From Manual Removal to the Method of Least Disturbance: Applied Strategies for Controlling *Polygala myrtifolia* in Coastal Moonah Woodland.

Brown, C. (2025).

Abstract.

In 2013, an 800-acre property within the Tootgarook Swamp at Boneo, Victoria, was placed under covenant to protect its ecological values. Approximately 130 acres of this site comprise Coastal Alkaline Scrub, including the threatened Moonah Woodland community—72% of which was heavily infested by *Polygala myrtifolia* (myrtle-leaf milkwort). This South African shrub forms dense thickets, suppresses native vegetation, and persists through a long-lived seedbank, making it one of the most challenging weeds in coastal ecosystems. Conventional control methods—including manual removal, thermal treatment, and broad-spectrum herbicides such as Glyphosate, Triclopyr, or Picloram + Aminopyralid—have historically been used, but often pose significant risks to non-target species or trigger unintended ecological feedbacks.

This study presents a decade of adaptive management observations, beginning with traditional manual and thermal techniques. From 2013 to 2017, these methods dominated but proved labour-intensive and counterproductive, as soil disturbance triggered mass germination from the seedbank. In 2018, the program pivoted to selective chemical control using Clopyralid—a pyridine carboxylic acid herbicide with high specificity for *Fabales* and *Asterales* species, including *Polygala myrtifolia*. This transition was guided by the principles of the Method of Least Disturbance (M.O.L.D.), which avoids soil disruption, retains dead biomass, and targets seedlings during cool-season germination windows.

By 2025, *Polygala* was reduced to scattered individuals managed through basal barking or targeted manual removal near vulnerable assets, achieving near-complete suppression while preserving habitat integrity. This case study demonstrates how timing, selectivity, and low-disturbance principles can transform restoration outcomes in fragile coastal ecosystems.

Note: A glossary of terms used in this document is outlined in Appendix A.

This report documents the selective control of *Polygala myrtifolia* using Clopyralid during the Boneo sweep, with a focus on *Fabales*-targeted intervention under the principles of the Method of Least Disturbance (M.O.L.D.). The M.O.L.D. framework is currently in its **final draft stage**, undergoing refinement through field validation and layered ecological modelling.

To preserve clarity and accessibility, several operational elements have been deliberately omitted from the main narrative and documented separately in Appendix B and the companion M.O.L.D. framework. These include:

- The integration of Haloxyfop to suppress invasive grasses (*Ehrharta erecta*, *Dactylis glomerata*)
- Visual avoidance strategies to protect native *Poa labillardierei*
- Downward pressure on rabbit populations through cover reduction and basal bark control of *Rhamnus alaternus* (Italian buckthorn), a known dry-season moisture source

These interventions were part of the full-sweep logic and reflect the layered diagnostic and feedback-collapse strategies trialled at Boneo. Collectively, they targeted what the M.O.L.D. framework defines as the **dark web of biodiversity**—a parasitic network of introduced species that reinforce each other's persistence through ecological exploitation. By collapsing multiple nodes in this network (e.g. invasive grasses, invasive shrubs, and faunal vectors), the program disrupted the architecture of invasive dominance and accelerated restoration outcomes.

These elements are excluded from the main body to maintain focus on the novel operational use of Clopyralid for *Polygala* control—a contribution not previously documented in published literature.

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Introduction.

Background on *Polygala myrtifolia* as an Invasive Species.

Polygala myrtifolia L., commonly known as myrtle-leaf milkwort, is a South African shrub that has become a significant environmental weed in southern Australia (Figure 1). Introduced as a garden ornamental in the mid-1800s, it is now naturalised across Victoria, South Australia, New South Wales, Tasmania, and Western Australia (Adair et al., 2011).

The species forms dense thickets, grows rapidly (up to 3 m in 18 months), and reaches sexual maturity within two years (Roberts et al., 2023). Its unchecked spread poses a major threat to biodiversity, invading over twenty-three vegetation communities and impacting numerous rare and endangered endemic species. Despite its widespread impact, *Polygala myrtifolia* remains undeclared nationally, though it is regionally listed in South Australia and considered high-risk in Victoria.

Polygala myrtifolia is recognised as a habitat-altering weed. Its presence disrupts key elements of remaining critical fauna habitats, with severe infestations transforming autochthonous ecosystems. These changes pose a significant risk of dominance, leading to widespread degradation and loss of essential habitat structures. As a result, substantial declines in fauna population densities and species diversity are likely to follow (Legg 2014).

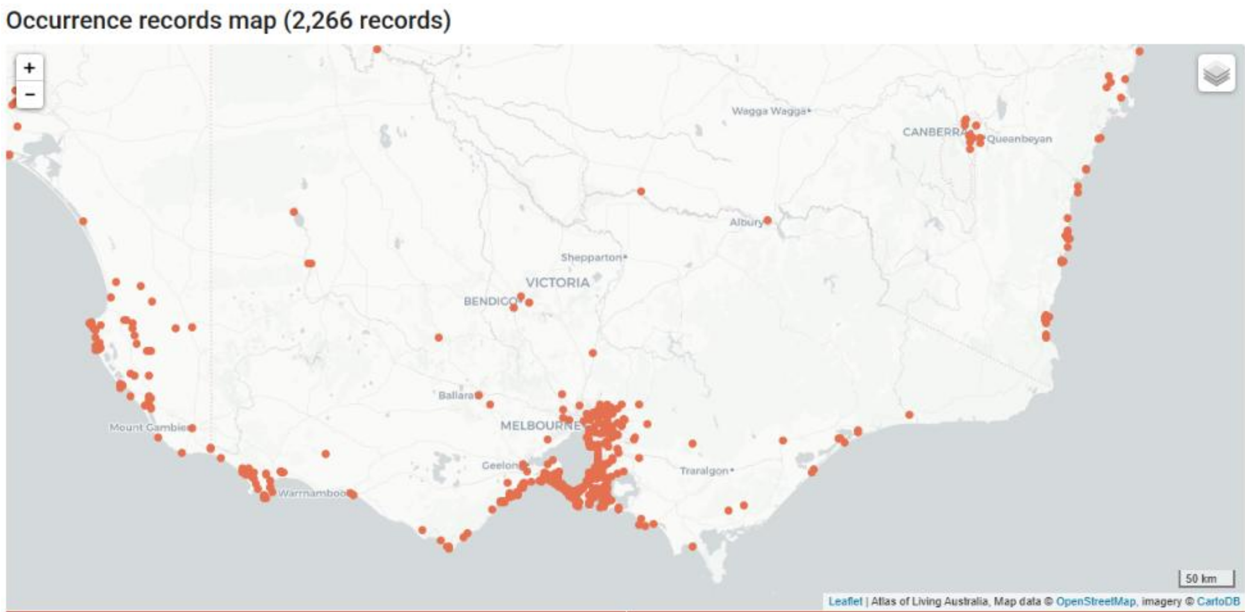

Figure 1 Polygala myrtifolia : Myrtle-Leaf Milkwort | Atlas of Living Australia (Atlas of Living Australia, n.d.)

A key factor in its invasive success is its reproductive strategy. Seeds are non-dormant, highly viable, and capable of germinating under a wide range of environmental conditions, including various soil pH levels, moderate salinity, and low moisture stress. Optimal germination occurs during autumn, winter, and spring (Roberts et al., 2023).

Importantly, soil disturbance significantly aids germination. Clearing vegetation or opening the canopy triggers rapid seedbank depletion and high seedling emergence (Glenelg-Hopkins CMA, 2012). Disturbed soils expose seeds to light and moisture, enhancing germination rates. Seedlings emerging in cleared areas often experience high summer mortality from heat and moisture stress, yet survival can occur where soil moisture persists, or microclimatic conditions provide refuge—while those under canopy cover generally show higher survivorship.

Ecological Risk.

- Forms dense monocultures that suppress native flora and disrupt ecological succession (Eyre Peninsula Landscape Board, n.d.).
- Rapid colonisation of intact vegetation, especially in rear dunes and shrublands.
- Soil-stored seedbanks remain viable for 3–10 years or more, enabling persistent regeneration (Eyre Peninsula Landscape Board, n.d.).

Germination Dynamics.

- Non dormant seeds exhibit high germination rates (up to 95%) across a wide range of pH and temperature conditions, especially during autumn to spring (Roberts et al., 2023).
- Germination occurs even under moderate salinity and low moisture stress, enhancing resilience in variable coastal environments.
- Emergence is highest on the soil surface, with buried seeds remaining dormant but viable, complicating control efforts (Roberts et al., 2023).
- Soil disturbance—such as clearing vegetation—triggers seedbank depletion and promotes seedling emergence**.** This means that manual removal, while effective in reducing adult plants, can inadvertently stimulate germination from the seedbank unless followed by additional control measures.

Roberts et al. (2023) did include quantitative data (Table 1) on emergence percentages at different burial depths for *Polygala myrtifolia*. Here is the relevant breakdown:

Table 1 - *Roberts et al. (2023) emergence data.*

Seed Emergence by Burial Depth	Emergence (%)
Surface-sown	48.33%
1	33.33%
2	18.33%
4	6.67%
8	0.00%

Interpretation.

- Sharp decline: Emergence dropped by ~30% between surface and 1 cm, and by ~85% between surface and 4 cm.
- Threshold depth: No emergence occurred at 8 cm, confirming that deep burial effectively suppresses recruitment.
- Management implication: Even shallow disturbance may inadvertently promote germination if seeds are left near the surface.

Traditional Methods of Control.
Manual removal, conventional chemical treatments, and fire represent traditional strategies for managing *Polygala* myrtifolia. Each method presents distinct advantages and limitations, contingent upon the extent of infestation, site sensitivity, and overarching ecological objectives. Nevertheless, these approaches may also significantly disrupt native ecosystems.
Manual removal typically entails uprooting plants, which can compromise soil integrity, expose bare areas, and elevate erosion risk—particularly on slopes or sensitive substrates. Such disturbance can facilitate secondary invasions by other weed species. Additionally, disturbances to soil structure

frequently trigger a mass germination event of *Polygala* myrtifolia seeds stored in the seedbank, potentially exacerbating reinvasion and complicating long-term control efforts.

While conventional chemical treatments are effective, they may present risks to non-target vegetation and soil microbiota, especially when broad-spectrum herbicides are employed. Repeated applications may result in residual chemicals, resistance development, and adverse effects on adjacent native flora and fauna.

The use of fire as a means to reduce biomass can also be ecologically disruptive. It has the potential to destroy habitat for autochthonous species, alter soil chemistry, and encourage the proliferation of fire-adapted invasive plants, thereby complicating restoration initiatives. Additionally, fires and other disturbances often stimulate synchronised germination of *Polygala myrtifolia* seeds, leading to dense regeneration that can undermine initial management successes. Further discussion regarding these methodologies will continue in the subsequent section with method details laid out in Appendix B.

A critical aspect of these disturbance-driven management techniques is their potential to create feedback loops that reinforce the very problems they aim to solve. When soil is disturbed or habitats are altered, conditions may favour rapid recolonisation by *Polygala myrtifolia* or other invasive species, setting off cycles of repeated invasion and further intervention. Such feedback mechanisms not only perpetuate ecological imbalance but can also necessitate increasingly intensive management, making it essential to recognise and mitigate these loops in any long-term control strategy.

Potential for Biological Control as a Suppression Method.

Classical biological control is under evaluation as a suppression strategy for extensive infestations of Polygala myrtifolia. Surveys conducted in South Africa have documented twenty-eight phytophagous species, with six—such as the psyllid *Diaphorina petteyi*, the eriophyid mite *Aceria myrtifoliae*, and a gall-forming *Dasineura* species—demonstrating potential to inhibit the plant's growth and reproductive capacity. These prospective agents necessitate comprehensive host-specificity and impact assessments to mitigate risks to non-target species, including horticultural cultivars and autochthonous *Polygalaceae* such as Love Creeper (*Comesperma volubile*). To date, no biological control agents have been introduced in Australia; nonetheless, this approach remains a promising element within integrated management and low-disturbance methodologies (Adair & Neser 1996; Adair et al., 2011). While generally less disruptive than physical interventions, biological control requires thorough evaluation to prevent unintended ecological effects. Inadequate agent selection or insufficient host-specificity testing may result in adverse impacts on closely related native flora.

Site Description.

In 2013, an 800-acre property located within the Tootgarook Swamp at Boneo was placed under covenant. On the western side of this property is approximately 130-acres consisting of the EVC 858 Coastal Alkaline Scrub, which includes Moonah Woodland as a component. An estimated 72% (figure 2) of this 130-acre section was found to be dominated by the invasive species *Polygala myrtifolia*.


Figure *2 Estimation of Polygala area Google Earth*

Coastal Alkaline Scrub (EVC 858) is a coastal vegetation class occurring on calcareous dunes and alkaline sands along Victoria's coastline, typically forming low woodland, shrubland, or closed scrub dominated by species such as Coast Tea-tree (*Leptospermum laevigatum*), Moonah (*Melaleuca lanceolata* subsp. *lanceolata*), Coast Beard-heath (*Leucopogon parviflorus*), and Drooping She-oak (*Allocasuarina verticillata*) (Moxham A, Claire et al. 2011). Within this class, the threatened community Coastal Moonah Woodland is most often found on stable hind dunes and calcareous deposits within 10 km of the coast. It is characterised by a canopy of Moonah, often co-dominant with Coast Tea-tree and Coast Wirilda (*Acacia uncifolia*), and an understorey of herbs, grasses, and climbers such as Love creeper *(Comesperma volubile)*, Thyme Rice-flower (*Pimelea serpyllifolia*), Kidney-weed (*Dichondra repens*), and Coast Swainson-pea (*Swainsona lessertiifolia*) (Moxham, et, al. 2010). Once widespread, this community now occupies less than 10% of its original extent, with remnants concentrated on the Mornington and Bellarine Peninsulas and in south-west Victoria. (Moxham, C., & Turner, V. 2009). Both the EVC and the woodland play vital roles in dune stabilisation, nutrient cycling, and habitat provision, but are highly vulnerable to weed invasion (e.g., *Polygala myrtifolia*, Rhamnus alaternus, *Asparagus asparagoides*), altered disturbance regimes, and human impacts, making their conservation a priority.

Site History including methods and effects of prior attempts at *Polygala* removal.

The site displays historical burn patterns across various areas. For example, in several sections of the Nepean Peninsula, burns have cleared vegetation, leaving dunes exposed (figure 3) to high winds, which has resulted in some dune crests being reduced to bare sand due to the complete loss of the seedbank (figure 4). Other sites exhibit low plant diversity, with burnt Moonah lanceolata (figure 5,6) and Leptospermum laevigatum strands and a limited presence of ground covers such as Dichondra repens and native grasses. While some areas are dominated by mosses and show minimal evidence of recent fire activity. Signs of attempted fire management are evident on Moonah (Melaleuca lanceolata) trees, where limbs have been removed using hand saws (figure 7). J.L. Brown who had approximately 4000-acres at the back of Rye, described these practices in the Melbourne Leader in 1912: *"The thicker the ti-tree the more easily is the land cleared for the sowing of melilotus. About one-fifth of the scrub is chopped down and stacked up against the balance. Experience teaches that in this way a maximum burn can be achieved. If a fire can be started on a hot day in February, when there is a strong northerly wind, the heavy covering of ti-tree soon becomes reduced to ashes."* (Leader, 1912)

Figure 3 1951 Rye, Boneo, Rosebud showing blow-outs from disturbance.

***Figure** 7 Burnt Moonah (Melaleuca lanceolata) cut limbs and hand saw.*

Figure 4 *– Calcified roots can be seen on the top of the blown-out dune crest still reasonably bare after at least 70 years.*

Figure 5 *Fire damaged ground dead M. lanceolata.*

Figure 6 *Fire damaged ground reshot M. lanceolata.*

After more than 80 years of continuous ownership, the property changed hands in 2001. The then owner initiated self-funded manual and thermal weed control targeting *Polygala myrtifolia*, including burning of removed biomass[1]. Despite these efforts, the scale and persistence of the infestation remained challenging to manage, and manual works continued through a period of transition that included the establishment of a covenant in 2013.

Prior to the placement of the 2013 covenant, Gannon (2012) documented widespread ecological degradation across the site, driven largely by woody weed invasion and historic grazing pressure. Species such as Myrtle-leaf Milkwort (*Polygala myrtifolia*), African Box-thorn, Bridal Creeper, Italian Buckthorn, Mirror-bush, Blackberry, Boneseed, and Cape Ivy were prevalent throughout the understorey, alongside herbaceous weeds like Catsear and various Ehrharta grasses. These invasives suppressed native recruitment and altered soil and light conditions, yet earlier weed control efforts had helped maintain relatively high levels of autochthonous plant diversity, with species such as Pterostylis cucullata, Dichondra repens, Austrostipa flavescens, Poa labillardierei, Acaena novae-zelandiae, and Clematis microphylla still present.

Among these, *"Polygala myrtifolia var. myrtifolia"* was singled out as *"dominant in the understorey"* and forming *"a dense monoculture."* The report emphasised its ubiquitous presence across multiple habitat zones, particularly within the Coastal Alkaline Scrub, where it was not confined to isolated pockets but had become structurally dominant. This persistent suppression of autochthonous shrub and herb layers was flagged as a significant threat to habitat integrity. Gannon's findings strongly reinforce broader field observations of extensive infestation and informed the need for sustained management, later formalised through covenant protections.

While earlier efforts began in 2001, this report documents removal techniques and ecological outcomes from 2013 onward, coinciding with covenant establishment and the formalisation of restoration logic.
The property changed hands again in 2024, marking a new phase in site stewardship.

[1] (The late M. Stahmer, pers. comm., 2013) Former employee and Former Mornington Shire Natural System Team.

Methods.[2]

Control of *Polygala myrtifolia* at Boneo was implemented through three primary approaches:

1. Manual removal,
2. Thermal removal, and
3. Selective chemical control using Clopyralid and basal bark techniques.

Detailed operational procedures, timing considerations, and safety protocols for all three methods are provided in Appendix B, which is essential for understanding the practical application of this study. Appendix B contains the step-by-step techniques, labour estimates, and risk profiles that underpin the ecological outcomes discussed in the main text. Readers seeking implementation guidance or comparative operational detail should refer directly to Appendix B.

Ecological Rationale for Method Selection.

Early phases (2013–2017) relied on manual and thermal removal to reduce mature biomass. While these methods achieved short-term canopy reduction, they introduced high soil disturbance, which activated the persistent seedbank. *Polygala myrtifolia* seeds are non-dormant, highly viable, and germinate most strongly near the soil surface. Disturbance during manual uprooting or thermal scorching lifted buried seeds into the emergence zone, triggering dense seedling cohorts and reinforcing a disturbance–germination feedback loop. This loop increased labour demand and slowed progress, as each intervention created conditions for further recruitment.

From 2018 onward, the program pivoted to selective chemical control, evolving in 2019 to the conceptual Method of Least Disturbance. This approach was chosen because it:

- Avoids soil disruption, preventing seedbank activation and erosion on fragile calcareous sands.
- Targets seedlings during cool-season germination windows (autumn–spring), intercepting plants before seed rain replenishes the seedbank.
- Retains dead biomass in situ, preserving microhabitats and stabilising soil, which supports passive succession and native recovery.
- Aligns with taxonomic selectivity, using Clopyralid to suppress Fabales and Asterales weeds while sparing native grasses and monocots.

This ecological logic reflects Roberts et al. (2023), who demonstrated that *Polygala* germination peaks under cool, moist conditions and declines sharply with burial depth beyond 4 cm. By minimising disturbance and timing interventions to seasonal vulnerability, selective chemical control interrupts the feedback loop that perpetuates invasion, enabling predictable seedbank depletion and long-term habitat stability.

The following sections focus on herbicide selectivity and timing strategies that underpin this transition.

[2] **Data status:** Where current-season figures (2025) are cited, they are provisional. Summary statistics and model calibration use finalised years unless explicitly stated.

Chemical Challenges of Broad-Spectrum Herbicides and the Selective Advantage of Clopyralid.

Among herbicides used to control *Polygala myrtifolia*, glyphosate is the only truly broad-spectrum compound, acting across both monocotyledonous and dicotyledonous plant clades. As a Group 9 herbicide (EPSP synthase inhibitor), glyphosate disrupts the shikimic acid pathway, which is essential for aromatic amino acid synthesis in all green plants. This universal mode of action makes it highly effective but also ecologically hazardous in conservation settings, where non-target impacts on native grasses, sedges, and forbs can compromise restoration outcomes.

In contrast, the use of selective auxin-type herbicides such as Fluroxypyr and Clopyralid reflects a long-standing scientific understanding of plant growth regulation, originating with Charles Darwin's 1881 observations on phototropism and chemical messengers in plants. These early insights, later expanded by Sachs and Went, led to the identification of indoleacetic acid (IAA)—a natural auxin—and the development of synthetic analogues that mimic endogenous hormonal pathways. Far from being arbitrary chemical interventions, these compounds operate within the same physiological systems that plants have evolved to use. This continuity underscores that selective herbicide use can be ecologically aligned, offering targeted suppression of invasive species while preserving native vegetation (Ruane, 2000).

- Glyphosate (a phosphonate herbicide) inhibits EPSP synthase, affecting all plant types including grasses, forbs, and woody species. Its non-selectivity can lead to significant non-target damage in native plant communities.
- Triclopyr and picloram, both pyridine-based synthetic auxins, mimic natural growth hormones but affect a wide range of dicots. Picloram, in particular, has a long soil half-life and high mobility, increasing the risk of off-target impacts and groundwater contamination.
- Aminopyralid, another pyridine carboxylic acid, shares similar persistence and mobility concerns, especially in sensitive ecosystems.

In contrast, Clopyralid (*3,6-dichloro-2-pyridinecarboxylic acid*) offers a more selective and environmentally responsive alternative. Mark Adams, proprietor of Local Native Flora, identified morphological similarities between *Polygala* flowers and leguminous species referenced on the Clopyralid herbicide label. In 2014, he conducted field trials at Camerons Bight, Rye, Victoria, to evaluate the efficacy of Clopyralid on *Polygala* control. A taxonomical explanation notes that *Polygala* and these legumes share similarities because both are classified within the fabales order.

- Clopyralid is a Group 4 synthetic auxin herbicide that targets specific broadleaf weeds—particularly species in the Asteraceae, Fabaceae, and Caryophyllales families—while sparing grasses and monocots (Tu et al. 2001).
- Clopyralid has a shorter average soil half-life of approximately 9.1-23 days (Tomco et al. 2016), and its primary degradation pathway is microbial metabolism. Soil bacteria and fungi break it down into simpler compounds, especially in soils with high organic matter and active microbial communities (Thorsness, &. Messersmith. 1991).
- Unlike glyphosate, Clopyralid does not inhibit protein synthesis, but instead causes unregulated cell elongation and division, leading to vascular collapse in susceptible species.
- It is more water-soluble and has lower adsorption potential than picloram, meaning it binds less tightly to soil particles and is more readily degraded in biologically active soils (Tu et al. 2001).

These properties make Clopyralid particularly suitable for selective control in restoration areas, where preserving native grasses, forbs and minimising soil disturbance are priorities. Its formulations (e.g.

Lontrel Advanced®, Clopyralid 300®), enables with careful application precise treatment of *Polygala myrtifolia* with minimal collateral damage.

Herbicide Resistance Risk of Clopyralid.

While resistance to Clopyralid is rare globally, cases have been reported in agricultural weeds such as *Sonchus spp.* and *Cirsium arvense* under high, repetitive selection pressure (Riechers, D.E., et al. (2024). Evidence from global reviews (Teagasc, Syngenta) and resistance-management guidance indicates that *"inappropriate timing of applications—e.g., treating outside the plant's active growth phase or during stress periods—significantly increases resistance risk."* This timing factor is often more critical than simply increasing herbicide concentration: poor timing produces sub-lethal exposure and survival of tolerant individuals, accelerating resistance evolution. Conversely, applying during *"autumn–spring"* (Roberts et al. 2023), when plants are metabolically active, maximises translocation and minimises survival of partially affected plants; raising concentration cannot compensate for poor timing and may increase off-target damage without improving long-term control.

Herbicide formulation and concentration considerations of Clopyralid (*3,6-dichloro-2-pyridinecarboxylic acid*).

Clopyralid is a selective, systemic herbicide that acts as a synthetic auxin, disrupting vascular function and growth regulation in actively growing broadleaf plants. Its mode of action requires metabolic activity, which is absent in dormant seeds. As such, Clopyralid does not affect the seedbank directly and does not stimulate germination. This property makes it particularly suitable for ecological weed control strategies that aim to minimise disturbance, such as the Method of Least Disturbance *(More about the thinking behind M.O.L.D.—including how it avoids disturbance and supports native recovery—is outlined in Appendix G.)*, where avoiding seedbank activation is critical to maintaining habitat integrity and preventing secondary weed outbreaks.

Multiple sources support this conclusion. The U.S. Bureau of Land Management's Ecological Risk Assessment for Clopyralid (2014) reports no evidence of seedbank stimulation, and the herbicide's effects are limited to existing vegetation. A peer-reviewed study by Esen et al. (2022) assessed Clopyralid at high concentrations on Mediterranean pine seeds and found no germination stimulation; instead, germination speed was reduced at elevated rates, confirming an inhibitory—not activating—effect. Additionally, the US EPA's Interim Registration Review Decision for Clopyralid (2020) does not identify seedbank stimulation as a risk, further reinforcing its suitability for low-disturbance applications. Its effects depend on how much it disrupts the plant's hormonal balance. The difference between low and high concentrations comes down to how auxin signalling pathways respond to overstimulation versus complete inhibition:

Low Concentrations.

- At low doses, Clopyralid mimics natural auxins (like indole-3-acetic acid, IAA) but in an unregulated way (MSU Extension, 2025).
- This stimulates RNA, DNA, and protein synthesis, which are processes normally triggered by auxins during growth.
- The result is uncontrolled cell division and elongation, but without proper coordination.
- This disorganised growth destroys vascular tissue integrity, leading to twisting, swelling, and eventual plant death (MSU Extension, 2025; Tu et al. 2001).

Analogy**:** It is like giving a plant too many "grow" signals without structure—cells divide chaotically, and the plant collapses from internal dysfunction.

Low dose = overstimulation → uncontrolled growth → vascular collapse

High Concentrations.

- At high doses, the auxin signalling system becomes overloaded and shuts down (NC State Extension, 2025).
- Instead of stimulating growth, it inhibits cell division and elongation because the plant cannot process the overwhelming signal.
- This leads to growth arrest, tissue necrosis, and rapid plant death (NC State Extension, 2025; Sterling et al. (2004).

Analogy**:** It is like applying to much power to an electrical circuit—too much signal causes a complete breakdown rather than overactivity.

High dose = inhibition → no growth → tissue death

Personal communication indicated that concentrations of 2.5 ml/L caused substantial non-fatal damage to the native bower-spinach, Tetragonia implexicoma, with visible suppression persisting for at least three years before recovery. To minimise harm to native species, trials reduced concentration sequentially to 2.0, 1.5 and 1.0 ml/L. Because 1.0 ml/L produced only an approximate 60% fatality rate on *Polygala myrtifolia*, a working concentration of 1.3 ml/L was adopted. Although Roberts et al., 2023 does not study herbicide effects, its demonstration that *Polygala* has very high germination and emergence from the soil surface explains why an incomplete kill (≈60%) is operationally inadequate: remaining plants and continually high seedling recruitment can quickly restore populations unless control achieves higher immediate mortality or is followed by frequent follow-up treatment. From these observations we propose a working hypothesis: clopyralid concentration can be tuned to selectively suppress particular broadleaf taxa within an order owing to interspecific differences in auxin sensitivity, transport dynamics, and tissue architecture (Michelmore et al., 2024; Leyser, 2018). Evidence that closely related species may differ in endogenous auxin levels and receptor sensitivity, producing variable physiological responses to synthetic auxin herbicides, further supports this mechanism (Solanki & Shukla, 2023; Michelmore et al., 2024). While formal validation is pending, field trials suggest a practical benefit for operational restoration: calibrated dosing can improve suppression of priority targets while even further reducing off-target injury, and Roberts et al., 2023 explains why *Polygala's* life-history makes robust control essential to prevent rapid reinvasion.

Results.

Executive Summary.

The site has transitioned into a low-effort maintenance phase following years of targeted selective chemical control and adherence to the Method of Least Disturbance. Current conditions reflect long-term stability, with minimal regrowth, rare seedling cohorts, and exceptionally low hours per acre. However, a residual risk of germination persists due to the historic seedbank accumulated during earlier manual removal efforts and past seed input. Continued vigilance through targeted follow-up remains essential to prevent seed rain and maintain system stability.

The Shape of Intervention - Areas Method Year Interpretation.

2013 Manual Removal of *Polygala*
Area: 43.71 acres

A large-scale manual removal effort targeted mature *Polygala myrtifolia* across 130 acres of Moonah woodland, establishing a baseline cover of approximately 72%. Operations were conducted more during the dryer periods of the year. The operation focused on cutting and clearing mature shrubs, effectively reducing above-ground biomass. However, this approach also disturbed the soil and exposed shallow seed reserves, creating conditions that triggered pronounced germination pulses during both autumn and spring. While initial reductions in mature plant density were achieved, these gains were counteracted by seedbank activation, initiating sustained seedling recruitment under a high-disturbance regime.

2014 Manual Removal of *Polygala*
Area: 31.63 acres

Manual clearance continued at scale, with considerable time investment and substantial removal of mature *Polygala* myrtifolia plants. Vegetative cover dropped to approximately 24%, reflecting strong progress in reducing mature plant density. However, the intensity of removal—often involving chain-sawing through tangled shrubs and fallen trees—maintained surface-level disturbance. This disturbance kept the seedbank exposed and biologically accessible, enabling seedling cohorts to persist even through warmer seasons, particularly with the breaking of the millennium drought. The net outcome was a visible reduction in canopy cover, but persistent germination pressure driven by disturbance remained a limiting factor in long-term suppression.

2015 Manual Removal of *Polygala*
Area: 31.24 acres

Operations shifted to previously missed sections and follow-up zones. Although total hours invested were lower than in the initial campaign, dense seedling carpets emerged in areas previously disturbed. Manual removal remained focused on residual mature plants and attempts to suppress seedling emergence—including the use of thermal control. However, this may have inadvertently exacerbated *Polygala* infestations due to soil disturbance and conditions conducive to germination following heat exposure. Adair et al. (2012) noted the species' resilience and disturbance-driven spread, while Roberts et al. (2023) confirmed its high germination potential under autumn–spring conditions and shallow burial—suggesting that fire or heat-based treatments may unintentionally promote recruitment.

2016 Manual Removal of *Polygala*
Area: 7.01 acres

Although the treated area was relatively small (7.01 acres), total labour input remained high at 1,520 hours due to dense regrowth and extensive seedling carpets requiring meticulous, plant-by-plant attention. Hours per acre spiked significantly, illustrating how disturbance-driven emergence demanded disproportionate effort without materially reducing seedbank pressure. This phase clearly demonstrated that manual control during periods of heavy seedling recruitment is both labour-intensive and operationally inefficient. The trend also highlighted emerging labour challenges, with increasing difficulty in sustaining manual efforts at scale as recruitment rates began to outpace available resources.

2017 Manual Removal of Polygala
Area: 29.14 acres

Total labour hours matched 2015 levels (3,312) but were distributed across a larger area (29.14 acres), indicating constrained resources and a shift in strategy. Operations prioritised *Polygala myrtifolia* plants nearing maturity (at risk of flowering) to prevent immediate seed rain, while substantial seedling cohorts were left untreated. Germination pressure peaked across approximately 25% of the site, and vegetative cover remained at 32.5%, suggesting that manual efforts were no longer outpacing recruitment. These trends underscored growing labour challenges, with manual control increasingly unable to match the scale and persistence of seedbank-driven emergence without a strategic pivot. Projections indicate that cover may have rebounded toward 40% by 2018–2019 and could have continued rising in the absence of significant intervention—initiating a compounding feedback loop of constrained effort and ecological recovery.

2018 Selective Chemical Removal of *Polygala*
Area: 28.57 acres

A strategic pivot to selective chemical control using Clopyralid transformed the management trajectory. Low soil disturbance, combined with well-timed foliar application at seedling emergence, reduced vegetative cover to approximately 27.7%. Retaining dead biomass in situ minimised habitat shock, prevented seed rain, and initiated systematic seedbank depletion. This year marked a critical inflection point—shifting from disturbance-driven rebound risk to controlled suppression. The transition also signalled a potential easing of labour intensity per acre, as chemical methods began to outperform manual efforts in both efficiency and ecological stability.

Field observations suggest that standing dead biomass often decomposes more rapidly than cut and stacked material, particularly in moist, well-ventilated environments. This is likely due to increased exposure and accessibility for decomposers such as fungi, termites, and borers. While formal comparisons remain limited, this ecological process supports low-disturbance control strategies by accelerating natural breakdown and reinforcing habitat continuity.

2019 Selective Chemical Removal of *Polygala*
Area: 85.26 acres

With a strategic shift toward autumn–spring operations, program coverage expanded significantly, while hours per acre declined sharply compared to the manual control period—indicating substantial gains in operational efficiency and reduced recruitment pressure. Larger areas were treated rapidly with high selectivity, intercepting cohorts just before maturity. In many cases, plants were nearing flowering, making it a race against time to prevent seed rain. By curtailing seed release, the residual seedbank began to deplete at an accelerated rate, transitioning the system into a scalable suppression phase.

2020 Selective Chemical Removal of *Polygala*
Area: 49.42 acres

Selective chemical control continued to suppress emergence pulses and prevent seed rain. Hours per acre remained low and stable despite high seedling density, reflecting improved efficiency and reduced recruitment pressure. This year marked a consolidation of the depletion trend: fewer plants reached maturity, seedbank withdrawals exceeded deposits, and the site advanced toward a maintenance phase. Although the treatment window was shorter, considerable progress was achieved—alongside targeted control of Rhamnus alaternus.

2021 (COVID-19).

The primary focus shifted to basal barking *Rhamnus alaternus*, while incidental *Polygala myrtifolia* follow-ups were conducted when encountered during targeted operations. Scattered seedlings posed minimal risk; however, conspicuous individuals near Rhamnus alaternus were spot-treated to prevent seed rain—sustaining pressure on the residual seedbank without re-disturbing soils.

2022 Selective Chemical Removal of *Polygala*
Area: 82.33 acres

Operations transitioned further into a maintenance phase, characterised by reduced total hours and modest hours per acre—effectively capturing residual cohorts without reactivating disturbance. Seedbank depletion was within reach, with emergence limited to patchy, low-density pulses. Effort centred on methodical targeting across the entire site, sustaining the downward trajectory and reinforcing long-term suppression. As *Polygala* stems broke down, visibility improved markedly, allowing works to proceed more quickly and precisely. The addition of a second spray unit further enhanced coverage and efficiency

2023 Selective Chemical Removal of *Polygala*
Area: 68.09 acres

The central cover estimate declined to approximately 1.8% (modelled), indicating minimal regrowth and effective long-term suppression. The integration of selectivity, low-disturbance techniques, and strategic timing created conditions where native groundcovers and microhabitats could persist or recover, while *Polygala* was reduced to broken groups. Follow-up interventions were light-touch, focused solely on intercepting seed rain and sustaining suppression without reactivating disturbance. A systematic drive to revisit all treated areas ensured no pockets were missed, reinforcing site-wide coverage and maintaining pressure on the residual seedbank.

2024 Selective Chemical Removal of *Polygala*
Area: 26.83 acres

Untreated areas from the previous year—deferred due to reduced operational hours—contributed to a slight increase in the treatment footprint this season. While some *Polygala* plants were older than ideal for early-phase control, none had reached maturity, and seed rain risk remained low. Ensuring comprehensive coverage through selective chemical application was essential to maintain control and enable precise follow-up interventions without reactivating disturbance.

2025 Basal Bark Chemical Removal of *Polygala*
Area: 93.81 acres

The site advanced into a low-effort maintenance phase, requiring only occasional basal bark treatments or manual removal. Mature plants were scarce, seedling cohorts were infrequent, and hours per acre remained minimal—demonstrating long-term stability achieved through selective chemical control and the Method of Least Disturbance. In many areas, plant density was too low to justify foliar application, reinforcing the shift toward precision-based follow-up. A systematic sweep was conducted to ensure no individuals were missed, maintaining pressure on the residual seedbank and protecting the gains achieved. Nevertheless, a residual risk of germination persists due to the substantial seedbank accumulated during years of manual removal and historical seed input, underscoring the need for continued vigilance. Important: 2025 figures are provisional, based on hours logged to September 2025. These values are not included in statistical calculations and are presented only to illustrate the maintenance-phase trend.

Table 2 Hours, Area, and Method.

Year	**Method**		**Area (acres)**	**Total Hours**	**Hours per Acre**	**Interpretation Based on Germination & Maturity**
2013	Manual		43.47	8100	186.33	Focused on mature plant removal; disturbance triggered seedbank activation
2014	Manual		31.63	10404	329.24	Continued mature plant removal; high effort reflects dense infestation.
2015	Manual		31.24	3312	106.02	Effort shifted to missed and follow-up zones, but disturbance—especially from thermal control—triggered dense seedling emergence and may have inadvertently promoted *Polygala* recruitment.
2016	Manual		7.01	1520	216.83	Follow-up mature plant removal: high hours reflect seedling intensity despite smaller area.
2017	Manual		29.14	3312	113.65	Plants began outpacing manual control; nearing seed maturity.
2018	Chemical		28.57	3312	115.92	Shift to chemical control enabled precise targeting of seedlings and larger plants during peak germination.
2019	Chemical		85.26	3312	38.84	Autumn–spring operations enabled efficient, selective treatment at scale, intercepting cohorts before seed rain and accelerating seedbank depletion.
2020	Chemical		49.42	1932	39.09	Continued chemical control, germination in cooler months. Hours drop show others moved to *Rhamus alaternus*
2021	Basal Bark		x	x	x	Focus on Italian Buckthorn (*Rhamus alaternus*) [*polygala* scattered seedlings were not at-risk obvious plants near *Rhamnus alaternus* were spot-treated though to prevent seed rain]
2022	Chemical		82.33	3024	36.73	Operations are beginning to enter a maintenance phase with reduced hours and improved visibility, enabling precise targeting of residual cohorts and accelerating seedbank depletion.
2023	Chemical		68.09	2418	35.51	*Polygala* fragmented with minimal regrowth after selective low-disturbance treatments, and light follow-ups plus systematic revisits sustained suppression.
2024	Chemical		26.83	1152	42.93	The treatment footprint modestly expanded to include previously deferred areas with slightly advanced vegetation, requiring thorough selective chemical control to restore suppression and enable precise, low-disturbance follow-up.
2025	Basal Bark/hand[3]		93.81	576	6.14	The site entered a low-effort maintenance phase marked by long-term stability and precision-based follow-up, though residual seedbank risk demands ongoing vigilance.

Phase	**Years**
Manual and Thermal Control	2013–2017
Selective Chemical Control (Clopyralid)	2018–2020 2022-2024
Maintenance and Monitoring	2021, 2025

[3] **Provisional: 2025** figures reflect hours logged to date (as of September 2025) and as works continue. This figure has not been used in the statistical calculation and is shown to highlight it is effective follow up strategy.

Descriptive Analysis.
The germination study in (Roberts et al., 2023). reveals that *Polygala myrtifolia* seeds are non-dormant**,** highly viable, and capable of rapid germination under a wide range of environmental conditions. Germination rates exceeded 90% under optimal temperatures (25°C–15°C) and were unaffected by light or soil pH. Seeds remained viable for over 10 years and could germinate from shallow burial depths, with emergence peaking at the soil surface.

These traits directly correlate with the observed challenges in manual control efforts. In 2013 and 2014**,** intensive manual removal successfully eliminated most mature plants, temporarily suppressing regrowth. However, by 2016, despite a smaller team completing mature plant removal, the rapid regermination from the persistent seedbank outpaced manual efforts. This inefficiency is reflected in the uptick in hours per acre (216.83), prompting a strategic shift to chemical spraying in 2018.

Chemical control proved more effective at targeting seedlings during their vulnerable emergence phase. Efficiency gains from 2018 onward: starting at 115.92 hours per acre in 2018, dropping to 38.84 hours per acre in 2019, and averaging 51.50 hrs/acre across the chemical phase. Reflecting substantial efficiency gains — align with the germination study's recommendation to control seedlings immediately upon emergence**.** The data also supports the use of seasonal spraying during autumn, winter, and spring, when germination is most active.

Manual Control Phase (2013–2017).
Early efforts focused on the manual removal of mature plants, requiring intensive labour and resulting in high disturbance:

- 2013: 186.33 hrs/acre —The Beginning manual effort dealing with mature dense infestations.
- 2014: 329.24 hrs/acre — increased effort due to dense infestations.
- 2015: 106.02 hrs/acre — follow-up control targeting missed mature plants and emerging seedlings. Efficiency improved slightly, but regrowth pressure remained high.
- 2016: 216.83 hrs/acre — Area labour intensity, reflecting the challenge of controlling dense seedling carpets with a smaller team.
- 2017: 113.65 hrs/acre — despite reduced hours per acre, plants began to outpace manual control as efforts focused on particular plants with signs of maturity and potential seed rain. This prompted a strategic shift to chemical control in 2018.

These years contributed to significant seedbank accumulation due to soil disturbance and incomplete removal.

Chemical Control Phase (2018–2024).
The introduction of Clopyralid in 2018 marked a turning point:

- 2018: 115.92 hrs/acre — targeted larger plants as well as seedling flushes during germination.
- 2019–2020: Efficiency improved dramatically (~39 hrs/acre), with reduced biomass and better suppression.
- 2021: Focus on Italian Buckthorn (*Rhamus alaternus*) [*polygala* scattered seedlings were not at-risk. Though obvious plants near *Rhamnus alaternus* were spot-treated though to prevent seed rain]
- 2022–2024: Beginning shift towards maintenance phase; hours per acre stabilised between 35–43, indicating effective prior control and reduced emergence.

Chemical control aligned with *Polygala*'s germination traits, allowing for strategic timing and minimal disturbance.

Basal Bark Follow-up (2025).[3]

- 2025: Just 6.14 hrs/acre, reflecting rapid walkthroughs and spot treatments. Few mature plants remain, and the focus is on preventing seed rain.

Correlation Between Germination Traits and Control Efficiency.
The control efficiency of *Polygala myrtifolia* at Boneo is strongly influenced by its germination biology. These traits have shaped the transition from manual to chemical control and informed the timing and method of interventions.

Key Germination Traits.

1. **Seedbank Persistence.**
   Seeds remain viable for over 10 years, meaning even successful removal of mature plants does not eliminate future germination risk. This persistence was evident in the Auditing Compliance of Year 7 (2020), which reported significant recruitment of *Polygala* in previously treated areas, despite prior control efforts.

2. **Seasonal Germination Peaks.**
   Germination is most prolific during cooler months (autumn to early spring). The Boneo follow-up audit visit in November 2020 documented carpets of seedlings in southern sections of the site, aligning with seasonal emergence patterns and confirming the need for timely chemical intervention during these periods.

3. **Light Independence.**
   Polygala seeds germinate under canopy or shaded conditions, making manual removal less effective in suppressing future growth. The auditing Year 7 visit Images from (2020) show dense carpets of seedlings in areas where mature plants had been targeted, suggesting that increased light and moisture availability post-removal may have triggered germination

4. **Burial Depth Sensitivity.**
   Seeds buried deeper than 4 cm typically do not germinate. Manual removal, which disturbs the soil, may inadvertently bring dormant seeds closer to the surface. In contrast, chemical control minimises soil disruption, helping suppress emergence. This is supported by the declining hours-per-acre data from 2019 onward, indicating reduced seedling emergence following strategic chemical applications.

Observed Correlation with Control Efficiency.
The hours-per-acre data from 2013 to 2025 illustrates how germination traits influenced control outcomes:

- **Manual Control (2013–2017).**
  - High labour intensity: 186.33 hrs/acre (2013), 329.24 (2014), 106.02 (2015), 216.83 (2016), and 113.65 (2017).
  - Soil disturbance activated the seedbank, requiring repeated follow-up.
  - Site reports from 2019 and 2020 show that areas previously cleared manually still experienced dense seedling carpets.

- **Chemical Control (2018–2024).**

- Efficiency improved: 115.92 hrs/acre (2018), dropping to ~39 hrs/acre by 2020.
- Targeted herbicide application during germination peaks suppressed emergence.
- Compliance documents noted reduced biomass and fewer mature plants, confirming effectiveness.

- **Basal Bark Follow-up (2025).**
  - Just 6.14 hrs/acre, reflecting a shift to rapid walkthroughs and spot treatments.
  - Site observations confirm few mature plants remain, and control focuses on preventing seed rain.

Efficiency, Effectiveness, and Ecology:

Patterns in cover reduction and labour demand revealed two vastly different trajectories for manual and chemical control. To capture these dynamics and test what might have happened under alternative strategies, a simple mechanistic model (Appendix D) was developed. This model links three critical elements—cover change, seedbank risk, and labour demand—under contrasting management regimes. By formalising these relationships, it moves beyond descriptive trends to explain why outcomes diverged: how disturbance, seedbank accessibility, and timing interact to shape restoration success. The framework also enables counterfactual analysis, showing what continued manual control would have meant for cover and effort. Figure 8 illustrates this integration of observed data with modelled projections, providing a clear view of how management choices influence both efficiency and ecological stability over time**.**

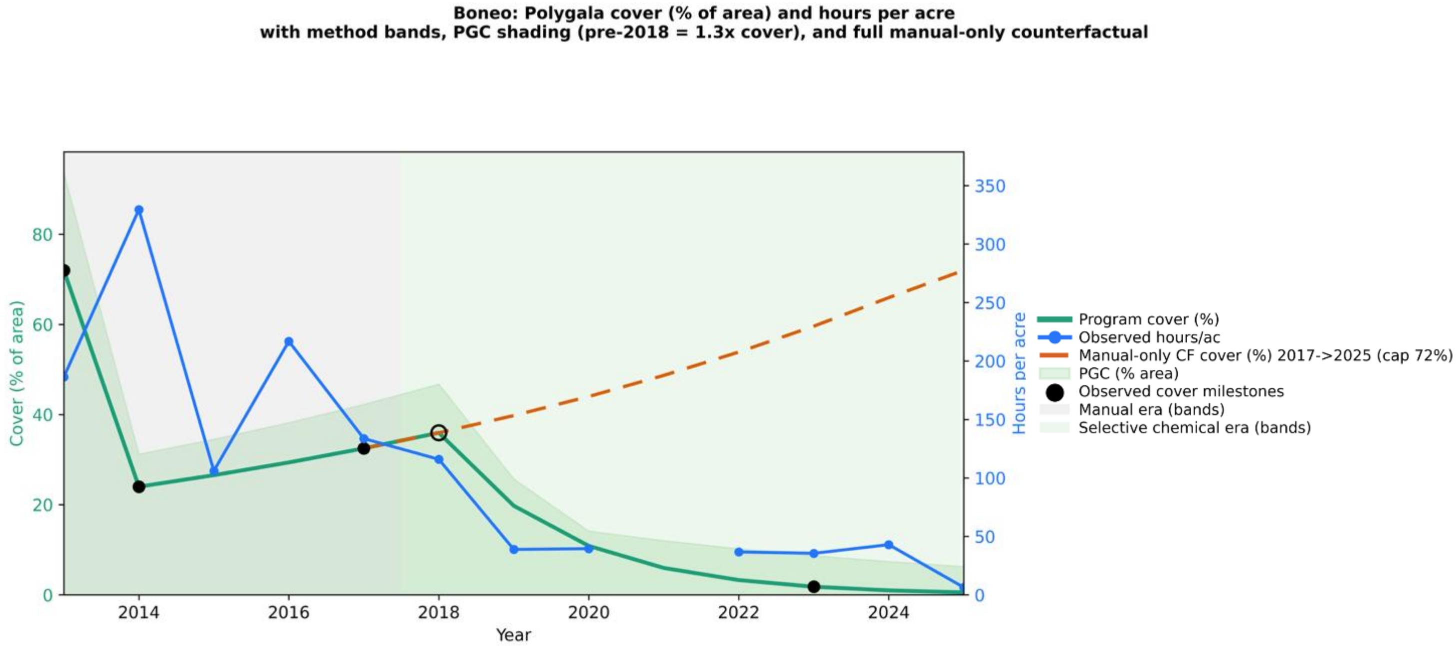

Figure 8. Mechanistic model of cover and effort trends under contrasting control strategies. Solid green line = observed program trajectory (% cover decline under selective chemical control); Dashed orange line = manual-only counterfactual *shows rebound risk* (projected rebound capped at 72%); Light-green shading = Potential Germination Coverage (PGC) concept; Blue line = observed hours per acre; Grey band = manual era (2013–2017); Green band = selective chemical era (2018–2025); Open marker = START-2018 anchor; Filled markers = observed cover milestones; 2025 marker denotes provisional data (works ongoing as of September 2025). Model parameters and averages exclude provisional year.

Model logic: Manual removal assumed proportional rebound (compound annual growth rate) due to disturbance-driven seedbank activation; chemical control modelled as exponential decay reflecting sustained suppression and prevention of seed rain. PGC overlays seedbank accessibility risk, decaying after low-disturbance herbicide adoption.

Assumptions: Constant annual rates for rebound and decay; uniform site conditions; simplified seedbank dynamics via PGC term; excludes stochastic events (e.g., rabbit disturbance, extreme weather).

Limitations: Projections are indicative trends rather than precise forecasts, and the model does not incorporate spatial heterogeneity, seasonal anomalies, or logistic saturation effects. This study acknowledges several constraints that shape interpretation of the mechanistic model and field results. It assumes constant annual rebound and decay rates, simplifying seasonal variability and operational fluctuations that occur in real-world programs. The site is treated as spatially uniform, overlooking microhabitat differences that influence germination and control efficacy. Seedbank dynamics are condensed into a single Potential Germination Coverage (PGC) term, omitting depth-specific emergence probabilities documented in Roberts et al. (2023). Stochastic factors such as rabbit disturbance, wind throw, or extreme rainfall are excluded, despite their potential to reactivate germination. Climate variability and interannual anomalies are not incorporated, which may alter germination windows or herbicide performance. Operational assumptions also presume uninterrupted program delivery, whereas delays in funding or labour availability could shift outcomes. Future refinements could integrate stochastic modules and climate variability for greater realism, but for now, projections should be interpreted as comparative indicators rather than absolute predictions.
These constraints should be considered when interpreting Figure 8, which illustrates projected cover and effort trends under contrasting management scenarios.

Interpretation.

High labour intensity of manual control (2013–2017).
From 2013 to 2017, manual removal of *Polygala myrtifolia* at Boneo demanded extraordinary labour, with large teams investing up to 285 hours per week during the early years. In 2013 and 2014, crews of 9–11 people focused on mature plants, but despite these efforts, disturbance from manual clearing triggered widespread regermination. By 2016, even with a smaller team working intensively on 7.01 acres, the workload soared to 216.83 hours per acre, highlighting the inefficiency of manual control as plants rapidly outpaced removal. Between 2015 and 2017, weekly hours dropped to 108, yet regeneration continued across the entire original area, forcing a strategic shift toward selective chemical control. This transition dramatically reduced labour demands, with selective chemical methods from 2018 onward requiring far fewer hours per acre despite treating larger areas—such as 139 acres in 2019—underscoring how manual control was not only labour-intensive but ultimately unsustainable.

Selective chemical era (2018–2025).
Timed, selective application of Clopyralid with minimal disturbance effectively suppressed seedlings and prevented seed rain, enabling predictable seedbank depletion and a sustained decline in *Polygala myrtifolia* cover. Retention of dead biomass supported the least-disturbance pathway, reducing secondary germination triggers.
This strategic shift in 2018 marked a turning point: hours per acre dropped sharply as chemical control replaced the disturbance-driven, labour-intensive manual removal. Efficiency gains continued through 2025, culminating in a low-maintenance phase.

The concept of Potential Germination Coverage (PGC)—representing seedbank accessibility—illustrates this trend. Elevated by prior disturbance, PGC remained high into early 2018 before decaying rapidly between 2018 and 2020. Despite dense germination persisting into 2020, the observed reduction in control effort reinforced the effectiveness of the method of least-disturbance chemical strategy.

Cover dynamics and effort trends.
Under manual weeding, cover rebounded at an annual rate of approximately 10.63%, calculated from observed milestones (2014 = 24%, 2017 = 32.5%) using a compound annual growth formula. A modelled counterfactual projection shows that, if manual control had continued, cover would have approached the original 72% envelope by 2025. In contrast, selective chemical control initiated at START-2018 produced an exponential decline, with a decay factor of 0.5494 per year, reducing cover to 1.8% by 2023. PGC, scaled above canopy cover pre-2018 to reflect seedbank risk, collapsed rapidly after chemical control eliminated seed rain and upward redistribution. Observed hours per acre fell from over 200 during the manual era to less than 10 by 2025, confirming substantial efficiency gains and reinforcing the ecological benefits of low-disturbance, cool-season Clopyralid applications.

Model Framework and Literature Context.
The analysis uses a parameter-driven mechanistic model that integrates:

- **Manual rebound function**:

$$\text{Cover}_{t+1} = \text{Cover}_t \times (1 + r_M), r_M = 0.1063$$

- **Chemical decay function**:

$$\text{Cover}_{t+1} = \text{Cover}_t \times f_C, f_C = 0.5494$$

- **PGC overlay**:
  pre-2018: $\text{PGC}_t = 1.3 \times \text{Cover}_t$;
  post-2018: piecewise decay (0.55 for 2019–2020, 0.85 thereafter).

- **Efficiency curve**:

$$E(t) = \frac{\text{Hours}(t)}{\text{Area}(t)}$$

This approach aligns with frameworks reviewed by Thompson and Olden (2021), who examined mechanistic invasive species models, and with applications by Bagavathiannan et al. (2020) using exponential and logistic functions for weed population dynamics. The exponential decay component reflects principles used by Storkey (2004) to model early seedling growth rates in temperate weeds. Full mathematical details—including parameter derivation and functional forms—are provided in Appendix D.

The choice of exponential decay and rebound functions reflects the biological and operational dynamics observed at Boneo. Manual removal created a disturbance-driven feedback loop, where seedbank activation produced proportional increases in cover—best represented by a compound annual growth rate (rebound function). Conversely, selective chemical control suppressed recruitment and prevented seed rain, producing a consistent proportional decline in cover over time—an exponential decay pattern. These forms are widely used in weed population modelling because they capture multiplicative processes: germination and growth accelerate under disturbance, while mortality compounds under sustained suppression.

To complement these modelled trends, field observations provide tangible evidence of this shift in site condition:

Observed Decline in Polygala Cover.
Field observations and compliance reports confirm a marked reduction in Polygala myrtifolia cover and maturity during the monitoring period. In 2020, site audits documented numerous mature and semi-mature plants alongside dense patches and carpets of seedlings, indicating persistent recruitment pressure. By late 2021, follow-up inspections reported no mature Polygala and only scattered small plants, with previously carpeted areas successfully treated. Indigenous grasses and understorey species were noted as responding positively, suggesting that control efforts not only suppressed Polygala dominance but also facilitated native vegetation recovery. This transition from dense infestations to scattered individuals reflects the effectiveness of sustained, low-disturbance chemical control and underpins the observed improvement in site condition.

Hypothesis and Supporting Reasoning.

Selective chemical removal—using low-disturbance, timed applications of Clopyralid—is considered best practice for managing *Polygala myrtifolia* because it aligns with the species' germination ecology, interrupts the disturbance feedback loop observed at the Boneo site, and delivers sustained suppression while protecting habitat structure. Research by Roberts et al. (2023) confirms that *Polygala* seeds germinate prolifically under a wide range of conditions, especially during autumn, winter, and spring. This means that any soil disturbance, such as manual removal, can trigger mass germination, reinforcing a feedback loop of regeneration that undermines control efforts.

A null hypothesis assumes that there is no significant difference in efficiency or ecological disturbance between manual removal and selective chemical control using Clopyralid. It suggests that any observed differences in hours-per-acre or regrowth rates are due to random variation or site-specific factors rather than the control method itself. This statistical baseline ensures that conclusions about the superiority of chemical control are only drawn when supported by compelling evidence.

In contrast, the alternative hypothesis proposes that selective chemical control is significantly more efficient and ecologically less disruptive than manual removal. Clopyralid is a selective, systemic herbicide that targets broadleaf weeds while sparing native grasses and many forbs. Its mode of action mimics plant hormones, disrupting vascular function and leading to plant death without stimulating germination (BLM, 2014). This aligns with *Polygala*'s germination ecology and allows for strategic, timed applications that suppress regrowth without triggering new emergence. The Boneo site's history illustrates how manual removal led to widespread regeneration due to soil disturbance, whereas chemical control stabilised the system and reduced regrowth pressure.

Roberts et al. (2023) show that *Polygala myrtifolia* seeds germinate easily—they are non-dormant, highly viable, and reach about 93–95% germination under alternating temperatures of 25 °C/15 °C, regardless of light. This means seedlings can appear under canopy or in open patches whenever moisture and temperature align. Germination works across a wide pH range (4–10), so soil chemistry will not limit spread. Dry spells slow emergence, but cool, moist seasons—autumn, winter, and spring—trigger strong flushes, which is critical for Boneo because these periods coincide with peak recruitment pressure. Seeds emerge best at the surface and not at depths around 8 cm, though they stay viable for years. Disturbance that brings buried seeds up greatly increases short-term recruitment. For Boneo, where past manual removal caused soil disturbance and seedbank activation, this evidence reinforces that minimising disturbance and intercepting seedlings during cool, moist seasons is essential for long-term success. Disturbance-heavy methods will only amplify the problem by exposing buried seed.

Polygala myrtifolia exhibits a high degree of disturbance adaptability, allowing it to persist and proliferate across both highly disturbed and long-undisturbed environments. Moxham and Turner (2008) observed that *Polygala* was common in recently burnt sites and in areas unburnt for over a century, but notably less abundant in zones with intermediate fire histories (Appendix F). This bimodal distribution suggests that *Polygala* can exploit freshly disturbed environments—where competition is low and bare ground is abundant—as well as stable, shaded systems where its persistent seedbank and shade tolerance support long-term survival. These findings align with Roberts et al. (2023), who demonstrated that *Polygala* seeds are non-dormant, highly viable, and capable of germinating under a wide range of environmental conditions, including moderate salinity, low moisture stress, and variable pH. Germination peaks during cool, moist seasons (autumn to spring), and is strongly influenced by burial depth, with emergence highest at the soil surface and absent beyond 8 cm. Together, these studies reinforce the importance of low-disturbance control methods that avoid activating the seedbank or creating conditions conducive to mass germination, particularly in sensitive coastal ecosystems.

Early manual removal (2013–2017) was extremely labour-intensive—2016 alone required over 216 hours per acre—and despite big efforts, regermination quickly outpaced control. This was linked to soil disturbance activating the seedbank. From 2018, switching to selective Clopyralid spraying during seedling flushes changed the game: low disturbance, dead plants left as habitat, and sharp drops in labour (around 35–43 hours per acre by 2022–2024). By 2025, the site was in maintenance mode at just 6.14 hours per acre, with very few larger plants left. The key lesson: low-disturbance, selective herbicide control works far better than disturbance-heavy methods, but rates must be managed to avoid off-target impacts.

A site-specific model (Figure 8) integrates Roberts et al. (2023) with field observations from Boneo to explain changes in *Polygala myrtifolia* cover over time. Central to the model is the concept of Potential Germination Coverage (PGC)—the proportion of the site likely to experience seedling flushes if conditions and seed availability allow. This is influenced by Emergence Likelihood, which describes how readily seeds can germinate based on their position in the soil profile. Disturbance increases emergence likelihood by moving seeds closer to the surface, while low-disturbance conditions reduce it. This reflects Roberts et al.'s (2023) depth–emergence relationship, where germination is strong at the surface but absent at depths beyond 8 cm. Seasonal weighting favours autumn, winter, and spring, consistent with laboratory and field evidence showing that cool, moist conditions drive germination flushes.

To capture the site's trajectory, the model incorporates lag-awareness through the PGC term, calibrated from Roberts et al.'s findings. It shows that a manual-only counterfactual—where disturbance remained high—would likely have sustained elevated cover through 2025. This is illustrated by a dashed line extending the manual upward trend from 2017 to the 2018 anchor, representing the expected rebound if high disturbance had continued. In contrast, the actual trajectory reflects the shift to selective chemical control: seed rain ceased, disturbance collapsed, and cover declined rapidly, reaching a maintenance phase by 2025.

The 2017 anchor is pivotal. Manual removal had pushed seeds near the surface, creating peak emergence potential. When low-disturbance herbicide control began in 2018, both emergence likelihood and seed input dropped sharply, causing the PGC curve to fall—exactly as confirmed by Boneo field data. These findings support selective chemical removal as best practice for Coastal

Alkaline Scrub/Moonah Woodland. It aligns with germination biology, minimises seedbank activation, reduces hours per acre, and preserves habitat integrity under the Method of Least Disturbance.

Why selective chemical removal with low-disturbance Clopyralid is best practice?

Selective foliar spraying offers clear advantages over manual removal because it tackles both the biological drivers of *Polygala* recruitment and the operational challenges of large-scale control.

- First, it avoids activating the seedbank. Manual uprooting and clearing disturb the soil and lift buried seeds into the high-emergence zone near the surface, as shown by Roberts et al. (2023). In contrast, Clopyralid spraying leaves soil structure intact, reducing the chance of new germination in the following season.

- Second, it intercepts the seasonal germination window. Laboratory evidence shows that *Polygala* germinates most strongly in cool, moist periods—autumn through to spring. Timed herbicide applications during these flushes kill seedlings before they set seed, steadily depleting the seedbank without replenishment. (Roberts et al. 2023).

- Third, because germination is independent of light, seedlings emerge under canopy as well as in open patches, so foliar spraying is effective in shaded understories without canopy opening, which would otherwise increase emergence risk, as shown by Adair et al. (2012).

- Fourth, the approach is highly efficient and scalable. After the 2018 pivot to selective chemical control, labour per acre dropped sharply—from hundreds of hours under manual removal to around 35–43 hours per acre by 2022–2024, and just 6.14 hours per acre in 2025 during maintenance. This operational record demonstrates that low-disturbance selectivity scales where manual methods fail.

- Fifth, it supports ecological stewardship through the Method of Least Disturbance; retaining dead biomass helps stabilise fragile calcareous sands and preserve microhabitats, reducing collateral impacts on native species and maintaining ecological integrity, as demonstrated by Shen et al. (2023) and Zhou et al. (2022).

- Finally, Clopyralid's selectivity allows precise, low-rate spot applications. Observations of sensitivity in species like *Tetragonia implexicoma* reinforce the need for a conservative, minimum-effective-dose strategy combined with monitoring to manage off-target risks.

Limitations and Safeguards.
To keep best practice truly effective, two key safeguards are essential.
First, off-target risk exists if rates are too high or application technique is poor. Notes on native sensitivities highlight the need for lower rates, coarse droplets, spray shields, and strict nozzle discipline to protect non-target species.
Second, the seedbank has a long tail, as Roberts et al. (2023) confirms, meaning annual surveillance remains critical. Factors like rabbit activity, wind throw, or incidental disturbance can reopen emergence windows, so maintaining zero tolerance for seed rain is vital to prevent reinfestation.

Discussion: *Polygala myrtifolia* Management; Germination Ecology and Disturbance Response

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Relevance of Roberts et al. (2023) Data.
Roberts et al. provide the mechanistic foundation for understanding *Polygala myrtifolia's* invasion dynamics. Their study shows that seeds are non-dormant, germinate at exceedingly high rates (93–95%) under cool-season temperatures (25°C–15°C), and are light-independent, meaning germination occurs under canopy as well as in open areas. They also demonstrate that emergence is strongly depth-dependent—nearly 50% at the soil surface but absent at ~8 cm—and that seeds remain viable for years. These traits explain why soil disturbance is a critical driver of recruitment: any action that moves seeds upward into the top few centimetres dramatically increases emergence potential. Additionally, Roberts et al. confirm that germination is most active during autumn–spring, aligning with the seasonal windows when Boneo observed seedling flushes.

Why Boneo Observations Match Roberts et al.
The Boneo site data from 2013–2017 reflects exactly what Roberts et al (2023) predict: manual removal and thermal methods, which involved uprooting and clearing, caused significant soil disturbance. This disturbance redistributed seeds toward the surface, creating ideal conditions for germination during cool, moist periods. As a result, despite heavy labour inputs (e.g., 216.83 hrs/acre in 2016), regrowth outpaced manual efforts by 2017. This is consistent with Roberts et al.'s (2023) depth-emergence curve and their conclusion that disturbance accelerates recruitment from persistent seedbanks.

Early management approaches often assumed that accelerating germination would rapidly exhaust the seedbank. However, this concept is operationally flawed in large-scale restoration: field and synthesis studies report the same pattern—germination without least-disturbance conditions and rapid interception commonly amplifies cohort density, increases labour demand, and reinforces a disturbance–seedbank feedback loop (Weidlich et al., 2020; Guo et al., 2019). At Boneo, disturbance-driven germination produced exactly this outcome, matching those broader findings and showing that disturbance-based strategies can reinforce, rather than resolve, the underlying problem (Boneo data; Weidlich et al., 2020; Guo et al., 2019).

When Boneo pivoted to selective chemical control with Clopyralid in 2018, the program aligned with Roberts et al.'s (2023) recommendation to target seedlings immediately upon emergence. Foliar spraying during autumn–spring germination windows suppressed seedlings before seed rain, while minimal soil disturbance prevented further activation of the seedbank. This strategy reduced hours per acre by ~77% compared to manual methods and drove cover down to near-zero by 2023, entering a low-maintenance phase by 2025. These outcomes validate Roberts et al.'s (2023) findings in a real-world context: low-disturbance, timed chemical control is the most effective way to exploit the species' germination ecology for long-term suppression.

Long-Term Seedbank Risk.

Polygala myrtifolia (myrtle-leaf milkwort) maintains a persistent soil seedbank, with viable seeds commonly remaining for 3–10 years or longer. Emergence is concentrated near the soil surface and negligible below ~8 cm, meaning seedlings may continue to appear for many seasons following disturbance—even after canopy cover approaches zero (Roberts et al. 2023; Weeds Australia 2024). Cool, moist periods further favour germination, reinforcing the need for zero tolerance to seed rain and annual follow-up until the residual seedbank is exhausted (Roberts et al. 2023; Weeds Australia 2024). While manual and thermal removal may seem straightforward, both often trigger unintended ecological consequences. Soil disturbance—whether through uprooting, dragging, or heat application—activates dormant seeds, prompting flushes of new growth. This response is not incidental but intrinsic to the biology of *Polygala* itself.

Moxham & Turner (2011) found that remnants situated within an infrastructure matrix—urban, rural, and roads—consistently supported higher frequencies of exotic shrubs such as *Polygala myrtifolia*. This pattern was strongly linked to disturbance factors including trampling, soil compaction, and weed invasion, rather than land use alone. Their ordination analysis confirmed that disturbance was a significant driver of community composition ($r^2 \approx 0.52$), highlighting that infrastructure acts as a proxy for human disturbance. Field observations at Boneo reflect this dynamic: manual and thermal removal created substantial soil disturbance, triggering mass germination from the seedbank and reinforcing a feedback loop of reinfestation. This disturbance–germination cycle reflects broader patterns documented in invasion ecology, where altered disturbance regimes create reinforcing feedback loops that sustain invasive dominance (Gaertner et al., 2017). Transitioning to low-disturbance selective chemical control broke this cycle and aligned management practice with the ecological insight that disturbance—not mere proximity to infrastructure—underpins *Polygala* dominance (Moxham & Turner, 2011).

Polygala's germination is strongly influenced by burial depth. Seeds buried deeper than 4 cm rarely germinate, but manual removal disrupts soil layers and brings dormant seeds closer to the surface, where light and moisture favour emergence (Roberts et al. 2023). Compounding this is *Polygala's* light independence—its seeds can germinate even under shaded conditions. Yet when canopy or dead biomass is removed, increased light penetration can further stimulate seedling emergence (Roberts et al. 2023).

Seasonal timing intensifies these effects: germination peaks during cooler months, from autumn to spring. If removal coincides with these periods, the combination of soil disturbance and seasonal triggers can produce dense carpets of seedlings (Roberts et al. 2023). Adding to the challenge is *Polygala's* seedbank persistence—seeds can remain viable for over a decade, meaning any disturbance may provoke long-term regrowth pressure and necessitate repeated follow-up treatments. This longevity reinforces the need for strategic, low-disturbance approaches.

Even when aboveground cover collapses, the soil remains a reservoir of viable seeds capable of germinating in pulses under favourable conditions; reviews of weed ecology more broadly note that seedbank persistence and disturbance-driven emergence are well documented (Schwartz-Lazaro and Copes 2019; Benvenuti and Mazzoncini 2021) and may apply to *Polygala myrtifolia* where direct evidence is lacking. Effective management of *Polygala myrtifolia* therefore requires not just removal, but a long-term strategy grounded in ecological understanding, operational realism, and sustained monitoring, with species-specific follow-up where available (Schwartz-Lazaro and Copes 2019; Benvenuti and Mazzoncini 2021).

Breaking this feedback cycle reduces regrowth pressure and accelerates restoration. The seedbank behaves like a loaded spring, releasing cohorts whenever conditions align. Best practice therefore focuses on preventing new seed rain while systematically depleting the existing bank over multiple years (Haring & Flessner, 2018; Norsworthy et al., 2018).

Invertebrate activity, particularly by ants, plays a subtle but important role in passive seedbank suppression. While some ant species may contribute to seed dispersal, their soil bioturbation—through tunnelling, mound-building, and nest maintenance—can also facilitate seed burial. These activities, alongside leaf litter accumulation, rain splash, and wind-blown sediment, gradually move seeds into deeper soil layers. For *Polygala myrtifolia*, which shows zero emergence beyond 8 cm depth (Roberts et al., 2023), such burial significantly reduces germination risk. Within the M.O.L.D. framework, ants are considered ecological allies: their activity supports passive seedbank depletion without triggering emergence. This reinforces the principle that low-disturbance management not only avoids activating the seedbank but also enables natural processes to suppress it over time (Bewley et al., 2013).

***Polygala myrtifolia*: Why Manual and Thermal Removal Triggers a Feedback Loop.**
Despite their appeal as "chemical-free" options, manual and thermal methods often conflict with the "Method of Least Disturbance"—a principle critical to managing coastal weed dynamics. Uprooting plants exposes buried seeds to light and moisture, triggering germination (Roberts et al. 2023). Flame and thermal treatments strip protective groundcover and destabilise the soil microclimate, accelerating seedling emergence and increasing erosion risk, especially on fragile coastal sands. Moss and litter cover declined in frequently burnt sites (Appendix F), reducing microhabitat availability and compounding erosion vulnerability (Moxham & Turner 2008). These findings support the rationale for retaining dead biomass in situ under the Method of Least Disturbance.

Even small-scale removal of *Polygala* seedlings carries significant risks. Pulling disturbs the upper 0–4 cm of soil—the critical zone where dormant seeds are most likely to germinate when brought closer to the surface. This disruption can lift or loosen buried seeds, increasing their exposure to moisture and triggering fresh germination. In mixed vegetation zones, uprooting also threatens native species: fine roots of herbs, forbs, and shrubs may be torn or severed, especially where root systems are interwoven, and small native seedlings can be inadvertently dislodged. Repeated pulling degrades soil structure, weakens plant anchorage, and heightens erosion risk—particularly on sandy substrates. It may also compromise beneficial mycorrhizal networks essential for native plant health and nutrient uptake.

Frequent fire events in Coastal Moonah Woodland have been shown to reduce structural complexity, shifting vegetation from layered woodland to grassy shrubland (Moxham & Turner, 2008). Obligate seed regenerators—including canopy species such as Melaleuca lanceolata and Acacia uncifolia—declined significantly with increasing fire frequency, reinforcing the ecological risk posed by heat-based control methods, which may deplete seedbanks before regeneration can occur. Exotic species, particularly grasses, increased under repeated fire, suggesting that disturbance may facilitate secondary invasions (Moxham & Turner, 2008). These findings align with field observations at Boneo, where thermal and manual disturbance triggered dense seedling carpets of *Polygala myrtifolia*. Operationally, these methods are also costly and labour-intensive. Between 2013 and 2017, manual control averaged 190.41 hours per acre, peaking at 329.44 hours in 2014. Even in 2016, effort remained high at 216.83 hours per acre, until chemical control was introduced and dramatically reduced labour demands.

While chemical control is often viewed with scepticism by some in conservation circles, this study demonstrates that selective herbicide use—when guided by ecological timing, taxonomic specificity, and low-disturbance principles—can outperform manual methods in both efficiency and ecological outcomes. The assumption that manual removal is inherently safer or more sustainable is not supported by field data from Boneo, where disturbance-driven regrowth repeatedly undermined manual efforts and increased labour demand. Selective chemical control, by contrast, aligns with the Method of Least Disturbance and supports long-term habitat recovery.

If any manual seedling removal must occur it therefore needs to be approached with precision. It is most effective when targeted in known low-density zones, timed outside peak germination windows, and conducted with minimal soil disturbance to avoid seedbank activation and collateral damage. Declaring eradication after only three to five years of low emergence is premature. The Year 7 compliance letter (2020), which reported carpets of seedlings in previously treated zones, illustrates exactly what the biology predicts. Weed seedbanks operate on long timelines, and apparent success in the short term often masks residual risk (Roberts et al. 2023).

Method of Least Disturbance: Breaking the Feedback Loop with Selective Chemical Control.
Manual and thermal removal techniques—such as hand-weeding, slashing, and thermal control—have historically emphasised minimal disturbance and passive native regeneration. These approaches were often applied in small, relatively intact bushland, where weed pressure was low and native seedbanks remained viable. However, they typically avoided dense infestations to prevent triggering mass germination, and lacked operational nuance in addressing invasive species biology, seedbank persistence, and germination dynamics. Without adaptive strategies for high-pressure sites, these methods can falter when scaled to larger, degraded landscapes.
Manual and thermal methods perpetuate the disturbance–germination cycle, increasing regrowth pressure and labour demand. Manual removal and incidental soil disturbance during handling—such as ground movement by operators—lift seeds upward, triggering a feedback loop.
In contrast, selective chemical control avoids soil disruption, interrupts seedbank activation, and aligns with the Method of Least Disturbance—a principle critical for long-term restoration. This approach reflects broader restoration literature: early, selective chemical control is more scalable and less disruptive than delayed manual methods (Weidlich et al., 2020) and is consistent with Ecologically Based Invasive Plant Management principles, which emphasise restoring successional processes and minimising disturbance to accelerate ecosystem recovery (James et al., 2010).

The Method of Least Disturbance builds on these foundations with ecological precision and strategic clarity. It actively engages dense infestations using selective, low-impact techniques tailored to weed traits and site conditions. Rather than avoiding disturbance, it uses it judiciously—timed and targeted to suppress regrowth while protecting native resilience. It integrates field-based insights like visibility, seasonal timing, and equipment upgrades, and applies feedback logic to refine effort-to-impact ratios. This evolution retains the principle of minimal harm while enabling scalable, evidence-based restoration in complex environments.

The Method of Least Disturbance is designed to prevent the soil disruption that drives weed resurgence. For *Polygala myrtifolia*, this principle is critical because its seedbank remains viable for more than a decade and germination is strongly depth-dependent—nearly half of seeds germinate when exposed at the soil surface, yet none emerge from depths around 8 cm.

How Low-Disturbance Chemical Control Works.
The Method of Least Disturbance is most effectively applied through selective herbicides such as Clopyralid, which kill seedlings without disturbing the soil and do not trigger seedbank germination. This approach aligns with *Polygala's* germination biology by targeting seedlings during cool, moist seasons when emergence occurs, preventing seed rain and gradually depleting the seedbank. Dead plants are left standing, providing microhabitat and stabilising groundcover, which reduces erosion and supports native regeneration. It is safer, less physically demanding, and highly scalable for large infestations.

Why Selective Chemical Control Is Preferable.
Selective chemical control, particularly using Clopyralid, aligns with the Method of Least Disturbance, which prioritises minimal soil disruption and habitat retention. This approach offers several strategic advantages. First, herbicide application avoids soil disturbance, preventing activation of buried seeds. Dead plants remain in place, reducing erosion and maintaining ecological structure. Second, chemical control can be timed to coincide with seedling emergence, suppressing growth before maturity and preventing seed rain, which reduces seedbank replenishment.

Why Lower Herbicide Rates Matter.
Applying Clopyralid at low rates is essential for balancing control efficacy with ecological sensitivity. Lower rates reduce off-target damage, protecting native seedlings and ground flora. They also promote natural regeneration by minimising chemical impact and allow adaptive follow-up treatments ensuring the least harm to native species, compared to manual methods. As Roberts et al. (2023) emphasise, targeting control during peak emergence is critical to reducing long-term impact. This approach maximises effectiveness while minimising chemical input—achieving both ecological sensitivity and operational efficiency. Low-rate Clopyralid application produces minimal off-target effects, avoids soil disturbance, and supports biodiversity recovery. Impacts on sensitive species like *Tetragonia* may occur at higher concentrations, but these are manageable and can be substantially mitigated through close monitoring, careful observation, precise foliar placement, and the use of reduced herbicide concentrations.

Selective chemical control is not a shortcut—it is a stewardship approach that demands ecological literacy, restraint, and precision. It enables practitioners to protect native vegetation, reduce injury risk, and restore habitat integrity without triggering the disturbance cycles that perpetuate weed dominance. When applied with care and ecological insight, herbicide becomes a tool for restoration rather than disruption.

Cool-Season Efficacy of Clopyralid.
Research confirms that Clopyralid remains effective under cooler conditions when plants are actively growing. Temperature-response work shows no reduction at lower temperatures (≈18 °C), and some evidence indicates greater crop safety than at higher temperatures. Labels for Clopyralid-containing products permit application across a broad 8–25 °C range, supporting autumn–spring programs. The key determinant is active growth, not temperature alone (Sharpe et al. 2018; Corteva 2024).

Off-Target Risk and Temperature.
Applying Clopyralid during cooler conditions (autumn–spring) not only improves efficacy but also minimises off-target damage. Lower temperatures reduce volatilization and drift potential, while cooler, moist conditions enhance uptake and translocation (Sharpe et al. 2018; Syngenta 2023; Corteva 2024). Although Clopyralid remains effective across a broad temperature range, off-target injury risk increases at higher temperatures (≈27–28 °C and above), particularly under drought stress or when plants are not actively growing (Sharpe et al. 2018; EFSA 2018). Spraying during drought stress increases variability in uptake and can harm sensitive native species. Aligning operations with cool-season windows supports precision, ecological safety, and the Method of Least Disturbance.

Comparing Control Methods: What the Evidence Shows.

The preceding analysis demonstrates that control success depends on how each method interacts with *Polygala's* biology and the disturbance feedback loop. Table 3 consolidates these findings:
Table 3 Comparison of Control Methods

Method	Disturbance Level	Seedbank Activation Risk	Labor Intensity	Scalability	Impact on Feedback Loop	Other Notes
Manual Removal & Incidental Soil Disturbance	High	Very High (soil disturbance lifts seeds)	Very High	Low	Reinforces feedback loop	Risk of erosion; high injury risk
Thermal Removal (Flame/Steam)	High	High (removes cover, disturbs soil)	High	Low–Moderate	Reinforces feedback loop	Requires specialised equipment; high energy cost
Selective Chemical (Clopyralid)	Low	None (does not trigger germination)	Low	High	Interrupts the feedback loop	Requires accurate ID; minimal off-target risk if applied correctly

Interpretation: Manual and thermal methods perpetuate the disturbance–germination cycle, increasing regrowth pressure and labour demand. In contrast, selective chemical control avoids soil disruption, interrupts seedbank activation, and aligns with the Method of Least Disturbance—a principle critical for long-term restoration. This supports broader restoration literature: early, selective chemical control is substantially more scalable and less disruptive than delayed manual methods (Weidlich et al., 2020).

Strategic Restoration Management: Budget Timing, Ecological Outcomes, and Risk-Based Operational Decisions.

Polygala myrtifolia is most effectively controlled during the cooler months when soil moisture is elevated, plant stress is reduced, and follow-up treatments can be strategically timed ahead of peak summer growth. However, in the southern hemisphere, fiscal budgets often activate mid-year, typically at winter in July through to, some commencing in spring. Regardless of start date, the prevailing issue is misalignment with ecological timing. This delays mobilisation of on-ground capacity until the optimal treatment window is already narrowing, reducing operational efficiency, and compromising long-term outcomes. In contrast, northern hemisphere budget cycles often commence in what is their late summer or early autumn, enabling initiative-taking planning and timely intervention. To improve invasive species management outcomes, a fiscal change in phase is required—one that aligns budget availability with ecological opportunity. Crucially, this adjustment need not increase costs; it simply reallocates existing resources to match seasonal windows, enabling earlier engagement of ecological field teams and more efficient deployment of effort. By synchronising funding release with ecological timing, we can achieve greater productivity and ecological benefit without expanding budgets—avoiding reactive expenditure and maximising the value of each control round.

This proposed shift invites broader reflection on how fiscal structures can better support ecological logic. Rather than treating budget timing as fixed, government departments, councils, and other organisations could adopt adaptive models—such as rolling budget triggers, seasonal contingency allocations, or ecological priority windows—that enable earlier mobilisation without increasing total expenditure. Aligning budget cycles with ecological treatment windows is not only operationally sound but also cost-efficient and productivity-enhancing: when funding is delayed, crews mobilise outside optimal windows and require more labour hours and repeat interventions to achieve the same outcome. Adaptive budgeting can reduce hours per acre, increase operational productivity, and enable earlier seedbank drawdown without raising overall spend (Teagasc 2023; Syngenta Crop Protection 2023).

This alignment is particularly critical for species like *Polygala myrtifolia*, whose germination peaks during the cooler months of autumn through spring. As Roberts et al. (2023) demonstrated, germination rates exceed 90% under these conditions, with emergence strongly tied to shallow soil disturbance and seasonal moisture. Missing this window not only reduces treatment efficacy but risks triggering dense seedling cohorts that demand more intensive follow-up. Weidlich et al. (2020) similarly emphasise that timing is pivotal in restoration, and delays can entrench invasion dynamics and escalate long-term costs.

Efficiency is another key benefit. Chemical control is less labour-intensive and more scalable, enabling broader coverage with fewer resources. Data from Boneo illustrates this clearly: labour input dropped from 190.41 hours per acre under manual removal to 51.50 hours per acre with chemical control—a 72.95% reduction. Additionally, retaining dead biomass supports biodiversity recovery by providing microhabitat for native fauna and suppressing further weed emergence, whereas manual removal often strips this protective layer.

Seasonal funding, by contrast, creates reactive weed control—forcing managers to compress operations into narrow windows and undermining strategic outcomes. For *Polygala myrtifolia*, with its persistent seedbank and cool-season germination peaks, short-term funding cannot sustain the continuity required for eradication. Government departments and councils should prioritise multi-year funding programs that support integrated, adaptive management rather than single-season interventions. This approach reduces long-term costs, accelerates seedbank depletion, and improves ecological outcomes. The same logic applies to other invasive species with multi-year seedbanks and seasonal recruitment patterns (Roberts et al. 2023; Weeds Australia 2024; Teagasc 2023).

The question is not whether we can afford to change—but whether we can afford not to. As climate variability increases and ecological windows narrow, timing becomes a form of efficiency. Strategic reform in budget phasing offers a cost-neutral pathway to better outcomes—and a chance to align our systems with the very landscapes they aim to protect.

Field Observations and Rabbit Impact.
Observations during *Rhamnus alaternus* control in August 2021 reflect on the previous season's *Polygala myrtifolia* management:
"Effective spraying at lower rates requires full coverage from all sides, and minimal herbicide concentration reduces collateral damage. *Polygala* tends to propagate in disturbed areas, with seeds dispersing slightly by wind. When ground flora remains intact, seed spread is minimised. However, rabbits complicate management by sheltering under *Polygala*, digging around its base, and eliminating mosses and native grasses. This activity creates bare patches that favour germination, forming a feedback loop that amplifies *Polygala* dominance."

These observations highlight a critical distinction between human clearance and rabbit disturbance. Both activate the seedbank, but their impacts differ in scale and persistence:
disturbance → seedbank activation → mass germination → more disturbance.

Strategic Implications.
The recommended strategy is clear: apply low-concentration foliar Clopyralid, retain dead biomass, avoid manual methods that cause disturbance, and monitor for seedling emergence. Rabbit disturbance must be addressed through integrated management—such as exclusion fencing or population control (Appendix C)—to prevent habitat modification and secondary weed spread. This approach aligns with Roberts et al.'s (2023) call for adaptive, low-disturbance weed management and reinforces why manual or thermal removal is often counterproductive.

Key Distinction: Human vs Rabbit Disturbance.
Human clearance accelerates seedbank activation at scale, triggering short-term germination pulses that demand intensive follow-up. In contrast, rabbits sustain low-level disturbance over time, prolonging regrowth risk, and complicating restoration even in maintenance phases. Both pathways amplify *Polygala*'s resilience, making integrated management essential: selective herbicide strategies must be paired with rabbit control measures such as exclusion fencing or population reduction.

Rabbit Activity and Ecological Feedback.
Rabbits create micro-disturbance that is continuous and ecologically disruptive. By digging around *Polygala* bases and removing mosses and native grasses, they expose bare soil and reduce competition—favouring germination and reinforcing a feedback loop. Observations from 2021 confirm that rabbit disturbance undermines restoration even after chemical control, sustaining recruitment pressure in treated zones. Similar patterns are documented in coastal systems, where herbivory and digging accelerate weed spread by modifying soil structure and microclimate (Haring & Flessner 2018; Weeds Australia 2024).

Conclusion.

In ecological restoration, slow control is often mistaken for low disturbance, a misconception that can be ecologically counterproductive when managing systemic exploit species; these invaders exert disproportionate influence on ecosystem structure and function, anchoring invasive networks and driving feedbacks that suppress native regeneration. *Polygala myrtifolia*, for example, can rapidly reassert dominance after manual removal when disturbance triggers widespread germination, and D'Antonio and Meyerson (2002) document how disturbance-driven pulses of recruitment undermine piecemeal control. Delayed or fragmented interventions allow remaining plants to mature, reseed, and reinforce their foothold while repeated site visits increase trampling, soil exposure, and unintended disturbance, a pattern consistent with global analyses showing that delayed action worsens ecological degradation and complicates restoration (Weidlich et al., 2020).

The sustained effort to manage *Polygala myrtifolia* at Boneo reflects both the urgency of the threat and the evolution of restoration logic. Manual removal, used from 2001 to 2017, was initially the only viable option. While it reduced mature biomass, it also exposed the limitations of disturbance-based control—particularly its role in activating seedbanks and perpetuating infestation. Roberts et al. (2023) confirmed that *Polygala* seeds germinate prolifically near the soil surface, with emergence declining sharply beyond 4 cm burial depth. This highlights how even shallow disturbance can stimulate regrowth, complicating long-term control and necessitating ongoing monitoring.

The transition to selective chemical control in 2018 marked a strategic shift toward ecologically aligned management. The adoption of the Method of Least Disturbance—characterised by minimal soil disruption, seasonal targeting, and retention of dead biomass—enabled consistent suppression of *Polygala* with minimal collateral impact. The site now operates under a low-effort maintenance regime, with scattered individuals addressed through targeted follow-up. Restoration success at Boneo has hinged not on intensity alone, but on method refinement—balancing ecological integrity with operational feasibility.

This approach demonstrates that strategic intensity—not slowness—is key to minimising ecological disruption. Treating larger areas in fewer, well-timed passes using selective, low-disturbance methods (e.g., Clopyralid spot-spraying) suppresses systemic exploit species before they re-establish control (Lake et al., 2007). Clopyralid's selectivity and precision application make it ideal for sensitive ecosystems. Efficiency data from Boneo shows that this approach dramatically reduced labour hours per acre and prevented plants from reaching reproductive maturity. Restoration succeeds when ecological drivers are suppressed decisively—not revisited endlessly.

Between 2013 and 2017, manual control of *Polygala myrtifolia* demanded over 26,648 hours of labour, yet the associated soil disturbance triggered dense seedling carpets and sustained regrowth pressure. Despite short-term visual gains, the species' biology harboured a hidden dynamic that undermined long-term outcomes and primed the site for reinfestation — a cautionary example of how superficial success can mislead restoration programs.

Had manual control continued beyond 2018, projected labour requirements would have reached 64,835 hours. In contrast, the strategic shift to chemical control reduced actual labour to 17,536 hours, saving 47,299 hours — a 72.95% (assumes manual control would have continued during 2018–2024 at the average manual hours per acre) reduction. This efficiency gain stemmed from Clopyralid's alignment with Polygala's germination biology, which suppressed recruitment while minimising soil disruption.

The transition marked a pivotal shift from reactive clearance to function-based restoration, consistent with principles of biomass manipulation and feedback disruption (Suding et al., 2004). By 2025, the site had entered a low-effort maintenance phase, with minimal regrowth and stable ecological conditions — demonstrating the long-term efficacy of targeted chemical intervention when guided by ecological logic.

Statistical analysis confirms the alternative hypothesis: selective chemical control is significantly more efficient than manual removal. A two-sample t-test yielded a t-statistic of 3.26 and a p-value of 0.0238, indicating a statistically significant difference at the 95% confidence level.

These findings are reinforced by Roberts et al. (2023), who showed that *Polygala* seeds germinate prolifically under temperate conditions and at the soil surface, with emergence declining beyond 4 cm depth. This underscores the importance of surface-level suppression and early intervention—both strengths of selective chemical control. Broader research, such as Adair et al. (Australis Biological), attributes *Polygala*'s invasive success to low herbivory pressure and highlights the need for effective suppression strategies. While biological control remains under investigation, chemical methods—particularly those that minimise disturbance—are increasingly recognised as viable tools in coastal ecosystems.

The Boneo project demonstrated that Clopyralid was markedly more efficient and ecologically sensitive than manual removal for suppressing *Polygala* across large infestations. While manual methods are often assumed to be ecologically cautious, they frequently caused soil disturbance, triggered seedbank activation, and increased reinfestation risk—especially in sensitive Moonah woodland. In contrast, Clopyralid enabled targeted suppression with minimal off-target impact and preserved native vegetation. These outcomes align with broader research, such as Lugar & Nelson (2023), who found that selective herbicides outperformed manual control in managing *Rhaponticum repens*. However, their use of residual auxins showed diminishing control by year three and limited seedbank engagement. Clopyralid's specificity toward Fabales and Asterales, combined with its lower residual activity, suggests it may offer more ecologically sustainable outcomes.

Recent field evidence and restoration studies increasingly support the conclusion that selective chemical control is both more efficient and ecologically sustainable than manual removal in conservation contexts. Jarvis-Lowry et al. (2023) found that basal bark application of Triclopyr achieved over 95% mortality of *Clematis vitalba*, outperforming manual cut-stem methods treated with glyphosate gel. Hinkson et al. (2023) showed that fluazifop-P-butyl suppressed *Imperata cylindrica* while preserving native cover. Weidlich et al. (2020) further noted that chemical control methods are more scalable and less disruptive than manual approaches, particularly in regions with a high Human Development Index (HDI).

These findings point to a broader opportunity: herbicide selection should be guided by taxonomic specificity—at the order, family, and clade level. By cross-referencing herbicide selectivity profiles with native vegetation listings, land managers can identify chemical options that suppress invasive species while safeguarding autochthonous flora. This enables the development of an herbicide compatibility matrix, assessing each chemical for effectiveness, efficiency, and ecological sensitivity relative to site composition.

The integration of taxonomic herbicide matching into restoration planning represents a critical evolution of the Method of Least Disturbance. Traditionally applied to physical interventions, this principle now extends into chemical logic—where herbicide choice itself becomes a disturbance variable. By assessing herbicides through the lens of plant taxonomy and cross-referencing with native species, practitioners can pre-emptively identify treatments that suppress invasive targets while preserving ecological integrity. This desktop-based approach transforms chemical control into a precision-guided restoration strategy—one that honours both biodiversity and efficiency.

Images

Manual and Thermal removal period.

2013 August 22

Figure 9 *Polygala Myrtifolia growing out of fallen Strands of Tea-Tree Gaudium laevigatum (Former Leptospermum)*

2013 August 29

Figure 10 *A Kookaburra comes to explore the disturbance of manual removal the dense strand here follows along the dune far into the distance.*

2013 September 10

Figure 11 *A Drooping She-oak Allocasuarina verticillata struggles growing against the dense Polygala Myrtifolia.*

2014 October 28

Figure 12 *A burnt Moonah tree Melaleuca lanceolata next to dense growing Polygala myrtifolia.*

2015 March 18

Figure 13 *Taller Drooping She-oaks Allocasuarina verticillata above Polygala Myrtifolia that is approximately the same height of its previous manual removal treatment.*

2015 October 12

Figure 14 *Thermal weeding of a thick zone of Polygala Myrtifolia Seedlings you can see remnants of the previous manual removal on the ground at the back of the image.*

2015 October 12

Figure 15 *Thermally treated Polygala Myrtifolia can be seen wilting in the for ground of the image.*

2016 Jan 19

Figure 16 *Here you can see the previously stacked Polygala Myrtifolia in the centre of the image, on the right a new fresh stack with thick regrowth on the left. The creation of a negative feedback loop.*

2016 February 18

Figure 17 *Polygala stacked wherever it could be the like piles from the previous image are multiplied everywhere.*

2017 March 10

Figure 18 *The Polygala Myrtifolia regrowth is being to outpace the ability to deal with as it gets larger it is more physically taxing.*

2017 March 19

Figure 19 *The same area as* ***figure 18*** *seven actual working days later, you can see the large piles in the background just of the centre of the image to the left. The amount of on ground disturbance is obvious.*

2017 April 27

Figure 20 *The new growth on the Polygala is very noticeable and it is going to flower very soon creating seed rain unless dealt with. It is overwhelming the ability to deal with it through manual removal.*

Selective Chemical removal period.

2019 Nov 07

Figure 21 *Polygala Myrtifolia affected by the selective chemical treatment with Clopyralid.*

2019 November 11

Figure 22 *The same location as* ***Figure 18*** *&* ***19*** *Dead polygala from the previous seasons spray is standing all through the image middle from left to right.*

2019 November 28

Figure 23 *The selective chemical treatment is proving the ability to advance just in time the Polygala here was treated just days before and was getting close to reaching maturity and causing seed rain. In the image on the right you can see affected Polygala Myrtifolia, while the Leucopogon parviflorus is in a plant order that is unaffected by Clopyralid.*

2020 June 29

Figure 24 *A picture from an auditor at the site showing what feels like never ending seedlings of Polygala Myrtifolia.*

2020 June 29

Figure 25 *The germination of plants continues from the disturbed seedbank in densities that manual removal would never efficiently handle.*

2020 October 12

Figure 26 *The low concentration of Clopyralid showing damage to carefully sprayed Polygala Myrtifolia. The result being uncontrolled cell division and elongation, but without proper coordination. This disorganised growth destroys vascular tissue integrity, leading to twisting, swelling, and eventual plant death (MSU Extension, 2025; Tu et al. 2001). Resistance on Bower Spinach Tetragonia implexicoma is seen next to it.*

2020 October 12

Figure 27 *Showing the treated of seedling and the undisturbed soil, with a seedling Pimelea serpyllifolia to what is the left of the image just above centre, as small Ranunculus sessiliflorus is seen emerging from bellow the main Polygala seedlings in the image.*

2021 May 24

Figure 28 *Comesperma volubile another plant from the Polygalaceae family showing targeted careful selective spraying is a Stewardship Approach to Herbicide Application.*

2021 June 8

Figure 29 *Treated Polygala Myrtifolia in lower numbers a sign the method is providing the ability to control the situation. I the image foreground on the left you can see previous treated large Polygala stem with Bower Spinach Tetragonia implexicoma that was unharmed underneath it.*

2021 December 09

Figure 30 *Dead Polygala Myrtifolia thickets. natives' underneath are starting to regenerate.*

2022 May 18

Figure 31 *A view showing former Polygala stretching out to the distance. The Method of Least Disturbance appears to support passive seedbank suppression by allowing seeds to remain undisturbed and gradually become buried beneath accumulating litter and natural soil processes. Over time, ecological mechanisms such as leaf litter accumulation, soil bioturbation by macroinvertebrates (e.g. ants and detritivores), rain splash, wind-blown sediment, and soil cracking can move seeds from the surface into deeper layers of the soil. These natural burial processes are well-documented and play a critical role in seed persistence and emergence dynamics (Bewley et al., 2013). This passive burial reduces the likelihood of seedling emergence, particularly for species like Polygala myrtifolia, which shows a sharp decline in emergence with depth and no emergence beyond 8 cm (Roberts et al., 2023). By avoiding disturbance and allowing these natural processes to operate, M.O.L.D. may contribute to long-term seedbank depletion without triggering germination events.*

2022 August 5th

Figure 32 *Ground flora is filling in, and seedling emergence is dropping, former thickets of Polygala Myrtifolia is disappearing.*

2022 October 2

Figure 33 *A large patch of Swainsona lessertiifolia mixed with Hibbertia sericea and Austrostipa flavescens on the other side of the log to the right former Polygala treated Polygala with Clopyralid demonstrating a Stewardship Approach to Herbicide Application.*

2023 September 13

Figure 34 *Results seem good. Though constant monitoring and inspection is important checking and looking everywhere.*

2024 June 18

Figure 35 *A single Polygala treated here showing the results.*

2024 July 30

Figure 36 *The same are as* ***figure 17,*** *this area was originally called Polygala Valley as far back as 2001, where it was cut pilled and burned. Later it was brush cut low, and then physically removed each actions disturbing the soil and seedbank causing a feedback loop.*

2025 10 07

Figure 37 *Again the same area as **Figure 17 and 36** after the treatment the previous year.*

2025 September 09

Figure 38 *Scattered Polygala Myrtifolia while almost all previously sprayed Polygala has broken down compared to cut and stacked which in some locations created habitat for rabbits.*

2025 October 3

Figure 39 *Basal bark treated Polygala Myrtifolia allowing the treated plants to stay with minimal disturbance*.

2025 September 09

Figure 40 *Polygala germination a reminder to be constantly vigilant and forward planning*.

Acknowledgements

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Appendix A: Glossary of terms

Basal Barking:
A targeted herbicide application method where chemical is applied directly to the lower stem of woody weeds, avoiding foliar spray and reducing drift. Supports precision and low-disturbance control.

Cool-Season Germination Window:
The period from autumn to spring when *Polygala myrtifolia* seeds are most likely to germinate due to favourable moisture and temperature conditions. Strategic control during this window improves suppression outcomes.

Disturbance Feedback Loop:
A cycle where physical or thermal disturbance activates the seedbank, leading to mass germination, which then requires further intervention—often perpetuating the problem. Breaking this loop is essential for restoration success.

Ecological Stewardship:
The practice of managing land and ecosystems with care, responsibility, and long-term vision. In weed control, stewardship involves balancing effective suppression with protection of native biodiversity and habitat integrity.

Emergence Likelihood:
The probability that seeds in the soil will germinate under given environmental conditions, influenced by factors such as burial depth, moisture, temperature, and disturbance.

Herbicide Compatibility Matrix:
A planning tool that cross-references herbicide selectivity profiles with native vegetation listings to identify chemical options that suppress invasive species while protecting autochthonous flora. It operationalises the Method of Least Disturbance into chemical planning.

Method of Least Disturbance:
A restoration principle that prioritises minimal soil disruption and retention of dead biomass to avoid triggering weed germination and preserve habitat structure. It supports ecological recovery by maintaining microhabitats and reducing erosion.

Minimum Effective Dose:
The lowest herbicide concentration that achieves effective control of the target species while minimising off-target impacts and ecological disruption. This principle supports stewardship and precision in chemical application.

PGC (Potential Germination Coverage):
A dynamic, protocol-based framework that estimates the ecological risk of weed germination based on environmental cues (light, moisture, disturbance, temperature). PGC functions as a compliance gate within the M.O.L.D. system, guiding when, where, and how to intervene by signalling the likelihood and spatial extent of seedbank activation. It integrates ecological diagnostics with operational decision-making to minimise disturbance, suppress reinvasion, and protect native resilience.

Restoration Trajectory:
The observed or projected path of ecological recovery following weed control interventions. A successful trajectory reflects declining weed cover, reduced seedbank pressure, and increasing native species resilience.

Selective Auxin Herbicide:
A class of herbicides (e.g., Clopyralid) that mimic plant hormones to disrupt vascular function in

specific broadleaf species, with no impact on grasses and monocots at label rates or below. Used for selective control in sensitive environments.

Seedbank Activation:
The process by which dormant seeds are stimulated to germinate, often triggered by soil disturbance, light exposure, or seasonal moisture. Avoiding activation is key to long-term weed suppression.

Seed Rain:
The dispersal of seeds from mature plants into the surrounding environment, contributing to the replenishment of the soil seedbank and influencing future weed recruitment. Preventing seed rain is critical to long-term suppression of invasive species.

Systemic exploit species:
Systemic exploit species are non-native organisms that achieve and maintain landscape-scale dominance by leveraging a network of support species and processes. Their competitive traits (rapid growth, persistent seed banks, stress tolerance) are amplified by allied elements—faunal vectors, subsidised consumers, harbour plants, and recurring disturbances—which together form a self-reinforcing architecture that suppresses native regeneration and resists passive succession. The invader is therefore a network hub of degradation, not an irreplaceable keystone.
Definition (Brown, C., 2025)

Core characteristics

- Network-dependence — persistence relies on multiple support nodes rather than solitary functional centrality.
- Faunal support — animals act as vectors, subsidised consumers, soil engineers, or disturbance agents that maintain the invader's advantage.
- Amplifying feedbacks — the invader and its allies alter conditions (soil, fire regime, herbivory patterns) that favour reinvasion.
- Functional redundancy — the invader's role can often be filled by other invaders or processes, unlike true keystone species.
- Resistance to single-node removal — removing the dominant plant alone typically leads to rapid re-establishment unless supporting nodes are also addressed.

Diagnostic checklist

- Evidence of animal mediation: seeds in scats, preferential use of the invader for shelter or food, or elevated vector movement through invaded patches.
- Subsidy signals: higher densities or better condition of herbivores tied to invader biomass.
- Disturbance coupling: frequent erosion, fire, trampling, or clearing that creates establishment niches for the invader.
- Rapid reinvasion after removal: the invader returns unless other nodes are changed.
- Low co-evolutionary integration: absence of specialised mutualisms with native fauna that would indicate true keystone status.

Trigger Discipline:
A field protocol requiring applicators to pause and assess surroundings before spraying, ensuring correct identification and avoiding off-target damage. Reinforces precision and ecological accountability.

Appendix B: Methods

Manual Control Methods for *Polygala myrtifolia*
Manual removal of *Polygala myrtifolia* is best reserved as a tactical option in low-density infestations or maintenance phases, where isolated plants can be extracted with minimal soil disturbance and low risk of seedbank activation. In sensitive zones, early-stage interventions, or patches embedded within vulnerable native species, manual work may complement chemical control—but only if applied with restraint, precise timing, and ecological awareness.

As a standalone strategy, however, manual removal is ineffective. Without integrated follow-up and seedbank suppression, it risks amplifying regrowth pressure and exhausting labour resources. Accurate identification is also critical: juvenile *Polygala* shoots and seedlings can closely resemble native shrubs and coastal forbs, and inadvertent removal of desirable species undermines regeneration and wastes effort. Strategic use of manual control must therefore balance precision, timing, and ecological context to avoid compounding disturbance and ensure restoration integrity.

1. **Hand Pulling (Seedlings)**
    - Best for young plants with shallow roots.
    - Grasp the plant at the base and pull steadily to remove the entire root system.
    - Works best in moist soil to reduce root breakage.
      Effective for new incursions, isolated plants, and sterile plants.
    - manual removal inherently disturbs the soil and may break the roots of other plants.

    Estimated Effort:

    - **Seedlings:**

      Time per plant: 5–15 seconds per plant (or more if soil is hard or roots are deep).

      Efficiency: Slower in large infestations, may become uncomfortable in the same position over time.

      Risk: Soil disturbance can promote new weed germination, risk of breaking roots, including nearby off-target plants.

2. **Secateurs (Small to Medium Plants)**
    - Cut below the lowest green node.
    - Place material off ground.

    Estimated Effort:

    - **Small plants:**

      Time per plant:
      Slower (typically 5–15 seconds per plant, longer in difficult to reach locations (e.g. fallen timber inside other plants).

      Why: Requires bending, stretching, positioning and a physical cut bellow the green node for each plant.

Risk: Regrowth is likely unless the cut is made below the lowest green node; this method also demands greater physical effort and carries a higher risk of wrist and hand injuries from prolonged use of secateurs.

3. **Lopping (Mature Plants)**
    - Use loppers, cut Below the lowest green node to prevent resprouting.
    - Place material off ground.

Estimated Effort:

- **Mature plants:**

  Time per Plant: 25–50 seconds (using loppers, including cutting, and relocating material). If stems are thick and access is awkward, it can push toward the higher end.

  Efficiency: Requires bending or kneeling, careful positioning to avoid damaging nearby natives. A precise cut below the green node for effective kill, physical effort is significant, especially over long sessions.

  Risk: Physical strain (repetitive bending, wrist fatigue) and Tool safety risk (cuts, pinching hazards). Disturbance risk if branches drag across native plants during relocation.

4. **Chain-sawing Very Large Plants.**
    - For large mature shrubs, cut stems close to ground level.
    - Reduces soil disturbance compared to full uprooting.
    - Place material off ground.

Estimated Effort:

- **Large Shrubs:**

  Time per Plant: 50–150 seconds (including cutting and relocating material), lower end if access is easy and material can be stacked nearby; higher end if multiple cuts and heavy lifting are needed.

  Efficiency: Requires setup (chainsaw start, PPE). Is best suited for large shrubs where secateurs or loppers are impractical, multiple cuts may be needed for thick stems or branching. Additional time for safe relocation of heavy material.

  Risk: High physical and safety risk: Chainsaw injuries (kickback, cuts) and fatigue from handling heavy tools and material. Chance of injury as getting close to base of stump on steep dunes risks felling towards operator. Potential environmental risk to nearby natives during felling and relocation.

Why *Polygala Myrtifolia* Usually Does Not Resprout

- **Lack of Strong Lignotuber or Basal Bud Bank**
  Unlike many Australian shrubs or introduced woody weeds, *Polygala myrtifolia* does not have a lignotuber (a woody swelling with dormant buds) or a large underground bud bank. Its regenerative buds are mostly located on younger stems, not deep in the root crown.

- **Woody Root System with Limited Adventitious Buds**
  Mature plants develop a woody taproot and lateral roots, but these rarely produce new shoots once the above-ground stem is removed. If the cut is made **above a green node**, regrowth is likely.

- **Physiological Dependence on Photosynthetic Tissue**
  The plant relies heavily on its evergreen canopy for energy. When cut at or below the basal crown, the remaining tissue cannot sustain regrowth because stored reserves are minimal compared to species adapted to fire or heavy browsing.

Conditions for Successful Manual removal.

- **Cut Below the Lowest Green Node**
  If any green stem tissue remains above the root crown, it may sprout. Cutting flush with the soil or slightly below ground level is best.

- **Timing Matters**
  Cutting during dry or hot conditions reduces the chance of any latent buds activating because the plant is under stress and cannot mobilise resources.

- **Follow-Up Monitoring**
  Although a basal cut typically results in plant mortality, there are instances where resprouting may occur from shallow crown buds, particularly in younger specimens or when cuts are made too high. In highly moist and nutrient-rich soils, certain plants may also generate weak shoots from the crown.

Human Injury Risks from Manual Removal of *Polygala*

1. **Musculoskeletal Strain**: Repetitive pulling, bending, twisting, and hand tools can lead to:
   • Strains and sprains (especially in the back, shoulders, and wrists).
   • Overuse injuries from prolonged or awkward postures.

2. **Tool-Related Injuries**: Potential for cuts, blisters, or impact injuries when using loppers, secateurs, or chainsaws.

   - Loppers, secateurs, or hand pulling with leverage may result in blisters, bruises, or crush injuries if not properly managed.
   - Chainsaws present a risk of severe injury if not operated correctly.

3. **Trip and Fall Hazards**: Steep and uneven ground, loose soil, and plant debris are contributing factors.
   - Uneven terrain, concealed roots, and loose sand commonly found in Moonah woodland may increase the likelihood of falls.

- Personnel may encounter tripping hazards during weed removal activities especially when fatigued.

4. **Allergic Reactions or Skin Irritation**: Some plants, their sap, or soil organisms can cause dermatitis or allergies, such as rashes, upon contact.

5. **Snake or Insect Bites**: Common in dense vegetation during manual work. Moonah woodlands, especially in coastal Victoria, are known habitats for

   Venomous snake risks such as:
   - Tiger snakes
   - Lowland copperheads
   - White-lipped Snake
   - Eastern brown snakes (less common but possible)

   Risks:
   - Snakes may shelter at the edge of dense *Polygala* thickets or fallen logs.
   - They may also sun on *Polygala* thickets.
   - Weed removal disturbs their habitat, increasing the chance of surprise encounters.
   - Most bites occur when snakes are accidentally stepped on or provoked (The Sydney Children's Hospitals Network. n.d.).

   Safety Measures:
   - Wear thick boots and long pants.
   - Use tools to probe vegetation before reaching in.
   - Avoid working alone; maintain radio or phone contact.
   - If bitten, apply a pressure immobilisation bandage and seek urgent medical help.

   Bull Ant Risks: Bull ants (*Myrmecia spp.)* are aggressive and common in sandy, coastal woodlands.[4]

   Risks:
   - Their nests are often hidden in leaf litter or under shrubs.
   - They deliver painful stings, which can cause:
     - Severe local reactions.
     - Anaphylaxis in sensitive individuals.

   Safety Measures:
   - Be alert for ant activity and avoid disturbing nests.
   - Wear gloves and enclosed footwear.
   - Carry antihistamines or an EpiPen if allergic.
   - Avoid sitting or kneeling directly on the ground.

6. **Cuts, Scratches, and Punctures:**
   - *Polygala* and surrounding vegetation may have woody stems or thorns.
   - Risk of skin injuries from sharp tools or plant material (Business Queensland, n.d.).

[4] All long-term personnel at Boneo were bitten by a Bull Ant.

7. **Heat Stress and Fatigue:**
    - Manual labour in outdoor settings, especially in summer, can lead to dehydration, heat exhaustion, or fatigue (Safe Work Australia, n.d.).

General Safety considerations.

- Conduct a **site risk assessment** before starting.
- Educate personnel on **local fauna hazards**.
- Keep **first aid kits** on hand, including snake bite bandages and allergy treatments.
- Remember **snakes can be anywhere** so always expect them.
- Ensure **hydration** and **rest breaks** during longer sessions.
- Provide training on safe weed removal and tool use.
- Wear sturdy **gloves**, **long sleeves**, and protective **eyewear**.

Manual Labor Intensity – Mature *Polygala* Infestations

Controlling mature *Polygala myrtifolia* through manual methods is highly labour-intensive and requires careful planning, physical effort, and ecological awareness. These shrubs often form dense thickets with deep, woody root systems that resist easy removal.

High Physical Effort

- Mature plants develop thick stems and extensive root networks that demand sustained force to cut and dislodge.
- Manual cutting tools such as secateurs, loppers, occasionally chainsaws are required to sever the main stem.
  Repeated bending, lifting, and tool use over uneven terrain increases fatigue and strain, especially in large infestations.

Slow, Individualised Progress

- **Each** plant must be located, assessed, and treated individually.
- In dense infestations, visibility is often limited, and access to each plant may be obstructed by other vegetation.
- The time required per plant increases significantly with size, limiting overall efficiency.

Ecological Disturbance Risk

- Manual removal often disturbs soil, especially when roots are pulled, or larger plants dragged.
- This disturbance can trigger secondary weed invasion, particularly from species adapted to bare or disturbed ground.
- Follow-up monitoring and restoration may be needed to stabilise the site and prevent reinfestation.

Team-Based Operations

- Due to the physical demands and time constraints, manual control of mature *Polygala* often requires multiple personnel operating in coordination.
- Tasks may be divided between cutting, clearing, and follow-up.
- Effective communication and pacing are essential to avoid fatigue and injury.

Operational Planning

- Labour-intensive sites benefit from pre-assessment to identify infestation density, terrain challenges, and tool requirements.

- Task sequencing (e.g. cutting before clearing) and ergonomic strategies (e.g. rotating roles, using lightweight tools) can reduce strain and improve safety.

Thermal Weeding

Principle
Thermal weeding uses intense heat to kill plants by rupturing cell walls. The goal is not to incinerate the plant, but to briefly expose it to high temperatures (typically 100–120°C) that cause the plant cells to burst and dehydrate.
To prevent off-target damage, accurately recognising *Polygala myrtifolia* before thermal-weeding is essential; juvenile shoots and seedlings can closely resemble native shrubs and coastal forbs, and inadvertent removal of desirable species undermines regeneration and wastes labour.

1. **Equipment**
   - Thermal weeder unit: Usually powered by LPG (liquefied petroleum gas).
   - Torch or burner head: Directs the flame onto the target plant. (Usually puts out a temperature of 860°C-1900°C)
   - LPG or Butane tank: Supplies gas to the burner.
   - Fire-resistant gloves, goggles, and protective clothing, Minimum 20-litre water capacity firefighting backpack.

2. **Technique**
   - Sweep the flame across the weed for 1–2 seconds.
   - The plant should wilt within minutes to hours, indicating cell damage.
   - Avoid holding the flame too long—scorching or ignition is not the goal.
   - Repeat treatments may be needed for persistent or resprouting weeds.

3. **Timing**
   - Best applied to young seedlings, do not apply to plants larger than seedlings.
   - Do not use during high fire danger, windy conditions, or dry seasons.
   - Most effective when soil is moist even during light rain or showers.

4. **Site Considerations**
   - Works best on flat, open ground with minimal leaf litter.
   - Avoid near flammable bark, dry grasses, or sensitive native plants.
   - Not suitable for woody weeds or deep-rooted perennials.

5. **Risks of Using Weed Burners in Moonah Woodland Safety & Environmental Notes**
   - Always check local fire regulations and permits.
   - Carry fire suppression tools (e.g. water backpack, extinguisher).
   - Monitor for smouldering debris after treatment.

   5.1. Fire Hazard

   8. Flame weeding can easily ignite leaf litter, bark, or dry understorey vegetation, leading to uncontrolled fire.
   9. Even in cooler seasons, embers can smoulder and reignite later.

   5.2. Damage to Native Vegetation

   - Moonah trees and associated native flora often have sensitive bark and shallow roots.

- Heat from burners can scorch trunks, damage root systems, or kill seedlings and groundcovers sensitive to fire.

5.3. Soil Microbiota Disruption

- Thermal weeding can sterilise the topsoil, killing beneficial fungi, bacteria, and invertebrates.
  This affects nutrient cycling and plant-soil interactions, which are critical in restoration zones.

5.4. Disturbance to Fauna

- Many moonah woodlands support ground-dwelling fauna like lizard, skinks, and insects.
  Heat and smoke can displace or kill these species, especially those sheltering in dead wood, leaf litter, or soil.

5.5. Limited Effectiveness

- Germination is stimulated by fire and disturbance.
  This can lead to false confidence in control success and wasted effort.

5.6. Increased Erosion Risk

- Burning vegetation can expose soil, increasing erosion on slopes or coastal dunes.
  This is especially problematic in moonah habitats, which often occur on fragile sandy soils.

Labor Intensity – Thermal Weeding

Thermal weeding is a highly labour-intensive method requiring precision, vigilance, and strict safety protocols. It is best suited to small-scale applications under controlled conditions.

High Physical and Operational Demand

- Requires two trained personnel: one to operate the burner and one to monitor fire risks and assist with safety.
- Involves handling LPG tanks, burner units, and fire suppression gear across varied terrain.
- Applicators must maintain constant awareness of flammable materials, sensitive native vegetation, and fauna.

Slow and Repetitive Process

- Only effective on young seedlings, requiring multiple passes and repeat treatments for persistent species.
- Progress is slow due to the need for short, targeted exposure (1–2 seconds per plant) and careful flame control.
- Not suitable for large infestations or woody weeds.

Environmental and Safety Constraints

- Operations are limited to low-wind, moist conditions (e.g. damp or rainy days).
- High fire risk in dry or windy weather restricts use.
- Requires fire-resistant PPE, water backpacks, and post-treatment monitoring for smouldering debris.

Site-Specific Limitations

- Unsuitable near flammable bark, dry grasses, or sensitive native plants.

- High risk of off-target damage: Native vegetation, especially species with thin bark, shallow roots, or sensitive groundcovers, which can be scorched or killed by heat exposure, and native seedbank potentially destroyed.
- Can damage soil microbiota, disrupt ground-dwelling fauna, and increase erosion risk on exposed soils.
- *Polygala myrtifolia* has a strong germination response to heat and disturbance. Flame treatment may initially appear successful due to visible wilting, but the heat can stimulate seed germination, leading to a resurgence of seedlings. This creates a false sense of control success and may require additional follow-up treatments to manage new growth.

Selective Chemical Method with Clopyralid Herbicide
A QuikSpray motorised spray system was installed on a trailer, equipped with a 300-litre tank and a high-pressure pump. The unit includes a remote-controlled hose reel, which has been upgraded to hold three hundred metres of spray hose. This configuration enables operators to efficiently treat weeds across extensive areas with minimal repositioning of the unit.

Haloxyfop was added to the Clopyralid mix across the full sweep at Boneo to suppress invasive grasses, primarily Ehrharta erecta and Dactylis glomerata. These species were identified as structural components within the parasitic network sustaining *Polygala myrtifolia* dominance. Field calibration was undertaken to minimise off-target impacts, particularly on native Poa labillardierei. While complete protection was not achievable at effective rates, Poa's visual prominence enabled operators to apply a visual avoidance strategy—spray was withheld near Poa clumps to preserve habitat cues and reduce perceived degradation.

Austrodanthonia species, though finer and more difficult to avoid due to intermixing with Ehrharta, demonstrated notable resistance to drift. Originally classified as having acceptable sensitivity in the 1997 selectivity trials (Morgan & Conran, 1999), field calibration at Boneo—using a reduced rate of 0.26 mL/L—effectively shifted their operational status even lower to more acceptable sensitivity. This allowed for confident deployment in mixed assemblages without widespread collateral damage, validating the species-specific restraint logic underpinning the intervention.

This integration also served a secondary strategic purpose: placing downward pressure on rabbit populations by reducing cover and forage availability. It was coupled with basal bark control of Rhamnus alaternus (Italian buckthorn), a known dry-season moisture source for rabbits. The removal of this shrub further disrupted rabbit persistence and movement patterns, contributing to broader network collapse and reinforcing the layered intervention logic of M.O.L.D.

These elements were deliberately omitted from the main report to maintain focus on Fabales-targeted intervention logic and avoid introducing additional chemical and faunal complexity. They are documented here to clarify the full scope of the Boneo intervention and its role in validating the M.O.L.D. framework.

Training
Individuals applying registered chemicals outside of residential or commercial premises—such as situations extending beyond domestic use, like a homeowner treating weeds in their backyard—are required to hold an accredited qualification in agricultural and veterinary chemical handling (for example, Chemcert, Auschem, or comparable certification). Exemptions from this requirement only apply for domestic usage. Additionally, an ACUP is necessary if the user intends to employ restricted chemicals or engage in business activities other than as the landholder.

Minimum PPE Requirements.
Remember always refer to the label.
When preparing the spray:

- **Face shield**
- **Elbow-length PVC gloves** for mixing/loading concentrated product.

When spraying Clopyralid:

- **Chemical-resistant gloves** (e.g., PVC or nitrile)
- **Protective goggles**

After use and before eating, drinking, or smoking, wash hands, arms, and face thoroughly with soap and water. After each day's use, wash gloves, face shield, and contaminated clothing.

Setup and Operation:

1. **Mixing the Herbicide**

    - Fill the tank with clean water to about half capacity.
    - Add the required amount of Clopyralid herbicide (commonly 1.3–2.5 mL per L water for *Polygala* depending on site conditions).
    - Add any Spray Adjuvant recommended 1ml/L.
    - Top up with water to fill tank and agitate thoroughly.

2. **Spray Delivery**

    - The pump delivers herbicide through the 300m hose to a handgun, giving flexibility and adjustable spray patterns to target weeds.
    - Pressure is typically set between 150–250 Psi for foliar spraying, ensuring good coverage without excessive drift.

4. **Correct Identification of *Polygala myrtifolia***
    Misidentification remains one of the most common causes of off-target herbicide damage. In conservation settings, correctly identifying *Polygala myrtifolia* is critical. Key features include glossy, oval-shaped leaves arranged alternately or spirally, reddish stems on new growth, and a dense, shrubby growth habit. Its distinctive purple-pink pea-like flowers can appear year-round.

Equally important is recognising nearby species that may be susceptible to clopyralid, particularly native broadleaf plants. Even in low-diversity zones, off-target exposure can compromise regeneration or damage sensitive flora. Field crews should be trained not only to identify Polygala confidently, but also to recognise and protect vulnerable non-target species within or adjacent to the treatment area.

Adopt the "Trigger Discipline" Rule Before spraying, pause and assess.

- **Scan the area** around the target plant.
- **Ask yourself**: Is there any native or susceptible species in the spray path?
- **Only spray when you are certain** the target is correctly identified, and no off-target plants will be affected.

This simple discipline helps prevent unintended damage, especially in mixed vegetation zones where native species may be regenerating or hard to spot. It reinforces precision and accountability in every herbicide application.

5. **Application Technique**

    - Always plan out the works approach and access understanding the terrain where you may need to coil excess hose.
    - Target actively growing *Polygala myrtifolia* for best results.
    - Spray to wet the foliage thoroughly but avoid runoff of applied spray off the leaves.
    - Spray multiple sides of the plant to ensure good coverage.
    - Never spray above your head height, alternative techniques such as basal barking can be used.
    - Proceed methodically from the furthest extension of the hose length toward the spray unit to minimise the likelihood of traversing treated wet areas and to reduce the risk of hose entanglement.
    - One person is required for every 100 metres of hose to ensure effective handling and deployment.
    - Spray in calm conditions low wind conditions, spraying in a different location can also assist.
    - Use low-drift nozzles (e.g., coarse droplet size) to reduce spray drift.
    - Aid drift control with: Lower pressure = larger droplets = less drift. Enabling keeping the nozzle close to the target (30–50 cm above foliage).
    - Spray shield: Consider Shields or hoods help protect nearby natives if vulnerable,
    - Spray in a direction away of sensitive vegetation.

6. **Advantages**

    - Long hose reduces the need to reposition the vehicle.
    - Remote reel control improves efficiency and safety.
    - Ideal for selective herbicide application in sensitive environments.

7. **Safety & Clean-up**

    - Wear full PPE (gloves, goggles, long sleeves, chemical boots).
    - Avoid working alone; maintain radio or phone contact is essential for hose movement.

- Triple-rinse the tank and flush the hose after use.
- Dispose of rinsate according to local regulations (Agriculture Victoria, n.d.).
- Similar Safety Measures:
    - Trip and Fall Hazards,
    - Allergic Reactions or Skin Irritation (less likely as direct plant contact is reduced).
    - Snake or Insect Bites (less likely reaching into plant structures is reduced).
    - Wear thick boots and long pants.
    - Cuts, Scratches, and Punctures.
    - Heat Stress and Fatigue.

8. **General Safety considerations.**
    - Conduct a site risk assessment before starting.
    - Educate personnel on local fauna hazards.
    - Keep first aid kits on hand, including snake bite bandages and allergy treatments.
    - Remember snakes can be anywhere so always expect them.
    - Ensure hydration, job rotation, and rest breaks during longer sessions.
    - Provide training on safe weed removal and tool use.

Precision Over Speed: A Stewardship Approach to Herbicide Application in Conservation Areas
Spraying in conservation settings is not simply about applying herbicide — it is about making ecologically responsible decisions with every action. The complexity of the task often depends on the size and distribution of target weeds:

- Scattered seedlings and small plants slow progress due to constant visual scanning and decision-making — your brain works harder than your hands.
- Large shrubs and dense patches allow for faster progress with less cognitive load, even though more herbicide may be used.

To maintain ecological integrity:

- Apply the Minimum Effective Dose — avoid overuse.
- Spot-spray rather than blanket-spray — precision protects biodiversity.
- For large shrubs taller than head height, consider cut-stump or basal bark methods instead of foliar spraying to reduce drift and improve control.

Local vegetation knowledge is essential. Personnel must be familiar with the native species in their region — especially those vulnerable to herbicide exposure. This knowledge enables better decision-making in the field, helping to avoid off-target damage and support natural regeneration. It also strengthens the ability to distinguish target weeds like *Polygala myrtifolia* from native lookalikes, which may vary across different habitats.

Even experienced applicators must uphold exacting standards. Success depends on:

- Systematic evaluation of each site,
- Accurate identification of both target and susceptible non-target species,
- Informed, deliberate decision-making.

Efficiency improves with experience, but precision must always take priority — especially when working with less experienced personnel or in sensitive habitats. This approach ensures invasive species are controlled while native vegetation is safeguarded, aligning herbicide use with the principles of environmental stewardship.

Labor Sensitivity, Cognitive Load, and Injury Risk in Precision Herbicide Application
In conservation-focused weed control, labour intensity is shaped more by cognitive effort than physical exertion. Precision herbicide application demands careful decision-making, ecological awareness, and a deep understanding of local vegetation — all while maintaining safe and sustainable work practices.

High Labor Sensitivity
- Scattered seedlings and small plants require constant scanning, identification, and judgment.
- Applicators must distinguish target weeds from native species, often in mixed or regenerating vegetation.
- Local vegetation knowledge is critical — without it, decision-making slows and the risk of off-target damage increases.
- Precision techniques such as spot-spraying and applying the minimum effective dose require deliberate, careful action.

Lower Labor Sensitivity
- Dense infestations or large, easily identified shrubs reduce cognitive load.
- Visual decisions are quicker, and spraying can proceed with greater efficiency.
- Applicators with strong local plant knowledge move faster while maintaining precision.

Injury Risk Profile
- Precision herbicide use typically involves lower manual injury risk than more physically demanding control methods.
- Physical exertion is moderate and manageable, with risks mainly related to posture, repetitive motion (e.g. trigger use), and terrain navigation.
- Injury risk can be further reduced through ergonomic equipment, proper pacing, hydration, and training.

Balancing Efficiency, Safety, and Ecological Responsibility
While larger infestations may allow for faster progress, the conservation imperative remains; precision must override speed. Labor sensitivity increases when ecological risk is high — and that's exactly when careful, informed application matters most. At the same time, the reduced physical strain of precision spraying supports long-term sustainability and lowers injury risk, making it a safer and more effective approach for both experienced and emerging practitioners.

Estimated Effort:

Time and Effort by Plant Size

1. Seedlings.

- **Time per plant(s) 20-50cm diameter zone: Quick (1–2 sec),** with occasional nozzle adjustment for coverage. Care in observation is essential due to their small size and tendency to blend with native vegetation.
- **Why:** Seedlings are often hidden and require deliberate scanning and confirmation before spraying.
- **Spray action:** Quick (a short trigger pull), but the identification step dominates.

- **Efficiency – Edge Scan (Coastal Cliff Walk Analogy):** Like walking a cliffside path, you scan carefully for subtle forms tucked among native cover. Each decision is deliberate, balancing vigilance with restraint.
- **Risk:** Lower when using clopyralid due to its selectivity, but still present if misidentification occurs or if sensitive native species are nearby.

2. Small Plants

- **Time per plant(s) 20-50cm diameter zone: Quick (1–2 sec),** with occasional nozzle adjustment for coverage. Moderate overall.
- **Why:** Easier to see than seedlings but still require careful identification and ensuring no non-target plants in the spray path.
- **Spray action:** Still quick, but you may need to adjust nozzle for coverage.
- **Efficiency – Spot Strike (Archery Analogy):** Like drawing a bow, each strike is precise and intentional. You pause, assess, and release with care—avoiding collateral impact. Slightly better than seedlings because recognition is faster.
  Risk: Lower when using clopyralid due to its selectivity, but still present if misidentification occurs or if sensitive native species are nearby.

3. Mature Shrubs

- **Time per plant: (3–5 sec)** relative to size.
- **Why:** Large plants are obvious, so ID is quick. Most time is spent applying herbicide thoroughly (e.g., full foliage coverage, at least both sides of the plant).
- **Spray action:** Longer trigger time, possibly multiple passes**.**
- **Efficiency – Sweep Pass (Brushstroke Analogy):** Like laying down a brushstroke, you move with fluid control—adjusting nozzle and angle to ensure full coverage without excess. Higher because you can move confidently between obvious targets.
  Risk: Lower when using clopyralid due to its selectivity, but still present if misidentification occurs or if sensitive native species are nearby.

4. Large Shrubs / Dense Patches

- **Time per plant:** Lowest per unit biomass.
- **Why:** Plants are clearly visible and easily identifiable, allowing for quick recognition with minimal risk of misidentification or disturbance to surrounding vegetation.
- **Spray action:** Enables a calm, methodical spraying rhythm across multiple stems, supporting precise application and reducing the likelihood of overspray or collateral impact.
- **Efficiency – Application Stroke (Highway Analogy):** Like driving on a freeway—your path is clear, and your attention is forward-facing. You move steadily, applying herbicide across clearly visible stems with minimal interruption. However, just as a driver watches for exits or hazards, you remain alert for sensitive species like Love Creeper that may require a pause or change in approach. This stroke supports flow, consistency, and low disturbance.
- **Risk**: Risk of desensitisation or tunnel vision—missing sensitive species like Love Creeper embedded in dense growth.

Basal Bark Method with Triclopyr based Herbicide.

Training
Individuals applying registered chemicals outside of residential or commercial premises—such as situations extending beyond domestic use, like a homeowner treating weeds in their backyard—are required to hold an accredited qualification in agricultural and veterinary chemical handling (for example, Chemcert, Auschem, or comparable certification). Exemptions from this requirement only apply for domestic usage. Additionally, an ACUP is necessary if the user intends to employ restricted chemicals or engage in business activities other than as the landholder.

Minimum PPE Requirements:
Remember always refer to the label.
When preparing the chemical for basal bark use:

- **Face shield**
- **Washable hat**
- **Elbow-length Nitrile gloves** for mixing/loading concentrated product.
- **Wear cotton overalls** buttoned to the neck and wrists.

When basal barking with Triclopyr:

- **Chemical-resistant gloves** (Nitrile)
- **Protective goggles**
- **Washable hat**
- **Wear cotton overalls buttoned to the neck and wrists**.

After use and before eating, drinking, or smoking, wash hands, arms, and face thoroughly with soap and water. After each day's use, wash gloves, face shield, and contaminated clothing.

Setup and Operation:

Mixing the Herbicide

- Chemical: Triclopyr (commonly used for woody weed basal bark treatments)
- Carrier: Diesel or approved carrier oil
- Mixing Ratio: 1:60
- Standard mix: ~32 mL of Triclopyr per 1 L of diesel
- Mixing Steps:
    1. Fill a clean container with the required amount of diesel or carrier oil.
    2. Measure Triclopyr accurately using a graduated cylinder.
    3. Add Triclopyr to the diesel seal lid and shake bottle to ensure even distribution.
    4. Pour the mixture into a low-pressure spray bottle with appropriate wand (e.g. B&G extenda-ban) or applicator for basal bark treatment.

3. **Application Delivery**.

- Pressure is low between 15–25Psi and the wand should be a stream, not spray.
- The "thin line" in basal bark application refers to a narrow, continuous band of herbicide mixture applied evenly around the stem's circumference, typically from just above ground level up to about 30 cm, and always below the lowest branch. This placement avoids contact with the soil. The goal is to lightly wet the bark, so the chemical penetrates the cambium layer without forming a thick coating or causing runoff. Through capillary action, the herbicide subtly spreads along the bark's surface—like water creeping across paper—ensuring even coverage and effective absorption while minimising waste and environmental risk.
- For smaller plants apply a small 1-2ml amount to the tip of the plant it will run down the main stem this method is called apical stream technique.

9. **Correct Identification of *Polygala myrtifolia***

Misidentification remains one of the most common causes of off-target herbicide damage. In conservation settings, correctly identifying *Polygala myrtifolia* is critical. Key features include glossy, oval-shaped leaves arranged alternately or spirally, reddish stems on new growth, and a dense, shrubby growth habit. Its distinctive purple-pink pea-like flowers can appear year-round.

Equally important is recognising nearby species that may be susceptible to basal bark. Personnel should be trained not only to identify *Polygala* confidently.

Adopt the "Trigger Discipline" Rule Before treating, pause and assess.

- **Only treat when you are certain** the target is correctly identified, and no off-target plants will be affected.

While basal barking is extremely targeted. This simple discipline helps prevent unintended damage. It reinforces precision and accountability in every herbicide application.

Application Technique

- Always plan out the works approach and access.
- Target actively growing *Polygala myrtifolia*.
- Apply very small amount but avoid runoff.
- Use low-pressure non-drip wand like B&G extenda-ban or brush applicator.
- Only mix small quantities as it goes an exceptionally long way.

10. **Rotation and Timing for Resistance Management**

   - Rotate control methods to reduce selection pressure while protecting native vegetation. Use basal bark for mature or drift-risky individuals and manual removal only for very scattered plants among sensitive natives. Time these methods between major germination flushes (autumn to spring)—after foliar clopyralid rounds have suppressed seedlings and when new emergence is minimal. This avoids disturbing soils during peak emergence, limits seedbank activation, and lets personnel target isolated plants efficiently.

11. **Advantages**

- Ideal for selective herbicide application in sensitive environments.
- Ideal for hard-to-reach locations.
- Is the fastest method of treating any individual target species in scattered situations.
- Basal bark application supports the *Method of Least Disturbance* because treated plants remain *in situ*. This avoids soil disturbance, helps prevent seedbank activation, and retains structural habitat (microclimate, refugia). Given *Polygala myrtifolia's* persistent soil seedbank and disturbance-triggered emergence, minimising physical disruption is critical to long-term suppression.

12. **Safety & Clean-up**

- Wear full PPE (gloves, goggles, long sleeves, chemical boots).
- Avoid working alone; maintain radio or phone contact is essential.
- Equipment should never be used for anything other than basal barking with diesel or oil.
- Similar Safety Measures:
  - Trip and Fall Hazards,
  - Allergic Reactions or Skin Irritation (less likely as direct plant contact is reduced).
  - Snake or Insect Bites (less likely reaching into plant structures is reduced).
  - Wear thick boots and long pants.
  - Cuts, Scratches, and Punctures.
  - Heat Stress and Fatigue.

13. General Safety considerations.

- Conduct a site risk assessment before starting.
- Educate personnel on local fauna hazards.
- Keep first aid kits on hand, including snake bite bandages and allergy treatments.
- Remember snakes can be anywhere so always expect them.
- Ensure hydration and rest breaks during longer sessions.
- Provide training on safe weed removal and tool use.

Precision Over Speed: A Stewardship Approach to Herbicide Application in Conservation Areas
Basal Barking in conservation settings is not simply about applying herbicide — it is about making ecologically responsible decisions with every action. The complexity of the task often depends on the size and distribution of target weeds:

- Scattered plants slow progress to treat than compared to spraying, though basal barking provides a faster treatment than manual removal. Constant visual scanning and decision-making mean your brain works harder than your hands.

To maintain ecological integrity:

- Apply the Minimum Effective Dose — avoid overuse.
- Spot-treat every target plant — precision protects biodiversity.
- For large shrubs taller than head height, basal bark methods avoid drift and improve control.
- This method is surgically precise — like a needle that is a sledgehammer. It delivers targeted impact with minimal collateral disturbance, demanding both restraint and accuracy.

Local vegetation knowledge is essential. Applicators must be familiar with the native species in their region. This knowledge enables better decision-making in the field, helping to avoid off-target damage and support natural regeneration. It also strengthens the ability to distinguish target weeds like *Polygala myrtifolia* from native lookalikes, which may vary across different habitats.

Even experienced applicators must uphold exacting standards. Success depends on:

- Systematic evaluation of each site,
- Accurate identification of both target and susceptible non-target species,
- Informed, deliberate decision-making.

Efficiency improves with experience, but precision must always take priority — especially when working with less experienced personnel or in sensitive habitats. This approach ensures invasive species are controlled while native vegetation is safeguarded, aligning herbicide use with the principles of environmental stewardship.

Labor Sensitivity, Cognitive Load, and Injury Risk in Precision Herbicide Application

In conservation-focused weed control, labour intensity is shaped more by cognitive effort than physical exertion. Precision herbicide application — especially basal barking — demands careful judgment, ecological literacy, and a deep understanding of local vegetation, all while maintaining safe and sustainable work practices.

High Labor Sensitivity

- Scattered plants and small plants require constant scanning, identification, and judgment, seedlings cannot be targeted due to their small size.
- Applicators must distinguish target weeds from native species, often in mixed or regenerating vegetation.
- Local vegetation knowledge is critical — without it, decision-making slows and the risk of off-target damage increases.
- Precision techniques and applying the minimum effective dose require deliberate, careful action.
- Basal barking demands restraint and accuracy — each stroke is intentional, each decision ecologically informed.

Injury Risk Profile

- Precision herbicide use typically involves lower manual injury risk than more physically demanding control methods.
- Physical exertion is moderate and manageable, with risks mainly related to posture, repetitive motion (e.g. trigger use), and terrain navigation.
- Injury risk can be further reduced through ergonomic equipment, proper pacing, hydration, and training.
- Basal barking supports upright posture and reduces strain, especially when treating large stems, compared to manual removal.

Balancing Efficiency, Safety, and Ecological Responsibility

Larger infestations often slow progress due to stem volume and the need for consistent technique and ecological vigilance. However, basal barking remains faster than manual removal and far less physically demanding.

Labor sensitivity increases when ecological risk is high — and that's exactly when careful, informed application matters most.

Basal barking supports this balance by enabling high-efficiency treatment with low ecological disturbance. Its precision protects native vegetation while reducing physical strain, making it a safer and more sustainable approach for both experienced and emerging practitioners.

Estimated Effort:

Time and Effort by Plant Size

1. Small Plants

- **Time per plant:** Quick (1-2sec)
- **Why:** Easier to see than seedlings.
- **Trigger action:** Noticeably short press, a very small amount is required.
- **Efficiency:** Reasonably quick, always ensuring that no misidentification occurs.
- **Basal Barking Apical Stream Technique:** Can be used effectively on upright small plants by applying herbicide from the top down—like rain running along the stem. This mimics natural flow, allowing the herbicide to track the stem's surface with minimal disturbance to surrounding vegetation optionally use your foot to bend the plant and see the main stem.

2. Mature Shrubs

- **Time per plant:** Quick (2–3 sec)
- **Why:** Reasonable quick always ensuring that no misidentification occurs.
- **Trigger action:** Small short press.
- **Efficiency:** Reasonably quick, always ensuring that no misidentification occurs.
- **Basal Barking Note:** Ideal for mature stems — allows precise application with no drift and strong uptake.

4. Very Large Shrubs

- **Time per plant:** Quick (4–7 sec)
- **Why:** Easy to spot, minimal identification time easy to reach with wand to target main stem.
- **Trigger action:** Short enough to ensure treatment around the diameter of the stem.
- **Efficiency:** Reasonably quick, always ensuring that no misidentification occurs
- **Basal Barking Note:** Supports methodical, high-efficiency application where precision and rhythm are essential—like laying down a surgical brushstroke.

APPENDIX C: MANAGEMENT IMPLICATIONS AND STRATEGIC RECOMMENDATIONS FOR *POLYGALA MYRTIFOLIA*

Policy and Strategic Recommendations

Aligning Budget Timing with Ecological Windows

Current fiscal cycles often release funds mid-year (winter or spring), which misaligns with the optimal treatment window for *Polygala myrtifolia*—autumn through early spring. This delay forces reactive operations outside peak germination periods, reducing herbicide efficacy, increasing hours per acre, and amplifying resistance risk.

Evidence from Boneo:

- Germination peaks during cool, moist seasons (Roberts et al., 2023).
- Manual control during misaligned windows required up to **329 hrs/acre** (2014).
- Timely chemical control reduced effort to **~39 hrs/acre** (2019–2020).
- Delayed mobilisation inflates costs and prolongs seedbank persistence.

Health, Safety, and Precision Benefits

Aligning operations with autumn–spring windows improves:

- **Worker Safety:** Reduced heat stress, dehydration risk, and musculoskeletal strain.
- **Productivity:** Cooler conditions support sustained effort and cognitive performance.
- **Precision:** Lower drift and volatilisation risk; cooler, moist conditions enhance herbicide uptake and reduce off-target damage (Sharpe et al., 2018; Syngenta, 2023).

Global Evidence

Guo et al. (2019) highlight that restoration success depends on timing interventions to ecological windows and maintaining continuity. Misaligned schedules lead to disturbance-driven reinvasion, higher costs, and operational inefficiency. Aligning budgets with seasonal windows:

- Enables action during peak vulnerability for invasive species.
- Reduces off-target damage.
- Leverages priority effects for native recovery.

Fiscal Shift in Phase

> *"To improve invasive species management outcomes, a fiscal shift in phase is required—one that aligns budget availability with ecological opportunity. Crucially, this adjustment need not increase costs; it simply reallocates existing resources to match seasonal windows, enabling earlier engagement of ecological field teams and more efficient deployment of effort. By synchronising funding release with ecological timing, we can achieve greater productivity and ecological benefit without expanding budgets—avoiding reactive expenditure and maximising the value of each control round."*

Strategic Recommendations

1. **Adaptive Budget Triggers**

    - Introduce rolling or seasonal contingency allocations.
    - Align funding release with ecological opportunity, not fiscal convention.
2. **Multi-Year Funding Programs**
    - Move beyond single-season budgets to multi-year frameworks.
    - Supports continuity for species with persistent seedbanks (3–10+ years).
3. **Cost Efficiency**
    - Aligning budgets with ecological timing reduces repeat interventions.
    - Estimated savings at Boneo: **69,366 labour hours** avoided by strategic timing.
4. **Risk Mitigation**
    - Timely applications reduce resistance risk (Teagasc, 2023; Riechers et al., 2024).
    - Prevents seed rain and accelerates seedbank depletion.

Executive Summary for Decision-Makers

- **Problem:** Misaligned budgets → missed windows → higher costs and ecological risk.
- **Solution:** Seasonal budget flexibility + multi-year programs.
- **Outcome:** Lower labour demand, faster restoration, improved worker safety, reduced off-target damage, cost-neutral efficiency gains.

Operational Best Practices

- **Timing & Programmatic Approach:** Align operations with autumn–spring growth cycles; run multi-year programs (timed foliar rounds + rotational follow-ups + monitoring).
- **Winter Uptake Misconception:** Winter applications remain effective; slower symptom expression does not mean reduced control.
- **Cool-Season Efficacy:** Clopyralid effective at 8–25 °C when plants are actively growing.
- **Upper Temperature Caution:** Avoid hot, dry days (>28 °C) to reduce off-target risk.
- **Resistance Mitigation:** Rotate methods (basal bark for mature plants; manual for scattered individuals); maintain zero seed rain.
- **Method of Least Disturbance:** Keep treated plants in situ to avoid soil disturbance and seedbank activation.
- **Long-Term Monitoring:** Persistent seedbanks require annual surveillance and rapid response.
- **Rabbit Control:** Integrate rabbit management to prevent micro-disturbance that sustains *Polygala* dominance.

Manual Removal – When and How

- **Use Cases:** Low-density patches or single plants; sensitive sites where herbicide is restricted.
- **Conditions for Success:** Minimal soil disturbance; timing outside peak germination; clear annual follow-up plans.
- **Precautions:** Avoid widespread disturbance; monitor adjacent soil; train teams for selective removal.
- **Integration:** Combine manual removal with targeted herbicide and seedbank suppression; use strategically, <u>not as primary eradication.</u>

Appendix D: Mathematical Framework for *Polygala* Control Model

Manual Rebound Rate

Observed cover milestones:

- 2014: 24.0%
- 2017: 32.5%

Manual rebound rate r_M is calculated as:

$$r_M = \left(\frac{32.5}{24.0}\right)^{\frac{1}{3}} - 1 \approx 0.1063 \text{ (10.63\% per year)}$$

Chemical Decay Factor

Observed cover milestones: START-2018 anchor = 36.0%, 2023 = 1.8%

- START-2018 anchor: 36.0% (projected from manual trend)
- 2023: 1.8%

Chemical decay factor f_C is:

$$f_C = \left(\frac{1.8}{36.0}\right)^{\frac{1}{5}} \approx 0.5494$$

Decay factor (cover × 0.5494 each year) is not a %

Each year after 2018:

$$\text{Cover}_{t+1} = \text{Cover}_t \times f_C$$

Manual-Only Counterfactual

If manual weeding continued after 2017:

$$\text{Cover}_{t+1} = \min\big(72\%, \text{Cover}_t \times (1 + r_M)\big)$$

Where:

- $r_M = 0.1063$
- Cap = 72% (2013 envelope)

POTENTIAL GERMINATION COVERAGE (PGC)

Logic:

- Pre-2018:

$$\text{PGC}_t = \min(100\%, 1.3 \times \text{Cover}_t)$$

- Post-2018 decay:

$$\text{PGC}_{2019,2020} = \text{PGC}_{\text{prev}} \times 0.55, \text{PGC}_{2021+} = \text{PGC}_{\text{prev}} \times 0.85$$

OBSERVED HOURS INTEGRATION

Observed hours per acre plotted directly from field data (e.g., 2016 = 216.83 hrs/ac) to illustrate efficiency gains.

PARAMETER SUMMARY

- r_M(manual rebound rate): **10.63% per year**
- f_C(chemical decay factor): **0.5494 per year**
- Manual-only cap: **72%**
- PGC multiplier pre-2018: **1.3× cover**
- PGC decay factors: 0.55 (2019–2020), 0.85 (2021+)

APPENDIX E: STATISTICAL SIGNIFICANCE AND HYPOTHESIS TESTING

CONCEPT EXPLANATION

Statistical significance determines whether observed differences are likely due to chance or represent a real effect. The null hypothesis (H^0)assumes no difference between manual and chemical control. The alternative hypothesis (H^1) proposes that chemical control is more efficient and less disruptive.

Key terms: p-value, significance level (α), confidence interval, effect size.

EXAMPLE: TWO-SAMPLE T-TEST FOR HOURS PER ACRE

Manual mean = 190.41 hrs/ac; Chemical mean = 51.50 hrs/ac; Difference = 138.91 hrs/ac (~72.95% reduction).

$$t = 3.26, p = 0.0238 \rightarrow Reject\ H^0 at\ \alpha = 0.05.$$

Interpretation: Observed difference is statistically significant and practically meaningful.

APPENDIX F: APPENDIX TABLE FROM MOXHAM & TURNER (2008)

Species Name	Common Name	Fire Response	Status
Aira spp.	Hair-grass	Increases with fire	Introduced
Catapodium rigidum	Fern Grass	Increases with fire	Introduced
Centaurium spp.	Centaury	Increases with fire	Introduced
Cerastium spp.	Chickweed	Increases with fire	Introduced
Conyza spp.	Fleabane	Increases with fire	Introduced
Hypochaeris glabra	Silky Guinea-flower	Increases with fire	Introduced
Polygala myrtifolia	Myrtle-leaf Milkwort	Increases with fire	Introduced
Rhamnus alaternus	Italian Buckthorn	Stable or increases	Introduced
Oxalis spp.	Oxalis	Mixed response	Mixed origin
Acacia uncifolia	Coast Wirilda	Declines with fire	Native
Dichondra repens	Kidney-weed	Declines with fire	Native
Leucopogon parviflorus	Coast Beard-heath	Declines with fire	Native
Melaleuca lanceolata	Moonah	Declines with fire	Native
Swainsona lessertiifolia	Coast Swainson-pea	Declines with fire	Native
Thuidiopsis furfurosa	Golden Weft-moss	Declines with fire	Native
Daucus glochidiatus	Australian Carrot	Increases with fire	Native
Elymus scaber	Common Wheat-grass	Increases with fire	Native
Lachnagrostis billardierei	Cat's Ear (Flatweed)	Increases with fire	Native
Poa labillardierei	Common Tussock-grass	Increases with fire	Native
Senecio odoratus	Scented Groundsel	Increases with fire	Native
Hibbertia sericea	Coast tea tree	Intermediate fire response	Native
Carex breviculmis	Common Grass-sedge	Likely declines with fire	Native
Lagenophora stipitata	Coast Blown-grass	Likely declines with fire	Native
Alyxia buxifolia	Sea Box	Stable	Native
Austrodanthonia spp.	Wallaby Grass	Stable	Native
Austrostipa spp.	Spear Grass	Stable	Native
Banksia integrifolia	Coast Banksia	Stable	Native
Clematis microphylla	Small-leaved Clematis	Stable	Native
Convolvulus erubescens	Pink Bindweed	Stable	Native
Crassula sieberiana	Sieber Crassula	Stable	Native
Cynoglossum australe	Australian Hound's-tongue	Stable	Native
Ficinia nodosa	Knobby Club-sedge	Stable	Native
Lepidosperma gladiatum	Common Bottle-daisy	Stable	Native
Leptospermum laevigatum	Coast sword-sedge	Stable	Native
Pimelea serpyllifolia	Thyme Rice-flower	Stable	Native
Rhagodia candolleana	Seaberry Saltbush	Stable	Native
Tetragonia implexicoma	Bower Spinach	Stable	Native

APPENDIX G: METHOD OF LEAST DISTURBANCE (M.O.L.D.) FRAMEWORK [5]

The Method of Least Disturbance (M.O.L.D.) is a systems-based ecological restoration framework that redefines weed management as a process of stabilisation rather than introduced species clearance. Conventional high-disturbance methods—such as scalping, burning, or broad-spectrum herbicide use—often trigger seedbank activation, displace fauna, and deepen ecological debt. M.O.L.D. counters this by integrating ecological logic, taxonomic selectivity, and network theory to suppress invasive species while preserving native habitat integrity. Its approach prioritises restraint, precision, and timing, enabling practitioners to work with ecological processes rather than against them.

At its core, M.O.L.D. operates through seven interdependent principles: diagnose before acting, define disturbance thresholds, select least-disturbance methods, retain habitat structure, disrupt invasive networks, adaptive Monitoring–Intervention, and support passive succession. These principles are underpinned by a layered diagnostic model that treats ecosystems as dynamic networks rather than isolated species assemblages. By collapsing multiple nodes within invasive feedback loops—such as systemic exploit species, fodder plants, and feral animal dependencies—M.O.L.D. weakens the architecture sustaining invasion. Selective herbicides, applied at reduced rates during optimal seasonal windows, replace broad-spectrum clearing, while dead biomass and cryptogamic layers are retained as ecological assets to suppress weeds and support native recovery.

Field trials in Moonah Woodland, Victoria, demonstrate the framework's effectiveness: labour intensity dropped from over 190 hours per acre under manual removal to approximately 51 hours per acre using selective chemical control aligned with M.O.L.D. principles. Native species regenerated without artificial planting, and reinvasion rates declined significantly. By reducing disturbance, aligning interventions with ecological rhythms, and leveraging passive succession, M.O.L.D. offers a scalable, cost-effective, and ecologically sound pathway for restoration. It transforms practitioners into network stewards—interpreting ecological relationships, applying strategic pressure points, and enabling resilience without resetting the system.

Core Principles of M.O.L.D.

- **Diagnose Before Acting:** Understand the site as a dynamic system—map species, feedback loops, and ecological assets to avoid misdirected interventions.
- **Define the Disturbance Threshold:** Recognise what constitutes harmful intervention and avoid amplifying existing disturbance that could trigger seedbank activation or faunal displacement.
- **Select the Least-Disturbance Method:** Is it only a few plants that could be hand weeded? or is it more intensive? And disturbing? Prioritise selective herbicides and precision techniques over high-disturbance methods like broad acre clearing, scalping, fire or broad-spectrum spraying.
- **Retain Habitat Structure:** Treat dead biomass and cryptogamic layers as ecological assets that suppress weeds and support native recovery.
- **Disrupt Invasive Networks**: Collapse multiple nodes (systemic exploit species, fodder plants, harbour shrubs) simultaneously to weaken feedback loops sustaining invasive dominance.
- **Adaptive Monitoring–Intervention**: Use adaptive, cue-based monitoring to apply minimal follow-up interventions only when necessary.
- **Support Passive Succession**: Allow native species to reclaim space naturally, reducing long-term labour and chemical input.

OPERATIONAL LOGIC FORMULA

Action = f(D, T, S, τ, N, F)

Where:
D = Site Diagnosis (holistic assessment of flora, fauna, soil, feedback loops)

[5] Note: The Method of Least Disturbance (M.O.L.D.) framework is currently under active development (in final draft). This appendix presents working concepts and field-informed logic that are subject to refinement.

T = Disturbance Threshold (avoid amplifying harm)
S = Method Selectivity (least-disturbance technique)
τ = Seasonal Timing (aligned with germination and vulnerability windows)
N = Network Disruption (pressure-point targeting within invasive networks)
F = Follow-up Load (adaptive monitoring and patching)

SEVEN-LAYER ECOLOGICAL MODEL

The Seven-Layer Ecological Model, inspired by the OSI networking model, provides a diagnostic ladder for understanding ecosystem integrity and guiding precise, low-disturbance restoration. Each layer represents a different dimension of ecological function, from physical habitat to restoration strategy.

1. Physical Habitat: Soil structure, cryptogamic crusts, and habitat architecture.
2. Species Presence: Balance of native and invasive species.
3. Interaction Layer: Pollination, dispersal, and trophic links.
4. Disturbance Layer: Predation, soil disruption, and human activity.
5. Feedback Loop Layer: Self-reinforcing cycles like weeds sheltering rabbits, which disturb soil and trigger more weeds.
6. Network Dependency Layer: Hidden dependencies that sustain invaders—such as fodder plants supporting feral animals.
7. Restoration Logic: Timing, method selection, and sequencing of interventions.

Intervention begins at the first failing layer, applying precise, low-disturbance methods only where needed. Preserve intact layers to avoid cascading harm.

Why Use a Seven-Layer Ecological Model in M.O.L.D.?

Purpose

The Seven-Layer Ecological Model is a diagnostic tool that helps restoration practitioners understand ecosystems as interconnected systems, not just collections of species. It breaks down ecological complexity into seven functional layers, allowing practitioners to pinpoint where ecological processes are failing and intervene strategically and minimally.

Why Seven Layers?

This model is inspired by the OSI networking model used in cybersecurity, which separates system functions into layers to diagnose and repair failures without resetting the entire system. In ecology, this layered logic:

- Prevents unnecessary disturbance by identifying the first failing layer.
- Preserves intact ecological processes by avoiding system resets.
- Supports precision-based restoration by aligning actions with ecological function.

How It Works

Instead of reacting to visible weeds or symptoms, practitioners start at Layer 1 (Physical Habitat) and move upward. The first failing layer becomes the intervention point. This ensures that:

- Healthy layers are left untouched.
- Interventions are surgical, not systemic.
- Ecological debt is reduced, not deepened.

The Seven Layers Explained

Layer	Ecological Focus	Function
7. Restoration Logic	Timing, method selection, sequencing	Strategic layer for planning interventions
6. Network Dependency Layer	Hidden dependencies (e.g., fodder plants supporting feral animals)	Reveals architecture of invasive persistence
5. Feedback Loop Layer	Self-reinforcing cycles (e.g., weeds sheltering rabbits)	Sustains invasive dominance
4. Disturbance Layer	Predation, soil disruption, human activity	Amplifies invasion risk if unmanaged
3. Interaction Layer	Pollination, dispersal, trophic links	Supports ecological services
2. Species Presence	Native and invasive species composition	Indicates structural balance or imbalance
1. Physical Habitat	Soil structure, cryptogamic crusts, habitat architecture	Foundation of ecosystem stability

Example
Role of Rabbit Control in Disturbance Management
Within the M.O.L.D. framework, rabbit disturbance is addressed at Layer 4 (Disturbance) and Layer 5 (Feedback Loop). Rabbits perpetuate invasive feedback loops by creating bare patches that activate seedbanks and by sheltering under *Polygala* thickets, reinforcing weed persistence. Effective application of M.O.L.D. requires not only minimising human-induced disturbance but also mitigating faunal disturbance. Incorporating rabbit control measures—such as exclusion fencing or targeted population management—ensures that low-disturbance principles are upheld, preventing conditions that favour *Polygala* recruitment and supporting long-term ecological stability. Why Rabbits Are Not Layer 1

- Layer 1 focuses on abiotic structure: soil composition, cryptogamic crusts, and habitat architecture — the physical foundation of the ecosystem.
- Rabbits affect Layer 1 (e.g. by digging, compacting, or exposing soil), but they are not part of it. They are biotic agents of disturbance, not structural components.
- If rabbit-induced soil degradation becomes so severe that it **alters the physical habitat itself** (e.g. collapse of cryptogamic crusts, erosion, compaction), then **Layer 1 may be considered failing** — but the rabbits are still **drivers**, not constituents of that layer.

Strategic Implication

This model transforms restoration from reactive clearance to systemic repair. It empowers practitioners to:

- **Diagnose precisely.**
- **Intervene minimally.**
- **Restore resilience layer by layer.**