Review of current control methodologies of Madagascar ragwort (*Senecio madagascariensis* Poir.) and control trial design

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30 April 2025

Report for Northland Regional Council

Client Report Number 2505-NLRC243

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Executive Summary

AgResearch was contracted by Northland Regional Council via a medium advice Envirolink grant from MBIE to review current methods of control for Madagascar ragwort and to propose trials that would provide reliable advice for the control of the weed.

A literature review of the control of Madagascar ragwort was undertaken.

Overseas experts were contacted for advice and to gain insights about unpublished research, to avoid repeating work that has proven ineffective. Local farmers and weed control operatives were interviewed to understand the impact of the weed on them, and how they are currently controlling it.

Key findings:

- Madagascar ragwort is costly to Northland farmers, mainly in terms of reduced pasture utilisation.
- New infestations frequently establish from wind-blown seed.
- Hand weeding is frequently done, with good success in limited infestations, but poor success in larger ones.
- Herbicides are used to varying degree of success. There were several herbicides identified as effective for spot spraying (triclopyr-based mixtures, metsulfuron), and others effective at a broadcast scale when timed early (‘triple-mixes’ of 2,4-D, either flumetsulam or dicamba and the adjuvant Bonza®), but these face difficulties with clover safety and efficacy on larger plants.
- Madagascar ragwort establishes in areas of disturbance. Most of the affected pasture is kikuyu-based, but even that species can have issues with gaps. Optimising the competitivity of pasture is key to minimizing the impact of the weed.
- A combination of herbicides, hand-weeding, cultural control and biosecurity (hygiene measures) is necessary on individual farm level. At a larger scale, increasing awareness, communication and information dissemination, and participation in weed control will be necessary to prevent further spread.

Avenues of potential future research that were identified were:

- Optimising efficacy of 2,4-D based mixtures for broadcast spraying
- Evaluating modern adjuvants for improved efficacy of 2,4-D and other herbicides
- Evaluating herbicide ‘spikes’ – mixtures of 2,4-D with low doses of other herbicides including chlorsulfuron, metsulfuron, mesotrione – for efficacy with minimal clover damage
- Utilizing competitive pasture species to suppress Madagascar ragwort

1. Background

Senecio madagascariensis is a yellow-flowered weed from the daisy family Asteraceae (Figure 1). It grows as an annual, biennial or perennial plant (Sindel 1989), can flower all year-round and produces wind-dispersed achenes. Madagascar ragwort grows across a range of soil fertility conditions (Sindel 1989), especially in places where grasses grow, such as pastures, lawns and roadsides (Guido et al. 2024). It is toxic to livestock, with pyrrolizidine alkaloids (PAs), and increases in abundance in pasture as it is avoided by stock. Gaps in pasture from drought, insect damage or left by annual weeds are filled by new seedlings germinated from prolific wind-blown seed. While most of the seed produced drops near the base of plants, forming large seed banks, a not insubstantial amount is likely to float in the wind to colonise new pastures.

Figure 1. A Madagascar ragwort (*Senecio madagascariensis*) plant.

Originally native to southern Africa (including Madagascar), Madagascar ragwort has spread across the world, found in Australia, Hawai'i, Japan and parts of South America (Ramadan et al. 2011; Wijayabandara et al. 2022).

The date of its arrival in New Zealand is uncertain, but it has likely been present for a considerable period, though only correctly identified as being in New Zealand in 2022. Over the last 10 years, farmers in the Far North of New Zealand became increasingly concerned about the growing impacts of what was initially believed to be 'gravel groundsel '*Senecio skirrhodon'.* In response, entomologist Jenny Dymock collected samples from several populations across the North Island and, in 2022, phylogenetic analysis of these samples and samples from South Africa, Australia and Europe, confirmed that the species causing concern in the Far North was *Senecio madagascariensis*, and not *Senecio skirrhodon* (Schmidt-Lebuhn et al. 2022)

Known to tolerate drought (Sindel 1989). Madagascar ragwort grows in warm areas, and is limited by frost (Sindel and Michael 1992), though plants acclimated to colder temperatures can survive frosts. While it is currently only found in the Far North, climate models suggest there are places suitable for it across the North Island and lowland parts of the South Island (Wijayabandara et al. 2022). Although the data used in this model is incomplete, they do indicate a potentially larger range than is known currently (Figure 2).

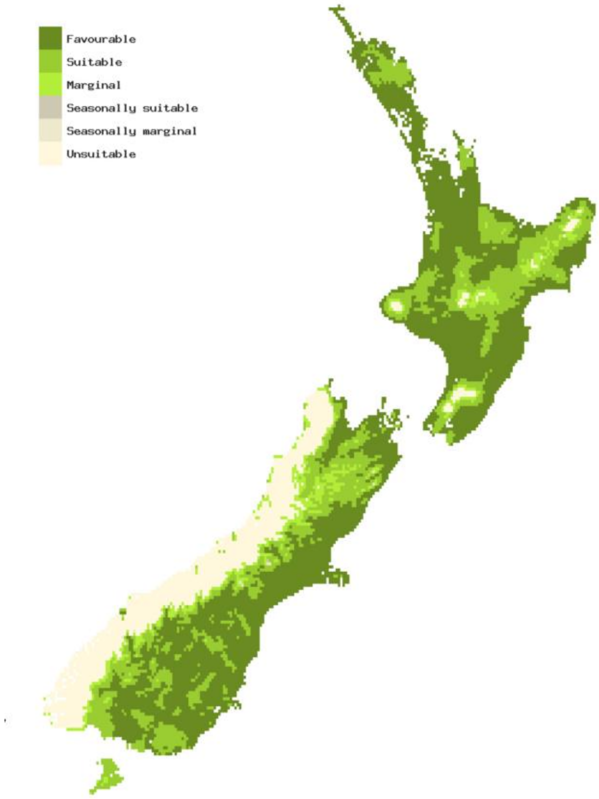

Figure 2. CLIMEX model showing the potential distribution of Madagascar ragwort based on parameters from (Wijayabandara et al. 2022), modelled by John Kean. Note: there are questions around the parameters used for this model which could over-estimate the range.

Madagascar ragwort is not currently classified as a pest in the Northland Regional Pest and Marine Pathways Plan (2017-2027). Gravel groundsel was included as a 'Sustained Control' category pest with a 'good neighbour rule' in place, requiring destruction of the plant within 50 metres of an adjacent property. An amendment to the Plan is underway to replace Gravel groundsel (*Senecio skirrhodon*) with Madagascar ragwort (*Senecio madagascariensis*).

To address this problematic weed, AgResearch was contracted by NRC (via an MBIE funded Envirolink medium advice grant) to review current methods of control for Madagascar ragwort and propose trials that would provide reliable advice for the control of the weed.

2. Methods

2.1.1 Literature survey

Literature was searched for by matching search terms to available titles, abstracts and keywords found in the databases: Scopus, CABI, Ovid, Google Scholar and Dimensions. Search terms used were “Senecio AND madagascariensis”, “Senecio AND madagascariensis AND control”.

- *Scopus*: there were 82 results. Papers ranged from biocontrol, genetic identification, toxicity on cattle, stem-boring weevils and grazing by sheep. Kusinara Wijayabandra produced a highly relevant publication which reviewed the biology, distribution and management of Madagascar ragwort, and another on the chemical management of it.

- *CABI*: there were ten results. A notable one referred to the toxicity of it to cattle in Colombia and poisoning of stock in Uruguay. A book chapter in ‘Plants, Mycotoxins and Related Toxins’ mentions the weed and non-chemical management of it.

- *OVID*: there were 207 results, but few were relevant.

- *Google Scholar*: another paper by Kusinara Wijayabandra was found on the plant and seed mortality of the weed after herbicide application; this paper identified several effective herbicides on mature Madagascar ragwort plants. A paper by Brian Sindel, with results from a farmer questionnaire a quarter of a century from the first observation provided insights into the way that Australian farmers have adapted their approach to the weed. A paper from Uruguay uncovered some of the explanatory variables for the spatial distribution of the weed.

- *Dimensions*: there were 27 results. They ranged from its invasive potential, distribution, genetics, impacts on native species, to interviews with farmers and methods of control. One of those was a study testing simulated herbivory on weed biomass and fecundity. Another tested the growth of Madagascar ragwort under different soil nutrient levels.

2.1.2 Expert and farmer interviews

Experts who have done research on Madagascar ragwort or are knowledgeable of the control of it were contacted.

- Professor Brian Sindel (New South Wales, Australia) was contacted.

- Communications with Professor Steve Adkins (Queensland, Australia) yielded valuable insight and unpublished work by Kusinara Wijiayabandara.

- Anaclara Guido (Uruguay) was contacted.

- Research on the weed from Japan and Hawai’i is dated or limited, and there are no practicing researchers.

Affected farmers and weed control operatives were interviewed.

- Dairy farmers (Julliane and Aaron Bainbridge) from the Aupōuri Peninsula.
- Dairy farmer Jesse Bagley from Ahipara Bay.
- A business manager (Craig Bell, Pāmu Farms) overseeing sheep and beef farms across Northland.
- A weed control operator (Chance Campbell, Northland Vegetation Control) working across multiple properties to control the weed.
- Additionally, conversations between affected farmers in the social media group ‘The Madagascan Ragwort Conundrum’ yielded insights into the impact and control of the weed.
- Email conversations with dairy farmer Vicki Stevens and Northland Regional Council pest control officers were also valuable.

3. Results

3.1 Impact of Madagascar ragwort

3.1.1 Impact on pastoral agriculture

The major impact of the weed in Northland is through a loss in pasture production. Cows, avoiding Madagascar ragwort plants, will leave tufts of grass around the plant ungrazed. As gaps open in the pasture, new plants will grow, eventually taking over pastures. In a Northland beef farm (a Pamu farm), declining carcass weights were attributed to the presence and impact of Madagascar ragwort on the farm's pasture quality; these carcass weights are now down to 65% of their level before the weed was present (Figure 3).

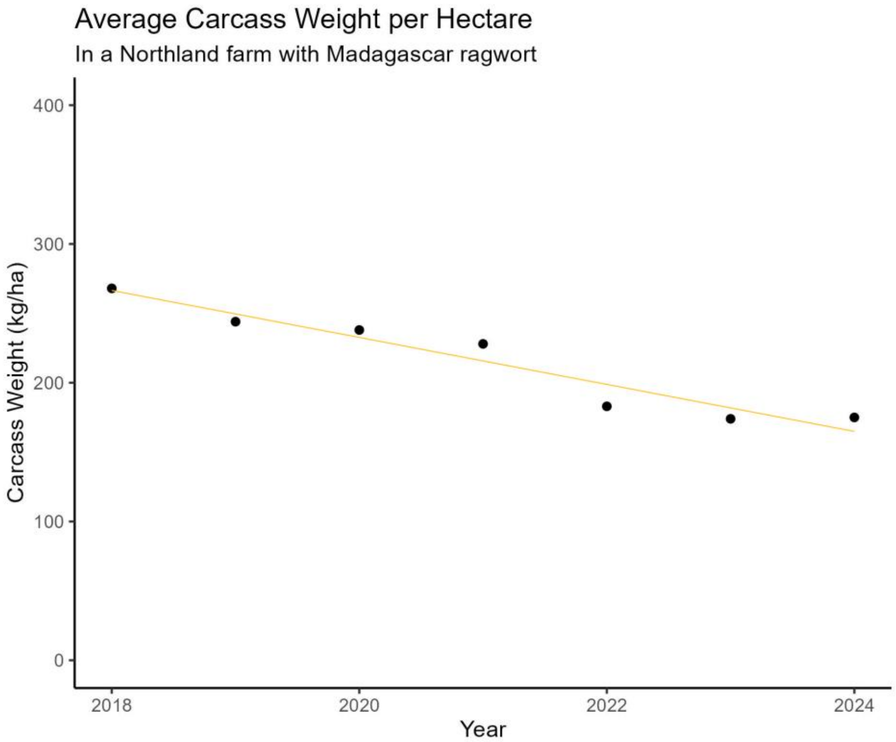

Figure 3. Reduction in carcass weight per ha recorded annually as Madagascar ragwort was observed to occupy more of the pasture (Records from a Northland Pāmu farm).

On average this loss in pasture production was estimated to be $300 per hectare (Craig Bell, pers. comm.). According to their estimates, an infestation of 35% cover, led to an average carcass weight loss of 81.5 kg. ha^{-1}. There are then further costs for controlling the weed. On that same beef farm, pasture was sprayed twice a year, at an estimated cost of $200 per hectare per year. In these pastures, the spray that controls the weed kills clover, and on this farm they decided to use nitrogen inputs to make up for the loss of clover. This suggests an annual combined yield lost and control-based cost of $500 per hectare for Madagascar ragwort.

Madagascar ragwort is mostly a problem for dairy and beef farmers. Pastures grazed by sheep in Northland typically do not have issues with Madagascar ragwort. Sheep will eat the plant (Bandarra et al. 2012), and are estimated to be 10-20× more tolerant than cattle to the toxins in the weed (Hooper 1978). Nonetheless, they are not immune and, especially at higher infestation levels, can still be poisoned.

Farmers observe the rapidity of invasion. “One year you might see three plants, the next year half the paddock is flowering” - Vicki Stevens. Aaron Bainbridge noted that the plant could quickly establish in a new paddock and within two years be a major problem. Plants can flower 42-70 days after emergence (Wijayabandara et al. 2022), and as flowers are indeterminate, continue to produce flowers throughout their lifetime. A single plant can produce 30,000 seeds annually (Egli and Olckers 2017), and plants in Northland can survive multiple years (Aaron Bainbridge, pers. comm.). Where control is not undertaken pastures become dominated by the weed (ground cover 60-70%), producing a large amount of seed to inundate their property and their neighbours’.

Farmers have observed wind dispersal of the weed over great distances. One example is seed germinating on a hilly part of a farm, 1.2 km from the nearest plants (Julliane Bainbridge, pers. comm.). There are no studies measuring the long-distance dispersal of Madagascar ragwort, though models of the wind dispersal of the related species South African ragwort (*Senecio inaequidens*) predicts 63.2% of seed falls in the first 10 metres, 99.8% of seed falls within the first 100 metres (Monty et al. 2008). Taking this into account with the assumed 30,000 seeds produced annually, for each plant, 60 seeds (0.2% of the seed produced) will travel over 100 metres. However, the same study also measured 6.25% of seed (1875 seeds for the example) being uplifted, and in certain wind (and terrain) conditions a large proportion of that will travel longer distances than 100 metres. Where there are large infestations of Madagascar ragwort, assuming similar behaviour to *S. inaequidens*, in the right conditions, a lot of seed will likely still spread beyond the 100-metre mark.

Farmers have observed that taller plants, such as pines and maize, act as a net, catching windborne Madagascar ragwort seed. The first time that the weed was seen in one farm was near trees (Julianne Bainbridge, pers. comm.). These areas that ‘catch’ the wind are also considered high-risk areas for new infestations in Australia (Virtue and Sheehan 2022).

Farmers in New South Wales believe that Madagascar ragwort is worst after a dry summer (Sindel and Michael 1988). This is true as well in Northland (Julliane Bainbridge, pers. comm.). Possibly, this is because disturbed patches take longer to recover, and gaps created by drought are easily colonized by seedlings. The same issue will happen for wet years, as paddocks that are pugged will have increased disturbance for seedlings to colonize (Virtue and Sheehan 2022). Northland farmers have observed that fragments of the plant can re-establish after trampling (Aaron Bainbridge, pers. comm.); this is more likely in moist conditions, but farmers observe that the weather wasn’t always particularly wet when the plants re-established.

Thirty-five percent of farmers in New South Wales considered Madagascar ragwort to be their worst weed in 1985 (Sindel and Michael 1988). More than twenty years later, the same proportion of farmers view it as their worst weed (Sindel et al. 2024). Interestingly, farmers who had the weed on their property for ten to twenty years classified it as a problem at higher frequencies than those who had the weed present for less than ten or more than twenty years (Sindel et al. 2024), suggesting that there is some degree of adaptation in farm management, or acclimation by the farmer to the weed.

3.1.2 Toxicity

Madagascar ragwort and other *Senecio* species are known to contain pyrrolizidine alkaloids (PAs) (Cheeke 1988). PAs are found in all parts of the plant, and twelve are known from Madagascar ragwort (Table 1; Gardner et al. (2006). The predicted toxicity (rodent oral toxicity) of the PA compounds found in Madagascar ragwort ranges from an LD_{50} of 34-85 mg per kg (Table 1).

Table 1. Pyrrolizidine alkaloids (PA) identified as occurring in Madagascar ragwort by Gardner et al. (2006) and their predicted acute rodent oral lethal doses (LD_{50} values) as estimated by ProTox (Banerjee et al. 2018; Günthardt et al. 2018).

Chemical	ProTox LD_{50} mg/kg
acetylsenkirkine	77
desacetyldoronine	-
doronine	45
florosenine	-
integerrimine	85
mucronatinine	-
otosenine	46
retrorsine	34
senecionine	85
senecivernine	85
senkirkine	77
usaramine	34

The amount of total PAs found in Madagascar ragwort populations range between 220-2000 mg per kg of plant material (Gardner et al. 2006). By contrast, ragwort (*Jacobaea vulgaris*) total PA concentration reached a peak during flowering up to 3100-6600 mg per kg (Hama and Strobel 2021); jacobine N-oxide, jacobine and senecionine N-oxide formed the largest contingency of PAs in ragwort. None of those three major PAs from ragwort are reported from Madagascar ragwort, but five other PAs are shared: integerrimine, otosenine, retrorsine, senecionine and senecivernine (Gardner et al. 2006; Hama and Strobel 2021). A very close relative, South African ragwort (*S. inaequidens*), contains seneciphylline, senecionine, platyphylline, jacobine, jacozine and otonecine (Günthardt et al. 2018). Ragwort toxicity is three orders of magnitude larger in summer than winter (Hama and Strobel 2021); probably this is similar in Madagascar ragwort. Those collected in Australia were during their winter (Gardner et al. 2006). So, possibly the toxicity of ragwort and Madagascar ragwort are within a similar range, though with slightly different PA profiles.

Pyrrolizidine alkaloids from ragwort can contaminate honey and bee-collected pollen (Kempf et al. 2011; Kast et al. 2018). Contamination from these alkaloids was a concern for apiculture in New Zealand (Symes and Lancaster 2021), even before Madagascar ragwort was confirmed to be in New Zealand. Interestingly, PAs were quite prevalent in Northland at the time of that study. Another study revealed widespread contamination of honey samples with PAs in parts of Australia where fireweed grows (Griffin et al. 2015). However, that study was criticised by the industry for 'exaggerating' the risk (ABC News 2016).

Nonetheless, if the weed invades more land, there is a chance that the risk for PA contamination in honey will increase, and there may be some impact on apiculture.

Toxicity is rarely a problem for farmers, as once cattle are familiar with it, they will avoid it. Poisoning is most likely when plants are young and stock are new to the weed or when it is in contaminated hay (Sindel et al. 2008). There is also a risk of poisoning as it becomes more palatable after it is slashed, mown or sprayed (but remains toxic). The biggest impact is not its toxicity itself but that it causes stock to avoid grazing it and around it ('shadow effect') leading to its spread in pasture and consequent reduced pasture utilization.

3.1.3 Distribution in Northland

A point raised multiple times was a need for a distribution map. This is made difficult by the problem of distinguishing Madagascar ragwort *(S. madagascariensis*) from gravel groundsel (S*. skirrhodon*). Often reports (even with photos) cannot always be reliably confirmed as Madagascar ragwort. Unlike gravel groundsel, Madagascar ragwort is more often found in habitats with grasses present, such as pastures, roadsides and lawns. It is morphologically distinct, with narrower calycular bracts (0.5-0.8 mm rather than 0.8-1.5 mm), a higher leaf length:width ratio (5-12 rather than 3-9) and a difference in leaf shape (not fleshy, more lanceolate; Schmidt-Lebuhn et al., 2022). However, the leaf characteristics are less reliable. Gravel groundsel plants that were cut back to a low height grew back with typically small, lobed and/or fleshy leaves, whereas plants cut back to a taller height had leaves that more resembled a typical Madagascar ragwort plant (Figure 4).

Figure 4. Leaf morphology of Madagascar ragwort and gravel groundsel plants grown back from being trimmed to different heights.

We have some idea of the distribution of the weed through collections made by Jenny Dymock, which were confirmed to be Madagascar ragwort (*S. madagascariensis*) through genetic testing (Schmidt-Lebuhn et al. 2022; Dymock and Winks 2024). Additionally, sixteen records from iNaturalist are available. While these are just photographic records, they display key characteristics of Madagascar ragwort and are found in habitats associated with grasses (Appendix 1). There are also several errant herbarium records from the New Zealand National Forestry Herbarium in other parts of the country (which probably are *S. skirrhodon* and were not included here). The breadth of its distribution spans the Far North, in areas above latitude 35.5 ˚S (Figure 5).

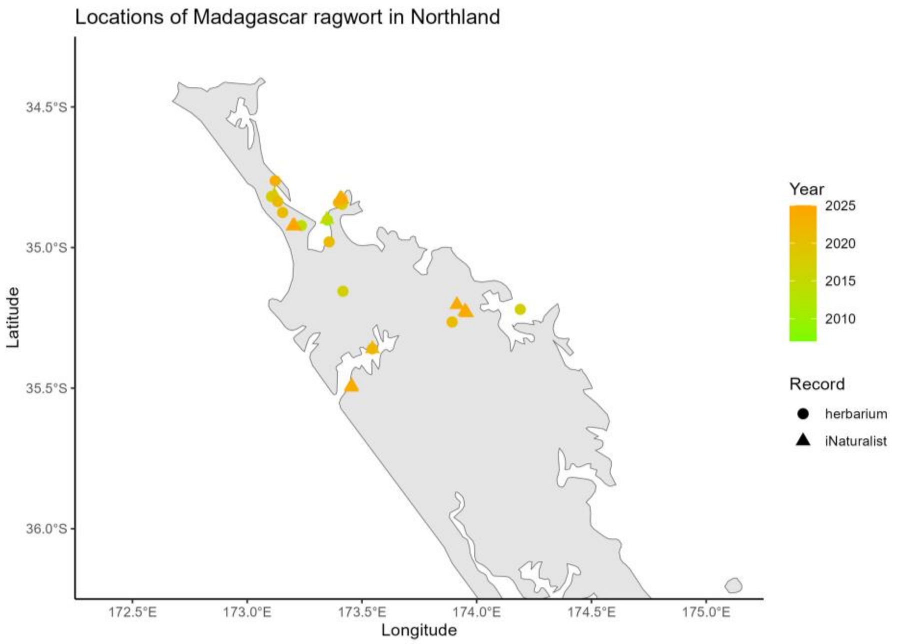

Figure 5. Map of known locations with Madagascar ragwort, based on iNaturalist and herbarium records.

Most records are from kikuyu pastures on the Aupōuri Peninsula and Karikari Peninsula (Appendix 1). There are a few from lakesides, lawns, several records of individual plants from urban areas in Kerikeri and some from roadsides along the Hokianga Harbour. There is one record of an individual plant from a bank on Moturua Island. A record east of Kaitaia on farmland beside the Victoria River is the most inland and isolated site (from these records). Madagascar ragwort is also said to be found in orchards and forestry, though no geo-referenced records have been made from those places yet. In every single iNaturalist observation the plant was flowering (throughout the year).

Northland farmers with the weed are also in favour of increased awareness of the weed to mitigate its spread. There is a need for knowledge extension to other farmers in Northland, farmers outside of Northland and to the general public.

3.2 Control of Madagascar ragwort

The major methods of control by farmers in Northland include hand-weeding (bag and burn) and herbicides. In Australia, hand-weeding, slashing/mowing, using competitive pasture and herbicides are the major methods (Sindel et al. 2024). There are also some who have tried cultivation, reducing stocking rates and grazing with sheep or goats.

3.2.1 Objectives

Depending on the level of infestation (size of infestation, prevalence in seedbank, age of plants) different methods of control should be used (Sindel and Coleman 2012).

A heavier infestation with large population sizes and older plants will require a more intensive, sustained control regime. A more moderate infestation might be kept under control in pasture with clover-safe herbicides and grazing management. A small patch of Madagascar ragwort should be eradicated with hand weeding and spot spraying, and isolated from other parts of the farm by active on-farm biosecurity and monitoring.

Farmers indicate that seeds germinate in spring and autumn in Northland. The optimal temperature range for germination of Madagascar ragwort is between 15-27℃ (Nelson and Michael 1982). Weed control needs to be concentrated just after those spring and autumn windows when soil temperatures are most favourable for germination, as early as possible to prevent plants becoming large and difficult to control. Our unpublished results from thermogradient table experiment indicate that it takes about four days for a Madagascar ragwort seed to germinate at its optimal temperature. The optimal temperature was calculated to be 21.4℃, the minimum temperature for germination was 1.4±6.8℃ and maximum temperature for germination 34.5±15.1℃ (Figure 5; unpublished data). These data suggest that germination in summer is also possible (assuming adequate moisture, and soil disturbance). Winter soil temperatures will also be above the minimum temperature for germination, suggesting winter germination (though slower) is also possible.

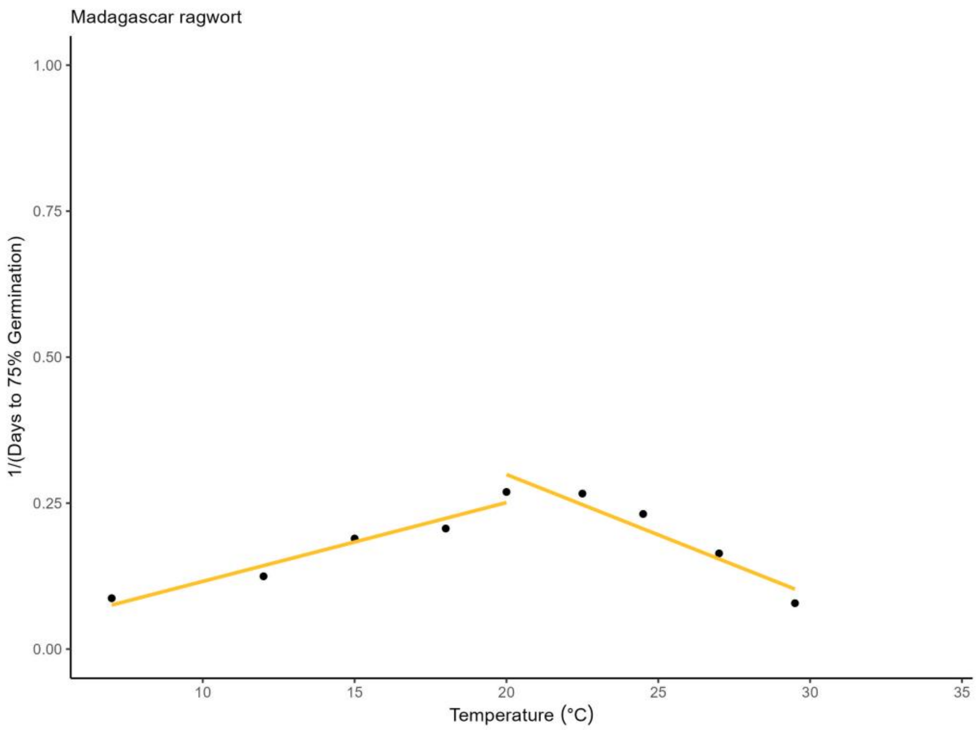

Figure 6. Germination rate (reciprocal of the number of days to 75% germination) of Madagascar ragwort seeds at different temperatures after 28 days (unpublished data). For example, as the germination rate is the reciprocal of the number of days to 75% germination, a rate of 0.25 corresponds to four days at that temperature to 75% germination.

3.2.2 Prevention

Practically, preventing new infestations is quite difficult. Seed can be wind-blown and travels easily over boundaries and from roadsides. In Uruguay, Madagascar ragwort distribution is associated with closeness to roads, presence of grass species and with more fragmented landscapes (i.e. more borders) (Guido et al. 2024). Spread from neighbouring properties and roadsides can be difficult to prevent, but communication with neighbouring land managers can improve this process. Unfortunately, in some cases, there can be nothing done about this, and influx of new seedlings must be constantly managed.

There are some other areas apart from property boundaries where new infestations are likely to appear (Virtue and Sheehan 2022). Hills and slopes and windbreaks (even individual trees) ‘catch’ incoming seed (as observed by Julianne Bainbridge). This tendency of seed to accumulate on windbreaks can be used positivity, by establishing windbreaks around paddocks to prevent seed from blowing into the paddock (Virtue and Sheehan 2022), and instead accumulating at the base of the trees, where they are more easily able to be controlled.

Places where brought-in feed has been introduced and spread out are at a higher risk of new infestations, as Madagascar ragwort can spread through contaminated hay. This is how it was thought to have spread to Hawai’i (Motooka et al. 2004; Wijayabandara 2021). Any farm equipment in contact with seeding Madagascar ragwort plants may be contaminated with seeds. So, any paddocks that were in contact with equipment from outside of the property are at a higher risk. There is a belief that Madagascar ragwort got into Northland with contaminated machinery from Australia more than two decades ago (this has not been proven).

By far the most favourable environment for Madagascar ragwort to establish is bare or disturbed ground. These include parts of paddocks that have suffered from drought, trampling, pugging or pest damage, but also high-traffic areas like roads, gateways, headlands, tracks and places near buildings (Virtue and Sheehan 2022). Maintaining high levels of ground cover (over-sowing with resilient, desirable plant species) and mitigating trampling and disturbance in these areas will limit the ability of the weed to establish.

Vigilance and rapid control in these high-risk areas could slow soil seed bank accumulation and the establishment of plants. When a new infestation is spotted, that paddock can be isolated and intensively controlled to prevent the weed spreading between paddocks. Plants could be spot-sprayed or pulled by hand. Fallen seed could even be vacuumed from new infestations where plants are pulled (this has been done for black grass *Alopecurus myosuroides* Huds. in Canterbury; Matilda Gunnarsson, pers. comm.).

Even within a farm it is important to maintain biosecurity. There is a risk of spread when moving any equipment or livestock from an infested paddock into a clean one. It might be worth monitoring the less affected paddocks so that any new plants can be controlled before they establish a seedbank. Fencelines are another area where seed can accumulate. Spraying out fence lines with glyphosate may help with this (however the bare soil created by spraying glyphosate will be a good environment for seed germination, so this should ideally be done in mid-winter, when germination rates are low).

Councils in Australia have been offering free disposal of the weed (Shoalhaven City Council 2024). An initiative like this could be useful in Northland to increase awareness of the weed.

3.3 Non-chemical control

3.3.1 Hand-weeding

Hand-weeding is an important and effective method. In early and light infestations, but even in some moderate levels of infestation, farmers pull plants by hand, bag and burn them. Hand-weeding is effective especially at lower levels of infestation and earlier in the season (before plants have set much seed). Small infestations of Madagascar ragwort can be pulled and disposed of. If plants are pulled and thrown into the paddock they can re-root and set seed (Sindel and Michael 1996), so it is best to burn or bag the plants. Care must be taken to minimize any disturbance of any seedheads to prevent this process from spreading seed throughout the paddock. Carrying spare durable bags on farm vehicles can allow for opportunistic removal of individual plants when doing other farm operations.

Above a certain level of infestation this is ineffective, and farmers report the same site coming back with more plants the next year (Jesse Bagley, pers. comm.). In those cases, it is likely that a large seed bank is present underneath the plants, and hand-weeding would need to be repeated many times before populations are reduced. It might be difficult to tell when exactly this point of diminishing returns is, and this will vary depending on the farm management, but clearly it depends on the amount of seed in the soil seedbank (this can be measured by sampling the soil and spreading it out on a tray to germinate or by observation of seedlings in the paddock). So, to avoid wasting time and effort, in these larger infestations, a different approach needs to be taken.

3.3.2 Mowing, slashing, topping and mulching

Slashing plants (at 5-10 cm height) increases plant mortality though it doesn't prevent plants from flowering (Sindel and Michael 1996). If poorly timed, it may actually worsen the problem by spreading seed. Furthermore, plants slashed during summer might be more likely to survive into their second year, and regrow from their stem (Virtue and Sheehan 2022). Only when repeated frequently, before plants re-grow produce seed, might defoliation work well. However, with the amount of effort it takes and the lack of efficacy, slashing is often a waste of time.

Mowing is best done when pasture is growing well; if done earlier in the lifecycle of the weed, it may promote regrowth and persistence over summer, and if done on slow growing pasture it may encourage the weed to outcompete the desired species (Sindel 1989). California thistle (*Cirsium arvense* L. (Scop.)) mown in the rain is believed to be more likely to become infected by its host-specific biological control rust fungus *Puccinia punctiformis* (F. Strauss) Röhl. (Henderson 2018) and is known to become infected by the wilt-causing fungus (*Verticillium dahlia* Kleb.; Skipp et al., 2013). There is a rust *Puccinia lagenophorae* Cooke. found in Northland that is a known biological control agent of Madagascar ragwort (Dymock and Winks 2024). Structures created by this fungus (aecia) provide an entrance for secondary infection by other pathogens, which in related species, causes plants to die (Hallett et al. 1990; Hallett and Ayres 1992). It might be possible that a similar effect could be attained by mowing Madagascar ragwort in the rain. However, a difference is that California thistles have a hollow stem that can catch water and fungal spores unlike the woodier stems and shallower root system of Madagascar ragwort.

Kikuyu (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone) dominated pastures are often mulched and under-sown with an annual ryegrass in autumn to ensure winter feed

(McCahon et al. 2021). Mulching is not believed to be effective on controlling Madagascar ragwort (Aaron Bainbridge, pers. comm.) and in fact is believed to spread the weed (Jesse Bagley, pers. comm.). Another issue with mulching is that cut Madagascar ragwort plants become more palatable to livestock, and pose a higher risk of poisoning; so, after mulching a paddock, it should not be grazed for 2 weeks (Wijayabandara et al. 2022). Some farmers under-sow their mulched kikuyu with grasses such as tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.); it is unknown if this will provide enough competition in autumn to suppress newly germinating Madagascar ragwort seedlings, but this may help.

When slashing or mowing, seed could accumulate on machinery, so care must be taken not to spread seed from affected paddocks to unaffected ones.

3.3.3 Sheep grazing

Grazing by sheep or goats can reduce Madagascar ragwort infestations (Thorne et al. 2005; Stigger et al. 2018). Sheep are 10-20 times less susceptible to pyrrolizidine alkaloids compared to cattle (Hooper 1978). In Brazil, Madagascar ragwort plants that were mown before grazing with sheep were near-completely eliminated (Bandarra et al. 2012). This is being done in New Zealand too; Pāmu Farms have been trying to use sheep strategically to remove the weed, however, they have not seen much success with sheep, and claim that even areas with sheep are struggling with the weed (Pamu New Zealand 2024).

3.3.4 Maintaining high ground cover

Disturbed pastures are at high risk of weed ingress (Tozer et al. 2011); bare patches in these pastures are often attributed to poorly persisting species, trampling and pugging damage, drought, insect damage and uneven nutrient distribution (patches of poor fertility). This, in combination with the high seeding pressure of Madagascar ragwort, create an environment suitable for colonization by the weed.

Kikuyu, and other tropical grasses, shouldn’t be grazed hard before autumn, to allow them to be competitive (Virtue and Sheehan 2022). Likewise, the density of cool-season grasses should be managed so that they are high in autumn. Intensive grazing opens the soil, giving the light-dependent Madagascar ragwort seeds an opportunity to germinate and grow (Sindel and Michael 1996). Paddocks with the weed should not be overgrazed.

Grazing management has a large effect on Madagascar ragwort (Virtue and Sheehan 2022). Pastures that are over-stocked will have poor persistence as desirable species become weakened and potentially damaged by trampling and (in the winter) pugging (Tozer et al. 2011). Conversely, animals stocked at a low rate will have more choice of feed and will ignore undesirable plants. The best grazing system for Madagascar ragwort is rotational grazing, where stock intensively graze paddocks for a short period of time before rotating to another paddock (which most dairy farmers do anyway). However, changes to future pasture systems (climate, new plant cultivars and species, pests and weeds) may require grazing management systems to change (Donaghy et al. 2021). Deferred grazing, a process where a certain proportion of a farms’ paddocks are prevented from being grazed during spring to autumn, has recently come back into public attention with recent work by Tozer et al. (2020). This is similar to what has been suggested already (increasing rest periods from grazing in affected paddocks) for the management of Madagascar ragwort in Australia (Thorne et al. 2005). A study has shown that grasses (including kikuyu and cocksfoot *Dactylis glomera* L.) were more competitive against

Madagascar ragwort without herbivory than with it (Fynn et al. 2019), which indicates that deferred grazing may work.

3.3.5 Nutrient management

There was some interest by farmers in improving soil health to mitigate Madagascar ragwort.

Altering the nutrient profile of the soil (e.g. adding fertilizer) is usually recommended to increase pasture competitivity, however certain weed species can compete better under high nutrient conditions. Madagascar ragwort can grow in soils with differing levels of fertility (Verona et al. 1982), but it grows preferentially in higher fertility soils (Wijayabandara et al. 2022). When grown with cereal oats (*Avena sativa* L.) at high nutrient levels, Madagascar ragwort outcompetes the oats (Sindel and Michael 1992). In that case, adding fertiliser may preferentially benefit the weed. However, the oats results do not apply to Italian ryegrass (*Lolium multiflorum* Vahl.), which, at higher densities, outcompeted Madagascar ragwort under higher soil fertility conditions (Sindel and Michael 1990). So, the species that the weed competes with is quite important to understand whether adding nutrients will aid with weed control or not. If it is growing with poorly competing species adding fertiliser may worsen the problem. This will differ depending on the season, kikuyu grows slower in winter for example. Conversely, when pasture (or a crop) is best placed to respond to fertiliser, it will compete better against the weed. Another factor to consider is the distribution of nutrients in a pasture, as uneven nutrient distribution encourages weeds to proliferate (Tozer et al. 2011). The aim of nutrient management (in the context of Madagascar ragwort) is to optimise the amount and distribution of nutrients in a pasture to favour growth of desired species.

There are a range of products ('biologicals') marketed on the basis that they will improve soil health, which is then expected to lead to a reduction in weed problems. There is interest for these in Northland. These sorts of products fit within the sphere of regenerative agriculture practices (Clothier et al. 2021). However, often the marketing for these relies on an aversion to 'chemicals' and these products are often inconsistent and lack peer-reviewed research confirming their efficacy (Farrell et al. 2017; Abbott et al. 2018), thus cannot be recommended. There are some 'alternative fertilizers' that are effective in increasing pasture production (Leech et al. 2019), though it isn't known if this would necessarily decrease weed abundance.

There was some indication that Madagascar ragwort preferred sandy soils (Julianne Bainbridge, pers. comm.), but was also found in peaty soil. The soil types noted in recorded observations of the plant were sandy or sandy loam soils (Appendix 1). In Australia, Madagascar ragwort prefers soils with good drainage, low compaction and high fertility, but can grow across different soil types (Sindel et al. 1998; Wijayabandara et al. 2022).

3.3.6 Cultivation

Despite the potential usefulness of cultivation, most Australian farmers did not rate it as an effective method, with only 5% using the method, and only 22% of them considering it a highly effective method (Sindel et al. 2024). However, herbicides were similarly poorly rated.

Cultivating the soil will kill seedlings but will also stimulate seed germination (Sindel and Coleman 2012). Larger plants may also re-establish, particularly if it rains soon after cultivation. However, when used in combination with herbicides, cultivation can deplete seed banks. Repeat light cultivations followed by herbicides to remove seedlings, will reduce the amount of the weed seed in the soil seed bank (stale seed bed technique).

Madagascar ragwort has poor germination at depths below 5 mm (Hooda and Chauhan 2024). Depending on how seed is vertically distributed, it may be possible to bury seed at greater depths. This tactic can be used once (or until the buried seed is no longer viable) but could greatly reduce the next flush of seedlings. If, however, another cultivation is done before the seed decays, the second cultivation will bring those buried seeds back toward the surface and stimulate their germination. Madagascar ragwort seed lasts 3-5 years in the seed bank, but this can occasionally extend to 10 years (Sindel and Coleman 2012; Wijayabandara 2021). So, if another cultivation is to be done, ideally it should be at-least five years after the previous.

3.3.7 Choosing competitive pasture species

It is well known that many weeds exploit poor pastures, and weeds such as Madagascar ragwort might be avoided if the pasture is competitive. Declining pastoral performance in Northland is becoming increasingly common, with ryegrass-clover pastures often lasting less than 3 years (Ussher and Hume 2015; McCahon et al. 2021). A range of species have been considered in the past, for suitability to the subtropical climate of northern pastures (Crush and Rowarth 2007; Teixeira et al. 2024). Many farmers in the Far North, willingly or otherwise, have kikuyu pastures (Percival 1978). However, even kikuyu can have issues where bare patches form and are colonised by weeds (Julliane Bainbridge, pers. comm.).

Species like tall fescue, meadow fescue and cocksfoot are showing promise as alternatives to ryegrass to sow in autumn. However, cocksfoot tends to grow as a bunch, and when grazed will leave open patches; likely to be favourable for Madagascar ragwort germination. Tall fescue and meadow fescue are being sown in some Far North pastures (Julianne Bainbridge, pers. comm.), though nothing of note about their competitivity against Madagascar ragwort was mentioned. It is possible that there are other species to consider that might be more competitive against Madagascar ragwort. Consideration of their germination and early competition with the weed, as well as their persistence and tendency to form gaps needs to be made.

Early competition between sown seedlings and Madagascar ragwort will determine the success of pasture establishment or scale of weed infestation. Madagascar ragwort has a reduced germination rate at cooler temperatures (though still does germinate; Figure 6). The later the sowing dates are, the slower Madagascar ragwort germinates. However, the same applies to most sown pasture species. Species like cocksfoot (*Dactylis glomerata* L.) and tall-fescue, considered to be good candidates for northern pastures, are sown in autumn in Northland (Teixeira et al. 2024). These species have low base temperature requirements (Monks et al. 2009), and for tall-fescue and meadow-fescue, have overlapping germination rate curves with Madagascar ragwort (unpublished data). Ryegrass (*Lolium perenne* L.) has a lower temperature requirement for germination than the fescues (Monks et al. 2009). Madagascar ragwort germination also slows as temperatures get higher (Figure 6), and this (toward 30℃) is where kikuyu seed has high germination rates (unpublished data). With adequate rainfall, summer sowing may be possible for kikuyu (and other sub-tropical grasses).

In a survey of farmers in Queensland, while most said no pasture species was effective in controlling Madagascar ragwort, kikuyu was the best of the pasture species listed (which included other C_4 grasses, ryegrass, phalaris and clovers; (Wijayabandara 2021). Kikuyu was also the best species in a survey of farmers in New South Wales (Sindel and Michael 1988). However, other studies did not consider kikuyu (or cocksfoot) to be strongly competitive against the weed (Fynn et al. 2019). Kikuyu plants grown from seed did not compete well with Madagascar ragwort in a pot experiment (Steve Adkins, pers. comm.).

A common suggestion to reduce weed pressure in pastures is to maximise sown species diversity (Tozer et al. 2016; Tozer et al. 2017; Ghanizadeh and Harrington 2019). This has been suggested for Madagascar ragwort in Australia (Virtue and Sheehan 2022). Regenerative agriculture seed mixtures have become widely available in response to this widespread demand. These diverse pastures in theory could increase competitivity against Madagascar ragwort by (i) having different times of the year where they have optimal growth and (ii) competition for a wide range of resources, limiting any exploitable resource for the weed (Ghanizadeh and Harrington 2019). There were no farmers in the Far North that had mentioned trialling any of these diverse pastures against Madagascar ragwort.

The simplest system to increase diversity would be incorporating a summer-active and winter-active grass species. This is done in Northland, where cool-season grasses are under-sown into kikuyu pastures to improve winter production (Teixeira et al. 2024); this is another recommended practice in Australia to increase competition against Madagascar ragwort (Virtue and Sheehan 2022). This is done by first mulching the kikuyu, then direct drilling into it (Teixeira et al. 2024). However, there will be some disturbance caused by this which will increase Madagascar ragwort germination. So this could be improved by sowing when temperatures get cooler, and choosing species and cultivars suited toward this, with high germination rates in colder temperatures and strong early competition. Applying fertilizer will increase sown seedling growth but will also stimulate Madagascar ragwort growth. The effect of this will differ by species (Sindel and Michael 1990; Sindel and Michael 1992), and could be optimised.

3.3.8 Re-sowing pasture and cropping

The Programmed Approach™ of pasture renewal involves spraying glyphosate in autumn-spring-autumn and planting a winter and summer crop in between the glyphosate applications before sowing new pasture (Lane et al. 2009). This method will probably be helpful for moderate to heavy Madagascar ragwort infested paddocks, as it allows for the weed to germinate and be killed multiple times, depleting the seed bank. If the pasture is sown at a high density, it will be even more effective in preventing the weed from re-establishing, as shown by Sindel & Michael (1990).

Pasture seeded by direct-drill will have less germinating Madagascar ragwort seedlings to compete with than those that are cultivated. Increased sowing rates of ryegrass will limit weed establishment initially, but will limit clover establishment, and effects do not appear to carry on to the second year (Armstrong et al. 2002).

Maize is a good option for the summer crop, as it is a competitive species and is tolerant of many herbicides. Several residual and post-emergent herbicides are available in maize that should kill Madagascar ragwort (Ngow et al. 2021). However, some farmers have observed higher germination of Madagascar ragwort in the autumn after maize has come off (Aaron Bainbridge, pers. comm.). So, it may be important to apply herbicides in new pasture established after maize (such as the 2,4-D or flumetsulam or the mixture that contains them both and Bonza®) in paddocks with Madagascar ragwort in the seedbank. If seedbank numbers are still high after maize, it might be worth planting a winter crop, then another summer crop before re-establishing pasture. Annual ryegrass or cereal oats are good options and are an opportunity to apply stronger herbicides without risk of clover damage. Another possibly useful crop are herbicide tolerant brassicas (Cleancrop®), which are immune to the herbicide chlorsulfuron (Dumbleton et al. 2012), which should kill seedling Madagascar ragwort. After the summer crop, if seedbank numbers are finally driven down, new pasture which be in a better position to establish, which will limit weeds like Madagascar ragwort from establishing. This is a long process but, especially in heavy infestations, will pay off.

3.3.9 Cover cropping

Cover crops, when chopped and left on the soil surface can inhibit seedling germination. This has been proven in a glasshouse experiment for Madagascar ragwort and wheat residue (Hooda and Chauhan 2024). It is likely other, more suitable plants could be grown. Winter cover crops planted before a summer maize crop reduced weed emergence (Trolove et al. 2023). These cover crops included blue lupin, mustard, vetches and clovers and cereal species. This approach is possibly too expensive at a larger scale to be practical in pasture, though could be effective in certain situations.

3.3.10 Biological control

Biological control was not the focus of this present report. A report by Chris McGrannachan et al. (2023) covered biological control of Madagascar ragwort in New Zealand. Another paper by Dymock & Winks (2024) recorded already present natural enemies and indicated future work scouting for biocontrol agents in South Africa. Some of the natural enemies identified by Dymock & Winks (2024) appear to have some success in reducing Madagascar ragwort fecundity (the rust *Puccinia lagenophorae* reduces the number of stems on the plant, the fly *Sphenella rufriceps* (Macquart) infests and destroys seed inside seedheads and an aphid was also recorded though no note on its impact was made). The authors of that paper did not consider the current natural enemies of Madagascar ragwort to be capable of sufficiently reducing its abundance. Farmers were interested in biocontrol agents but (as biological control agents typically require years of research to select and then approve for release) they need solutions for the short term as well.

3.4 Chemical control

There is a difference in opinion about the efficacy of herbicides in Northland. Despite many who use herbicides to good success (Table 2), there are some that consider herbicides to be ineffective. Mostly, this stems from issues with controlling older, woodier, plants, managing the high abundance of seeds in the soil seedbank and dealing with multiple germination flushes. A large proportion (35%) of Australian farmers also hold reservations about the efficacy of herbicides, after decades of fighting the weed (Sindel et al. 2024). Despite this shared opinion, herbicide usage for those Australian farmers increased significantly. The most often used herbicide is 2,4-D, frequently used in a mixture (referred to as a ‘triple mix’) with another herbicide and an adjuvant to improve efficacy.

Table 2. Herbicides used by farmers and weed control operatives in Northland on Madagascar ragwort.

Product	Active Ingredient(s)	Application	Notes
	2,4-D amine	broadcast	Considered to have limited control by itself. Effective on smaller plants but not larger ones.
Sprinter® + Kamba® + Bonza®	2,4-D amine + dicamba + adjuvant	broadcast	This is one of the 'triple mixes' that locals refer to. It has a good kill rate, even kills most of the older plants but severely suppresses clover. Lower rates of the Kamba® will be less damaging to legumes but less effective on larger plants.
Sprinter® + Valdo® + Bonza®	2,4-D amine + flumetsulam + adjuvant	broadcast	This is another 'triple mix'. It is not as effective on larger plants than the mix with Kamba® but safer on legumes.
not specified	2,4-D + flumetsulam	broadcast	This mixture should be limited to seedlings under 5 cm high as it has limited efficacy on larger plants.
Associate	metsulfuron	broadcast or spot spray	Effective, but damaging to pasture (especially ryegrass and clover – only for use in kikuyu swards, even so will cause damage).
Conquest	picloram, triclopyr	spot spray	Spot spray for escapes from winter spraying. Effective. Causes yellowing in kikuyu but it will recover.
Tordon™ PastureBoss™	aminopyralid, triclopyr	spot spray	Spray in a 1 m^2 area around patches of the weed. Kills clover.
Tordon™ Brushkiller XT	picloram, aminopyralid, triclopyr	spot spray	Spray any escapes. Kills clovers.

3.4.1 Herbicides identified in overseas studies

Several products (including single active ingredient or multiple active ingredients) were identified as effective on Madagascar ragwort from studies in Australia and Hawai'i (Table 3). However, not all of them are available in New Zealand**.** The rates used in these overseas trials were intentionally not mentioned in this report, as herbicide rates overseas do not necessarily apply here, with different soil and climactic conditions and therefore could be misleading**.**

Table 3. Herbicides used in trials on Madagascar ragwort overseas.

Product	Active Ingredient(s)	Availability in New Zealand	Application	Clover damage	Efficacy on larger plants
	2,4-D amine	yes	broadcast	minor	weak
	2,4-D ester	yes	broadcast	harsher than 2,4-D amine	weak
	2,4-D sodium salt	no	broadcast	minor	weak
	MCPA	yes	broadcast	harsher than 2,4-D	weak
HotShot®	aminopyralid, fluroxypyr	No, nor any mixture of these two actives.	spot spray	fatal	strong
Grazon™ Extra*	aminopyralid, picloram, triclopyr	No, but similar products are available.	spot spray	fatal	strong
Tordon® RegrowthMaster	aminopyralid, picloram, triclopyr	No, but similar products are available.	spot spray	fatal	strong
	clopyralid	yes	spot spray	fatal	moderate
	dicamba	yes	spot spray	fatal	moderate
	triclopyr	yes	spot spray	fatal	weak
	tebuthiuron	no	spot scatter (granules)	fatal	strong
Bromocide®	bromoxynil	Not for pasture, but a bromoxynil product is available for cereals.	broadcast	minor	moderate
Jaguar®	bromoxynil, diflufenican	Not for pasture, but for ryegrass / clover seed crops.	broadcast	minor	targeted at seedlings
Brush Off®	metsulfuron	yes	spot spray	fatal	strong
	glyphosate	yes	spot spray or weed wiper	suppresses at higher rates	strong

*not to be confused with Grazon™ which is just triclopyr

3.5 Broadcast application of herbicides

One of the main challenges with spraying Madagascar ragwort in pasture is clover safety. Many of the most effective products will also kill clovers. Some consider the hit on the clovers worth it when compared to letting Madagascar ragwort plants seed and increase in abundance (later causing a financial hit from loss in utilisation). To make up for the lost clovers, they need to add nitrogen inputs.

The most often used herbicide for broadcast application on Madagascar ragwort in Northland is 2,4-D amine. However, larger, woody plants will not be killed with 2,4-D alone.

Many are now using 'triple mixes' that include 2,4-D amine (Sprinter®), either flumetsulam (Valdo®) or dicamba (Kamba®), and the adjuvant Bonza®. According to those farmers, the mixture with dicamba is more effective on larger plants but causes more damage to clover. Adjusting the rates of these products can increase efficacy or mitigate clover damage.

For all of the herbicides sprayed broadcast on Madagascar ragwort, stock should not be allowed to graze dying plants. This is as their palatability increases when they begin to die while their toxicity remains, leading to increased risk of poisoning (Sindel et al. 2008). Some of these herbicides have specific withholding periods, but stock should be excluded for longer than those specifications if plants are still in the process of dying to avoid poisoning. Spraying from helicopters and even drones is an option that some farmers are using. Due to withholding periods, spraying needs to be done in a patchwork fashion to prevent grazing of recently sprayed areas. A complete 'sweep' using a helicopter to spray all paddocks would not be possible in dairy farms for that reason.

Some of the herbicides recommended for spot spraying here (Table 3) will also work when sprayed broadcast but only in pastures without legumes, as they will kill them. HotShot™ (aminopyralid and fluroxypyr), Bromicide® (bromoxynil), Brush Off® (metsulfuron) and some of the aminopyralid, picloram and triclopyr based products (Grazon™ and Tordon® RegrowthMaster) were effective on Madagascar ragwort in kikuyu pastures in Australia (Wijayabandara et al. 2023). Most of those will cause minor or no damage to pasture grasses, but metsulfuron will significantly stunt and sometimes kill grasses as well as legumes. Clopyralid was effective when sprayed broadcast effectively in kikuyu pastures (Motooka 2001). Dicamba was slightly less effective, but still reduced Madagascar ragwort cover (Motooka 2001). Triclopyr is ineffective (Anderson and Panetta 1995; Motooka 1998; Motooka 2000), and also damages kikuyu (Holden 2024).

Weed wipers are not as commonly used now but may have a use for Madagascar ragwort; two passes of glyphosate will kill 94% of Madagascar ragwort plants (Sindel and Coleman 2012). This is best done after grazing, when plants stand above the pasture. A similar system called Wet Blade®, which is a type of mower that applies herbicide to cut stems, was used successfully in Hawai'i with 2,4-D, metsulfuron or aminopyralid (Utilizing Wet Blade® to control Fireweed 2009).

3.5.1 2,4-D and 2,4-D-based mixtures

2,4-D is a relatively cheap chemical. Trials overseas have shown that it is effective on Madagascar ragwort. It often used (frequently in a 'triple mix' with other herbicides) in the Far North. 2,4-D, and any mixtures containing it, have a withholding period of one week.

2,4-D can be formulated in different ways, with the most common ones being the dimethylamine salt (2,4-D amine) and the butoxyethyl or ethylhexyl ester (2,4-D ester) forms (Peterson et al. 2016). 2,4-D amine was considered to be quite effective on Madagascar ragwort and caused no damage to grass or clover components of the pasture (Anderson and Panetta 1995). The amine version is safer on clovers than 2,4-D ester and also MCPA (Motooka et al. 2004). However, used alone it can have low efficacy on larger plants: 2,4-D amine had poor control of larger Madagascar ragwort plants in a field trial in Hawai'i at three different rates, and 2,4-D ester had poor control on larger plants as well (Motooka et al. 2004). The sodium-salt formulation isn't available in New Zealand but has proven slightly more effective than the amine formulation in Queensland (Anderson and Panetta 1995).

The mixture of 2,4-D (Sprinter®), flumetsulam (Valdo®) and Bonza® spraying oil is one that some farmers in the Far North are using with success on Madagascar ragwort. However, this combination does not lead to complete control, particularly for larger plants. This mixture, or one with just 2,4-D and flumetsulam, have not been evaluated in overseas trials before. Another mixture used in Northland is 2,4-D (Sprinter®), dicamba (Kamba®) and Bonza®, which has higher efficacy on larger plants than the other 'triple mix.' A similar version of that was tested in Australia with little clover damage and moderate efficacy on the weed (Anderson and Panetta 1995), however in Northland, clover damage is reported. The mixture with flumetsulam is said to cause less clover damage than the dicamba mixture. Other mixtures of 2,4-D tested in the Australian study were not viable: the mix with diclorprop was ineffective and the mixture with atrazine caused damage to grasses and clover (Anderson and Panetta 1995).

Similar to those 'triple-mixes', a method of adding small amounts of other herbicides to 2,4-D was devised to control common ragwort and nodding thistle by James & Rahman (2008). Ragwort treated with 2,4-D ester alone had 43% control at the low rate and 67% at the high rate. With additives chlorsulfuron, mesotrione or aminopyralid, control increased significantly. 2,4-D amine alone was more effective than the ester formulation, but less effective than the ester + mesotrione or ester + chlorsulfuron (high rate); the same ingredients when instead mixed with 2,4-D amine had similar levels of control. However, control decreased with plant age (as ragwort developed into larger, multi-crowned plants) for all mixtures, so it is possible that these will still have limited efficacy on adult Madagascar ragwort plants. Other herbicides might work well when added in small amounts to 2,4-D and may be worth testing on Madagascar ragwort, for instance metsulfuron.

A key component of the 'triple mixes' used in Northland is the adjuvant Bonza®. Spray adjuvants are occasionally used with 2,4-D to reduce spray drift but can be used to increase control by various means (Holloway and Edgerton 1992; Schortgen and Patton 2020). Adjuvants were shown to increase the efficacy of 2,4-D on Madagascar ragwort (Anderson and Panetta 1995). In that study, one of the adjuvants (a non-ionic adjuvant LI-700®) also increased the efficacy slightly for the 2,4-D and dicamba mixture. LI-700® is available in New Zealand, though it is unknown if it is any better than Bonza® or other available adjuvants when used in these mixtures.

3.5.2 MCPA and MCPB

MCPA is one of the herbicides used for Madagascar ragwort control in Hawai'i (Motooka et al. 2002; Motooka et al. 2004). MCPA was effective on rank Madagascar ragwort when applied at the high rate, which led to 88% control, but not at lower rates, which only caused 32% control (Motooka 2000). MCPA efficacy, like many herbicides, decreases when plants are stressed, such as during droughts (Motooka 2001). MCPA, like 2,4-D, does cause some damage to clovers (Ghanizadeh and Harrington 2019). There are also products containing MCPB, or both MCPA and MCPB, but these are typically more expensive and less effective on (especially larger) weeds than MCPA (Ghanizadeh and Harrington 2019). MCPA (and also mixtures of MCPA and 2,4-D) is considered less effective on common ragwort than 2,4-D (Thompson and Saunders 1984); probably this applies to Madagascar ragwort as well. There is a two week withholding period for MCPA.

3.5.3 Flumetsulam and other group 2 herbicides

Flumetsulam, thifensulfuron-methyl and tribenuron-methyl are frequently used in pasture to kill broadleaf weeds such as giant buttercup and dock (Ghanizadeh and Harrington 2019). None of these have been evaluated for Madagascar ragwort overseas. As their targets are typically smaller herbaceous plants rather than large bushy plants, they are possibly likely to be less effective on older Madagascar ragwort plants. Thifensulfuron does not control ragwort, so is unlikely to be effective on Madagascar ragwort. Tribenuron will kill ragwort but is not safe to use on clovers. Of these, the most promising is flumetsulam ,which is already used in one of the 'triple mixes'. This 'triple mix' of flumetsulam (Valdo®) with 2,4-D and Bonza® has shown some efficacy in Northland, though larger plants are not always killed. There is also a flumetsulam, MCPA and MCPB product available for pasture in New Zealand (Tribal Gold®) with good clover safety, but it is unknown how effective it is on Madagascar ragwort. Flumetsulam has a two week withholding period.

3.5.4 Bentazone and bromoxynil

Bentazone can be used in new pasture, and is safe on clovers, but is only effective on some weeds (Holden 2024), and usually only on very small plants. So, by itself it might not be effective on Madagascar ragwort (it doesn't kill some other Asteraceae weeds though it does kill mayweeds). There are two products that include bentazone as part of a mixture, one with MCPB, and one with flumetsulam (Holden 2024). Both of these are also clover safe. However, it is unknown if these mixtures are effective on Madagascar ragwort. It is likely they will be useful for small seedlings only. There is a one to two week withholding period for bentazone.

Bromoxynil has been identified to have potential in Australia and was one of the earliest registered herbicides for Madagascar ragwort in Queensland (Anderson and Panetta 1995). However, bromoxynil is considered a contact herbicide and will have less of an effect on woodier plants. It didn't perform as well as metsulfuron or any of the hormone-based mixtures in the field or on older plants (Wijayabandara 2021; Wijayabandara et al. 2023) and was considered to be underperforming by farmers (Anderson and Panetta 1995). Bromoxynil will cause slight, temporary damage to clovers (Sindel 1989) and requires an eight week withholding period (Virtue and Sheehan 2022). A bromoxynil and 2,4-D mixture was suggested by Sindel and Coleman (2012). Bromoxynil is available for cereals as a single active ingredient (Bromotril®) and also as a mixture with ioxynil and mecoprop-p (Image®), with MCPA and dicamba (several products), and with diflufenican (Jaguar®), but none of these are not registered for pasture in New Zealand. A bromoxynil-diflufenican mixture applied early after the first rainfall in autumn is effective in reducing seed germination (Virtue and Sheehan 2022). There is potential with bromoxynil (and mixtures containing it), but it is not registered for use in pasture in New Zealand and appears to have limited efficacy on larger plants.

3.5.5 Carfentrazone and saflufenacil

Carfentrazone (Hammer® Force) is frequently used with glyphosate for burndown before establishing pasture, but also in mixtures with hormone-based herbicides (e.g. 2,4-D, MCPA) or sulfonylureas (e.g. flumetsulam) in cereal crops. Carfentrazone is a contact herbicide that rapidly desiccates plants and is used in mixtures with other herbicides to accelerate death but also has claims to improve control on larger weeds like mallow. It does cause damage to clovers (Cumming 2002; Davy et al. 2015). Saflufenacil (Sharpen®) is in the same mode of action group as carfentrazone, so has similar properties and is used similarly (with glyphosate when preparing paddocks for pasture). It will also knock down clover but dissipates to levels no longer phytotoxic to clovers in less than two weeks (Rahman et al. 2014).

Neither carfentrazone nor saflufenacil are registered for use in established pasture. It is possible that they could improve Madagascar ragwort control when used in mixtures, though no research on this has been done. Like with other herbicides, carfentrazone and saflufenacil will increase the palatability of weeds like Madagascar ragwort, so paddocks sprayed should not be grazed while plants are still dying.

3.6 Spot spraying

Spot-spraying should be used for two main purposes: (i) removing new infestations and (ii) controlling larger, woodier plants. For the first purpose, if the infestation is small enough, simply pulling and bagging plants might be more effective. Otherwise, glyphosate, and other non-selective herbicides can be spot- or patch-sprayed to control Madagascar ragwort.

3.6.1 Glyphosate

Glyphosate is a good choice for spot spraying, but, as it will result in bare ground and does not have residual activity, weeds in the soil seedbank such as Madagascar ragwort will re-establish (Harrington et al. 2017; Wijayabandara et al. 2022). So, for glyphosate, timing will be important. If spraying before autumn, the bare patches created by glyphosate might be filled with new Madagascar ragwort seedlings. However, if sprayed later, when temperatures are lower, or in summer, when temperatures are higher than the temperature for Madagascar ragwort's optimal germination rate (Figure 6), there may be less risk of gaps filling with its seedlings. Glyphosate can also be applied with a weed wiper, where it is applied to plants growing above pasture (Sindel and Coleman 2012). Sometimes other herbicides (e.g. the contact herbicide Hammer® Force) are mixed with glyphosate to improve weed control.

3.6.2 Triclopyr, mixtures and other hormone herbicides

There are several hormone-based mixtures used for brush weeds that have proven effective on Madagascar ragwort. These will be more effective than glyphosate as a spot spray as they will limit further germination around the plants, however they will cause damage, some long term, to clovers (Harrington et al. 2017).

Triclopyr-amine as a single active ingredient is ineffective on larger Madagascar ragwort plants and had poor control in field trials (Anderson and Panetta 1995; Motooka 1998; Motooka 2000). Triclopyr is damaging to kikuyu (Holden 2024), causing yellowing and stunted growth in the short term, so it should be used with caution in kikuyu pasture.

Mixtures of aminopyralid, picloram and triclopyr are effective on all sizes of Madagascar ragwort (Wijayabandara 2021). These are available in New Zealand. They also reduced seed viability when sprayed on flowering plants (Wijayabandara 2021). One of these (Grazon™ Extra) was considered to be the most effective herbicide by farmers that are controlling Madagascar ragwort. A triclopyr and picloram mix (similar products are available in New Zealand under the names Conquest, Triumph Gold and Victory Gold) was ineffective in a field trial in Queensland (Anderson and Panetta 1995). However, good results were observed in Northland spot-spraying Conquest (Jesse Bagley, pers. comm.).

Aminopyralid is available as an individual active ingredient herbicide in New Zealand but most studies showing successful control of Madagascar ragwort use do not use it by itself but rather as part of mixed products. There has been some success with aminopyralid (Milestone) in Hawai'i (New Herbicides in Fireweed Management 2009). The granular aminopyralid and picloram mixture Tordon™ 2G Gold is applied as a spot-treatment to ragwort plants and could be used similarly for Madagascar ragwort. HotShot™, a mixture of fluroxpyr and aminopyralid gives good control of Madagascar ragwort (Wijayabandara 2021), was able to kill large plants (Steve Adkins, pers. comm.), though it causes some damage to kikuyu and is not registered for pasture in New Zealand. Another granular herbicide (Buckshot™) containing picloram is available in New Zealand, though no overseas trial has evaluated a single-active picloram product on Madagascar ragwort.

Clopyralid is effective on three month old Madagascar ragwort plants, though it kills desirable legumes (Anderson and Panetta 1995). Field trials have shown that it can reduce cover of larger plants to <2% (Motooka 2001). Dicamba is not as effective as clopyralid on larger plants, but at a higher rate can reduce cover to 5% (Motooka 2001). Dicamba used in one of the 'triple mixes' to kill Madagascar ragwort in a broadcast spray to good levels of efficacy, though kills clover. There are more products containing mixtures of synthetic auxin herbicides available for cereals (not registered for pasture) such as mixtures of mecoprop, MCPA and dicamba (Hat-Trick), and mecoprop, MCPA and dichlorprop (Duplosan Super). None of these have been evaluated on Madagascar ragwort.

Many of these hormone-based mixtures are good options for spot-spraying larger plants. For all of these, stock should be excluded from grazing near treated plants until they have died off.

3.6.3 Metsulfuron-methyl

Metsulfuron has shown to be effective on Madagascar ragwort. Unlike glyphosate, it will have a residual effect, preventing seedlings from germinating. However, because of its toxicity to clovers and pasture grasses (Harrington et al. 2017), is only viable for spot- and patch-spraying. There is an at-least three-month period before ryegrass and clover can be sown into metsulfuron-sprayed areas. Stock need to be excluded for at-least three days after spraying.

Overseas however, it has been sprayed broadcast. In Hawai'i, in kikuyu pastures, metsulfuron reduced Madagascar ragwort cover to 7% in a field trial compared to the untreated with 25% cover (Motooka 2001). Seedlings and juvenile plants were killed in a pot study in Australia but mortality for adult plants was low (Wijayabandara 2021). In the field, the same rate was able to kill adult plants, reducing Madagascar ragwort density to 0% within 2 months (Wijayabandara et al. 2023). In another study metsulfuron was effective but caused damage to clovers, which was worse at the higher rate (Anderson and Panetta 1995). Metsulfuron damages emerging ryegrass and clover seedlings, requiring at least 3 months before any new seed is over-sown (Holden 2024). A metsulfuron-chlorsulfuron mix (Cimarron® Plus) had some success in Hawai'i in a kikuyu pasture (New Herbicides in Fireweed Management 2009). Metsulfuron applied to ragwort and nodding thistle plants killed all seeds (James et al. 1999). This level of success was not quite achieved on Madagascar ragwort, though a large proportion of seed was killed by metsulfuron and other herbicide in an Australian trial (Wijayabandara et al. 2023)

Metsulfuron is a good option for spot spraying older, difficult plants and preventing seed from germinating around them, but will cause high levels of damage to pasture, and should not be used by waterways, so should be used with care.

3.6.4 Tebuthiuron

Tebuthiuron is formulated as granules to scatter into the soil. It has been successfully used to control Madagascar ragwort in Hawai'i (Motooka et al. 2002; Motooka et al. 2004), achieving 95% control when applied onto a plot with adult Madagascar ragwort plants (Motooka 2000). However, it isn't available in New Zealand.

3.7 Using herbicides effectively

3.7.1 Spray timing and frequency

New seedlings and young plants should be sprayed before they develop into larger plants. Large amounts of seedlings emerge in spring and autumn in Northland. For those using herbicides to control the weed in Northland, plants are sprayed with a 2,4-D based mixture in autumn or winter, then any escapes and new germinations are killed in spring by either spot-spraying or broadcast spraying different herbicides. By late spring, plants might be too hard to kill with the mixture used for broadcast spraying. Larger, wood-stemmed plants that are multiple years old will not be killed by these mixtures either.

Larger plants can take months to die (Wijayabandara et al. 2023), so it is important that developing flowerheads do not produce viable seeds. Most herbicides will not kill seed that is already developed, however the majority of developing and immature seed will be killed when plants are sprayed with metsulfuron and aminopyralid-based mixtures (Wijayabandara, 2021, James et al. 1999).

3.7.2 Avoiding herbicide resistance

There are some concerns about 'resistance'. The term 'resistance', is referred to in the colloquial sense, which has a meaning more similar to the concept of 'herbicide tolerance' rather than evolved herbicide resistance.

There is a belief that Madagascar ragwort can "adapt" to herbicides. For example, plants sprayed (even with something like Tordon™ PastureBoss™ – aminopyralid & triclopyr) will die back above-ground initially, but 9 months later will grow back from lower parts of the plant to become an even more pernicious perennial weed (Vicki Stevens, pers. comm.). Most plants become more tolerant to herbicides as they increase in size. This is particularly true for species which develop woody stems such as Madagascar ragwort (Wijayabandara et al. 2023). Some types of physiological responses are known, where plants become more tolerant after sublethal exposure (Virtue and Sheehan 2022). This is not "adaptation" in the evolutionary sense and should not be confused with evolved herbicide resistance.

Evolved herbicide resistance has never occurred before in Madagascar ragwort but has in several other *Senecio* species to various herbicides overseas (Heap 2024). Like with many other weeds, the repeated and frequent use of a single herbicide could quickly lead to evolved herbicide resistance in Madagascar ragwort, leaving only a few herbicide options for its ongoing control. It typically takes about a decade for a resistant weed to become prevalent enough to be noticed, though this depends on the species and the herbicide; giant buttercup took twenty years to evolve flumetsulam resistance (Harrington 2018). There have been several weeds in pastures resistant to herbicides in New Zealand including thistles and giant buttercup (Ghanizadeh and Harrington 2019). These have become resistant to 2,4-D, MCPA and flumetsulam. To prevent resistance from evolving, unrelated chemical groups (different modes of action) should be rotated between and other forms of non-chemical management should be used to drive down the weed seed bank.

3.8 Integrated management of Madagascar ragwort

Integrated weed management (IWM) utilizes chemical, biological, mechanical and cultural methods to control weeds. It is necessary to consider all available methods to best deal with Madagascar ragwort (Thorne et al. 2005; Sindel and Coleman 2012; Virtue and Sheehan 2022).

3.8.1 No infestation and early infestation

Paddocks that are close to roads, on the tops of hills, or have had equipment, people or vehicles brought in from other farms should be monitored for Madagascar ragwort. In early infestations, all plants should be eradicated, for this, close monitoring combined with hand-pulling and spot-spraying is most effective (Sindel and Coleman 2012). If spotted, plants need to be removed before they set seed. If they are suspected to have set seed, places where plants were should be marked and visited again for spot-spray treatments with something like metsulfuron that will have residual activity on the seed bank.

3.8.2 Moderate infestation

Moderate infestations of Madagascar ragwort may not have major impacts on production now, but if left uncontrolled will become heavy infestations. Practices that control Madagascar ragwort, but do not have major impacts on pasture or production, can be used. Herbicides that are less toxic to clovers and pastoral grasses, such as 2,4-D based mixtures, can be used here to eliminate any younger Madagascar ragwort plants. Larger plants will likely have a seed bank surrounding them and should be spot-sprayed and monitored. Cultivation or any practices that disturb or drag soil through a paddock should not be done to prevent the weed spreading through the paddock.

3.8.3 Heavy infestation

Heavy infestations of Madagascar ragwort will provide a seed source for the rest of the farm and neighbouring properties. These should be dealt with severely to prevent spreading the weed further and entrenching it in the paddock by building up seed bank levels. Broadcast application of strong herbicides, even at the cost of legumes, will pay off in the long term. In these paddocks, one season will not be enough, and repeated control is necessary to drive down seedbank numbers. Once plants are killed off, approaches like over-sowing competitive pasture species, and managing grazing so that desirable plants are in the best condition to supress the weed, will be helpful to reduce infestation levels. Any equipment coming off these paddocks should be thoroughly cleaned, and hay should not be harvested from these paddocks.

3.9 Control in other environments

Madagascar ragwort is primarily a weed of pasture however it is known to grow along roadsides and in the natural environment.

3.9.1 Roadsides

One major source, that is likely to increase in prominence if the weed continues to spread, is the invasion from roadsides into pasture. As was found in Uruguay, Madagascar ragwort distribution is associated with roadsides (Guido et al. 2024). Other pastoral weeds in New Zealand have been spread along roadsides into farmland, for example yellow bristle grass (James et al. 2019). Mowing of grassed roadsides might inadvertently spread Madagascar ragwort long distances, as contaminated equipment is moved between sites. This could happen year-round (as the weed flowers year-round). Plants growing on roadsides and near roadsides should be controlled to prevent its rapid spread. This would involve a combination of pulling, spraying and managing vegetation so that it competes with the weed. Roadside facing hedges (or other windbreaks) could go a long way in protecting adjacent pastures.

3.9.2 Natural environments

Madagascar ragwort has also been found in natural environments such as lake shores in Northland. There was some concern that Madagascar ragwort would become a problem in dune environments in Northland. Studies in Australia revealed that Madagascar ragwort grew much less vigorously in dunes than pasture (Radford and Cousens 2000). The close relative, gravel groundsel (*Senecio skirrhodon*), is more renowned for its dune habitat. Possibly, Madagascar ragwort could spread into dunes from coastal pastures, but it is more associated with grassy areas (Guido et al. 2024).

Grassed areas (for instance, tracks beside forestry) might have Madagascar ragwort populations. These habitats will provide a refuge which are important for the invasion of this plant (like stepping stones between pastures). Plants found in these places can be pulled or sprayed.

3.9.3 Urban environments

There are a few observations on iNaturalist of the plant in towns like Kerikeri growing beside footpaths (Appendix 1). Due to the difficulty of distinguishing the plants from gravel groundsel, many of these might be overlooked. Like natural environments, these plants could establish refugial habitats with grasses present, such as parks and lawns.

In these places, repeated mowing should eventually kill Madagascar ragwort plants. However, less frequently mown lawn, the plant will persist. There is also risk of mowing equipment unintentionally spreading seed from lawn to lawn, or park to park. Pulling and disposing or spot-spraying are both easy to do in lawns.

4. Recommendations

There are many studies overseas of the chemical control of Madagascar ragwort, however, many of the successful treatments kill clovers. These chemicals, and the mixtures currently being used in Northland, need to be evaluated for their efficacy in New Zealand conditions, in a New Zealand pastoral system.

Areas of research that farmers identified as important included:

- understanding its distribution
- effective herbicidal control (particularly larger plants)
- non-chemical control
- biological control
- soil treatments that would prevent weed germination

Proposed areas of research were identified based on the needs of Northland farmers and on gaps in research. These include confirming the efficacy of 'triple mixes' widely used in the Far North in a pot trial, evaluating other herbicide active ingredients to add in combination ('spikes') with 2,4-D, comparing the effect of various adjuvants used with 2,4-D, assessing the seed longevity of Madagascar ragwort, assessing the suppressive effect of cover crops, optimising control of Madagascar ragwort in paddocks coming off of maize, increasing competition by sowing competitive pasture species, evaluating deferred grazing and evaluating mowing in the rain.

4.1.1 Evaluating the efficacy of 2,4-D-based 'triple mixes' for broadcast spraying with consideration of clover safety

There are a few different mixtures used by Northland farmers. Some of these have been used to good degrees of success but can cause clover damage. The two main versions have 2,4-D in combination with an adjuvant (Bonza®) and either flumetsulam (Valdo®) or dicamba (Kamba).

An experimental design to evaluate these mixtures could involve treating potted Madagascar ragwort plants of three growth stages: small (single stem, 8-10 leaves), juvenile (multiple nodes, side shoots present, >20 cm height) and adult (multiple side shoots, flowering, woody stem) with several treatments:

a. untreated
b. 2,4-D
c. 2,4-D + low rate of flumetsulam
d. 2,4-D + higher rate of flumetsulam
e. 2,4-D + low rate of flumetsulam + Bonza
f. 2,4-D + higher rate of flumetsulam + Bonza
g. 2,4-D + low rate of dicamba
h. 2,4-D + higher rate of dicamba
i. 2,4-D + low rate of dicamba + Bonza
j. 2,4-D + higher rate of dicamba + Bonza

White clover plants at three growth stages (small – rosette, juvenile – about 3 months with branching, adult – about 12 months no longer reliant on the taproot) would also be included. Plants would be assessed weekly for symptoms, then weighed a month after spraying.

Expansion of this into a possible field trial would depend on the site, but areas of pasture with even levels of infestation would be selected and sprayed with the spiked herbicide treatments using a backpack sprayer. These mixtures could also be assessed for plant back period for clover by planting white clover into soil sprayed with the mixtures 2, 4 and 6 weeks after spraying and monitoring them for herbicide symptoms then weighing them.

4.1.2 Herbicide 'spikes'

The results from (James and Rahman 2008) are likely to transfer to Madagascar ragwort. Mixtures of 2,4-D and small amounts of herbicides from other groups such as chlorsulfuron, flumetsulam, metsulfuron and mesotrione may be effective on Madagascar ragwort. Herbicides such as Sharpen® (saflufenacil) and Hammer® Force (carfentrazone) are often added to glyphosate to improve burndown speed, these may be helpful additives to increase control of Madagascar ragwort. This concept is similar to those mixtures already used in Northland (and will use similar methods), but will evaluate herbicides that have not been considered yet in Northland:

a. untreated
b. 2,4-D
c. 2,4-D + low rate of chlorsulfuron
d. 2,4-D + higher rate of chlorsulfuron
e. 2,4-D + low rate of metsulfuron
f. 2,4-D + higher rate of metsulfuron
g. 2,4-D + low rate of mesotrione
h. 2,4-D + higher rate of mesotrione
i. 2,4-D + low rate of saflufenacil
j. 2,4-D + higher rate of saflufenacil
k. 2,4-D + low rate of carfentrazone
l. 2,4-D + higher rate of carfentrazone

4.1.3 Optimising spray additives with 2,4-D

Spray adjuvants are occasionally used with 2,4-D to reduce spray drift but can be used to increase control by various means (Holloway and Edgerton 1992; Schortgen and Patton 2020). Some of these have been proven to increase the efficacy of 2,4-D on Madagascar ragwort (Anderson and Panetta 1995). In the Far North, some farmers add an organosilicone penetrant to 2,4-D (Julianne Bainbridge, pers. comm.). The adjuvant Bonza® is an important component of the 2,4-D based 'triple mixes' used in the Far North. There is also another that was tested in a 'triple mix', Amigo® (Joanna Barr, pers. comm.), but does not seem to be widely adopted. Adjuvant chemistry is continually improving and now some adjuvant oils such as Expedient™ and improved organosilicone adjuvants should be tested. A pot trial could be done to compare a range of adjuvants, including Bonza® and LI-700®, with 2,4-D (and 2,4-D mixtures with dicamba or flumetsulam) on different life stages of Madagascar ragwort. The methods would be similar to the other suggested pot trials.

4.1.4 Control of Madagascar ragwort in paddocks following maize

Many farmers in Northland dealing with Madagascar ragwort grow maize. In some paddocks, maize will be cropped, but afterward, after autumn re-grassing, large amounts of Madagascar ragwort seedlings germinate, and those paddocks are said worse off than before they were cropped. Typically, if annual ryegrass is planted after maize, herbicides such as flumetsulam and Thistrol® Plus (MCPA, MCPB) are used. Otherwise, some paddocks will be re-established into ryegrass-clover pasture (Lane et al. 2009).

Plot trials in a site with Madagascar ragwort in the seedbank coming off of maize could be done to evaluate different sown species options (e.g. winter annual crops such as annual ryegrass and cereal oats or establishing a classical ryegrass-clover pasture) with different post-emergent herbicide treatments (e.g. untreated, flumetsulam, MCPA/MCPB, bentazone, Tribal® Gold).

4.1.5 Suppression of Madagascar ragwort through early competition with new pasture species

There are a range of pasture species that have been evaluated in the past and now for their suitability to subtropical northern pastures. Species including cocksfoot, kikuyu, paspalum (*Paspalum dilatatum* Poir.), ryegrasses, fescues and microlaena (*Microlaena stipoides* (Labill.) R.Br.) are considered to suppress Madagascar ragwort (Virtue and Sheehan 2022). However, several of those listed, especially the s*tatus quo* ryegrass-clover pastures, do not perform well in Northland, suffering from issues with weeds and pests as well as hotter temperatures and drought. Gaps left by dying pasture species will provide bare ground for Madagascar ragwort seedlings to germinate and colonise pasture from. Even kikuyu has been said to perform poorly against Madagascar ragwort (Julliane Bainbridge, pers. comm.). Slow growing kikuyu in winter will not compete well. A common practice in kikuyu pastures is to under-sow them with cool-season grasses (Teixeira et al. 2024); this is recommended in Australia for suppression of Madagascar ragwort (Virtue and Sheehan 2022).

There are two aims: (i) to find species suited to Northland conditions that will prevent gaps from being formed and (ii) to find species with strong early competitivity to compete with high seedbank loads of Madagascar ragwort.

A list of pasture species suited to northern pastures will be gathered from other work done with emphasis on seed availability. These species will be sown in containers with Madagascar ragwort, possibly at different sowing dates (different soil temperatures), in a competition experiment (at different ratios of Madagascar ragwort to sown species), and monitored for growth (measuring size, time to reach certain BBCH growth stages, number of flowers produced) before termination of the experiment (possibly in summer) when plants will be weighed and reproductive output measured.

4.1.6 The effect of deferred grazing

Grazing management has a large effect on Madagascar ragwort, where it is affected by rotational versus set stocking, stocking rate and intervals between grazing. There is some indicated that deferred grazing, the practice of shutting paddocks from grazing from spring to autumn to let the pasture reseed and compete with weeds (Tozer et al., 2020) is likely to mitigate Madagascar ragwort infestations (Virtue and Sheehan 2022). A plot trial, with various levels of Madagascar ragwort infestation in two pasture types (kikuyu or ryegrass-clover), would be assessed against different simulated grazing regimes. These would be simulated by defoliating plants to a certain height at different intervals, as done by Tozer et al. (2024).

4.1.7 Cover crops

Cover crops have been used effectively in the winter rotation before maize (Hackell et al. 2022; Trolove et al. 2023), but are too impractical for use at a pasture wide scale. These cover crops, when left as residue, are believed to reduce weed germination by (i) expressing allelopathic compounds and (ii) blocking light. The most effective species for suppressing weed germination have been cereals (Trolove et al. 2023). However, there are often issues with variability for cover crop studies, which often have differing results by site (Osipitan et al. 2018). Targeted cover crops to suppress weed growth may be a useful tool in heavily infested paddocks. A possible field trial could evaluate some of these cover crops, that have already proven effective in Waikato conditions, in the Far North for Madagascar ragwort suppression. This would involve selecting a heavily infested paddock, spraying it out with glyphosate, then measuring the seed bank and weed presence before planting cover crops, at harvest, and after several months.

4.1.8 Seed longevity

Following heavy infestations of the Madagascar ragwort, even after good weed control and establishment of pasture cover, there will likely still be a component of the seed bank buried to a depth where it will not germinate and lay dormant. It is of interest to farmers how long seeds persist in the soil to best manage these paddocks (to know the risks of practices such as cultivation). Madagascar ragwort has heteromorphic seed, with darker-coated seed having increased dormancy (Sindel and Coleman 2012). Previous studies have indicated most seed persists for 3-5 years but can extend to 10 years in certain conditions (Sindel and Coleman 2012; Wijayabandara 2021). Seed longevity of Madagascar ragwort could be investigated using the Kew Gardens Controlled Aging Test (CAT). This should give some indication as to how long and existing soil seed bank of Madagascar ragwort seed is likely to last in the absence of new seed being added. A study like this could potentially sample multiple populations of the weed to see if there is any variation in Northland.

5. Acknowledgements

We thank Northlanders Julianne Bainbridge, Aaron Bainbridge, Vicki Stevens, Jesse Bagley, Craig Bell and Chance Campbell, Northland Regional Council biosecurity experts Sara Brill, Ceres Sharp and Joanna Barr, and scientists Steve Adkins, Brian Sindel and Anaclara Guido for sharing their knowledge. We also thank John Kean (AgResearch) for providing the CLIMEX model. We thank Joanna Barr (NRC), Sarah Jackman (AgResearch) and Chris Buddenhagen (AgResearch) for comments on the draft report. This project was funded by the MBIE Envirolink Medium Advice Grant 2505-NLRC243 to Northland Regional Council.

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Appendices

5.1.1 Observations of *Senecio madagascariensis* in Northland

Appendix 1. *Observations of Senecio madagascariensis in Northland.*

Observation	Year	Location	Lat.	Lon.	Notes
AK298689	Feb-07	Aupōuri Peninsula	-34.90	173.35	dry lake bed
AK353095	Mar-14	Aupōuri Peninsula	-34.92	173.24	dry lake bed
CHR 589922	May-17	Aupōuri Peninsula	-34.82	173.11	sandy soil
iNAT 16249711	Sep-18	Aupōuri Peninsula	-34.81	173.12	kikuyu-lotus lawn under an open tree
CANB 953779.1	Oct-21	Aupōuri Peninsula	-34.84	173.13	
CANB 953783.1	Oct-21	Aupōuri Peninsula	-34.88	173.15	
AK388242	Oct-22	Aupōuri Peninsula	-35.36	173.55	
AK386990	Mar-23	Aupōuri Peninsula	-34.76	173.12	grazed kikuyu pasture with Juncus tenuis dichotomus
iNAT 261802905	Feb-25	Aupōuri Peninsula	-34.92	173.21	kikuyu pasture, dairy farm (same as iNAT 261802982)
iNAT 261802982	Feb-25	Aupōuri Peninsula	-34.92	173.20	hilly track, kikuyu pasture with clovers, (same farm as iNAT 261802905)
CHR 589923	May-17	Kaitaia	-35.16	173.42	alluvial soil
iNAT 1832239	Aug-15	Karikari Peninsula	-34.90	173.35	near edge of Lake Waiporohita
CHR 589921	May-17	Karikari Peninsula	-34.85	173.41	sandy loam
iNAT 89752421	Jun-21	Karikari Peninsula	-34.83	173.41	underneath canopy of Cape honeyflower
CANB 953778.1	Oct-21	Karikari Peninsula	-34.84	173.40	
CANB 953780.1	Oct-21	Karikari Peninsula	-34.98	173.36	
CHR 678067	Sep-22	Karikari Peninsula	-34.83	173.41	same as iNaturalist: 135083377
iNAT 135083377	Sep-22	Karikari Peninsula	-34.83	173.41	kikuyu-lotus pasture
iNAT 194368584	Nov-23	Karikari Peninsula	-34.83	173.41	by roadside with kikuyu
iNAT 194177267	Dec-23	Karikari Peninsula	-34.83	173.40	pasture with rushes, kikuyu, sweet vernal and dock
iNAT 245035014	Sep-24	Karikari Peninsula	-34.83	173.41	with clover in carpark
AK363616	Jan-17	Bay of Islands	-35.22	174.19	observed as a single plant on a bank
CANB 953777.1	Oct-21	Kerikeri	-35.26	173.89	
iNAT 175157748	Jul-23	Kerikeri	-35.23	173.96	under shade with grasses
iNAT 263571126	Jan-24	Kerikeri	-35.23	173.95	growing in a crack beside a footpath
iNAT 216995530	Apr-24	Kerikeri	-35.23	173.95	growing through a drain
iNAT 252357578	Nov-24	Kerikeri	-35.20	173.91	pasture beside the road with California thistle and daisy
iNAT 142271061	Oct-22	Hokianga	-35.36	173.55	roadside
iNAT 168597017	Jun-23	Hokianga	-35.50	173.45	roadside by plantain, kikuyu, tall fescue
iNAT 230247521	May-24	Hokianga	-35.49	173.45	old quarry

5.1.2 Management of Madagascar ragwort at different growth stages.

Appendix 2. *Management of Madagascar ragwort at different growth stages.*

Stage	*Seed*	*Seedling*	*Juvenile*		
			Side shoot formation	*Stem growth*	*Vegetative growth*
Description	From a dry seed, to imbibition, to just before the cotyledons breach the soil surface.	From cotyledon stage to the first pair of true leaves, to multiple true leaves.	From the first side shoot being formed to multiple side shoots.	From the first internode formed on the main shoot to multiple internodes.	This stage does not really occur however the plant can re-root if fragmented in wet weather.
Picture					
Management	Prevent any seed from coming in. If there are nearby populations seed may drift in with the wind or arrive through contaminated machinery (soil not washed off), or through stock. Try to maximise groundcover to prevent seedling establishment (avoid using herbicides).	Herbicides will be effective now but must be timed correctly so that seedlings are all germinated before they are hit. 2,4-D or the 2,4-D, flumetsulam and Bonza® 'triple mix' would be effective. Any missed seedlings might need to be spot sprayed later.	Plants are getting larger, so certain herbicides may not have as good control. For example, the 2,4-D, dicamba, Bonza® 'triple mix' might be more effective here. However, the plant is still small, 'juvenile', and control is good. It is important to ensure pasture grows well to outcompete young Madagascar ragwort plants.	The plants are becoming 'adult' plants are becoming harder to control with herbicides. Some plants may get woody at the base and won't die when sprayed with herbicides like 2,4-D or the 'triple mixes.' If possible, they can be pulled. They are not flowering, so a non-chemical approach like mowing could be attempted, though there is a risk of plants growing back woodier.	Plant re-established from roots (maybe after disturbance and with moist soil) will be more susceptible to herbicides before they develop into larger, woodier plants.

Stage	Adult				
	Inflorescence formation	*Flowering*	*Fruiting*	*Ripening*	*Senescence*
Description	From the first flower bud visible until its first petal is exposed.	From the first flower to mass flowering on the plant, ending when the first flower begins to develop seeds.	From the first seedhead forming with pappus emerging until the achenes reach their final size.	As the achenes ripen from a light brown to dark brown. They may already start to leave the plant.	As the plant dies off successively from lower leaves to the entire plant.
Picture					
Management	Plants are becoming woodier, so stronger herbicides or mixtures are required. Herbicides that are sprayed broadcast, if even still effective, (possibly the 2,4-D, dicamba and Bonza® mixture) on plants of this size will likely also damage clovers. Cutting or mowing may delay flowering but will cause the plants to become woodier and harder to kill.	Prevent any of the live plant from setting seed. Mowing will do this but might accidentally prolong the plants' life. Pulling plants, if possible, should be done now before any seed is set. This is a great time to spot spray as seeds would not yet be formed, and the plant is putting its resources into flowering. Herbicides like metsulfuron or one of the aminopyralid-based mixtures will prevent kill any developing seed.	Any seeds on plants will be easily blown. If there are plants in this stage it might be feasible to bag them. However, it is important not to disturb the seedheads when doing this.	Seed is viable and a large proportion of it can germinate immediately. Mowing might accidentally spread seed. It is important to ensure machinery is clean when leaving infested paddocks.	Where plants are dead there is likely seed in the soil below. Note where these were and in the next flush of seedlings take care to control them. Cultivating soil will spread any of these seeds and encourage germination. Some proportion of the seeds will have dormancy and may emerge years later. Establishing desirable plants in these bare patches will mitigate germination of Madagascar ragwort.

5.1.3 Heteromorphic seeds of Madagascar ragwort.

Appendix 3. *A photograph of the heteromorphic seeds of Madagascar ragwort. Madagascar ragwort creates different types of seeds, with a large proportion of seed produced light-brown and viable three days after collection (Nelson and Michael 1982), and another contingent of green and dark-brown seeds with increased dormancy (Sindel and Coleman 2012).*