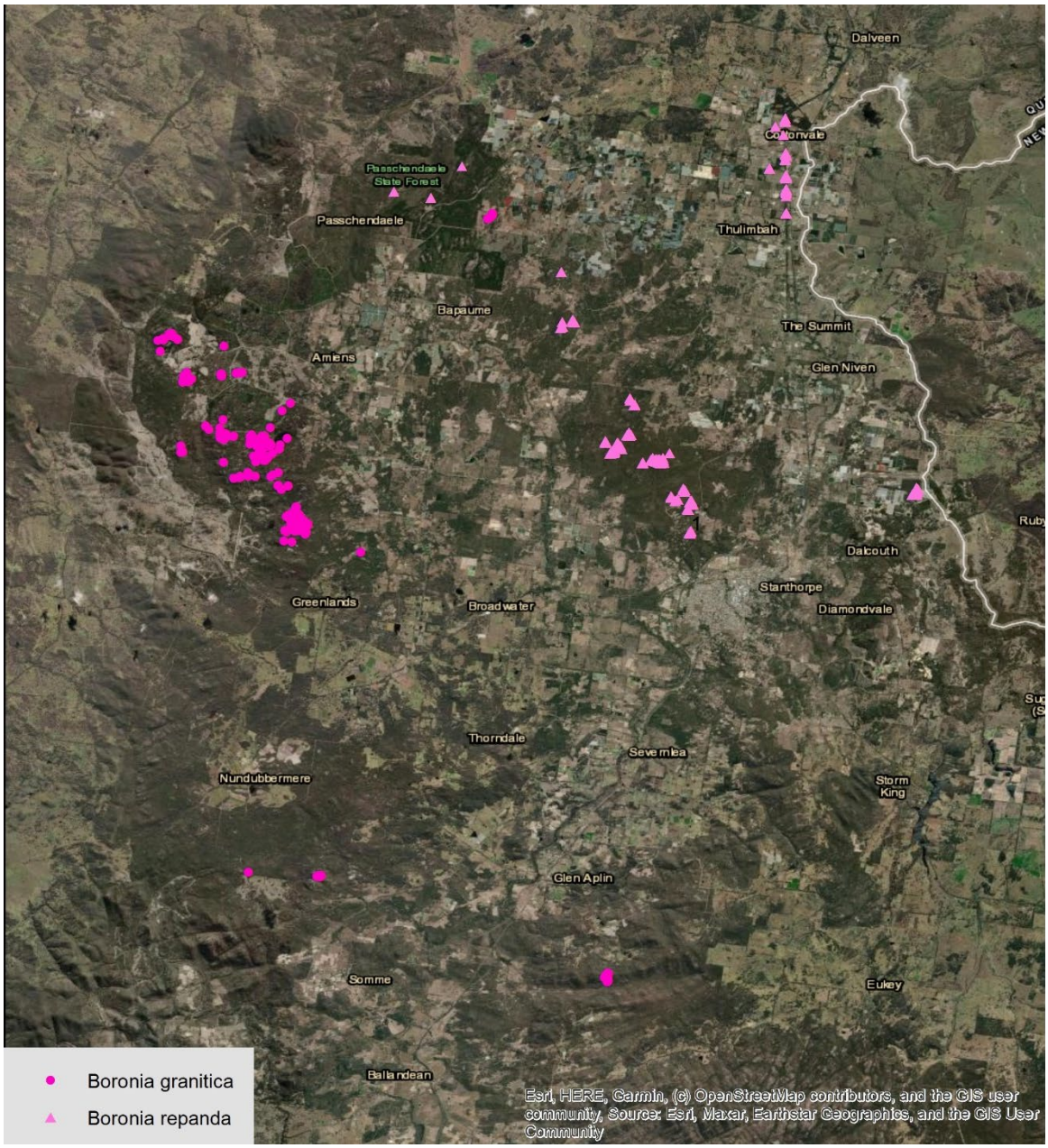

Figure 1. The distribution of granite boronia and repand boronia on the Granite Belt properties surveyed for this project.

Repand boronia

Repand boronia is known from several scattered sites in the Granite Belt and at one adjacent site in New South Wales near the border with Queensland, where the majority of the population occurs [8].

Repand boronia typically grows in sandy soils derived from granite and, in contrast to granite boronia, often grows in shaded or dappled sites, in heathy dry sclerophyll forest, removed from rock outcrops (Figure 2) [8]. Some plants grow in almost full sunlight. In most forest sites repand boronia would be highly exposed to fire, although some sites have not burned for several decades. Repand boronia mostly occurs in colonies, often with plants growing within half a metre of each other. Over small areas, e.g. 10–20 square metres, they are often the most common plant.

Figure 2. Boronia repanda growing in dappled light in forest sites (in the foreground).

2.3 Growth and longevity

Granite boronia

The 2002 national recovery plan for granite boronia says it 'appears to have a slow growth rate' and that it 'may flower in its third or fourth year … consistent with the estimated primary juvenile period of 4–8 years for other restricted outcrop shrubs with similar regenerative strategies' [5]. On the Granite Belt, the growth rate varies considerably. At some sites in 2020–22, including during a period of unusually high rainfall, we observed plants flowering precociously within their first year, although whether they produced seed is not known. In shaded areas the growth is slower – with some plants not flowering after 3 years in a shady site below a rocky outcrop where seedlings emerged in 2020, in contrast to similar-aged boronias on the same property that had flowered (Egernia Nature Refuge).

The recovery plan for granite boronia suggests it lives for about 15 years. We estimate 15–20 years based mainly on the population at Horan's Gorge Nature Refuge, which germinated enmasse after a fire in 2002 and were mostly dead by 2022. Most plants probably die by 15 years of age. The largest plants are not found in large groups, occurring often as single plants that appear to have outlived their cohort.

Repand boronia

Repand boronia grows slowly, consistent with its location in shaded woodland understorey. It appears to be a long-lived plant that survives mainly by persisting rather than by regular reproduction. The capacity of many nearly dead or depleted plants to resprout vigorously from the base after a drought is unusual for a shrub in this region and suggests that plants might be able to survive for decades in this way. They grow mainly on sites with dense litter on the ground that would limit seedling growth.

This boronia has thin wiry stems, and many adult plants end up having some or all of their stems pinned to the ground by branches, often of small size, that have fallen from canopy trees. The shrubs seem well adapted to this. The pinning could reduce browsing damage from macropods by turning obvious shrubs into tufts of leaves emerging from litter on the ground. This growth form is beneficial

along the railway line where lopped branches and old sleepers have been discarded and sometimes dumped on boronias.

Figure 3. Two repand boronias that were pressed to the ground by shed eucalypt stems. Had they not been pinioned, these plants would probably have exceeded half a metre in height.

2.4 Reproduction

2.4.1 Flowering and pollination

The recovery plan for granite boronia reports 'preliminary' observations that it flowers in its third or fourth year [5]. The conservation advice for the federal listing says that time to first flowering is unknown [6].

Following the emergence of seedlings after rains in 2020 and 2021, we observed many plants flowering within their first year, based on reports from landholders, mostly those with high sun exposure. Plants in more shaded sites flowered in their second year, or had not yet flowered, especially those with browsing damage. Therefore, the time to first flowering ranges from less than 1 year to probably 3–4 years.

There is no published information about the time to flowering for repand boronia. After the September 2019 bushfire, both resprouting plants and seedlings produced flowers within about a year at one property (Appendix 2, Gardner property, figure 4). But the only 2 seedlings recorded at this site prior to the fire did not flower before they died a few years later during the drought. The difference could be due to higher soil moisture, nutrients from ash, higher light levels after fire, or all three.

Both boronia species flower annually: *B. granitica* regularly in late winter–spring and *B. repanda* variably throughout much of the year, but most prolifically in spring. Both have a longer flowering season than most other Granite Belt plants.

Figure 4. Buds on a resprouting repand boronia in June 2020 (left), within 8 months of a fire that destroyed all above-ground parts. A profusely flowering repand boronia (right). Photos: John and Ursula Gardner (left), Michael Jefferies (right)

All boronias in section Valvatae are described as self-incompatible, thus requiring pollen transfer for fertilisation [5]. This has been confirmed to be the case for repand boronia (Don Sands pers com to Liz Bourne).

Boronias are pollinated by insects. Mostly bees, but also beetles, flies, moths and butterflies, have been reported as pollinators of various boronia species [9]. The flowers emit volatile oils, which are likely to act as insect attractants.

The recovery plan for granite boronia reports that beetles have been seen on flowers (just at one location) and that beetles are thought to be involved in the pollination of other boronias [5]. Heliozelid moths have been recorded on both granite boronia and repand boronia [1]. These moths have been identified as pollination specialists on boronias in south-west Western Australia, including as an exclusive obligate pollinator for one species, brown boronia (*Boronia megastigma*) [10]. Such a relationship is highly unusual in nature – with reliance on one pollinator entailing considerable ecological risk. Although speculated, there is no evidence that such a relationship exists for either of the Granite Belt boronias. The species in Western Australia known to have heliozelid pollinators appear to have flowers with a 'wacky morphology' – such as unusually coloured petals or petals barely open; giant, black, sterile stamens; large bulbous stigmas and strong perfumes [1]. Neither repand nor granite boronia appear unusual in such respects.

During the project we and other project contributors observed several types of insects on the boronia flowers, although insect presence seemed occasional rather than regular (perhaps one reason the flowers are long-lasting). For granite boronia the recorded visitors were European honey bees and small beetles. For repand boronia, the recorded visitors were bee flies, native bees, European honey bees, moths and beetles (including pintail beetles) (Figure 5).

Figure 5. Insect visitors to repand boronia include pintail beetles (left) and bee flies (right). Photos: Muchos Insectos (left) and John Gardner (right).

Insect pollinators can cross-pollinate only over short distances. Because the populations of both boronia species are highly fragmented (Figure 1), due largely to clearing for agriculture and probably also a lack of regular fire or too much fire, there is a risk of inbreeding. Limited pollinator movements could help explain how different populations of each boronia species have come to vary in their responses to fire and drought-breaking rains. If insects are carrying no pollen between the populations, and each population is so small it has limited genetic diversity, they may evolve distinctive response to fire and rain, reflecting local conditions and available alleles.

2.4.2 Seed production, dispersal and longevity

There is almost no information about these topics for the two boronias.

Seed viability in family Rutaceae is known to be highly variable and germination cues are poorly understood. The only relevant information on seed production for the Granite Belt boronias came from a 2009 study of the fill and/or viability and germination of seeds of 112 Rutaceae species stored in the New South Wales Seedbank, which included repand boronia [11]. Only 30% of the tested repand seeds were filled, the third lowest proportion of the 19 boronia species tested. For the species tested for germination (not repand boronia), seed fill was generally significantly higher than seed viability.

Low seed fill can be a species trait, or result from inbreeding depression in small populations, seed predation or environmental conditions such as prolonged drought impacting on pollination or seed development [11]. The low seed fill of repand boronia, if it is consistent across the population, implies that population growth may be constrained by a lack of viable seed. This is consistent with the low level of recruitment observed in most sites. Nonetheless, there were dense flushes of seedlings (up to several hundred) at a few sites in Broadwater State Forest during the project period.

Very large flushes of granite boronia seedlings (ranging from a few hundred to thousands over small areas) have emerged after fire, suggesting that seed viability is not a limitation.

Boronia species have limited seed dispersal capacity. Sclerophyllous Rutaceae species ballistically release seeds when their fruits mature [12]. Landing only a short distance away from their parent, some seeds are probably then shifted further by ants. Both granite boronia and repand boronia have an elaiosome (a fleshy edible attachment) likely to attract ants. Ants are known to disperse the seeds of granite boronia [13]. Other seeds would be shifted by water.

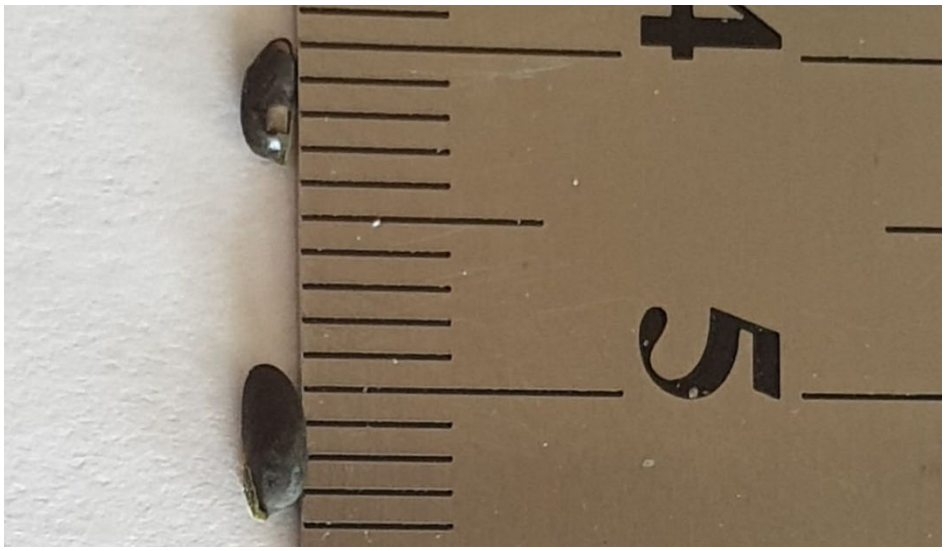

Figure 6. Repand boronia seeds, up to 4.5 mm long, with elaiosomes. Photo: John Gardner

The recovery plan for granite boronia says its soil-stored seed bank is thought to be small and moderately long-lived [5]. Our observations indicate the seed bank is substantial in some sites – for example, one site in Passchendaele State Forest produced a dense stand of 1,500–2000 even-aged granite boronias (about 7 years of age), and at least 5,000 boronias have germinated since 2020 on the slopes of Mt Ferguson. These germination events may not have exhausted the seedbank. The seedbank of granite boronia is likely to be quite long-lived, as indicated by thousands of seedlings that have recently emerged in the southern section of Passchendaele State Forest where live adults are very scarce, presumably due to a lack of fire for more than 40 years.

2.4.3 Germination

Rutaceae plants are often considered difficult to germinate – probably due to gaps in knowledge about the complex interactions between multiple fire-related and other environmental cues needed to, firstly, break seed dormancy and then stimulate germination [14,15].

Rutaceae seeds are generally physiologically dormant [11,14]. This means their seed coat is permeable to water and oxygen (they are not physically dormant) but hormones act to suppress germination even when conditions such as light and temperature are suitable for germination [16]. Seed dormancy has evolved to limit germination during times when the fragile seedlings are unlikely to survive. It enables the accumulation of seeds in the soil from which plants can emerge during optimal times such as after fires, after an intervening period that may extend for decades [16]. Plants with seeds of varying degrees of dormancy can 'distribute their offspring across time and bet-hedge against unpredictably variable environments' [17]. Physiological dormancy can be overcome by a period of dry after-ripening, seasonal stratification or other biological processes during burial, but has not been studied in boronias [15]. Loss of dormancy is progressive and some species cycle in and out of dormancy in response to seasonal variations in temperature and soil moisture.

There have been no studies of the factors breaking seed dormancy or promoting germination in granite boronia or repand boronia. That there is a strong relationship between fire and germination in both species is clear, but whether heat shock or smoke, or both, are critical is not known. Fire can stimulate germination of boronia only once seed dormancy has been alleviated [15]. Nothing is known about what breaks seed dormancy in boronias.

Until 2020, we would have said that fire was essential for germination of granite boronia on the Granite Belt. On many sites that had not burned for 20 years or more, the species had almost died out. But during 2020–22, thousands of seedlings emerged in the absence of fire after drought-breaking rains, particularly in the northern part of its range. This was a highly unusual event – not previously seen by any landholders or local experts we spoke to. The 2002 recovery plan refers to one mass germination event in the absence of fire but with no detail about the conditions preceding it [5]. The federal conservation advice notes 2 NSW sites with significant populations where fire has not been recorded for at least 50 years [6].

3. Boronias and fire

Fire warrants its own section because of its importance to the conservation of boronias and its centrality to the project aims.

3.1 A literature review

In fire-prone regions, plant species can persist by either resprouting from a lignotuber or other similar structure (resprouters) or by recruiting from seed stored in the soil or on the plant (seeders). Occasionally, both occurs.

A critical strategy for the seeders is the possession of a seed bank, which permits persistence when environmental conditions are unfavorable for other life stages [18]. For many species, recruitment between fires is rare or does not occur. Obligate seeding species can suffer decline when fires are either too frequent to allow the establishment of a sizeable seedbank or too infrequent to stimulate recruitment as the adults die.

After fire is the ideal time for plants to germinate – when there are fewer competing plants and more soil nutrients available from ash [19,20]. Many species in fire-prone environments have therefore evolved to germinate after fire – cued to smoke, heat or both. There is no information about which cues work for granite boronia and repand boronia. But there have been experiments on 3 related boronia species in section Valvatae, which have returned a consistent result.

One study of 7 boronia species from the fire-prone heaths and woodlands around Sydney found that germination for all species was negligible without fire cues [14]. The researchers tested the seeds in a laboratory with combinations of heat shock (exposure to a temperature of 90°C for 10 minutes), smoke, and temperatures representing different seasons. For 5 of the 7 species, the maximum germination response followed smoke treatment alone. But for the 2 species from section Valvatae, *B. fraseri* and *B. ledifolia*, heat shock was essential, and the maximum response came from a combination of smoke and heat. For *B. ledifolia*, there was no germination except when both cues were applied and, even then, fewer than 20% of the seeds germinated, indicating dormancy had not been consistently broken [14]. A similar experiment on other boronia species found that *B. keysii*, also in section Valvatae, also responded best to the combination of heat shock and smoke [19].

Although this does not mean that granite boronia and repand boronia are alike in also needing heat shock and requiring or benefiting from smoke, the researchers suggest this could be characteristic of all Valvatae boronias and 'deserves further investigation' [14,19].

How heat shock promotes germination is not known [15]. Temperatures exceeding 120°C are typically lethal to seeds, but heat is likely to be reduced to non-fatal levels at soil depths beyond 1–2 cm [12]. For boronias with larger seeds and thicker testas, such as *B. fraseri* and *B. ledifolia* and other Valvatae species, it has been suggested that the testa restricts radicle growth and embryo enlargement, and that heat shock weakens the structural integrity of the testa and lowers its resistance to radicle penetration [14].

More is known about the effect of smoke. Various chemicals that promote germination have been identified in smoke – karrikins, cyanohydrins and nitrates [21]. They are water soluble but may be able to persist in soil for several years. The concentration of smoke cues that reaches seeds is influenced by the timing and amount of rainfall, soil depth of seeds, and the amount of smoke produced [21].

3.2 Our observations of fire responses and germination

Prior to the project period, in September 2019 a wildfire burned sites with repand boronia in and around Broadwater State Forest. Intentions for prescribed burning elsewhere, particularly across the long-unburnt southern section of Passchendaele State Forest, were stymied by wet weather. We were thus not able to realise the project intention to monitor granite boronia populations after fire.

Granite boronia

As specified in the recovery plan, granite boronias are killed by fire, even if they only suffer leaf scorch. Lacking a lignotuber or similar structure (confirmed in this project), they do not resprout. Regeneration after fire relies on germination – it is an obligate seeder. In the Granite Belt, there is strong correlative evidence that fire is usually essential for germination of granite boronia.

Prior to 2020, at most sites where there had been no fire for at least 15–20 years, there had been a progressive decline in the numbers of granite boronias as adults died. This was the case at several sites – Hillview Nature Refuge, Horan's Gorge Nature Refuge, Egernia Nature Refuge, Tumbledown Nature Refuge, Bungawarrah Nature Refuge, Harslett farm, and the southern section of Passchendaele State Forest. At Horan's Gorge Nature Refuge, for example, we recorded just 130 boronias in 2020 compared to ábout 1,000 in 2009, all of which had germinated after a fire in 2002.

Prior to 2020, the vast majority (probably about three-quarters) of known granite boronia plants on the Granite Belt occurred in the one regularly burned site, in Passchendaele State Forest. There is a clear demarcation in that forest between regularly burned and long unburned sections. In 2020, we recorded more than 90% of the adults in the regularly burned parts.

However, we found that granite boronia can recruit very successfully in the absence of fire. Since 2020, after drought-breaking rains, large numbers of *B. granitica* seedlings have emerged in a few sites that have not burned for several decades – in the thousands in the southern section of Passchendaele State Forest and the adjacent Harslett farm, and in the hundreds on nature refuges at Greenlands. This is consistent with an observation in the recovery plan that 'fire may not always be a prerequisite for germination', with recruitment noted in a heathland that 'appeared not to have carried a fire for several years' [5]. Some recruitment also occurred on a few other private properties, mostly those in the northern part of the range, but not consistently on all properties.

Figure 7. A flush of granite boronia seedlings in October 2020 in the absence of fire (Egernia NR).

We don't have a wholly convincing explanation of the germination response of granite boronia in the absence of fire. It wasn't consistent across the region, occurring only in the northern part of the range, mainly in and around Passchendaele State Forest. The largest population on private land recorded during extensive surveys in 2008 and 2009, at Horan's Gorge Nature Refuge, at the southern end of the range, did not show any germination response during 2020–2022.

One hypothesis is that thick smoke emanating from a wildfire in the Amiens area in September 2019 stimulated germination. But the response was not consistent even in the northern areas and there have previously been severe fires in the Granite Belt, including near Horan's Gorge Nature Refuge, which have not precipitated recruitment. Even if the smoke in 2019 was unusually heavy and exceeded a certain threshold, it seems unlikely that a germination response would occur at properties more than 10 km from the fire. The response to fire evolved to enable seedling emergence when there is much less competition from other plants, which is undermined if plants also emerge where there has not been fire. It is also inconsistent with the prediction that heat shock is required for germination of boronias in section Valvatae.

Another hypothesis is that the severe drought in 2018–19, with 2019 having the lowest rainfall on record for Stanthorpe, substituted for fire in stimulating germination. This could be consistent with the suggestion that heat shock stimulates germination in related boronias by weakening the structural integrity of the testa and lowering the resistance to radicle penetration [14] – for desiccation can reportedly rupture the testa of other species [22]. Droughts resemble fires in killing competing plants and thus providing an advantage to seedlings. However, this again does not explain the inconsistent response across the region (we do not have records to indicate that the drought was any more severe in the northern part of the granite boronia range than in the south).

The inconsistent response across the granite boronia range could potentially be explained by within-species variation, which has been reported to be considerable in other species, particularly with post-fire seed regeneration [23]. Inconsistency could benefit the species by maximising the chances of some seeds being available to germinate at ideal times. Inconsistency may arise when populations are fragmented, as they are on the Granite Belt.

Repand boronia

Repand boronia consistently resprouts after fire, including after hot fires. We recorded resprouting in all sites burned in a wildfire and associated backburning in September 2019, including where the fire was very hot (crown fire). On one private property near Broadwater State Forest, where each plant had been recorded prior to the fire, more than 90% resprouted after fire (Appendix 2, Gardner property).

That repand boronia is a resprouter is consistent with what is reported for NSW populations [8]. But it is contrary to advice on the website of the Queensland Government[3] and the listing advice under the EPBC Act, both of which report that repand boronia in Queensland is killed by fire and is an obligate seeder.

In some sites, repand boronia also germinated from seed, typically 1–2 years after the fire. This response was inconsistent, however, ranging from a couple of areas in Broadwater State Forest with dense flushes of seedlings to others with few or no seedlings.

The degree to which repand boronia relies on fire for recruitment is not clear. On the private property near Broadwater State Forest where the landholders have monitored the population for about 15 years, almost no recruitment (just 2 seedlings) was recorded until after the fire. But in the

[3] https://apps.des.qld.gov.au/species-search/details/?id=17841

southern part of the range, at Applethorpe, recruitment is occurring in sites that have not burned for some decades. The population at the aerodrome reserve, with the biggest surveyed population, has plants of different ages, including young plants.

Figure 8. Repand boronia resprouting in January 2020, 4 months after a hot fire in September 2019 (Gardner property near Broadwater State Forest).

3.3 Recommendations

Prescribed burning, granite boronia

Clarke and Fulloon (1997/1999), who determined the fire response attributes of 45 rare plants in Torrington State Conservation Area, recommended that plant populations of 'high sensitivity' to fire frequency not be burnt more frequently than 8–10 years, nor have fire excluded for more than 20 years [5,24]. This recommended frequency seems justifiable for the Granite Belt, based on the positive responses of granite boronia to regular burning in parts of Passchendaele State Forest (about every 7–10 years), the longevity of the plant (15–20 years) and the decline of populations on most unburned sites.

The Queensland Parks and Wildlife Service has been intending to burn the southern section of Passchendaele State Forest for the past 2–3 years but has been stymied by unsuitable weather conditions. This represents an opportunity to learn about the fire response of granite boronia after a long period of no fire. Because parts of this southern section now have a lot of young boronia plants, which emerged after the drought broke, it would be advisable to avoid burning at least some of these areas. It would be useful to compare the effects of burning and not burning in such sites. The consultants and the Stanthorpe Rare Wildflower Consortium are committed to establishing monitoring sites and comparing post-fire responses when the planned burn proceeds (hopefully in 2023).

The federal conservation advice recommends avoiding the use of prescribed fire between mid-autumn and late spring. This is mostly not feasible on the Granite Belt due to the high fire risks in other seasons.

Most landholders with granite boronia on their properties are committed to its conservation, but it is difficult for many of them to undertake prescribed burning (partly due to the risks of fire spread beyond individual properties). It would be helpful to establish a service to provide expert advice and on-ground help with fire management for properties on the Granite Belt with threatened plants.

Prescribed burning, repand boronia

The available information suggests that burning regimes for repand boronia should be site specific. At the northern sites (around Broadwater State Forest), occasional fires are likely to be beneficial for recruitment, particularly where populations are in decline and not showing any signs of recruitment over many years. However, at the south-eastern sites, particularly at the Stanthorpe aerodrome reserve, where there is a healthy multi-aged population in a long unburned section (and none in a burned section), we recommend not burning that population. The NSW Government has commissioned fire response research on the population near the Queensland border, near the aerodrome reserve, which should provide the information needed to recommend a burning regime for the nearby sites. It could, however, be inappropriate for other sites.

Research on fire responses

More research is needed to clarify the fire responses of both granite boronia and repand boronia. Although it is clear that granite boronia benefits from regular burning, it is unclear whether hot fires and cool fires are both beneficial and equally so. Low-intensity fires for fuel reduction can be detrimental if plants are killed but the heat of the fire is insufficient to stimulate the germination of buried seeds [25].

For repand boronia, research is needed to determine the role of fire in germination. It is important to investigate and compare its fire response in different sites, which may benefit from different fire regimes.

It would be useful to investigate any other germination events for both boronias that occur in the absence of fire to try to determine likely precipitating factors.

Very little or nothing is known about the fire responses of most threatened, near-threatened or probably threatened species on the Granite Belt. Of 44 such species, there is some information (not necessarily definitive) about 14 species (Appendix 1). Investigating the fire responses of all threatened species on the Granite Belt should be a high priority.

4. Other threats

Apart from adverse fire regimes and drought impacts, the only other significant threat is browsing of granite boronias. The other threats noted in the second aim of the project – damage from feral pigs, weed invasion and clearing – were of minor current significance.

4.1 Browsing

Browsing by goats is a significant threat for granite boronia – as noted in the recovery plan. All sites with goats – Passchendaele State Forest and the Greenlands nature refuges – show browsing pressure on granite boronia. On Egernia Nature Refuge goats have on 2 occasions been observed browsing granite boronias, and one of the browsed shrubs subsequently died due to a goat tugging on the foliage, which broke the main stem. Most plants survive a bout of browsing but lose a large proportion of their foliage and their potential for reproduction in that year. Granite boronias often grow at the base of outcrops favoured by goats, judging by the presence of scats, which likely exposes them to repeated browsing. Macropods appear to browse granite boronia as well, but usually at low levels.

Goats and swamp wallabies (the main native browser) have been observed with binoculars and their browsing behaviours are different. Wallabies take a few bites from one plant then move to another, while goats will stand in one spot for five minutes and remove a large proportion of the nearby foliage, plus they roam in groups rather than alone. Granite boronias have softer foliage than most Granite Belt plants and that probably suits goats. Unless goats can be better controlled, they are likely to become a very serious threat as they spread and their numbers increase.

Goats also browse heavily on the endangered *Bertya recurvata*, which is now extremely scarce in Passchendaele State Forest (we recorded fewer than 10 plants) and on the Greenland nature refuge properties.

The nature refuge landholders at Greenlands have an agreement with Sporting Shooters to regularly provide feral animal control. However, they are unable to keep up with population increase because the goats range over an extensive area in very rough terrain. There are no dingoes or wild dogs to serve as predators. A judas goat operation over the entire area, including the state forest, is probably the only feasible way to stop goats becoming an increasingly serious threat to threatened plants.

We found little evidence of browsing on repand boronia. It is less often found near outcrops favoured by goats.

4.2 Habitat destruction

Clearing has presumably been a significant cause of decline for both boronias in the past, although more so for repand boronia because it inhabits woodlands on flats that would have been cleared for farming whereas the rocky areas favoured by granite boronia are largely unsuitable for farming.

The one site known to have been subject to clearing in recent times was along the railway line at Cottonvale, where a track was cleared in an area known to have repand boronias.

Some boronia sites in Passchendaele State Forest would have been destroyed for planting pine trees. There may be opportunity in the near future for some habitat recovery. Hancock Queensland Plantations, which manages the pine plantations, intends to focus its operations in the more

productive areas, which means that some areas formerly planted with pine are likely to be rehabilitated. This could be of potential benefit to granite boronia, unless changes to the soil or other types of disturbance have rendered these areas unsuitable. Management of regenerating sites may be needed to prevent weed invasion.

Figure 9. Feral goats in the vicinity of granite boronias (Egernia Nature Refuge). Goats were seen to destroy a nearby mature boronia by breaking the stem. The dead shrubs in the background are due to the drought in 2019, during which there was extra browsing pressure on many plants. .

4.3 Recommendations

As a matter of urgency, control goats in Passchendaele State Forest and surrounding private properties to prevent them becoming an unmanageable problem in future. The only effective method in this rugged country may be use of a Judas goat. This will also benefit the endangered *Bertya recurvata* and other species.

5. Species status

5.1 The population and status of granite boronia

Like many obligate seeders, granite boronia is subject to large population fluctuations, depending on fire regimes and rainfall.

By early 2020, granite boronia was in a poor state across most of its range, due to the end-of-life attrition of adults, exacerbated by drought deaths, and very limited recruitment in most sites except in regularly burned parts of Passchendaele State Forest. In some sites, the boronias were also subject to browsing damage by goats and probably also macropods. Most populations on private properties and those in southern Passchendaele State Forest had severely declined.

Since early 2020, when substantial falls of rain broke the region's worst drought on record, there has been a dramatic revival of some populations in the northern part of the granite boronia range, particularly in the long unburned southern section of Passchendaele State Forest and on the adjacent property, Sow and Pigs. Although the total population has substantially increased since the start of this project due to the post-drought revival, the decline on several private properties remains of concern. The persistence and recovery of granite boronia across its current range will depend on more regular burning on private properties and in the unburned section of the state forest.

At the beginning of 2020, we estimate the granite population was about 5,000 (on the known sites), which is consistent with numbers recorded more than a decade prior, about 7,000 in 2008 and 2009 (Table 2). Since 2020, the population of mature plants has probably doubled to tripled, due to mass germinations after drought-breaking rainfalls. The most remarkable increase has occurred on the slopes of Mt Ferguson, with more than 5,000 boronias (and possibly up to 10,000) emerging since 2020, which is at least 30 times the population recorded in 2008 (Table 2). Most have flowered within 1–2 years and are up to a metre in height. While many of the recent boronia recruits have flowered, and are therefore counted here as mature, it is too early to know what proportion of these and any additional seedlings will survive and reproduce. The younger flowering plants might not produce many viable seeds. There has been considerable attrition of seedlings noted on some properties (e.g. Egernia Nature Refuge), and this is probably the case in most places, particularly in shallow or large-grained soils that dry out after a few weeks without rain.

Granite boronia is said to have been common or abundant on the Granite Belt – from Amiens to Ballandean – until about 60 years ago [26]. The population decline since then has been attributed mainly to too-frequent fire [26]. However, given the documented declines on properties that haven't burned in several decades, including the southern part of Passchendaele State Forest, a lack of regular burning is also likely to have been a substantial driver of decline. Black cypress pines (*Callitris endlicheri*) benefit from lack of fire, and they reduce habitat for boronias when they grow in dense stands. Substantial cypress thickening has occurred in some areas.

With the recent boost in the granite boronia population and with much of the population on public land managed in part for conservation, the future of this species in Queensland is not at risk in the short-term. However, the trend of decline on most private properties, including on nature refuges, means that the area of occupancy could continue to decline in the longer term. This would be the case if adverse fire regimes continue to apply or if feral goat populations increase and spread to new areas.

Table 2. Granite boronia populations at some sites, pre-2010 and post-2020

Area	Numbers pre-2010 (year: # mature plants)	Numbers post-2020 (year: # mature plants + seedlings)
Passchendaele State Forest	2008: 5,000	2020–21: 4,000 (+ thousands of seedlings)
Boatfield property	2008: not recorded	2020: 180 (+ 20 seedlings)
Harslett Farm (Mt Ferguson)	2008: 157	2022: >5,000 (+ seedlings)
Harslett farm (Sow & Pigs)	2008: 315	2021: 12 (+ >500 seedlings)
Egernia Nature Refuge	2008: 120	2019–20: 20 (+ hundreds of seedlings)
Tumbledown Nature Refuge	2008: 65	2019–20: 63 (+ hundreds of seedlings)
Bungawarra Nature Refuge	2009: 124	2022: 0
Hillview Nature Refuge	2009: 250	2020: 70 (+ ~600 seedlings)
Horan's Gorge Nature Refuge	2009: 1,000	2020: 130 (+ 30 seedlings)
Total (approximate)	7,000	>10,000

Sources: 2008 survey: Holmes & Holmes [27]. 2009 survey: Donatiu [28]. 2020–2022: this project.

5.2 The population and status of Boronia repanda

In contrast to granite boronia, repand boronia does not appear to undergo large population fluctuations. Instead, it is a remarkably persistent plant, able to endure unfavourable conditions, and resprout after fire, including hot fires. It can also survive falling limbs crushing the plants. With a few exceptions, the numbers recorded in this project are comparable with those recorded in 2008 and 2009 (Table 3).

Table 3. Repand boronia populations at some sites, pre-2010 and post-2020

Area	Numbers pre-2010 (year: # mature plants)	Numbers post-2020 (year: # mature plants + seedlings)
Broadwater State Forest	2008: 575	2020–21: 700 (150 resprouting + thousands of seedlings)
Kurrajong Nature Refuge	2008: 140 2009: 50	2020: 50 (+20 seedlings)
Gardner property	Unrecorded	2020–21: 31 (31 resprouting, 28 seedlings)
Hibberd property	Unrecorded	2020: 18 (+ 3 seedlings)
Railway & road reserves	2008: 120	2020: 265
Donnelley's Castle	2008: 15	2020: 6
Doctor's Gully, Groen property	2008: 280	2021: 340
Doctor's Gully, 2 other private properties	2008: 190	No access
Aerodrome reserve	2008: 150	2020: 1,200

6. Conclusion

6.1 Summary of project achievements against aims

Following are the project aims and some notes about the extent to which they were achieved.

1. Assess the current population size and distribution of the most important subpopulations of Boronia granitica (endangered) and Boronia repanda (endangered) on the Granite Belt.

> *Achieved. There were a few private properties with known populations that we were unable to access – permission was not granted – but we surveyed the majority of properties across the known range.*

2. As a basis for future management, during the surveys document any threats observed – particularly signs of browsing and likely sources (eg goats, deer), damage from feral pigs, weed invasion, drought impacts, inappropriate fire regimes, clearing.

> *Achieved. At all sites surveyed we noted any threats observed or volunteered by the landholders.*

3. Assess recent recruitment rates – document numbers of seedlings and juveniles, and determine whether recruitment, where found, is occurring in response to fire or in its absence.

> *Achieved. This was a major focus of the project, due to significant post-fire and post-drought recruitment.*

4. Set up fire monitoring sites through mapping and photo monitoring as a basis for assessing the response of the boronias to future prescribed burning and wildfires in the Passchendaele and Broadwater state forests.

> *Partly achieved. We mapped all surveyed populations in detail but did not set up monitoring sites due to the cancellation of prescribed burning due to wet conditions. This will be done in future once we are confident that prescribed burning will proceed.*

5. Assess the impacts of fire by monitoring subpopulations of *B. granitica* and *B. repanda* in Passchendaele and Broadwater State Forests, if and when the forest managers do prescribed burning or wildfires occur (including subsequent to the project period).

> *Not achieved in Passchendaele due to a lack of prescribed burning*. *Partly achieved in Broadwater after a wildfire in 2019 that occurred prior to the project proceeding, thus precluding the possibility of before and after comparisons. The consultants and the wildflower consortium intend to continue this work.*

6. Encourage land managers to mitigate threats – eg by fire management and fencing or pest control for browsing impacts (including subsequent to the project period).

> *Achieved and to be continued. We discussed management with landholders on the sites we surveyed, including the managers of Passchendaele State Forest. We presented at a local workshop on fire management.*

6.2 Compiled recommendations

Following are general recommendations, mostly compiled from the recommendations in previous sections. Appendices 1 and 2 also contain some recommendations for particular properties.

The project consultants and members of the Stanthorpe Rare Wildflower Consortium are committed to ongoing work with boronias – in particular to monitor post-fire responses when prescribed burning does occur and monitor the survival of plants that have germinated since the breaking of the drought.

Life history attributes

Landowners, Stanthorpe Rare Wildflower Consortium: Continue documenting the life cycle attributes of the 2 boronias, including germination responses, seedling survival, time to maturity, potential pollinators, seed production, longevity and causes of mortality.

Fire regimes

Researchers, landholders, Stanthorpe Rare Wildflower Consortium: Monitor and document the germination responses of each boronia to wildfires and prescribed fire, recording fire history, fire season and intensity. Where feasible, establish monitoring sites prior to prescribed burns.

Stanthorpe Rare Wildflower Consortium: As a priority, monitor the responses of granite boronia and other threatened plant species such as *Bertya recurvata* to prescribed burning in the southern part of Passchendaele State Forest, including in monitoring sites established and surveyed prior to burning.

Queensland Parks and Wildlife Service, Hancock Queensland Plantations, Stanthorpe Rare Wildflower Consortium: As has been occurring, liaise prior to any prescribed burning in Passchendaele State Forest about granite boronia sites that would be best to protect from fire (e.g. where there are many young plants) and to enable pre- and post-burn surveys for response monitoring.

Stanthorpe Rare Wildflower Consortium: Recommend prescribed burning regimes to landholders with granite boronia populations at a frequency of no greater than about 10 years and up to about 20 years. For landholders with repand boronia populations, recommend a burning regime based on the state of the boronia population at each site and whether recruitment is occurring in the absence of fire, also taking into account the general state of vegetation.

Queensland Government, Australian Government: Update online information about the fire response of repand boronia, specifying that it is a resprouter and removing text that it is an obligate seeder.

Feral goats and other browsers

Queensland Parks and Wildlife Service, Hancock Queensland Plantations, landowners (Greenlands): As a high priority, remove goats from Passchendaele State Forest and surrounding private properties to prevent them becoming an unmanageable problem in future and further endangering *B. granitica* and other threatened species such as *Bertya recurvata*.

Landowners, Stanthorpe Rare Wildflower Consortium: Document any significant browsers on granite and repand boronia and other threatened plant species. If feral goats spread to new areas, seek early action to try to eradicate them before they become entrenched.

Other

Stanthorpe Rare Wildflower Consortium: As opportunities arise, survey additional properties within the range of the 2 boronia species.

Stanthorpe Rare Wildflower Consortium: Undertake surveys in about 5 years time to monitor population trends on the most important sites for each boronia species, including on sites where there was a strong germination response after the 2019 drought.

Hancock Queensland Plantations, Stanthorpe Rare Wildflower Consortium: Work together to monitor the rehabilitation of sites in Passchendaele State Forest being returned to native forest, including documenting whether there is natural regeneration of boronia in areas formerly planted with pines.

Landowners, *Stanthorpe Rare Wildflower Consortium*: With permission from the Queensland Department of Environment and Science, harvest seeds from repand boronia and granite boronia to test whether they will readily grow from seed in a pot, with a view to supplementing populations at sites where they are declining. This would include checking whether seeds are filled (as a lack of fill may be a problem for repand boronia in particular).

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Appendix 1. Site notes, Boronia granitica

Here are summaries of site notes for the surveyed properties, going from north to south. A few very small sites were omitted.

Passchendaele State Forest

Managers: Queensland Parks & Wildlife Service, Hancock Queensland Plantations Pty Ltd

Estimated population (2020): 4,000 mature plants, many thousands of seedlings.

Passchendaele State Forest has long been regarded as the most important site for the species in Queensland, with about 70% of the state population recorded there in surveys in 2008 and 2009 (Table 2). Prior to 2020, we estimate more than 80% of the Queensland population occurred in this forest, due to declining populations on private properties. The population had probably also declined in the forest (we estimated 4,000 compared to 5,000 a decade prior). Boronias in some sites showed signs of drought stress (sparse leaves) and were severely browsed, including by feral goats. Unless these are controlled, goats are likely to become a major threat to boronias in the future, as has been the case in some New South Wales sites [5].

The main reason for the relative abundance of granite boronia in the state forest has presumably been the regular burning of sites for protection of the pine plantation. Prior to 2020, at least 90% of the state forest population occurred in the regularly burned areas, particularly in an area south of Forestry Road last burned in 2013. A prescribed burn attempted in 2020 in the same area largely failed and it has been too wet since then to burn. For the prescribed burn in 2020, we liaised with the forest managers and provided details of boronia populations (see map below), which enabled the burn managers to protect important populations by raking buffers. Burning is helpful, but not if it kills young boronia stands that have not contributed many seeds to the soil bank.

Many thousands of seedlings emerged in both the unburned and the regularly burned areas during 2020–2022, starting after substantial rainfall in early 2020. At many sites in the long-unburned southern section of the forest, seedlings emerged where no adults had survived. It appears there has been germination around most of the rocky outcrops of the southern part of the forest (not comprehensively mapped). Mass germination of *B. granitica* has previously been observed by members of the consortium and other locals only after fire. The boronias that germinated after the drought have shown variable growth rates – many growing quickly and flowering within a year while others have remained small and are yet to flower. The difference appears to be due to different light levels, and could also reflect soil variation, but this has not been systematically tested.

The Queensland Parks and Wildlife Service plans to burn the southern part of Passchendaele State Forest with aerial ignition. This area has not burned since 1980 and several species are likely to benefit, including the threatened *Bertya recurvata* and *Dodonaea hirsuta.* Prior to 2020, there were very few mature *B. granitica* plants left in the southern section. The timing of the planned burn is unfortunate for the thousands of seedlings that have emerged since 2020, as the young plants are unlikely to have produced many seeds to replenish the seedbank. But the burn is likely to be patchy and many young boronias are likely to be protected from fire by rocks. Some populations could be protected by avoiding nearby ignition. We expect that the losses will only be partial and the environmental benefits would exceed the costs.

The managers of the pine plantation, Hancock Queensland Plantations Pty Ltd, have advised the wildflower consortium that they plan to condense their operations to the most productive areas and

potentially rehabilitate the less economic areas. This may offer opportunities for boronia to re-establish in some former forestry areas, although the potential for this has never been tested. The forestry managers have indicated an interest in working with the wildflower consortium to monitor rehabilitation.

Recommendations:

- Monitor the granite boronia population in the southern section of the forest.
- Prior to prescribed burning, particularly for the long-unburned southern section of the forest, QPWS and the wildflower consortium collaborate to identify sites to protect from fire and establish monitoring sites to undertake pre-burn and post-burn surveys to monitor germination, time to flowering, survivorship.
- Control feral goats in collaboration with surrounding landholders.

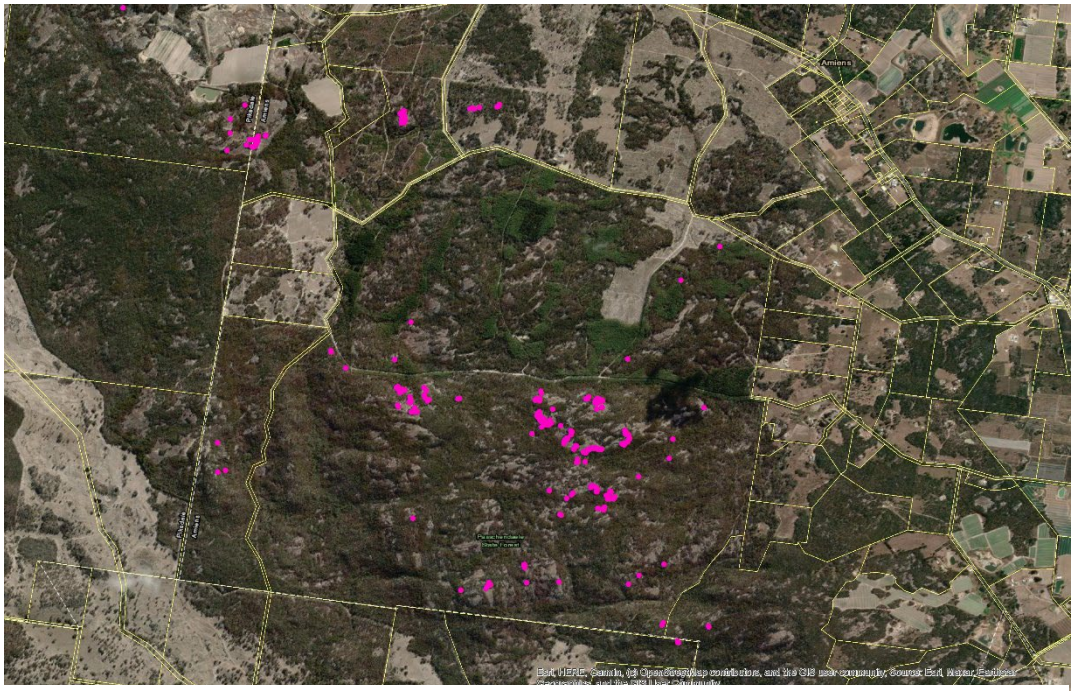


Figure 10. Records of *Boronia granitica* in 2020--2021. As shown here, most boronias grow south of Forestry Road. Until 2020, most were in the regularly burned area just south of Forestry Road, in the area on the map below.

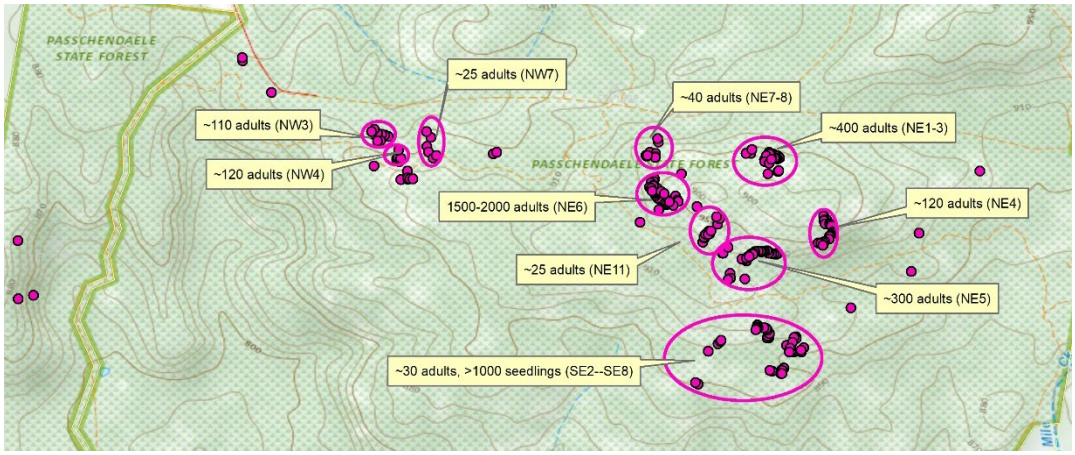


Figure 11. A map provided to forest managers to enable protection of important boronia populations during a prescribed burn in 2020.

Harslett farm, Amiens

[redacted]

Estimated population: (a) Sow and Pigs section (September 2021): 12 adults, >1,000 seedlings; (b) Mt Ferguson (September 2022): 5,000–10,000 plants (not feasible to count).

The Sow and Pigs boronia population is scattered among granite pavements. In 2008, 315 adults were recorded, so there has been a >90% decline in adult numbers over 14 years, with just 12 recorded in 2021. This is the same pattern of decline recorded in other unburned sites. No fire has been recorded in recent decades. However, hundreds of seedlings have emerged since substantial drought-breaking rains in 2020.

The Mt Ferguson population is scattered over a large hillside area (RE 13.12.2/13.12.6). In spring 2022, it was a mass of prolifically flowering plants, almost all of which have emerged since 2020. The landowners had only ever previously seen a few scattered boronias in this location (the family has been on this farm >100 years). In 2008, 158 adults were recorded [27]. The new recruits were first noted by the landowners in October 2021. This area has not burned for >100 years. In spring 2022, the boronias were already up to 1 metre high and had flowered precociously (within 1 year). The only browsing noted was near a track and attributed to swamp wallabies.

Recommendation: Establish monitoring sites on the slopes of Mt Ferguson to monitor the rate of survival of the plants that germinated in 2020–21.

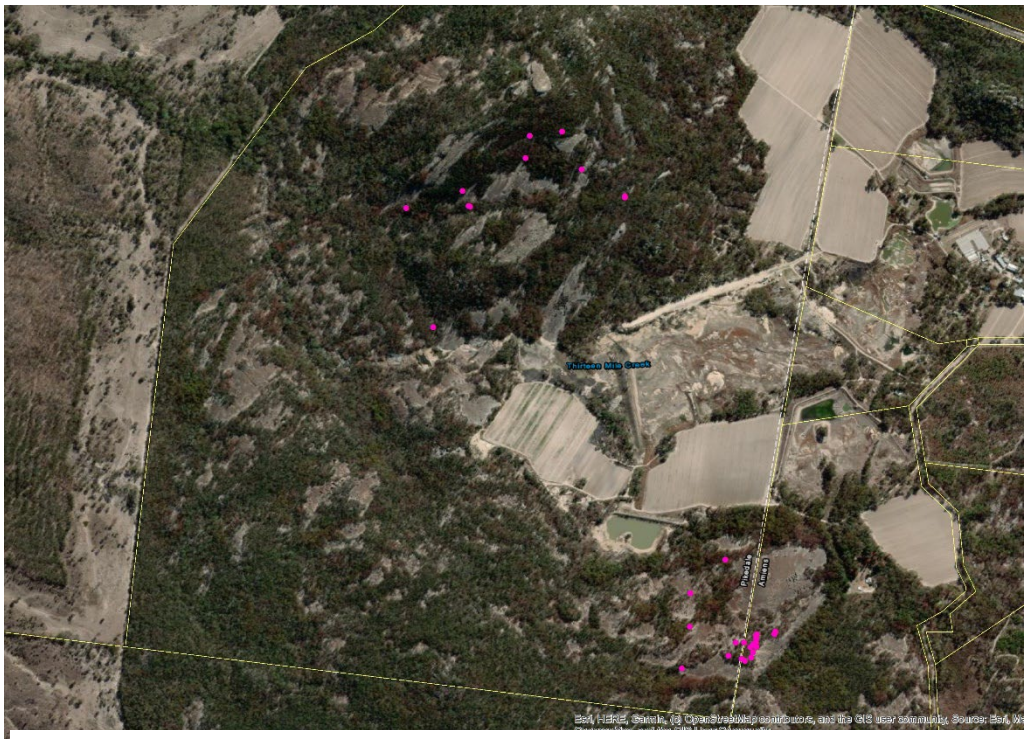


Figure 12. The 2 main sites for granite boronia are the slopes of Mt Ferguson (top left) and a rocky pavement area known as Sow and Pigs (bottom right). The Mt Ferguson points are only roughly indicative of the area and do not reflect the thousands of boronias now growing here.

Boatfield property, Amiens

[redacted]

Estimated population (September 2020): ~180 mature plants and 20 seedlings at 2 sites.

All boronias had germinated since a fire in 2010 that burned the entire property. Lots of seedlings emerged after the fire, but many didn't survive. Nonetheless, there were more boronias in 2020 than when the Boatfields bought the property in 2004. Most are 50–100 cm in height, with a maximum stem diameter of 1.2 cm. The vegetation on the property was badly hit by drought. A few boronias had recently died. Browsing damage was evident on several boronias, but uneven. No goats have been seen by the landholders, but up to a dozen deer are regularly recorded. There was heavy browsing of a few *Callitris* and *Cryptandra* seedlings. The boronias were heavily in flower and were being visited by honey bees). The landholder says the stand had rarely looked this good. In 2023 the landholder reported that additional seedlings had emerged but didn't survive a recent dry period. Unusually for granite boronia, many plants here are growing on flat ground, not immediately adjacent to granite outcrops (though outcrops are close by).

Figure 13. Some boronias on the Boatfield property are unusual on the Granite Belt for not growing near a granite outcrop (top right). The boronias on this property (shown centre on the map) are near a

Greenlands properties

Egernia Nature Refuge: [redacted]

Estimated population (2019–2020): 18 + hundreds of seedlings

Tumbledown Nature Refuge: [redacted]

Estimated population (2019–2020): 63 + hundreds of seedlings

Dragonweyr Nature Refuge: [redacted]

Estimated population (2019–2020): 10 + seedlings

These 3 nature refuge properties (RE 13.12.2/13.12.6), like the southern part of Passchendaele State Forest, have not had a wildfire for at least 50 years. Prior to 2020, granite boronia had become very sparse, dwindling to a few dozen mature plants. On Egernia Nature Refuge, for example, a population of 120 plants in 2008 had declined by 80% to about 20 plants. After the drought-breaking rains, hundreds to thousands of seedlings have emerged, including in at least one site (on Egernia) where no adults had been seen – below a rock pavement in fairly densely shaded woodland. As expected, there has been considerable attrition of seedlings, with some apparently lost to browsing and others during dry periods. A couple of seedlings wilted and died for no apparent reason, perhaps from pathogen attack. Seedlings growing a few metres away were not affected. Among surviving seedlings, growth rates are proving to be very variable, even among plants growing close together (but not close enough to limit each other), with some showing substantial growth and others very little. Differences in shading and soil properties may explain this, and differential browsing certainly explains some variation.

Patchy burning on Tumbledown Nature Refuge appears to have precipitated some germination, although it is not possible to distinguish between that and the germination following rainfall in areas where there had been no fire. In one site on Tumbledown where about 20 seedlings have come up since rainfall, the landowner was told that hundreds used to flower there every spring.

The boronias on these properties are at great risk from feral goats, which were allegedly released by a neighbour more than a decade ago. They number at least 40 and the population is growing despite attempted control by shooters. Boronias have been frequently damaged by browsing, particularly during the drought. The most vulnerable boronias are those that grow close to pools that goats drink at, around outcrops favoured by goats, and beside regularly used bush tracks near these. Goat dung is often found near heavily browsed plants.

Recommendations:

- In collaboration with the managers of Passchendaele State Forest, implement an effective program to control goats.
- Undertake prescribed burning near boronias and monitor the outcomes.
- Monitor the survival of seedlings that have germinated since 2020.

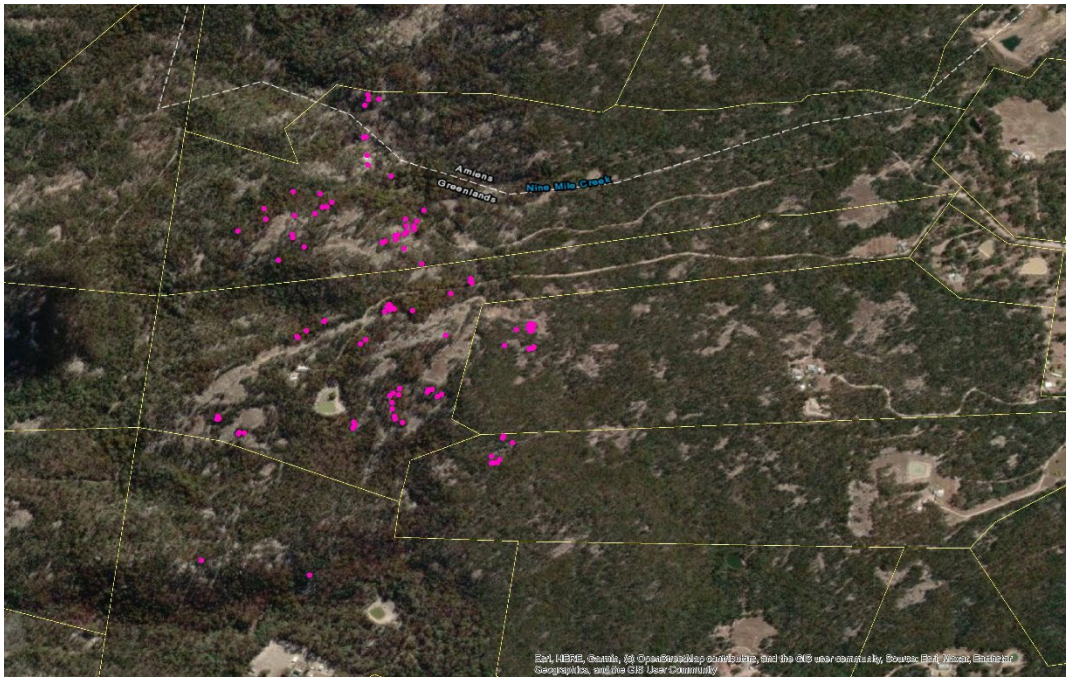


Figure 14. Most of the boronia population in the Greenlands area is on the 3 nature refuge properties (Egernia, Tumbledown and Dragonweyr). The forest here has thickened considerably due to a lack of fire for about 50 years. Some is subject to periodic cool prescribed burns.

Bungawarrah Nature Refuge

[redacted]

Estimated population (spring 2020): none found (searches by landowner)

There are 2 known sites for granite boronia on this property. In December 2006, a wildfire caused by a lightning strike and subsequent backburning burned all known granite boronia plants. Prior to that, the most recent fire had been 24 years previously.

At site 1, on rock pavement above a creek, 97 seedlings were counted 11 months after the fire, in November 2007. There had been 4–5 adults there in the late 1990s. In spring 2009, 87 plants were recorded at site 1 [28]. But within 4–5 years, most post-fire plants had died. The few that survived grew to a maximum height of about 2 metres and flowered regularly. They may have died in the 2018–19 drought as they were in shallow soil on a rock pavement. The site is currently choked out by grass.

At site 2, a few ridges away to the south in a south-facing gully (with some protection from fire), 12 post-fire seedlings were recorded in November 2007, and 37 mature plants were recorded in spring 2009 [28]. In July 2016, there were 8 remaining plants, 1–1.5 m high, flowering. Site 2 has not been checked recently.

Prescribed burning will probably be necessary to restore granite boronias to this property, if there is still a seedbank.

Recommendation: Undertake burning in sites where there used to be boronias.

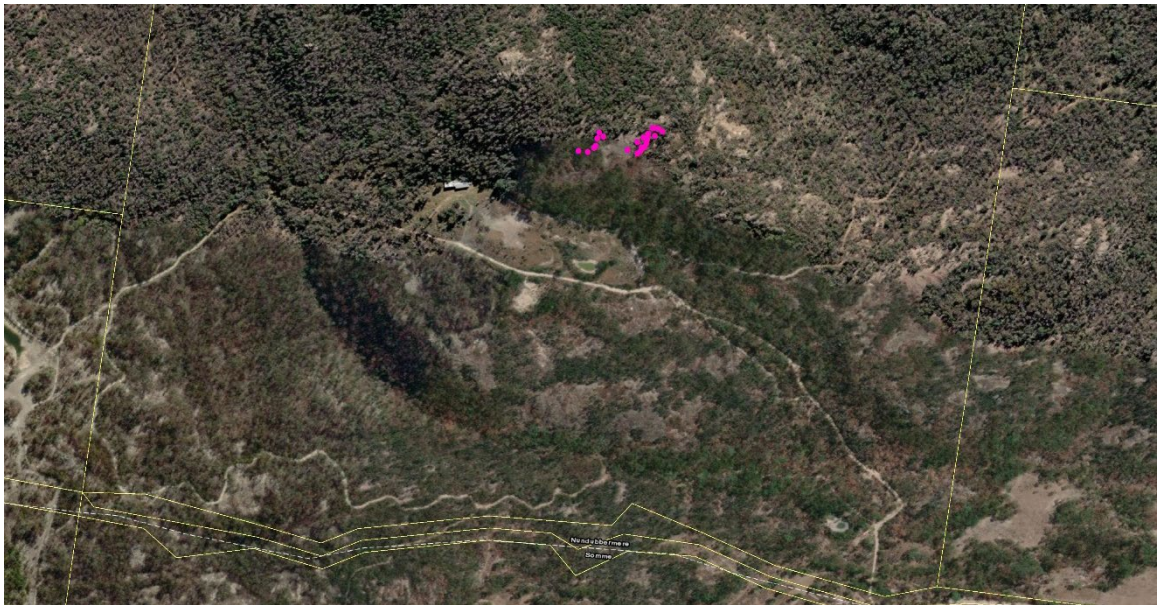
Hillview Nature Refuge

Manager: [redacted]

Estimated population (September 2020): 70 mature plants and 600+ seedlings.

Most boronias are likely to have germinated since a large fire in February 2009. In 2020, many had tufts of leaves at the ends of long bare stems (not seen at other sites), but the plants look healthy. The surrounding vegetation had been badly hit by drought, with many dead shrubs and trees. Most boronias were 1.2–1.5 metre tall with a maximum stem diameter of 1.5 cm. One plant surrounded by rock that presumably escaped the fire had a stem of 1.8 cm. *B. granitica* is occupying only a small part of what seems like suitable habitat. *B. anethifolia* also occurred on this site.

Strong browsing damage was evident on *Philotheca*, *Cryptandra*, *Exocarpus*, *Kardomia*, *Harmogia densifolia.* But there was only minor browsing damage on *B. granitica*. The owners have not recorded goats but have seen deer (eg recent tree damage due to antlers). Macropod dung was evident.



Heumen/Luhrman property, Nundubbermere

Managers: [redacted]

Estimated population (September 2020): 0 adults, 200–220 seedlings

The landowners knew of just 6 adults, which all died during the drought. The 200 or so seedlings emerged after rain in February 2020. They are scattered below a small granite outcrop where there used to be adult plants over a total area of about 30 m^2. The landowner reported in February 2023 that about two-thirds have survived and most are 60–90 cm. They flowered in spring 2022. About 10 additional seedlings have emerged in a nearby spot.

There has apparently been no fire on this property since the 1950s. This is consistent with the dense cypress growth and few shrubs on the property. There were no signs of browsing on the seedlings. The landholders see deer regularly in winter but there are no goats.

Recommendation: Undertake prescribed burning in areas near the current boronia population or around rocky outcrops and monitor the outcomes.

Figure 15. The boronia seedlings have emerged through thick ground layer into a shaded area, but appear to be thriving and flowered within 2 years.

Horan's Gorge Nature Refuge

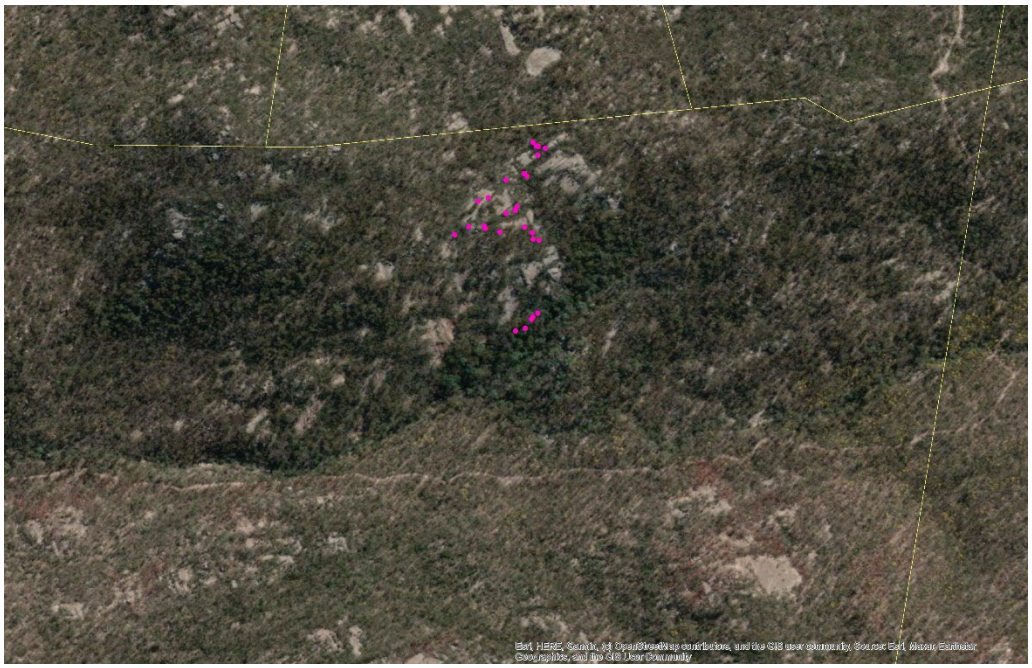
[redacted]

Estimated population (October 2020): ~130 adults and 30 seedlings

This property previously had the largest known population of granite boronias on private land with about 1,000 plants recorded in 2009 on 2 sites [28]. Most emerged in response to a fire in 2002, so are about 20 years old. The numbers have since declined by about 85% to 130 plants, many of which are senescing, and occur now in just one site. There has been no fire since 2002. There were plans for a prescribed burn in 2022, but it did not proceed due to too much rain. The landowners report that there has been little germination since the drought ended, with just 12 seedlings counted in July 2022. Why there has been so little germination in contrast to that on properties in the northern part

of the range is one of the puzzles about granite boronia. The boronias are not browsed. There are no goats on the property.

Recommendation: As intended by the landowners, undertake prescribed burning and monitor the outcomes.



Appendix 2. Site notes, Repand boronia

Here are summaries of site notes for several of the surveyed properties, going from north to south. A few smaller sites (e.g. Donnelleys Castle) are omitted.

Groen property, Doctor's Gully

[redacted]

Estimated population (August 2021): 340 adults, no seedlings.

This is the largest known population on private land (RE 13.12.2). The number of plants has apparently increased by about 20% over the past 13 years, with 280 individuals recorded in August 2008 [29]. There were healthy plants of various ages, but no seedlings, on and around rock pavement and in forest (RE 13.2.2). During the time of this landowner (since 1994), there have been no fires. The landowner has seen pigs and deer (and does not wish to control them) and sheep were grazed on the property until 2 years prior. There are no signs of browsing on the boronias. No management problems were apparent.

There are known to be repand boronia populations on at least 2 other properties in this area, but we could not obtain permission to access them (letters were sent via the Southern Downs Regional Council requesting permission).

Broadwater State Forest

Manager: Queensland Parks and Wildlife Service

Estimated population (2020–21): 700–800 + >1,000 seedlings

This forest (RE 13.12.2) is a major stronghold for repand boronia. Most of the southern part burned in the September 2019 wildfire and other parts were subject to backburning during the fire. Although the fire was very hot in many places (it was a crown fire), large numbers of repand boronias were able to survive by resprouting from below ground. We do not know the proportion that survived but given that the boronia population appears to have slightly increased since surveys in 2008 (when there were about 600), it appears that most probably did survive (as was the case for a nearby property where pre-fire numbers were known, see Gardner property below).

There was also a germination response in some areas, but this was patchy, ranging from none in most sites to extensive in just a few sites. This could be related to fire intensity, with some anecdotal observations that sites with the most germination did not burn as intensively as other sites with only resprouting boronias. In one 0.4 hectare area we counted just over 100 resprouting adults and an estimated 1000 juveniles. In contrast to the germination response of granite boronia to drought-breaking rains even in the absence of fire, the germination response of repand boronia in the forest seemed more likely to be due to the fire because the response in unburned areas was nowhere near as intense.

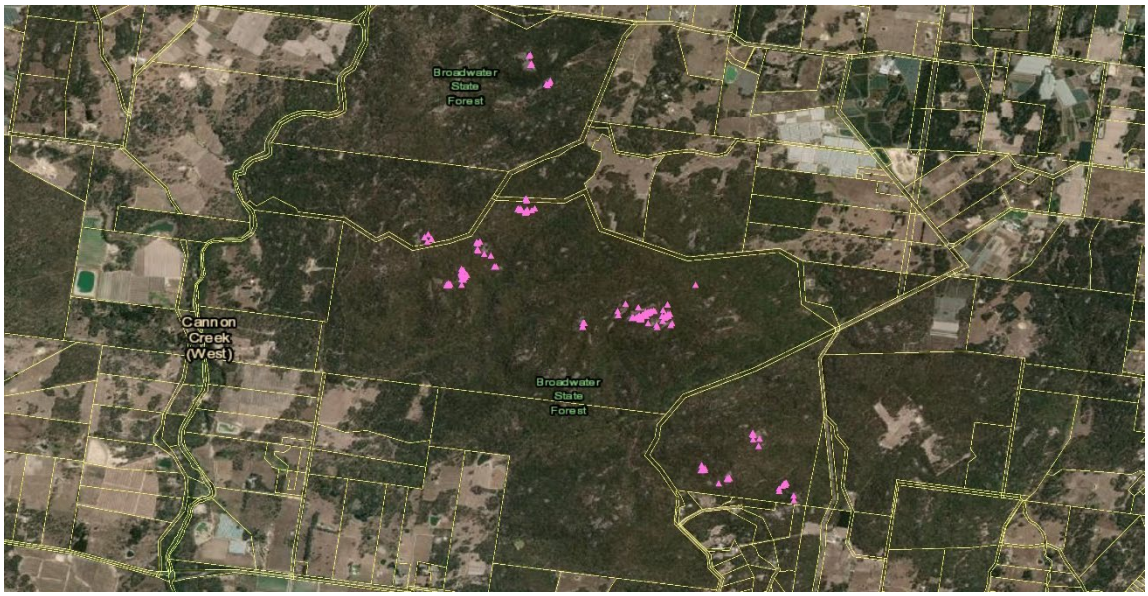


Figure 16. Resprouting boronias in Broadwater State Forest in March 2020 in an area backburned in September 2019.

Kurrajong Nature Refuge

[redacted]

Estimated population (March 2020): 50 adults (4 resprouting), 20 seedlings.

This forest site (RE 13.12.2) has not had a wildfire since about 1956, reflected in thickening of Callitris and Leptospermum. The owner did a cool burn in 3 of the 4 locations in 2014. The 50 adults we recorded is equivalent to the number recorded in a 2009 survey, suggesting that the cool burn in 2014 did not precipitate much or any germination. However, the number in 2020 is fewer than the 140 recorded in 2008 (the disparity between the 2 surveys conducted within a year of each other is not explained). The landowner says the numbers and their condition have declined. The boronias here are smaller (<40 cm high) than at other sites and have been heavily browsed – by macropods, according to the landowner (no goats). He said they were previously 4—5 times larger. They are typically multi-stemmed at the base rather than a single vertical shoot. They probably died back from drought (or browsing) and resprouted following the heavy rains. There has been no post-drought browsing despite 20 cm flushes of lush new growth, but there is green feed everywhere to attract the attention of browsers. The evidence fits them being good drought fodder because they are soft (low fibre), but not highly desired when there is ample feed.

Figure 17. The boronia population on Kurrajong Nature Refuge (north of the road) is near other boronia populations in Broadwater State Forest.

Figure 18. Boronia habitat in Kurrajong Nature Refuge subject to a prescribed burn in 2014.

Gardner property, Stanthorpe

[redacted]

Estimated population (January–April 2020): 31 resprouting plants, 8 seedlings. December 2021: 20 additional seedlings.

The repand boronias are growing near the summit of a hill, many below a granite outcrop, where they are likely to be receiving a rainfall subsidy. The light is mostly dappled. They have been monitored by the landowners for about 15 years.

A severe wildfire in September 2019 burned the entire site. The fire was hot enough to have destroyed 2 nearby houses. All hollow-bearing trees on the property were destroyed and some fallen logs and trees were reduced to ash. Before that, there hadn't been a fire since 1974. Boronia resprouting from below-ground occurred rapidly – despite the plants having been under stress during the drought (appearing very twiggy). Within 4 months after the fire (when surveyed in January 2020), the resprouting foliage was already 10–20 cm high and appeared lush. The original stems protruded above ground by about 5 cm. The 6 seedlings also recorded in January 2020 were growing in the competitive zone, close to the presumed parent, indicating limited seed dispersal. One seedling was just 16 cm from a resprouting adult. Additional seedlings (n=20) emerged in late 2021 in a site where the original plants had died about 4 years prior to the fire. Currently, there are 17 seedlings in this site, ranging in height from 2 to 10 cm in a 2 x 2 metre area.

The population had been in decline prior to the fire, with about 25% having died over the previous 13–14 years, including a few recent losses during the drought. Although the boronias had flowered each year, there had been very little recruitment, with only 2 seedlings recorded since 2011. These emerged some time prior to the drought, barely grew, did not flower, and died during the drought.

Just prior to the fire in September 2019, there were at least 34 plants. About 90% of these resprouted within 4—6 months after the fire. If most seedlings survive, the pre-fire population will have almost doubled. Twenty of the seedlings emerged in a site where all adults had died prior to the fire. The resprouting plants and some seedlings flowered within a year, but few seeds were produced (John and Ursula Gardner pers comm). During the recent drier weather, the boronias have struggled, with at least 3 mature plants and some seedlings dying.

Red-necked wallabies, wallaroos and swamp wallabies visit the property, but there is no sign of browsing on the boronias.

The Gardner property in January 2020 (left), 4 months after an intense wildlife, by which time repand boronias were vigorously resprouting (right).

Hibberd property, Stanthorpe

[redacted]

Population estimate (October 2020): 18 adults (17 resprouting), 3 seedlings

Most of this property burned in September 2019 although apparently not as severely as elsewhere. The boronias occupied a small area amongst boulders. All except 1 were resprouting. The one unburned plant and several of the resprouters were flowering. The landowner thought it likely that the 18 mature boronias constituted the entire population prior to the fire.

The Hibberd property just after a wildfire in September 2019. Photo: Kylie Hibberd

Rail and road reserves

Manager: Queensland Rail: railway reserve, Cottonvale

Population estimate (February 2020): 350 in the railway and adjoining road reserve

These boronias show little evidence of stress from drought. They were flushing new growth from upper stems and flowering well. They show no sign of browsing. There is a dense ground layer of fallen leaves and stems, which is likely to impede the emergence of boronia seedlings. The bark on most trees has no charcoal, indicating that fires are rare or absent along the railway line. This indicates that most of the shrubs are old. No seedlings were seen. A few plants were growing on the bare bank of the railway easement and these could have been young plants that recruited without fire. But the number of plants on bare ground is very limited, indicating that bare ground is insufficient to stimulate germination. Along some stretches introduced pines are established and a thickening of these poses a threat to the population. One plant was doing well only 30 cm from a pine, but at another site a parent pine was surrounded by a dense grove of pine seedlings under which nothing was growing. The recent bulldozing of a track is likely to have killed some boronias (they were previously recorded in the vicinity. Railway track maintenance includes the lopping of protruding branches, which have been thrown on the vegetation, including on a few boronia plants. Greater care should be taken to avoid damage. In contrast to most other sites, some boronias along the railway grow in almost full sunlight, in clearings with no trees directly above them but with a few trees a little to the north that would filter out some light.

Recommendation: Queensland Rail develop a management plan for the threatened plant species in this rail reserve (which includes the critically endangered black grevillea as well as repand boronia) to include ecological fire management and weed management. Ensure that maintenance and track building do not impact on threatened species.

Repand boronia can flower despite strong competition from bracken if there are no trees to increase the shade.

Aerodrome reserve

Manager: Southern Downs Regional Council, Stanthorpe Aerodrome, Pegum Road, Applethorpe

Population estimate (December 2020): 1,200 mature plants.

This forest (RE 13.12.2) site is a stronghold for repand boronia. The boronias here had several different age classes. Many plants were covered in flowers and had new growth. Plants here had suffered more from the drought that those along the railway. Some had only a few surviving tufts of old leaves, plus many new leaves sprouting at their bases. The size of the resprouts implies that plants that looked nearly dead retained large stores of sugar or starch in rhizomes. One plant had no original leaves and would have been assumed dead before the rain. Plants with no basal resprouting were in the minority.

This site was surveyed in 2008, but only 150 repand boronias were reported. It seems unlikely that the population has increased 8-fold in only 12 years, so we assume that some were missed in 2008.

The area where the boronias are growing does not appear to have burned in recent years (we could not obtain information about the fire history), but adjacent sections of the reserve have a lot of blady grass and charcoal on trees. The density of blady grass suggests that a number of fires have swept through this reserve, though not recently judging by bark.

The reserve has some bare ground in which boronia seedlings could sprout (though no seedlings were seen). Animal diggings were contributing to creation of bare ground. There had been some light browsing of the boronias, but far less than on pea bushes (*Pultenaea hartmannii*) growing near them.

The wildflower consortium liaised with the Southern Downs Council about management of the reserve – to remove rubbish (dumped by the neighbouring orchardist) and to protect the repand boronias from a planned burn.

Recommendations:

- Avoid burning the area with repand boronias – they appear to be doing well and germinating without fire.
- Council monitor the reserve to ensure it is not used as a dumping ground.

Boronia habitat in the aerodrome reserve. It is surrounded by orchards and an aerodrome.

Appendix 3. Fire responses of threatened Granite Belt plants

Species	Common name	Family	Endemicity	National status (EPBC Act)	Qld status (NC Act)	Fire response	
						Obligate seeder / resprouter	Post-fire germination / flowering
Acacia pubifolia	Wyberba wattle	Fabaceae	Granite Belt, nNSW	Vulnerable	Vulnerable	Variable across range? [30]	
Acacia ruppii	Rupp's wattle	Fabaecea	Granite Belt, nNSW	Endangered	Vulnerable	Obligate seeder [31]	
Agiortia cicatricata		Ericaceae	SEQ, nNSW		Near threatened		
Allocasuarina rupicola	Shrubby she-oak	Casuarinaceae	Granite Belt, nNSW		Near threatened	Obligate seeder [pers obs]	
Bertya glandulosa		Euphorbiaceae	Granite Belt		Vulnerable		
Bertya recurvata		Euphorbiaceae	Granite Belt		Endangered		
Boronia amabilis	Lovely boronia	Rutaceae	Granite Belt		Near threatened		
Boronia granitica	Granite boronia	Rutaceae	New England Tableland	Endangered	Endangered	Obligate seeder [31,32]	Mass germination
Boronia repanda	Repand boronia	Rutaceae	Stanthorpe Plateau	Endangered	Endangered	Resprouter [pers obs]	Patchy germination [pers obs]
Caladenia atroclavia	Black club spider orchid	Orchidaceae	Granite Belt	Endangered	Endangered		
Conospermum burgessiorum	Smokebush	Proteaceae	New England Tableland		Near threatened		

Species	Common name	Family	Endemicity	National status (EPBC Act)	Qld status (NC Act)	Fire response	
						Obligate seeder / resprouter	Post-fire germination / flowering
Corunastylis sigmoidea	Dave's Creek midge orchid	Orchidaceae	SEQ		Near threatened		
Cyanothamnus inflexus subsp grandiflora		Rutaceae	Granite Belt				Mass germination [33]
Cyanothamnus inflexus subsp inflexus	Rock boronia	Rutaceae	Granite Belt, nNSW				
Cyanothamnus inflexus subsp. montiazura	Blue mountain boronia	Rutaceae	Granite Belt				
Diuris parvipetala	Slender donkey orchid	Orchidaceae	Qld, NSW		Vulnerable		
Dodonaea hirsuta	Hairy hopbush	Sapindaceae	Granite Belt, nNSW		Vulnerable	Obligate seeder [34]	Mass germination [pers obs]
Eucalyptus codonocarpa	New England mallee	Myrtaceae	New England Tableland		Near threatened		
Eucalyptus dalveenica	Dalveen blue box	Myrtaceae	Granite Belt		Critically endangered		
Eucalyptus mckieana	McKie's stringybark	Myrtaceae	New England Tableland	Vulnerable			
Eucalyptus scoparia	Wallangarra white gum	Myrtaceae	New England Tableland	Vulnerable	Vulnerable		

Species	Common name	Family	Endemicity	National status (EPBC Act)	Qld status (NC Act)	Fire response	
						Obligate seeder / resprouter	Post-fire germination / flowering
Euphrasia orthocheila subsp. peraspera		Orobanchaceae	Granite Belt, nNSW		Near threatened	Obligate seeder [31]	
Grevillia scortechinii subsp scortechinii	Black grevillea	Proteaceae	Granite Belt	Critically endangered	Critically endangered	Resprouter [Donatiu pers comm]	
Hakea macrorrhyncha	Tall needlebush	Proteaceae	Granite Belt, nNSW		Vulnerable	Obligate seeder [32,34]	
Hibbertia elata	Tall guinea flower	Dilleniaceae	Granite Belt, central NSW		Near threatened		
Hibbertia tenuifolia		Dilleniaceae	Granite Belt, nNSW				
Homoranthus inopinatus		Myrtaceae	Granite Belt		Critically endangered		
Homoranthus montanus	Mountain mouse bush	Myrtaceae	Granite Belt	Vulnerable	Critically endangered		
Homoranthus papillatus	Mouse bush	Myrtaceae	Granite Belt		Critically endangered		
Kardomia granitica		Myrtaceae	Granite Belt	Vulnerable	Endangered		
Kardomia silvestris	Woodland babingtonia	Myrtaceae	Granite Belt, nNSW		Endangered	Obligate seeder [31]	
Leionema ambiens	Forest phebalium	Rutaceae	New England Tableland		Near threatened	Obligate seeder [35]	

Species	Common name	Family	Endemicity	National status (EPBC Act)	Qld status (NC Act)	Fire response	
						Obligate seeder / resprouter	Post-fire germination / flowering
Lepidium peregrinum	Wandering peppercress	Brassicaceae	Qld, NSW	Endangered			
Macrozamia occidua		Zamiaceae	Sundown NP	Vulnerable	Vulnerable		
Macrozamia viridis		Zamiaceae	Granite Belt		Endangered		
Melaleuca flavovirens	Green bottlebrush	Mytraceae	New England Tableland		Near threatened		
Melaleuca williamsii	Prickly bottlebrush	Myrtaceae	Granite Belt	Vulnerable	Vulnerable	Resprouter [32]	
Mirbelia confertiflora		Fabaceae	Granite Belt, nNSW		Near threatened		
Persoonia daphnoides		Proteaceae	Northern New England Tableland		Near threatened		
Phebalium glandulosum subsp. eglandulosum	Rusty desert phebalium	Rutaceae	Granite Belt, nNSW	Vulnerable	Vulnerable	Obligate seeder [31,32]	
Phebalium whitei	White's phebalium	Rutaceae	Granite Belt	Vulnerable	Vulnerable		
Prostanthera petraea		Lamiaceae	Northern New England Tableland		Near threatened		
Tylophora woollsii	Cryptic forest twiner	Apocynaceae	Granite Belt, nNSW	Endangered	Endangered	Obligate seeder [31]	
Zieria graniticola		Rutaceae	Granite Belt		Endangered		