Manaaki Whenua
Landcare Research

Feasibility of biological control of Madagascar ragwort, *Senecio madagascariensis* Poir.

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Feasibility of biological control of Madagascar ragwort, *Senecio madagascariensis* Poir.

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Objectives

- Undertake a literature review to identify potential biocontrol agents for *S. madagascariensis* and determine the feasibility of releasing them in New Zealand.
- Assess the achievability of successful biocontrol of *S. madagascariensis* in New Zealand.
- Estimate and outline the cost of implementing a biocontrol programme for *S. madagascariensis* in New Zealand.

Background and Results

- *Senecio madagascariensis* Poir. is an annual or short-lived perennial herb in the family Asteraceae. It is native to southern Africa, including Madagascar, the Mascarene Islands, coastal Mozambique, eastern Zimbabwe and South Africa (Eastern and Western Cape Provinces, KwaZulu-Natal). *Senecio madagascariensis* has been introduced to several other regions around the world, including Argentina, Brazil, Colombia, Uruguay, Hawaii, Kenya, Japan, eastern Australia, and New Zealand.
- *Senecio madagascariensis* has only recently (2017) been recognised as present in New Zealand – and as such, it has no legal classification as a pest or unwanted species in the country. Specimens collected from Northland were identified as *S. madagascariensis* and the species was subsequently listed as present in New Zealand in the *Checklist of the New Zealand Flora*.
- *Senecio madagascariensis* can have severe detrimental impacts, particularly in pastureland. When *S. madagascariensis* invades pastureland, it competes with favourable pasture species for soil moisture, nutrients, and light, causing a decline in pasture species and reducing useable foraging area for livestock. The pyrrolizidine alkaloids of *S. madagascariensis* are toxic to livestock, particularly cattle. Repeated ingestion of small amounts of these alkaloids can cause hepatic lesions and progressive hepatic injury over weeks or months, resulting in eventual liver failure and death. Other symptoms include slowed growth in young cattle, photosensitivity, diarrhoea, muscle spasms, and reduced milk production.
- The genus *Senecio* belongs to tribe Senecioneae, the largest tribe of the Asteraceae family. Due to morphological plasticity and taxonomic uncertainty, *S. madagascariensis* has been placed in a species complex (referred to as the '*Senecio inaequidens* complex'), comprised of six southern African species of *Senecio*, three of which are considered invasive in various parts of the world.
- More than 40 species of *Senecio*, and allied genera such as *Brachyglottis*, are represented in New Zealand. These include endemic species with high conservation values, and native and exotic selections used as ornamental garden plants. Because of

the wide range of related species, host specificity testing of prospective biocontrol agents may need to be relatively broad within the New Zealand representatives of tribe Senecioneae.

- *Senecio madagascariensis* is a current target for biological control in Hawaii (Hawaii Department of Agriculture) and Australia (CSIRO), with support from the University of KwaZulu-Natal in South Africa. A moth, *Secusio extensa*, has been released in Hawaii to try to control *S. madagascariensis*, but to date damage by this agent has been minimal. It would not be a good candidate agent for New Zealand or Australia because it attacks several Asteraceae species.
- Seventy-four arthropods were identified in association with *S. madagascariensis*. Of these, only three initially looked promising as potential biocontrol agents – the stem-boring weevil (*Gastroclisus tricostalis*) the stem-boring moth (*Metamesia elegans*) and a stem-boring/capitulum-feeding moth (*Platyptilia* sp.). However, all three species have proven difficult or unsuitable as biocontrol agents in Australia, with only *G. tricostalis* moving to the host specificity testing stage.
- Eight fungal pathogens were identified in association with *S. madagascariensis*. Two of these – *Aecidium* sp. and *Ustilago* sp. – look potentially host-specific but severity of damage is either lower than desired (*Aecidium* sp.) or unknown (*Ustilago* sp.).

Conclusions and recommendations

Biocontrol may be a viable and advisable control option for the management of *S. madagascariensis* in New Zealand, but no natural enemies have yet proved promising as potential biocontrol agents (with the exception of several agents for Hawaii). Current host-testing of *G. tricostalis* in Australia has revealed it is not host specific and there is no plan to continue the biocontrol programme beyond this host testing.

Recent genetic analysis has suggested that Australasian populations of *S. madagascariensis*, including those from New Zealand, may not have originated from KwaZulu-Natal, South Africa, as once believed. In light of this, it would be prudent to conduct genetic analyses to compare *S. madagascariensis* populations from the native range outside of KwaZulu-Natal to those of Australasian populations, to determine from where Australasian populations have originated. Potential native range surveys could follow, depending on the results of the genetic analysis. Any biocontrol programme will need to include fostering collaboration and relationships with researchers involved with biocontrol programmes targeting *S. madagascariensis* in South Africa, Hawaii, and Australia.

We recommend the following actions. (All cost estimates are NZ$).

- Identify whether collaborations and/or data sharing are possible with CSIRO, University of KwaZulu-Natal, Hawaii Department of Agriculture, and other institutions around collecting samples of *S. madagascariensis* for genetic testing and host specificity testing for potential *S. madagascariensis* agents.
  Estimated cost: $500–$2000.
- Conduct genetic analyses of populations of *S. madagascariensis* in New Zealand, Australia, and within the broader native range. **Estimated cost:** $50,000–$100,000.

- Depending on the results of genetic analyses, conduct further native range surveys (outside of KwaZulu-Natal region) of *S. madagascariensis* to identify potential biocontrol candidate agents. **Estimated cost:** $100,000–$150,000.
- Conduct surveys to identify potential natural enemies of *S. madagascariensis* in New Zealand. This will help identify associated invertebrates and pathogens, such as predators and native analogues, that may affect the efficacy of potential biocontrol agents. It will also help identify whether there are any potential biocontrol agents already present in New Zealand (avoiding wasting time and effort importing an organism that already occurs here). This information is fundamental for subsequent applications to release novel biocontrol agents. **Estimated cost:** $50,000–$60,000.
- Determine if host testing of agents can be conducted by potential collaborators in South Africa, Australia, or Hawaii, or if host testing would need to be conducted in New Zealand.
    - *If host testing can be done by collaborators*: Arrange for shipment of NZ host test plants and organise subcontract for host testing by collaborating researchers overseas. **Estimated cost:** $55,000–$65,000.
    - *If host testing to be done in NZ*: Arrange shipment of agents into containment and establish rearing colony. **Estimated cost:** $30,000–$60,000 per agent. Undertake host specificity testing of potential agents, particularly for native New Zealand *Senecio* spp. **Estimated cost:** $60,000–$100,000 per agent.
- Apply to release agents in New Zealand from containment (once they have been deemed suitable for release). **Estimated cost:** $55,000–$75,000.
- Undertake mass-rearing and release of agents in New Zealand. **Estimated cost:** $50,000–$100,000 per species.
- Monitor establishment success of agents. **Estimated cost:** $30,000–$50,000.
- Evaluate the success of the project. **Estimated cost:** $100,000.

1 Introduction

The feasibility of developing a biological control programme against fireweed, *Senecio madagascariensis* Poir., in New Zealand was assessed by Manaaki Whenua – Landcare Research for Northland Regional Council.

2 Objectives

- Undertake a literature review to identify potential biocontrol agents for *S. madagascariensis* and determine the feasibility of releasing them in New Zealand.
- Assess the achievability of successful biocontrol of *S. madagascariensis* in New Zealand.
- Estimate and outline the cost of implementing a biocontrol programme for *S. madagascariensis* in New Zealand.

3 Background

3.1 Global distribution, biology and ecology of *Senecio madagascariensis*

Senecio madagascariensis Poir. is an annual or short-lived perennial herb in the family Asteraceae. It is native to southern Africa, including Madagascar, Mascarene Islands, coastal Mozambique, eastern Zimbabwe and South Africa (Eastern and Western Cape Provinces, KwaZulu-Natal; Figure 1; Sindel 1986; Wijayabandara et al. 2022). *S. madagascariensis* has been introduced to several other regions around the world, including Argentina, Brazil, Colombia, Uruguay, Hawaii, Kenya, Japan, eastern Australia, and New Zealand (Figure 1; CABI 2023a). Genetic studies have revealed that introduced populations of *S. madagascariensis* in Hawaii and Australia are most closely related to populations from the KwaZulu-Natal region in South Africa (Scott et al. 1998; Le Roux et al. 2006) although for Australian populations this has recently been contested (Schmidt-Lebuhn, Egli, Grealy et al. 2022). Its detrimental impact on pasture lands has seen *S. madagascariensis* declared as a noxious weed in many parts of its introduced range. In Hawaii, it was included on the Hawaiian State Noxious Weed List in 1992 (Starr et al. 1999) and it was declared as an invasive alien species under the Invasive Alien Species Act in Japan in 2006 (Tsutsumi 2011). In Australia, *S. madagascariensis* was deemed a Weed of National Significance in 2012 (Olckers et al. 2021).

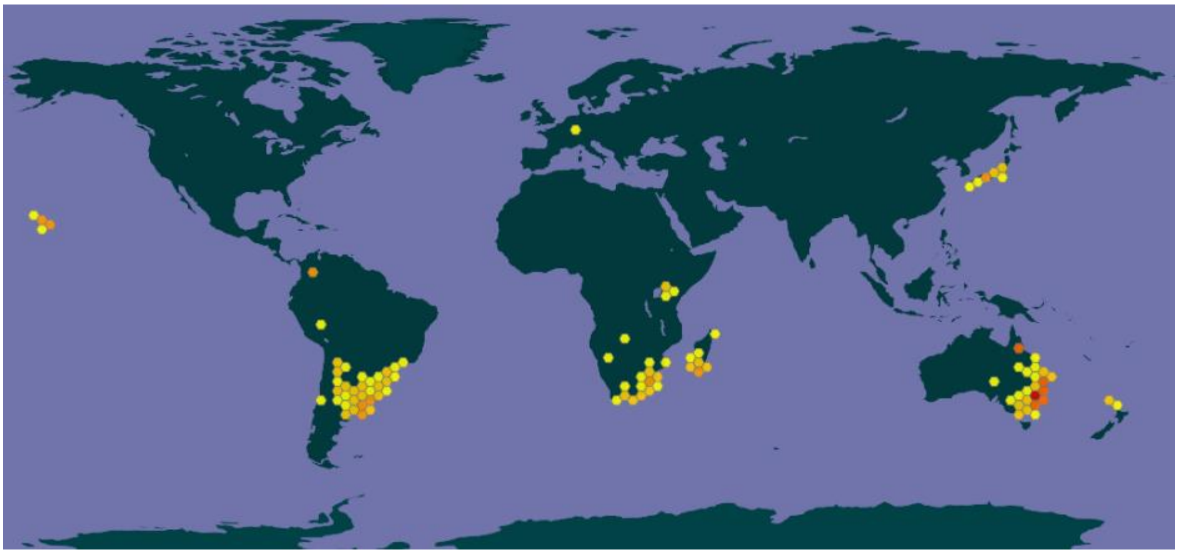

Figure 1. Global distribution of *Senecio madagascariensis*. (Source: GBIFa, CC BY 4.0)

Senecio madagascariensis, also known as fireweed or Madagascar ragwort, is typically 20–60 cm in height and occasionally has multiple branching stems (Panziera et al. 2018). It is hairless to sparsely hairy with predominantly simple, narrow leaves arranged alternately in the mid-region of the stems (Panziera et al. 2018). Some leaves are divided and exhibit one or two narrow, triangular lobes located centrally on each side. Leaves are 3–10 cm long with 15–25 small teeth along the blade edges. The leaf water content of *S. madagascariensis* has been shown to be higher than other plant species during wet conditions and lower during dry periods, with an ability to rapidly increase water content when water is abundant (Kellner et al. 2011). *Senecio madagascariensis* can have either shallow, branched annual roots or a perennating taproot with numerous fibrous roots at a depth of 10–20 cm (Watson et al. 1984). Vegetative reproduction can occur from root fragments and intact roots and rooting along stems that lie along the ground (Sindel et al. 1998).

Flower heads of *S. madagascariensis* are bright yellow and daisy-like in appearance and occur at the top of stem branches in groups of 2–20 (Figure 2; Panziera et al. 2018). Each flower head contains 50–70 florets of which 13–15 have petals 5–10 mm long (Panziera et al. 2018). Involucre are 4–6 mm long and 3–5 mm in diameter. Flowering can occur throughout the year in both the native and introduced range but predominantly during spring and autumn (Hillard 1977; McFadyen & Morrin 2012) and flowering can commence as early as 4–6 weeks post-germination (Egli & Olckers 2015). Flowers are pollinated by insects such as hoverflies and European honeybees (Sindel et al. 1998). The fruits of *S. madagascariensis* are achenes measuring 1.5–2.5 mm in length and 0.3–0.45 mm wide (Sindel 1986). The achenes are cylindrical and shallowly ribbed, bearing short hairs or bristles in 9–10 longitudinal lines or bands (Sindel 1986). They are commonly green with light brown in colour but can also be dark or light brown (Verona et al. 1982). Seeds are 1.5–2.5 mm long with pappus measuring 3.5–6.5 mm in length (Panziera et al. 2018). Between 160 and 200 capitula and 25,000–30,000 seeds can be produced by a single plant per annum in Australia (Radford & Cousens 2000; Prentis et al. 2007). In Hawaii, upwards of 200,000 seeds produced in a season has been reported and 6–8 generations can be produced per year (Reimer 2008; Krushelnycky et al. 2018). Natural dispersal is via wind, but seeds can also be transported via ship dry ballast, animals, vehicles or as a crop seed contaminant (Csurhes & Navie 2010; Dormontt et al. 2014). *S. madagascariensis* is diploid (2*n* = 20) and is an obligate outcrosser (Dormontt et al. 2014). It can also produce allelopathic compounds in the form of pyrrolizidine alkaloids that can deter herbivorous insects (Wei 2015). However, research from Australia has shown *S. madagascariensis* to have greater abundance and richness of insect herbivores than other *Senecio* species, despite the production of pyrrolizidine alkaloids (Harvey et al. 2015).

Figure 2. *Senecio madagascariensis.* Left: plant in pastureland. (Image: © Hamish Maule, MWLR.) Right: flowers of *S. madagascariensis.* (Image: © Kate McAlpine, CC-BY.) Both images sourced from iNaturalistNZ.

Senecio madagascariensis inhabits a range of land types, including disturbed areas such as roadsides, urban areas and grazed pastures, cool moist highlands, riverbanks, meadows, and areas characterised by sparse vegetation or low-statured species (Bartle et al. 2013; Krushelnycky et al. 2018; Wijayabandara et al. 2022). It prefers sub-tropical, maritime, and humid climates with annual rainfall between 500 and 1000 mm (Sindel et al. 1998). In drier regions, *S. madagascariensis* plants have an annual life cycle with a perennial life cycle exhibited in wetter regions (Krushelnycky et al. 2018). Mean annual temperatures between 12.4°C and 20.1°C favour its establishment within the introduced range (Sindel et al. 1998). In the native range of South Africa, *S. madagascariensis* is usually found at altitudes below 1500 m.a.s.l., but in tropical regions such as Kenya and Colombia it can grow at altitudes of up to 2800 m.a.s.l. (Sindel & Michael 1992). Seedlings of *S. madagascariensis* are frost sensitive and frost can reduce vigour in older plants (Sindel & Michael 1992; Le Roux et al. 2006). However, plants exposed to cooler temperatures have shown greater tolerance to frost than plants grown in warmer conditions that were then exposed to frost, suggesting that *S. madagascariensis* can become cold acclimated and that frost may not be as important a limiting factor in its spread (Sindel et al. 2008). *Senecio madagascariensis* favours high fertility soil that is well-drained and noncompact but is found on a wide range of soils, such as limed soil and sands (Wijayabandara et al. 2022). Input of additional resources can bolster *S. madagascariensis* recruitment, such as at recently burned sites or in pastures with added fertiliser (Sindel & Michael 1992; Questad et al. 2018). In different soil types and in different habitats, *S. madagascariensis* can develop distinct growth habits and dispersion strategies, and exhibit different leaf phenology (Ramadan et al. 2011; Dematteis et al. 2019, 2020).

3.2 Pest status and distribution in New Zealand

Senecio madagascariensis has only recently been recognised as present in New Zealand. As such, it currently lacks legal classification as a pest or unwanted species in the country. The true length of time that *S. madagascariensis* has been present in New Zealand is unknown. Historically, some populations of *S. madagascariensis* in New Zealand have been misassigned as the closely related, introduced species *Senecio skirrhodon* that has been naturalised in New Zealand since 1920 (Figure 3; Webb et al. 1998; New Zealand Plant Conservation Network 2023a). Concerns of *Senecio* weediness in Northland pastures prompted Jenny Dymock, an entomologist who provides biocontrol services to Northland Regional Council, to send specimens to the Allan Herbarium at Manaaki Whenua – Landcare Research in May 2017 (Schmidt-Lebuhn, Egli, Grealy et al. 2022). These specimens (CHR 589921–CHR 589923; AVH 2023) were identified as *S. madagascariensis* and the species was subsequently listed as present in New Zealand in the Checklist of New Zealand Flora (Schönberger et al. 2020) or BiotaNZ (Manaaki Whenua – Landcare Research 2023). A leaf sample of supposed *S. madagascariensis* collected from Pukenui, Northland, on 29 March 2021 was sent by Jenny Dymock to Ana Podolyan at Ecogene (Lincoln, NZ). The sample was compared with a Hawaiian sample, labelled *Senecio madagascariensis* at the Allan Herbarium at Lincoln. This showed that both the Northland sample and the Hawaiian sample were most closely matched with *S. inaequidans* (from Lesotho, South Africa) rather than *S. madagascariensis*. However, both the Northland and Hawaiian samples were neither clearly *S. madagascariensis* nor *S. inaequidans*. According to Ana Podolyan it is likely that hybridisation among these *Senecio* species is widespread. However, further samples of *Senecio madagascariensis* collected from the Aupouri and Karikari Peninsulas in the far north and from Kerikeri, Wellington (Waikanae) and New Plymouth were sent to CSIRO Canberra for DNA analysis on 26 Oct 2021. Results from the CSIRO DNA analysis in August 2022 confirmed that the specimens from the far north are *Senecio madagascariensis* (Figure 4). Specimens from the far north of Northland matched with some Australian *S. madagascariensis* specimens and it has been suggested that the Northland populations are derived from Australia (Schmidt-Lebuhn, Egli, Grealy et al. 2022). Specimens from Waikanae and New Plymouth were identified as *Senecio skirrhoden*.

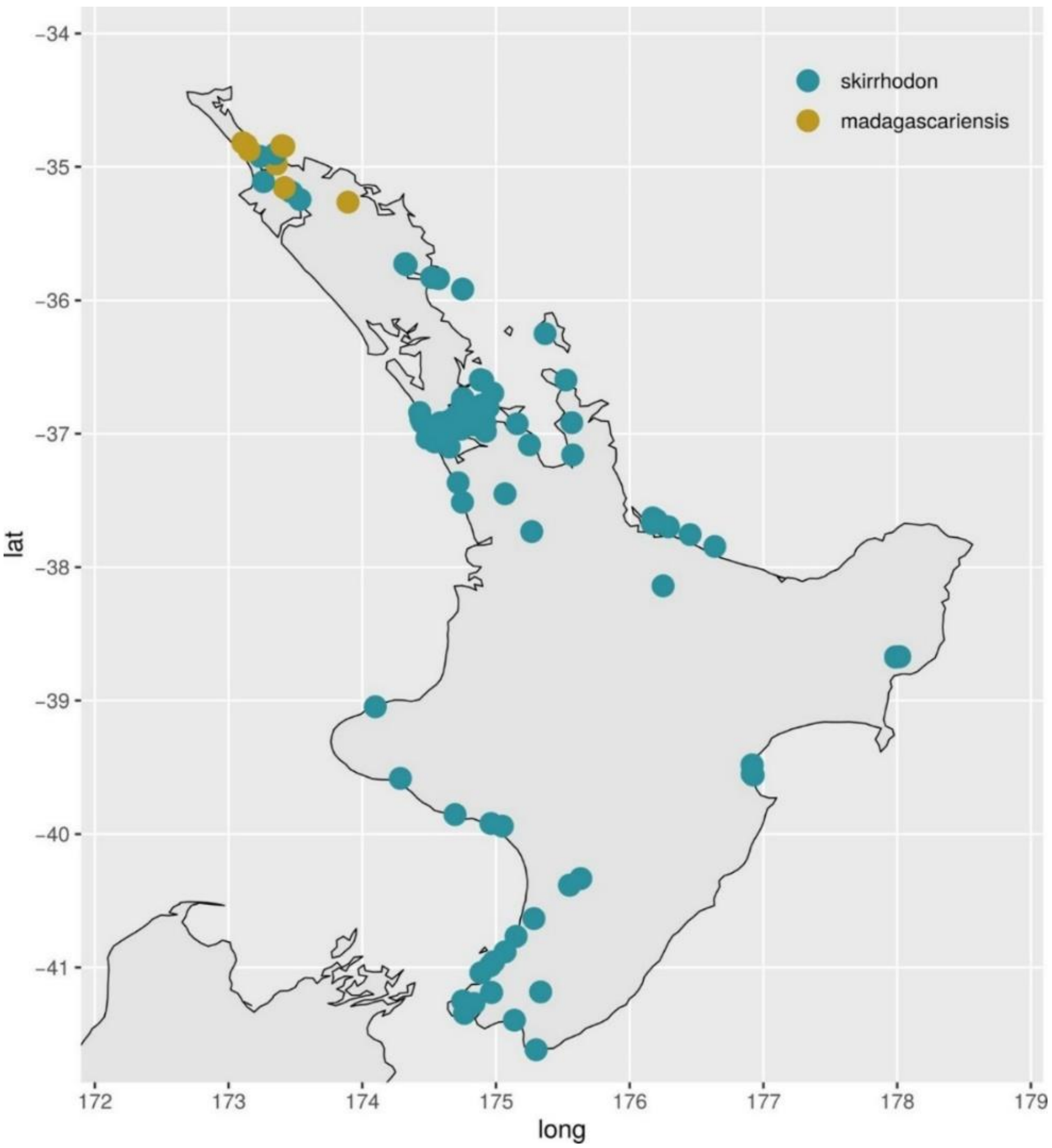

Figure 3. Map of the North Island of New Zealand showing geocoded specimens of *Senecio madagascariensis* (yellow) and *S. skirrhodon* (blue). (Source: Reproduced from Schmidt-Lebuhn, Egli, Grealy et al. 2022.)

In Northland *S. madagascariensis* is prevalent on the Aupouri and Karikari Peninsulas, the Victoria Valley south of Kaitaia, and valleys inland of Doubtless Bay, Kerikeri, Kapiro, and Kaikohe, with infestations rapidly increasing in these areas. It is thought to be dispersed as seed by wind or through stock movement from infected areas (Jenny Dymock, entomologist, pers. comm.). Recently, climatic suitability models have shown that most parts of both the North and South Islands are climatically suitable for *S. madagascariensis* (Wijayabandara et al. 2022).

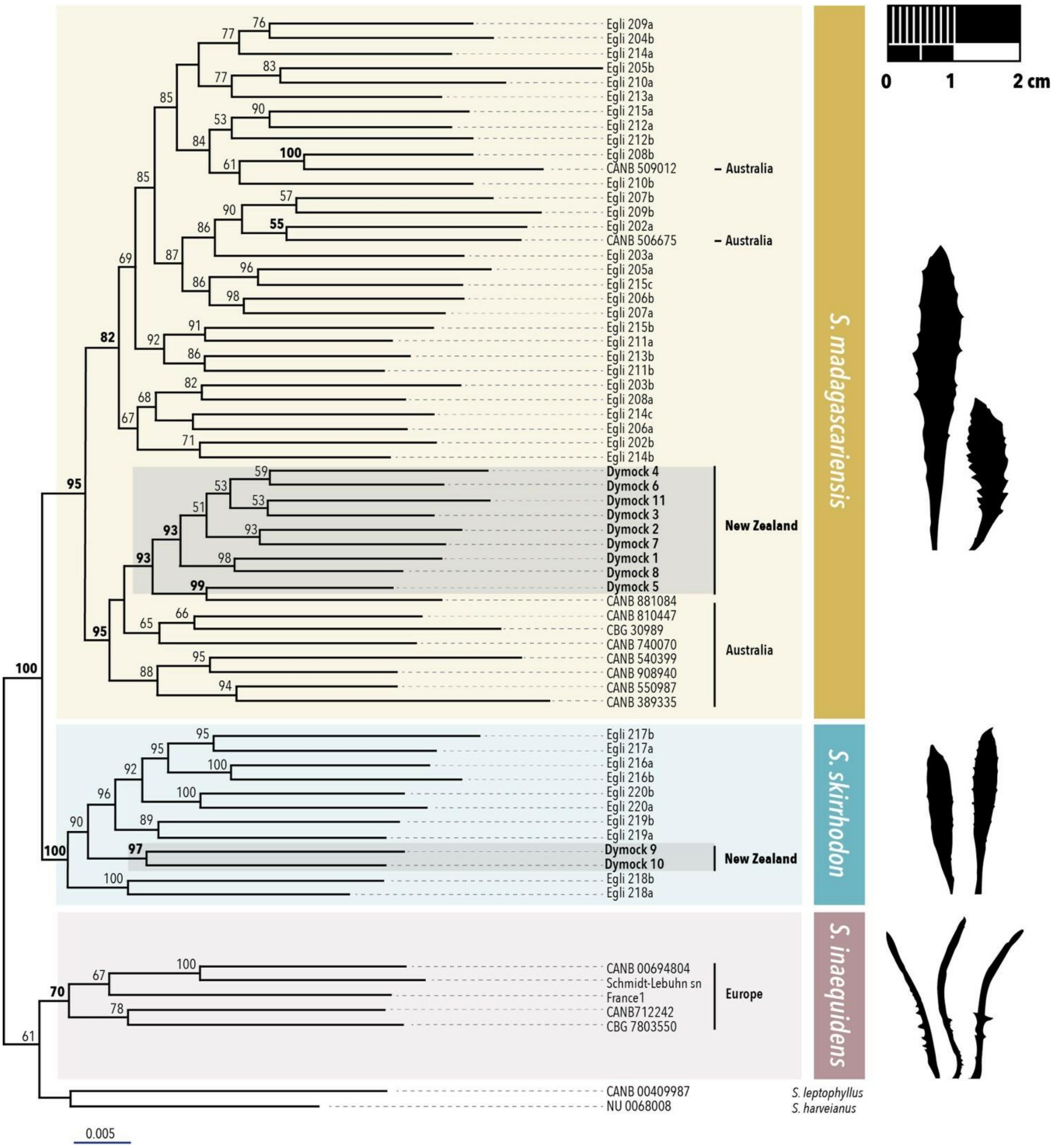

Figure 4. Part of the phylogenetic tree of Senecioneae showing the fireweed complex and where samples collected from New Zealand fit. Three main clades are highlighted with boxes: *Senecio inaequidens* (brown), *S. skirrhodon* (blue), and *S. madagascariensis* (yellow-gold). Silhouettes show representative leaf shapes of type specimens. (Source: Reproduced from Schmidt-Lebuhn, Egli, Grealy et al. 2022.)

3.3 Detrimental impacts of *Senecio madagascariensis*

Senecio madagascariensis can have severe detrimental impacts, particularly in pastureland. When *S. madagascariensis* invades pastureland, it competes with favourable pasture species for soil moisture, nutrients, and light, causing a decline in pasture species and reducing useable foraging area for livestock (Figure 5; Prentis et al. 2010; Egli 2017; Kushelnyckey et al. 2018). Land cover of *S. madagascariensis* can reach up to 60% and can reduce pasture productivity by 30%–40% (Thorne et al. 2005). Livestock tend to avoid

S. madagascariensis, which can contribute to the weed outcompeting desirable pasture species (Sindel et al. 2008). In Australia, a loss of profit from *S. madagascariensis* invasion of pastureland has been estimated between 15% and 50% (Sheppard et al. 2013). Annual economic losses for Australia have been estimated at US$2 million (Le Roux et al. 2006). For NSW alone, farmers have been estimated to lose A$5.4 million annually and the dairy sector A$250,000 (Csurhes & Navie 2010).

Figure 5. *Senecio madagascariensis* competing with ryegrass in pasture in Australia. (Image: © State of New South Wales through Department of Trade and Investment, Regional Infrastructure and Services.)

The pyrrolizidine alkaloids of *S. madagascariensis* are toxic to livestock, particularly cattle. In southern Brazil, 45,500 animals have been lost annually to poisoning by *Senecio* species, including *S. madagascariensis* (Mäder et al. 2016). Repeated ingestion of small amounts of the alkoloids, over weeks or months, can cause hepatic lesions and progressive hepatic injury, resulting in eventual liver failure and death (Panziera et al. 2018). Other symptoms include slowed growth in young cattle, photosensitivity, diarrhoea, muscle spasms, and reduced milk production (Csurhes & Navie 2010; Stigger et al. 2014; Egli 2017). Although livestock generally avoid *S. madagascariensis*, they can ingest small and inconspicuous plants, when forage is limited, or when it contaminates silage and hay (Csurhes & Navie 2010).

Senecio madagascariensis can pose a risk to native *Senecio* species through hybridisation. In Australia, *S. madagascariensis* can cross with the native *S. pinnatifolius* var. *pinnatifolius*, with both species producing hybrid seeds (Dormontt et al. 2017). However, no adult hybrids have been found, probably due to a postzygotic reproductive barrier (Dormontt et al. 2017). Calculations derived from frequency-dependent hybridisation relationships showed that the proportion of *S. madagascariensis* need only reach between 10% and 60% to produce more viable seeds than *S. pinnatifolius* when the two species co-occur (Prentis et al. 2007). This means that *S. pinnatifolius* var. *pinnatifolius* is at risk of local extinction in Australia in areas where it co-occurs with *S. madagascariensis* (Prentis et al. 2007).

3.4 Beneficial uses

Natural compounds isolated from *S. madagascariensis* (14-isovaleryloxy-1 and 2-dehydrocacalol methyl ether) have been reported as moderately effective as an antifeedant against the pest aphid *Myzus persicae* (Burgueño-Tapia et al. 2007). The pyrrolizidine alkaloids extract of *S. madagascariensis* has shown cytotoxic activity against cancer-derived cell lines in laboratory studies in Uruguay (Mondino et al. 2022). The floral scent of *S. madagascariensis* can induce a behavioural response in male *Aedes aegypti* mosquitoes, which are a main vector of arboviruses such as Zika, chikungunya and dengue (Kashiwagi et al. 2022). Plant carbohydrates are the only food source for male mosquitoes of *A. aegypti,* and they locate plant sugars through volatile compounds of plants (Kashiwagi et al. 2022). The volatile compound 1-nonene of *S. madagascariensis* was isolated as an attractant for male mosquitoes and when it was added to sugar-baited traps it significantly increased male mosquito mortality in traps (Kashiwagi et al. 2022). This suggests that adding flower cuttings or using volatile compounds of *S. madagascariensis* can improve the efficacy of baited traps against problematic mosquitoes.

3.5 Phylogeny and taxonomy

Botanical name: *Senecio madagascariensis* Poir.

Synonyms are listed in the Global Biodiversity Information Facility (GBIF 2023a) as:

- *Senecio bakeri* Elliott (1891)
- *Senecio bakeri* Scott Elliot (1891)
- *Senecio burchellii* Cabrera
- *Senecio incognitus* Cabrera (1941)
- *Senecio junodianus* O.Hoffm. (1900)
- *Senecio ruderalis* Harv. (1864/5).

Not to be confused with *Senecio madagascariensis* (Humbert) H.Jacobsen (1954), a synonym of *Kleinia madagascariensis* (Humbert) P.Halliday (1988) (GBIF 2023b; POWO 2023).

Wikipedia (2023a) displays a phylogenetic classification:

Kingdom: Plantae
    Clade: Tracheophytes
        Clade: Angiosperms
            Clade: Eudicots
                Clade: Asterids
                    Order: Asterales
                        Family: Asteraceae
                            Subfamily: Asteroideae
                                Tribe: Senecioneae
                                    Genus: *Senecio*
                                        Species: *S. madagascariensis*

Because of morphological plasticity and taxonomic uncertainty, *S. madagascariensis* was placed in a species complex (referred to as the '*Senecio inaequidens* complex' by López et al. 2008, and the '*Senecio inaequidens – S. madagascariensis* complex' by Schmidt-Lebuhn, Egli, Grealy et al. 2022). This complex comprises six southern African species of *Senecio*, three of which are considered invasive in various parts of the world (*S. madagascariensis*, *S. skirrhodon*, and *S. inaequidens*; Schmidt-Lebuhn, Egli, Grealy et al. 2022). CABI (2023a) notes 'Hilliard (1977) agreed that the maritime species, *S. skirrhodon* may be no more than a maritime form of *S. madagascariensis*, as suggested by Humbert (1963).'

Senecio madagascariensis has been considered as part of the '*Senecio inaequidens* complex' and conspecific with *S. inaequidens* because of their similar morphology (Lafuma et al. 2003; López et al. 2008). However, Radford *et al.* (2000) differentiated the two species, based on the micromorphology of the cypsela surface. Further distinction can be made from the number of chromosomes of both species. Using Argentinian material, López et al. (2008) confirmed $2n = 20$ for *S. madagascariensis*, differing from $2n = 40$ for *S. inaequidens* reported elsewhere (Goldblatt 1984; Radford et al. 1995).

The genus *Senecio* belongs to tribe Senecioneae, the largest tribe of the Asteraceae family (150 genera, and more than 3,500 species; Wikipedia 2023a). Almost one-third of Senecioneae species are from the genus *Senecio*. They exhibit a wide range of morphologies, including annuals, herbaceous and evergreen perennials, minute creeping alpines, shrubs, trees, climbers, succulents, and semi-aquatic plants (Wikipedia 2023a). Many species of *Senecio* are used in horticulture.

From the 150 genera of tribe Senecioneae, the following have representatives present in New Zealand:

- *Abrotanella**
- *Brachyglottis**

- *Crassocephalum*
- *Cremanthodium*
- *Curio*
- *Delairea*
- *Dolichoglottis**
- *Doronicum*
- *Emilia*
- *Erechtites*
- *Euryops*
- *Farfugium*
- *Gynura*
- *Haastia**
- *Jacobaea*
- *Kleinia*
- *Ligularia*
- *Othonna*
- *Pericallis*
- *Petasites*
- *Roldana*
- *Senecio**
- *Steirodiscus*
- *Telanthophora*
- *Traversia**
- *Tussilago*

*Genera suffixed with asterisks have representatives indigenous to New Zealand. Further investigation may uncover other exotic genera not listed in BiotaNZ, but present in New Zealand.

More than 40 species of *Senecio*, and allied genera such as *Brachyglottis*, are represented in New Zealand. These include endemic species with high conservation values, and native and exotic selections used as ornamental garden plants. Of species present in New Zealand, the fully naturalised *Senecio skirrhodon* (gravel groundsel) is likely to be the most closely related to *S. madagascariensis*. Because of this relatedness, in the first instance, *S. skirrhodon* should be prioritised for any host testing – negative impacts of the growth and fecundity of this plant would be seen as beneficial. Of the native New Zealand species, those belonging to 'Australasian Clade 3' (*Senecio biserratus*, *S. carnosulus*, *S. esperensis*, *S. lautus*, *S. pokohinuensis*, *S. radiolatus*, *S. sterquilinus*) are more closely related than others – some of these have high conservation values. Because of the wide range of related species, host specificity testing of prospective biocontrol agents may need to be relatively broad within the Tribe Senecioneae. New Zealand native outgroups elsewhere in the Senecioneae comprise *Abrotanella* (10–11 spp.), *Brachyglottis* (25–30 spp.), *Dolichoglottis* (2 spp.), *Haastia* (3 spp.), and *Traversia* (1 sp.; monotypic genus).

Schmidt-Lebuhn, Egli and Gooden (2022) conducted phylogenetic analyses of the Senecioneae in Australasia, to clarify taxonomic/evolutionary relationships to inform prospective biocontrol (Figure 6). They sequenced *Senecio skirrhodon* for the first time and confirmed it to be sister to *S. madagascariensis*, *S. harveianus*, and *S. inaequidens*. Several indigenous or endemic New Zealand species were resolved in their 'Australasian clade 3'.

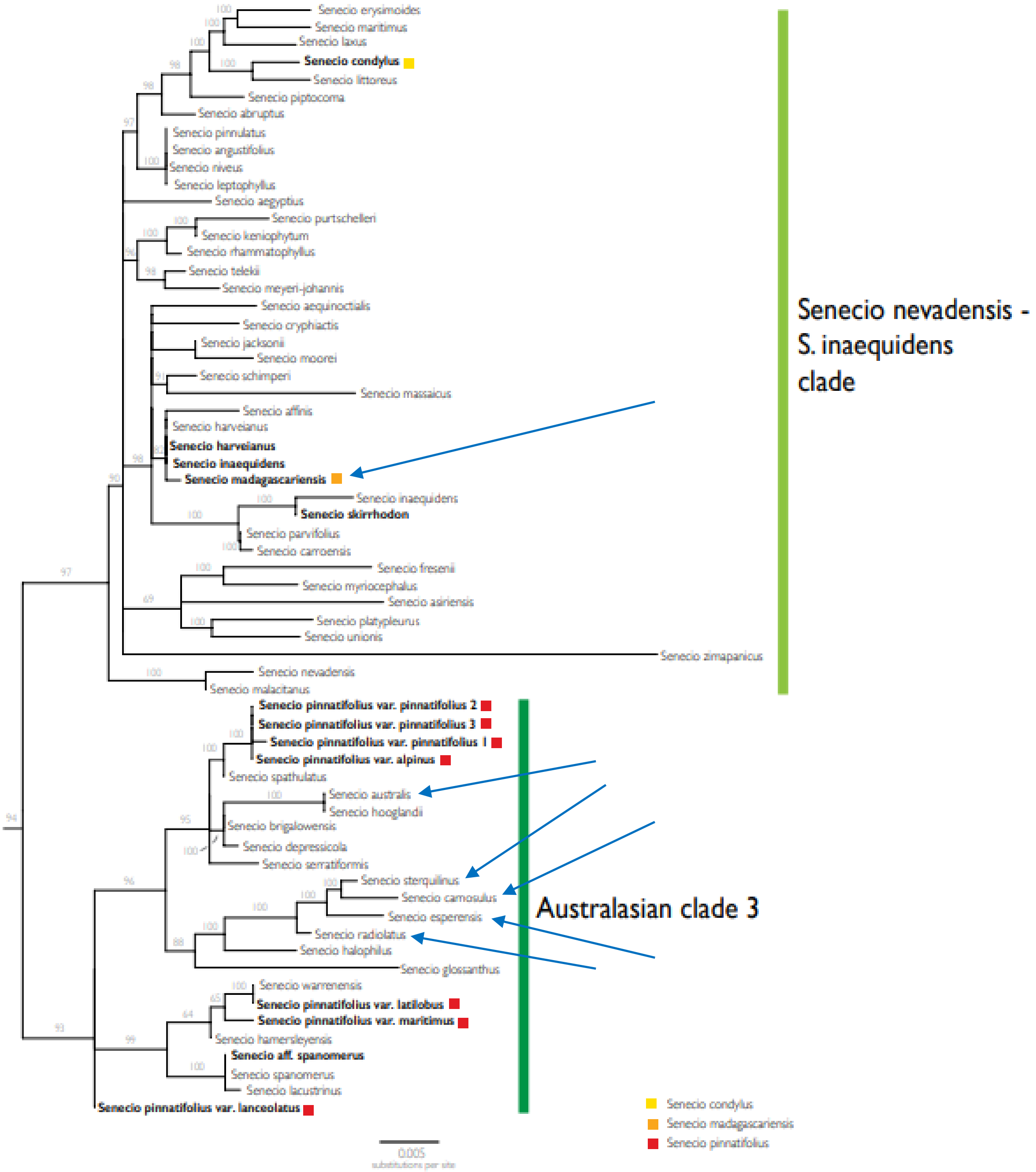

Figure 6. Ribosomal phylogeny showing the *Senecio nevadensis – S. inaequidens* clade and Australasian clade 3. (Source: Reproduced with permission and adapted from Schmidt-Lebuhn, Egli and Gooden 2022.) Blue arrows have been added to this figure to show New Zealand native species and the Southern African clade that includes *Senecio madagascariensis*.

Other phylogenies have been published that include New Zealand Senecioneae (Figures 7–10; Wagstaff & Breitwieser 2004; Pelser et al. 2007; Liew et al. 2021). Liew et al. (2021) included more New Zealand species than Schmidt-Lebuhn, Egli and Gooden (2022) in their 'Australasian Clade 3' – *Senecio carnosulus*, *S. esperensis*, *S. marotiri*, *S. pokohinuensis*, *S. radiolatus*, and *S. sterquilinus* are endemic to New Zealand, whereas *S. biserratus*) – is also indigenous to Australia. *Senecio lautus* may be endemic to New Zealand, as there is some doubt if it is truly present Australia (New Zealand Plant Conservation Network 2023b).

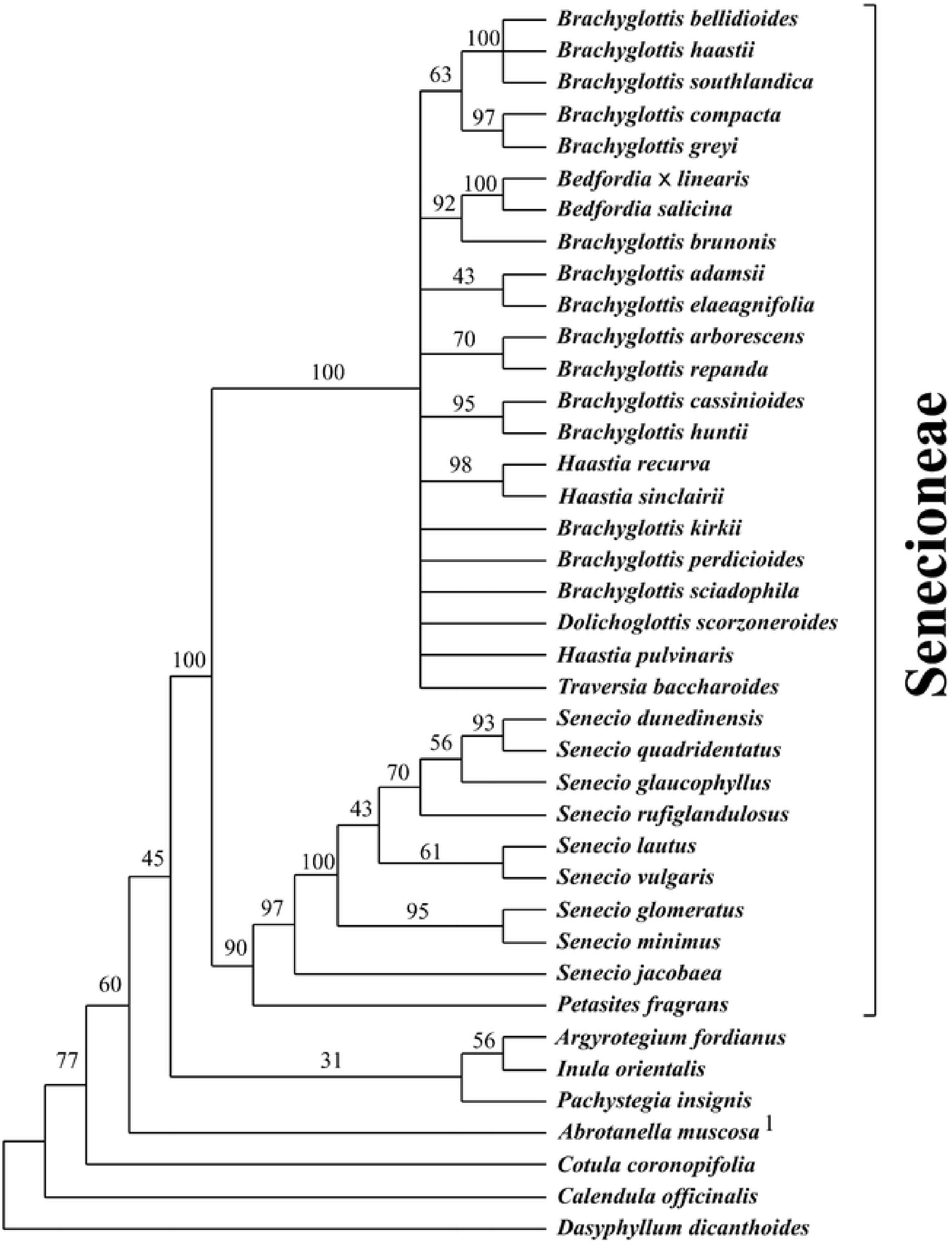

Figure 7. Strict consensus tree of New Zealand Senecioneae from combined analysis of ITS and 5′ *trnK/matK* sequences. (Source: Wagstaff and Breitwieser 2004.)

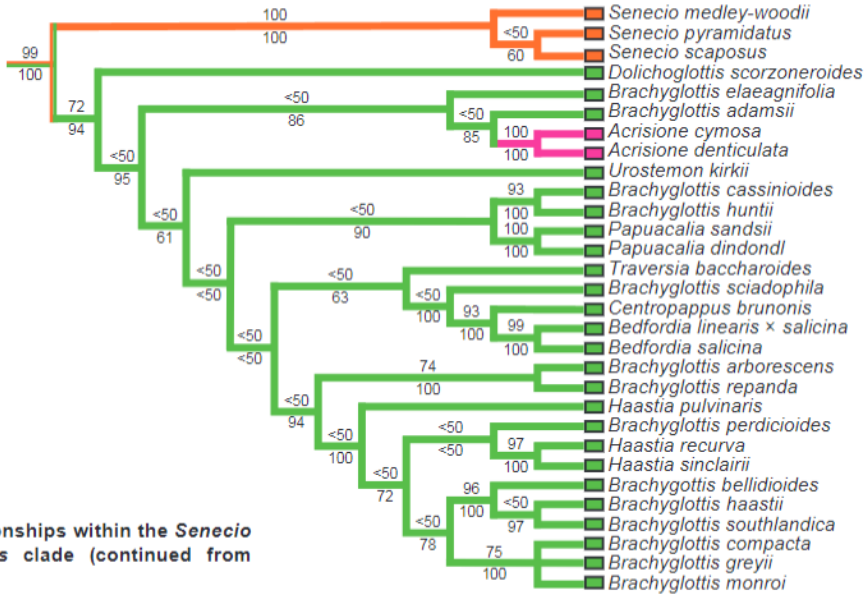

Fig. 1D. Phylogenetic relationships within the *Senecio medley-woodii-Brachyglottis* clade (continued from Fig. 1A).

Figure 8. *Senecio medley-woodii-Brachyglottis* clade retrieved by Pelser et al. (2007, Fig. 1D). Reproduced with permission.

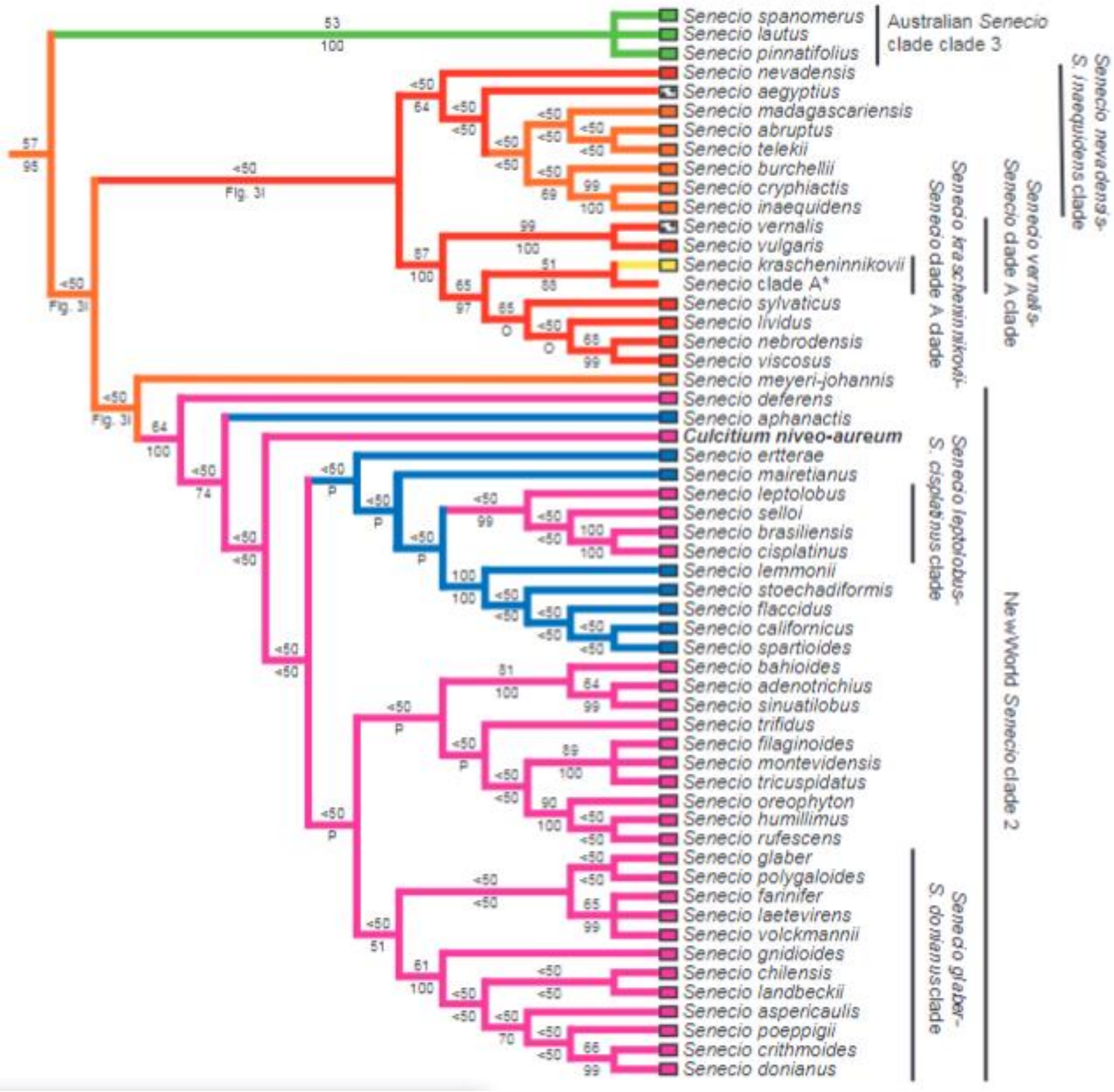

Figure 9. Phylogenetic relationships within subtribe Senecioninae. Note that *Senecio madagascariensis* is included in this phylogram. (Reproduced with permission from Pelser et al. 2007, Fig. 11.)

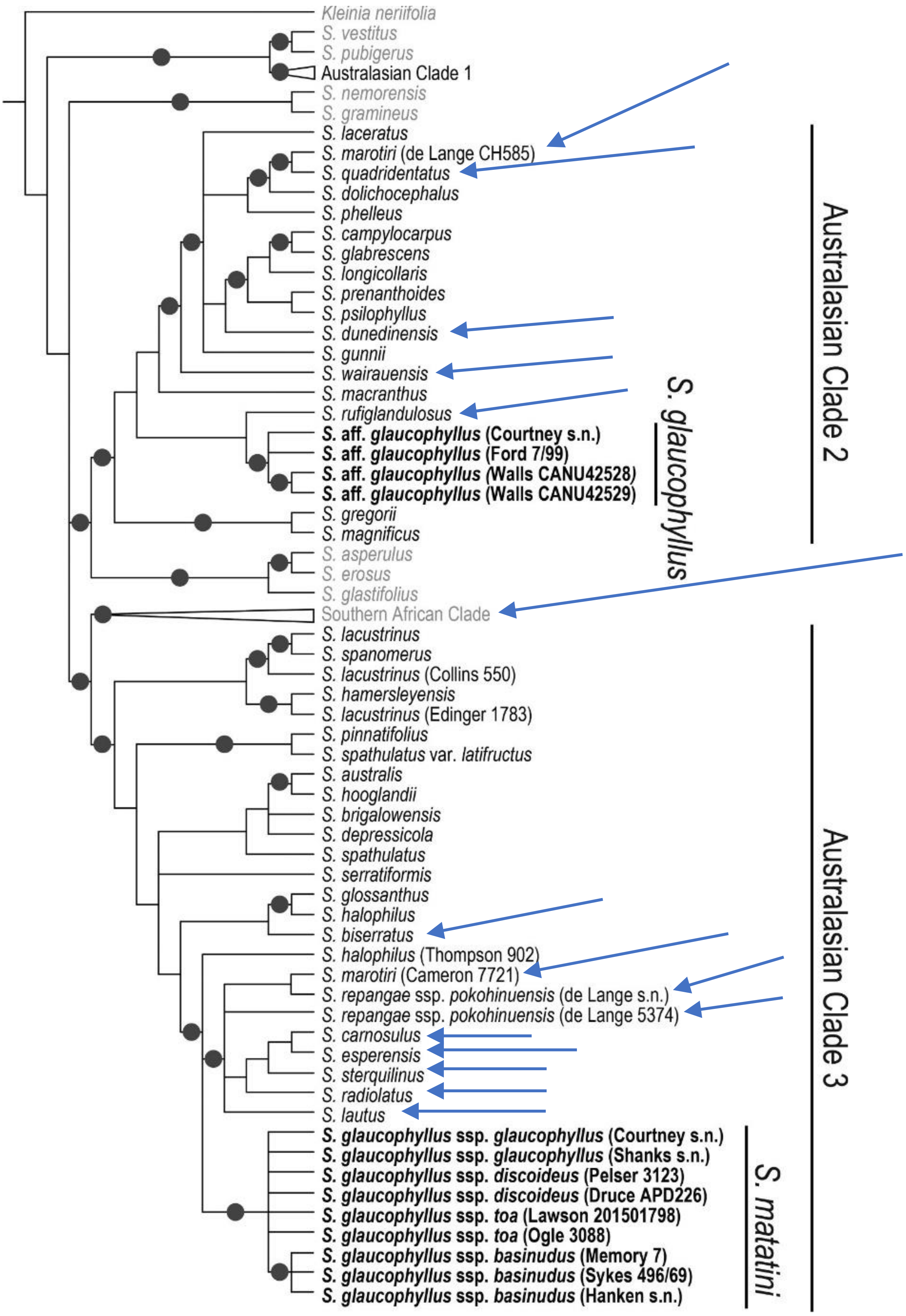

Figure 10. Bayesian inference majority rule consensus ITS phylogeny of Australasian *Senecio* and other relevant lineages. (Source: Reproduced and adapted from Liew et al. 2021.) Blue arrows have been added to this figure to show New Zealand native species and the Southern African clade that includes *Senecio madagascariensis*.

3.6 Potential for opposition to biocontrol

Opposition to biocontrol of *S. madagascariensis* is likely to be minimal. Potential opposition may occur from nurseries and growers that sell or produce other *Senecio* species commercially and are concerned about non-target impacts on commercial *Senecio* stock. Similarly, there may be concern from conservationists about the impact of a biocontrol programme on native *Senecio* species of high conservation value. Representative *Senecio* species of the native New Zealand flora should be included in host testing to ensure specificity of prospective biocontrol agents.

3.7 Control options

Control of *S. madagascariensis* can be costly in terms of money invested, time and labour. Control costs on farms in Australia were estimated at between A$1,000 and $9,000 per year per farm (Sindel et al. 2012; Sheppard et al. 2013) with 50 hours spent per farmer on control each year (Sindel et al. 2012). In Hawaii, an estimated US$11 million was deemed necessary to control *S. madagascariensis* across 162,000 hectares of invaded land (Ramadan et al. 2011).

For physical and mechanical control of *S. madagascariensis*, using slashers and mulchers can weaken plants to prevent them from reaching reproductive maturity, but this method needs to be repeated frequently to ensure most plants are affected (Wijayabandara et al. 2022). Ideally, this should be done when *S. madagascariensis* plants are small and when pasture is growing, to ensure effective competition of pasture species in restricting *S. madagascariensis* regrowth (Sindel & Coleman 2012). However, the risk of livestock poisoning can increase because *S. madagascariensis* that has wilted via mulching has higher concentrations of pyrrolizidine alkaloids and is more attractive to livestock, so it is recommended that pastures not be grazed for at least two weeks post-mulching (Sindel et al. 1998). Slashing may lead to subsequent spread of *S. madagascariensis* when control is carried out on reproductive plants and may also only delay flowering until later in the season (Wijayabandara et al. 2022).

Control by grazing sheep has been found to effectively reduce *S. madagascariensis* infestations. Stigger et al. (2018) suggested continual grazing by at least four sheep per hectare is required for efficient control. Bandara et al. (2012) demonstrated that mowing a 5.5-hectare pasture that was then grazed by 16 sheep almost eliminated an infestation of 18,507 *S. madagascariensis* plants over a 2-year period in southern Brazil.

Many different herbicide regimes have been suggested for *S. madagascariensis* control. Spraying during autumn to winter has been suggested as an ideal time for herbicide application, as this is when seedlings are small, and flowering is at an early stage (Sindel 1986). Chemicals such as 2,4-D formulations, bromoxynil, dicamba, fluroxypyr/aminopyralid, glyphosate, metsulfuron-methyl, tebuthiuron, tricoplyr, and tricoplyr/picloram/aminopyralid are some herbicides applications that have proven effective against *S. madagascariensis* at one or more different growth stages (Wijayabandara et al. 2022). A single application of fluroxypyr/aminopyralid, metsulfuron-methyl or tricoplyr/picloram/aminopyralid, with a follow-up application of bromoxynil has been suggested as sufficient to control *S. madagascariensis* infestations (Wijayabandara et al. 2023).

In New Zealand, herbicide treatments against *S. madagascariensis* in Northland are difficult and costly, requiring high chemical rates and specific management. Broadcast spray with either 2,4-D ester or amine using the highest label rate (2–3 litres per hectare) is suggested with follow up spot spray applications of Tordon^{TM} brushkiller until the flowering season. Once the plant has flowered, the kill rate with brushkiller is severely reduced. It has also been observed that poor, sublethal herbicide control can turn *S. madagascariensis* plants perennial, as happens with ragwort (Doug Foster, Northland Regional Council, pers. comm.).

3.8 Potential advantages and disadvantages of biological control

Investigating the potential use of biological control agents to manage *S. madagascariensis* invasions in New Zealand would be appropriate and useful, especially given its likely future spread out of the Northland region, and hence the national risk it represents to the entire pastoral farming industry. Control of the weed using mechanical and chemical methods is also problematic. Biological control is unlikely to provide a quick-fix solution to *S. madagascariensis* invasion but may provide a more cost-effective and sustainable solution over the long term. This is because continuous and active control is provided and potential agents can self-disperse to unmanaged and/or inaccessible invaded regions, increasing the area of control. Biocontrol is often used once all other control options have been exhausted. Control methods such as herbicides are often ineffective and costly throughout the introduced range of *S. madagascariensis*, giving further impetus toward identifying and utilising potential biocontrol agents (Wijayabandara et al. 2023). However, biocontrol can often be most effective when the density and invasion potential of the target weed are still increasing, making the early stages of invasion ideal for managing weeds through biocontrol (Delfosse 2005).

The potential benefits of biological control as a tool for weed invasion management are numerous, but success rates in biocontrol are highly variable (Schwarzländer et al. 2018). Nevertheless, biocontrol for weeds in New Zealand has had many successes over its more than hundred-year history. For those cases where complete biological control of a target species is not achieved, substantial or partial control is often still attained and is integrated into weed management alongside other control methods (Paynter & Flanagan 2004). Unsuccessful weed biocontrol programmes can occur when there is a failure to locate or establish the control organism, or it fails to have a significant impact on the target weed. However, in most cases, failure of weed biocontrol programmes result from the end of funding before all viable options are explored (Paynter & Flanagan 2004).

Predictable damage of non-target plant species from biocontrol agents (i.e. 'spillover effects') is a potential consequence of biological control (Paynter et al. 2020). These non-target plants are predominantly species that are closely related to the target weed and damage caused to them by agents is usually minor. Suckling and Sforza (2014) found that, of 512 insect agents released for weed biocontrol in 75 countries, 7.6% had minor non-target impacts and only 0.8% had adverse effects. Of the recorded non-target impacts, 77% belonged to the same family and 54% to the same genus as the target weed

(Suckling & Sforza 2014). Careful assessment before the introduction of the control agent is a reliable way to determine the risk of non-target impacts it poses to native and valued plants (Suckling & Sforza 2014; Downey & Paterson 2016). Non-target attacks, when they occur, are often localised events and are generally predictable due to the shared ancestry of the target weed and non-target species (Taylor et al. 2007). In New Zealand, cases of non-target attacks on native plant species are rare and cause minimal or minor damage (Paynter et al. 2020).

Weed biocontrol programmes can have huge economic benefits. In Australia, an economic analysis revealed an overall strong positive return on investment on weed biocontrol programmes, with a benefit of A$23.10 generated for every dollar invested in Australian weed biocontrol (Page & Lacey 2006). In South Africa, the benefit:cost ratios of biological control to ecosystem services ranged from 50:1 for sub-tropical shrubs to 3726:1 for weedy Australian trees (e.g. *Acacia*, *Leptospermum*, *Paraserianthes*; de Lange & van Wilgen 2010). For New Zealand, independent estimates of the net annual benefits from weed biocontrol were NZ$11-$217 million (Suckling 2013) or NZ$58-86 million (Fowler et al. unpubl data). Biocontrol of ragwort (*Jacobaea vulgaris*) by the ragwort flea beetle alone was thought to benefit the New Zealand dairy sector by over NZ$40 million (Fowler et al. 2016; Fowler et al. unpubl data). Similarly, the biocontrol of *S. madagascariensis* in New Zealand may save the pastoral farming industry huge costs in control and management that may be experienced if the weed is left unchecked to spread. The long-term approach of biological control to weed management solutions provides a lasting and substantial economic benefit unattainable by other conventional control methods.

3.9 Predicting establishment of biocontrol agents

Successful establishment of biocontrol agents, such as fungal pathogens and arthropods, is a required step in any effective weed biological control programme. Factors such as climate matching (van Klinken et al. 2003), flowering and fruiting times of target weeds, interspecific competition (Day et al. 2004), the number and size of agent releases (Memmott et al. 1998; Paynter et al. 2016), predation (Reilly et al. 2004), site fertility (Hovick & Carson 2015) and the timing of agent release (Day et al. 2004) can all affect the successful establishment of agents.

Currently, the leading predictor of successful establishment of new organisms is the number and size of agent releases. High rates of weed biocontrol agent establishment (about 80%; Manaaki Whenua – Landcare Research, unpubl. data) in New Zealand is helped by that organisation's large-scale technology transfer programme which operates in conjunction with community groups, the Department of Conservation, farmers, forest companies, iwi and regional councils (Fowler et al. 2000; Hayes 2000). These networks promote the rapid release of substantial numbers of agents across multiple regions of the country and help to ensure that successful establishment of biocontrol agents within New Zealand will continue to increase.

Coevolution of potential weed biocontrol agents and their host plants implies that both should be adapted to similar climatic conditions. This should, in theory, limit the difficulties posed by climate matching but certain circumstances exist where climate may become an issue. Target weed species often have a wider climatic distribution than pathogen or arthropod control agents (Goolsby et al. 2006). Establishment of some exotic weed species in novel ecosystems within the introduced range, that do not occur in the native range, is possible (Gallagher et al. 2010). Control of target weed species by potential agents that are unable to similarly adapt to these new ecosystems may be poor, or effective only in parts of the introduced range that are similar climatically to the native range. Changes in day length can impact the number of generations an agent may produce annually, and this can influence the likelihood of successful agent establishment, especially when it is confounded with climate sensitivity (Grevstad & Coop 2015). If agents are collected from a restricted region within the native range, then they may be ineffective at controlling a target weed, particularly if the distribution of the weed species encompasses a wide range of climatic and ecological conditions (van Klinken et al. 2003). However, biocontrol agents acquired from a specific region within its native distribution could prove beneficial when control in a subset of the target weed's fundamental niche is needed (Robertson et al. 2008). Because the introduced populations of *S. madagascariensis* in Australia and Hawaii have been found to originate from KwaZulu-Natal, South Africa (Le Roux et al. 2006), most recent surveys for natural enemies have focussed within that region. In instances such as these, species distribution modelling and climate matching techniques would help identify and locate suitable biocontrol agents. These modelling techniques may also be increasingly necessary for making predictions about successful biocontrol agent establishment when confronted with climate change (Olfert et al. 2016).

3.10 Predicting the impact of biocontrol agents

The a priori prediction of biocontrol agent efficacy is more challenging than predicting the likelihood of successful establishment (Cock et al. 2015). Factors affecting the likelihood of establishment (e.g. climate, competition, predation, etc.) may also influence the level of impact an agent has on both the target weed and potential non-target species. Preliminary testing significantly reduces the risk of potential harm to native species and ecosystems but criteria for determining a priori agent impacts on target weeds in field situations are less reliable (de Castro-Guedes & de Almeida 2017). The most accurate means to assess the impacts of biocontrol agents in the field is to conduct empirical tests and post-release monitoring (Blossey & Skinner 2000).

As with establishment, increasing the number of released agents can raise the likelihood of successful biological control (Denoth et al. 2002). Two to three agents are generally required to provide effective control of a target weed. However, effective control can also be obtained when the most damaging agent has been identified and released in substantial numbers, rather than multiple biocontrol agents (Denoth et al. 2002). Identifying the agent most likely to effectively control target weed populations is challenging but can substantially reduce the costs of biocontrol programmes.

Higher success rates of weed biocontrol are often achieved when using agents from specific taxonomic groups. A global analysis of establishment rates and weed biocontrol agent success revealed Coleoptera, Hemiptera, and fungal pathogens had the highest proportions of taxa causing heavy impact (or a combination of medium, variable, or heavy impact) to target weeds (Schwarzländer et al. 2018). Two Coleopteran families –

Curculionidae (weevils) and Chrysomelidae (leaf beetles) – have also been identified as the most effective taxa for controlling target weeds (Crawley 1989; Clewley et al. 2012). Of the pathogens, rusts (fungi in the order Pucciniales) are most commonly released for biocontrol of weeds, and they have had an excellent safety record (Barton (née Fröhlich) 2004; Barton 2012).

Parasitism, predation, and interspecific competition can all affect the outcomes of weed biological control programmes. In New Zealand, parasitism was found to be significantly associated with the failure of biocontrol agents to supress weed populations (Paynter et al. 2010). Using agents that do not have a native analogue (i.e. avoiding a closely related and ecologically similar native species to the agent) in the natural fauna is one method of avoiding the detrimental effect of parasitism. This is because it reduces the chance that the biocontrol agent will accumulate parasitoids that specialise on the native analogue as a host (Paynter et al. 2018). Predation is thought to be responsible for significantly reducing the impacts of another four biocontrol agents introduced to New Zealand (Paynter et al. 2018). Using the native analogue approach to predict predation impacts on biocontrol agents is less useful, as predators tend to be generalist feeders (Snyder & Ives 2001; Petráková et al. 2015; Paynter et al. 2018). One method to limit predation risk is to investigate the food webs and trophic structures of the target weed and its potential biocontrol agents in their native range. This may provide insight into how predation impacts can be mitigated or avoided in the introduced range (Paynter et al. 2018). Interspecific competition, especially from other biocontrol agents, can also reduce the efficacy of weed biocontrol programmes. Examples of this include interference competition between *Larinus minutus* Gyll. (Coleoptera: Curculionidae) and *Urophora affinis* Frfld. (Diptera: Tephritidae), two biocontrol agents released against spotted knapweed (*Centaurea stobe* L. ssp. *micranthos*). Interference competition between these agents reduced overall seed destruction of knapweed, relative to the destruction caused by the weevil attacking on its own (Crowe & Bourchier 2006). When considering multiple biocontrol agents for release against target weeds, selecting agents that damage different structures of the target weed (e.g. leaves, flowers, seeds, stems, roots) can help to reduce potential competition.

Prioritising host-specific agents for biological control programmes can help to reduce impact to non-target species. However, some biocontrol agents are highly specialised and, in some cases, can only thrive on certain subspecies, varieties – or even genotypes or forms – of the target weed. For example, the level of impact of the skeletonweed (*Chondrilla juncea* Ledeb.) rust fungus *Puccinia chondrillina* Bubák is significantly correlated to the weed's morphological form (Burdon et al. 1981). New Zealand populations of *S. madagascariensis* are closely related to most Australian populations, which in turn are derived from South African populations (Le Roux et al. 2006). Given this, it would be prudent to focus the search for biocontrol agents in South Africa (specifically the KwaZulu-Natal region) to ensure that natural enemies of *S. madagascariensis* are suitable against populations of the weed in New Zealand.

The human aspect of biocontrol programmes can often affect their efficacy. Consolidating the knowledge and understanding of multiple experts (e.g. scientists) and other professionals (e.g. rangers, farmers) toward systems of interest can help to determine the likelihood of biocontrol success (van Klinken et al. 2016). However, unidentified differences between stakeholders in what constitutes a ‘successful’ biocontrol programme can hamper progress to achieving biocontrol goals. For instance, certain stakeholders may anticipate that biocontrol agent impacts will occur faster than is reasonably feasible, which could negatively affect their impression of the biocontrol programme’s success. As with all biocontrol programmes, a programme targeting *S. madagascariensis* needs clearly defined aims from the outset that are known to all stakeholders, so that the success or failure of the programme can be accurately and objectively assessed.

3.11 Biological control initiatives targeting *Senecio madagascariensis*

Biological control programmes targeting *S. madagascariensis* have been initiated in both Hawaii and Australia. Efforts began in Hawaii in the late 1980s and surveys for candidate biocontrol agents conducted in Madagascar in 1999 by the Hawaii Department of Agriculture (Ramadan et al. 2011; McFadyen & Morin 2012). These surveys identified 11 insects and 1 rust fungus as potential agents, which were imported to Hawaii for host specificity testing (McFadyen & Morin 2012). One insect – the defoliating moth *Secusio extensa* (Lepidoptera: Arctiidae) – was deemed promising (Ramadan et al. 2011) and tested against 71 endemic and naturalised species across 52 genera (Ramadan et al. 2011). In a laboratory setting *S. extensa* lays eggs singly or in batches of up to 62 eggs (Reimer 2008). The larvae have five instars and a pupal stage, and the average life span (from egg to adult) is 41.1 days (Reimer 2008). The larvae, which are most active nocturnally, feed on the plant foliage but can also sever capitula by stripping the outer layers of the stems (Reimer 2008; Krushelnycky et al. 2018). Up to nine generations were produced in laboratory conditions when *S. extensa* were reared on *S. madagascariensis* (Reimer 2008). Although *S. extensa* fed on other Asteraceae species, these were all exotic to Hawaii, and the moth was approved and subsequently released at several sites on Maui and Hawaii Islands in February 2013 (Krushelnycky et al. 2018). Over 65,000 larvae have been reared and distributed to over 35 properties on the two islands (Krushelnycky et al. 2018). The moth was deemed unsuitable for release in Australia because of the extensive number of native *Senecio* species found there (McFadyen & Morin 2012).

Although *S. extensa* has established successfully in Hawaii it has not reached high densities on *S. madagascariensis* there. However, large populations have built up on the introduced Cape ivy, *Delairea odorata* (Krushelnycky et al. 2018). Possible explanations as to why *S. extensa* has failed to build up populations on *S. madagascariensis* in Hawaii include female moths being insufficiently attracted to *S. madagascariensis* plants as ovipositing sites, and that the poor nutritional quality of the plants is preventing large populations from establishing (Krushelnycky et al. 2018). *Delairea odorata* leaves have a higher nitrogen and water content compared to *S. madagascariensis* as well as having a lower carbon:nitrogen ratio and being more palatable (Krushelnycky et al. 2018 and references therein). These qualities may explain why *D. odorata* has acquired large populations of *S. extensa* in Hawaii.

Senecio madagascariensis was declared a biocontrol target in Australia by the Australian Weeds Committee in 1991 (Sheppard et al. 2013). Earlier surveys conducted in Madagascar in 1989 identified two moths (a stem- and root-borer, *Lobesia* sp. [Lepidoptera:Tortricidae] and a flower-feeder, *Phycitodes* sp. [Lepidoptera: Pyralidae]) which were imported into quarantine in Australia for host testing. However, both species failed to be host specific (Sheppard et al. 2013). A subsequent excursion to the KwaZulu-Natal in South Africa identified 11 insect species feeding on *S. madagascariensis* (Sheppard et al. 2013), including two promising species: the flower-head feeder *Homoeosoma stenotea* (Lepidoptera: Pyralidae) and the stem-borer *Melanagromyza* sp. (Diptera: Agromyzidae). However, both species proved difficult for acquiring substantial founder populations and they were not imported for host testing (McFadyen & Morin 2012). Due to funding constraints, the biocontrol project against *S. madagascariensis* in Australia was halted (Olckers et al. 2021).

In 2002, Meat and Livestock Australia funded a project to assess the potential of the rust fungus *Puccinia lagenophorae* as a biocontrol agent. *Puccinia lagenophorae* is native to Australia and found on a range of *Senecio* species (Sheppard et al. 2013) but had been found in association with *S. madagascariensis* in South Africa (Morin et al. 2009). Samples of the rust fungus (referred to as *Aecidium* sp.; Morin et al. 2009) were collected from eight sites in KwaZulu-Natal to test for virulence against *S. madagascariensis*. Genetic sequencing showed that the collected isolates were a mixture of both *P. lagenophorae* and interspecific hybrids with *P. lagenophorae* as one of the parents (Sheppard et al. 2013). These South African isolates were less virulent than Australian *P. lagenophorae* isolates against Australian *S. madagascariensis* plants and were thus deemed unfit for use as a biocontrol agent (Sheppard et al. 2013).

In 2010 a collaboration between CSIRO Australia and the University of KwaZulu-Natal recommenced the *S. madagascariensis* biocontrol programme in Australia. Surveys were conducted in KwaZulu-Natal in 2011 and 2012 and 15 insects were shortlisted as biocontrol candidates (Olckers et al. 2021). Five of these species – a root feeder, a capitulum and stem borer, a capitulum borer and two stem borers – were prioritised for further assessment in South Africa (Olckers et al. 2021). Assessments to date have focused on monthly surveys of *S. madagascariensis* populations in South Africa and those of closely-related *Senecio* species to determine the seasonal abundances of the five insects and assess their host ranges (Singh 2019; Zuma et al. 2021).

The root-feeding flea beetle, *Longitarus basutoensis,* (Chrysomelidae: Galerucinae: Alticini) was initially thought to be the most promising candidate of the five identified insects. However, its host range included other *Senecio* species, so it was deemed too broad for use as a biocontrol agent in Australia (Zuma et al. 2021). The capitulum-boring moths *H. stenotea* and *Platyptilia* sp. (Lepidoptera: Pterophoridae, which also feeds on the stems) were assessed in field surveys and through DNA barcoding and both were found to have more restricted host ranges than *L. basutoensis* (Egli et al. 2020; Singh et al. 2022). However, *H. stenotea* was associated with six non-target *Senecio* species, some of which are more distantly-related to *S. madagascariensis* than native Australian *Senecio* species (Mkhize et al. 2023). Thus, *H. stenotea* may not be suitable as a biocontrol agent in Australia. *Platyptilia* sp. was found to be associated with *S. harveianus* (a member of the *S. inaequidens* species complex) and *S. polyodon* (Mhkize et al. 2023). The congeneric *Playptilia isodactyla* has been highly successful in reducing capitulum production in Australia of the related weed *Jacobaea vulgaris* (Mhkize et al. 2023). Given this, and the considerable damage it can cause to both capitula and stems, the unidentified *Platyptilia* sp. was prioritised as a candidate agent in Australia (Mhkize et al. 2023). The two stem-boring insects *Gasteroclisus tricostalis* (Coleoptera: Curculionidae) and *Metamesia elegans* (Lepidoptera: Tortricidae) have both demonstrated restricted host ranges in past host specificity testing and are being considered as potential biocontrol agents in Australia (Egli et al. 2020; Singh et al. 2022; Mhkize et al. 2023). However, similar taxa to *M. elegans* have been recovered from *S. madagascariensis* in Australia, which may reduce its potential as a biocontrol agent in Australia (Holtkamp & Hosking 1993; Harvey et al. 2015; Egli & Olckers 2020). Furthermore, *G. tricostalis* host specificity tests at CSIRO, Australia have shown the weevil to have a broad host range under no-choice conditions (Ben Gooden, CSIRO Senior Research Scientist, pers. comm.). Several native Australian plant species can support development of F1 (first generation) adults and received significant stem damage. Multichoice trials have just begun to test whether the non-target plants are the preferred hosts for the weevil or not (Ben Gooden, CSIRO Senior Research Scientist, pers. comm.). In previous host specificity testing the weevil had shown to be highly host specific to the *Senecio inaequidens* species complex and caused significant damage to host plant stems (Egli & Olckers 2020; Gooden et al. 2021). Adult feeding damage on leaf tissue is minor relative to the extensive damage caused by larvae, which can hollow out the central pith of stems, leading to stem collapse (Gooden et al. 2021). Two weevil lineages were identified from *S. madagascariensis*, *S. inaequidens* and *S. skirrhodon* (Singh 2019) with adults appearing identical morphologically – and both are assumed to be maternal lineages of *G. tricostalis* (Olckers et al. 2021). The weevil has been imported into quarantine in Hawaii for host specificity testing and DNA barcoding using nuclear markers will be used to ascertain if these are maternal lineages or cryptic species (Olckers et al. 2021).

4 Methods

4.1 Identifying arthropod biocontrol agents for *Senecio madagascariensis*

We compiled a table (see Appendix 2) containing a list of arthropod herbivores that have been reported as associated with *S. madagascariensis* in both its introduced and native range world-wide. Information for this table was acquired by searching online databases, relevant internet sites and consulting with overseas experts. The following online databases were used:

- HOSTS – a Database of the World's Lepidopteran Hostplants, the Natural History Museum's world listing (Robinson et al. 2010): https://www.nhm.ac.uk/our-science/data/hostplants/search/index.dsml
- CABI Invasive Species Compendium (CABI 2023a): https://www.cabi.org/ISC

CAB abstracts, Current Contents, Google, Google Scholar, and Web of Science were searched using the terms '*Senecio madagascariensis*' or '*Senecio bakeri*' or '*Senecio burchellii*' or '*Senecio incognitus*' or '*Senecio junodianus*' or '*Senecio ruderalis*' or 'Madagascar ragwort' or 'fireweed' or 'Madagascar groundsel' and 'invertebrate*' or 'arthropod' or 'insect' or 'herbivor*'. It was important to include synonyms in the search terms in case they are used in literature and online sources.

4.2 Identifying fungal pathogens of *Senecio madagascariensis*

We compiled a table (see Appendix 3) of the fungi reportedly associated with *S. madagascariensis*. The information was obtained by searching online databases and internet sites. Online databases searched included:

- Biota of New Zealand (BiotaNZ) – Fungi database (Manaaki Whenua – Landcare Research 2023): https://biotanz.landcareresearch.co.nz/
- Kew Royal Botanic Garden Plants and Fungi species browser: https://www.kew.org/science-conservation/plants-fungi/species-browser
- USDA Fungus-Host Database (FDSM) (Farr & Rossman 2023): https://nt.ars-grin.gov/fungaldatabases/fungushost/fungushost.cfm
- Index Fungorum database: https://www.speciesfungorum.org/Names/Names.asp)
- MycoBank database: https://www.mycobank.org/quicksearch.aspx

In addition, Web of Science, Google, Google Scholar, Science Direct and CAB Abstracts were searched for associations and information using the terms '*Senecio madagascariensis*' or '*Senecio bakeri*' or '*Senecio burchellii*' or '*Senecio incognitus*' or '*Senecio junodianus*' or '*Senecio ruderalis*' or 'Madagascar ragwort' or 'fireweed' or 'Madagascar groundsel' and 'fung* or pathogen*'. Once a list was created, we sought further information about each fungus the published literature as well as in the previously mentioned online databases.

5 Results

5.1 Arthropods associated with *Senecio madagascariensis*

Seventy-four species of arthropods – all insects – were found to feed on *S. madagascariensis* (Appendix 2). These species were from six insect orders: Coleoptera (*n* = 10 spp.), Diptera (*n* = 19 spp.), Hemiptera (*n* = 24 spp.), Hymenoptera (*n* = 1 sp.), Lepidoptera (*n* = 18 spp.), and Thysanoptera (*n* = 2 spp.). Hemiptera had the most species (32.4% of total) recorded as feeding on *S. madagascariensis.* Many of the species were unidentified (indetermined species, *n* = 20; species identified to genus, *n* = 9), particularly in the orders Diptera and Hemiptera (Appendix 2).

A majority of species (*n* = 40) had no information on host specificity, which is unsurprising given that many species could not be identified, or only partially identified. Twenty species were polyphagous, and twelve species were considered specific to the tribe Senecioneae. Only three species were considered highly host specific: the weevil *Gasteroclisus tricostalis*, the plume moth *Platyptilia* sp., and the tortrix moth *Metamesia elegans*. Native range surveys in the KwaZulu-Natal region between 2011 and 2017 reported the three species as being host specific to the *Senecio inaequidens* species complex and highly damaging (Egli & Olckers 2020). However, DNA barcoding revealed that *Platyptilia* sp. also feeds on *S. polyodon* (Mkhize et al. 2023) and recent host testing of *G. tricostalis* has shown it to complete development and cause severe damage to several Australian native *Senecio* species in no-choice host testing (Ben Gooden, CSIRO Senior Research Scientist, pers. comm., August 2023). These three species are all stem borers and *Platyptilia* sp. also attacks the capitula. *G. tricostalis* is currently undergoing multichoice host specificity testing in Australia, but the other two agents have been deemed non-viable.

5.2 Fungal pathogens associated with *Senecio madagascariensis*

Four obligate biotrophic fungi and one oomycete have been recorded from *S. madagascariensis* including the rust fungus *Puccinia lagenophorae* and putative hybrids, *Aecidium* sp., a flower smut, *Ustilago* sp., white smut sp. nr. *Entyloma calendulae* and white blister (rust) disease caused by *Pustula* (= *Albugo*) *tragopogonis*, an oomycete. Two species could not be identified to species level but their impact on *S. madagascariensis* is discussed.

Fungal pathogens isolated from *S. madagascariensis* caused damage to leaves, stems and flowers. The fungi and their symptoms are outlined below.

- The rust fungus *Puccinia* nr. *lagenophorae*, endemic to Australasia, is a cosmopolitan species and causes swelling on the stems and leaves. *Puccinia lagenophorae* has spread to exotic host species such as *Bellis perennis*, *Calendula officinalis*, *Pericallis cruenta* and *Senecio vulgaris* in New Zealand (McKenzie 1998). It is known to be very destructive on *B. perennis* when they are grown as ornamental bedding plants (Dingley 1969). South African rust accessions, collected from *S. madagascariensis* during surveys for biocontrol agents (Morin et al. 2009) revealed a single accession identified as *P. lagenophorae* sensu lato. The remaining South African rust accessions were a mix of *P. lagenophorae* and interspecific hybrids. However, the South African accessions were no more virulent that the Australian isolates and considered unsuitable for release in Australia (Morin et al. 2009; Olckers et al. 2021).
- Another rust fungus, *Aecidium* sp. associated with South African *S. madagascariensis*. The *Aecidium* sp. found on the South African *S. madagascariensis* is a first record of a rust fungus occurring on the species (Morin et al. 2009). However, the South African *Aecidium* sp. isolates are of putative hybrid origin, with *P. lagenophorae* sensu lato as one of the parents.
- An oomycete, *Pustula tragopogonis* is the causal agent of the white blister (rust) disease of *Tragopogon* spp. (Holtkamp & Hosking 1993).
- A flower smut fungus, *Ustilago* sp. found on the flowerheads of *S. madagascariensis* in South Africa. Smut fungi are known pathogens of seeds and flowers and mostly infect angiosperms They often causing diseases of economic importance, especially in cereals. They form masses of dark, powdery spores in the leaves, stems, flowers, or fruits of their host plants (Allaby 2013).
- White smut leaf spot pathogen, sp. nr. *Entyloma calendulae* (Sheppard et al. 2015). This leaf smut occurs throughout New Zealand on *Calendula* (Dingley 1969). Cunningham (1945) noted that it is sometimes serious and reduces the calendulas' ornamental value.

Other fungi, identified during field surveys of *S. madagascariensis* in South Africa, included *Alternaria* sp., *Leptoshaerulina* sp., and *Phoma herbarum* (Bega Valley Fireweed Association 2008, 2023). The fungi and their symptoms of these fungi are outlined below.

- Saprophytic fungi *Alternaria* sp. found on dead *S. madagascariensis* material in South Africa.
- Leaf blight caused by *Leptosphaerulina* sp. is a weakly pathogenic fungus on *S. madagascariensis* in South Africa.
- *Phoma herbarum* is a cosmopolitan species in nature and infects various plant species. Fungi belonging to *Phoma* commonly occur on economically important crop plants where they can cause plant diseases. Symptoms range from leaf blight to root rot, and even wilting of the plant (Deb et al. 2020). However, they occur as saprophytes on a wide range of plants.

6 Conclusions

Much research has been conducted into the insect fauna and pathogens associated with *S. madagascariensis*, particularly in its native South Africa and Madagascar, and in the introduced range of Australia. Many of these species have not been identified, making it difficult to determine whether they are host specific and sufficiently damaging to the target weed. Despite this, five species (three insects and two fungal pathogens) had in previous studies been deemed as highly specific to *S. madagascariensis* or to the *S. inaequidens* species complex, of which *S. madagascariensis* is a member. However, more recent research into the host specificity of two of these agents have revealed they may not be as host specific as once believed.

The rust fungus *Aecidium* sp., despite being found only on *S. madagascariensis* in South Africa, may not be suitable as a biocontrol agent in New Zealand, and has been disregarded as a potential agent in Australia. This is because the rust fungus, which is an interspecific hybrid between *P. lagenophorae* and an unknown parent (Morin et al. 2009) was deemed less virulent than Australian *P. lagenophorae* (Sheppard et al. 2013), meaning that the damage it causes to *S. madagascariensis* may be insufficient. *Puccinia lagenophorae* is also indigenous to New Zealand (Manaaki Whenua – Landcare Research 2023) and may provide better control of *S. madagascariensis* here than the *Aecidium* sp. hybrid.

The smut fungus *Ustilago* sp. may be a promising agent, but more research would be needed to determine its suitability. This may include genetic analysis to determine what species it is, or at the very least determine what species are closely related to it within the *Ustilago* genus. Although it was only found on *S. madagascariensis* in South Africa, host specificity testing would be needed to ascertain whether it has a broader host range and to assess if it is sufficiently damaging. Other *Ustilago* species have been considered as biocontrol agents, including *U. sporoboli-indici* as an agent against invasive *Sporobolus* grasses in Australia (Steinrucken & Vitelli 2023) and a black smut (*Ustilago* sp.) against *Cortaderia jubata* in New Zealand. If proven to be host specific and highly damaging, it may make a complementary agent to the stem boring insects that have so far been considered as biocontrol agents for *S. madagascariensis*, given that *Ustilago* sp. attacks the flowers of its host.

The moth *Platyptilia* sp. also attacks the capitula, as well as feeding on the stems. This species looked to be highly damaging to both plant parts in the KwaZulu-Natal region of South Africa (Egli & Olckers 2020). However, reports from Australia suggest that it is less damaging than first anticipated and unravelling the taxonomy of the species was difficult (Ben Gooden, CSIRO Senior Research Scientist, pers. comm., August 2023). It was also found to feed on *S. harveianus* (a member of the *S. inaequidens* species complex) and the more distantly-related *S. polyodon* (Mhkize et al. 2023). For these reasons, *Platyptilia* sp. was deemed non-viable as a biocontrol agent in Australia (Ben Gooden, CSIRO Senior Research Scientist, pers. comm., August 2023). This may also mean *Platyptilia* sp. would not be a suitable agent in New Zealand. If it were to be considered, extensive host testing of native New Zealand *Senecio* will need to be conducted to ensure that *Platyptilia* sp. does not cause unacceptable levels of damage to these native *Senecio* species.

The tortrix moth *Metamesia elegans* has been reported as highly damaging to stems (Egli & Olckers 2020) and is restricted to the *S. inaequidens* species complex (Egli et al. 2020). However, native analogues of *M. elegans* were found feeding on *S. madagascariensis* in Australia, meaning its efficacy as a biocontrol agent may be diminished there due to competition with these native analogues (Holtkamp & Hosking 1993; Harvey et al. 2015; Egli & Olckers 2020). It has also proven difficult to rear, with the University of KwaZulu-Natal unable to collect *Metamesia* in the field, nor unable to establish a culture after 3 years of attempting to do so (Ben Gooden, CSIRO Senior Research Scientist, pers. comm., August 2023). Like *Platyptilia* sp., *Metamesia* has been deemed unviable as a biocontrol agent in Australia. If a New Zealand biocontrol programme for *S. madagascariensis* were to consider *M. elegans* as a potential agent, it would rely on a culture being produced for host testing, but given previous failed attempts, it may not be possible. It would also be crucial to conduct surveys of *S. madagascariensis* in New Zealand to identify arthropod herbivores associated with the weed target and any native analogues that may reduce the efficacy of *M. elegans*.

The stem-boring weevil *Gasteroclisus tricostalis* has been the most obvious candidate to pursue as a biocontrol agent against *S. madagascariensis* in Australia. This is because it was thought to be a highly damaging species that is restricted in its host range to the *S. inaequidens* species complex (Gooden et al. 2021). This species has already undergone host range testing in Hawaii and an anticipated release there is expected within the next two years (Ramadan et al. 2023). Unlike New Zealand and Australia, Hawaii lacks native species in the tribe Senecioneae (Ramadan et al. 2011) so it would be an ideal agent there. *Gasteroclisus tricostalis* is also undergoing host testing at CSIRO's Black Mountain laboratories in Canberra, Australia and at the University of KwaZulu-Natal, South Africa, to ascertain if it is a suitable biocontrol agent for release in Australia (Gooden et al. 2021). However, no-choice tests have shown it can develop on a range of native Australian *Senecio* species and can also cause significant damage to them (Ben Gooden, CSIRO Senior Research Scientist, pers. comm., August 2023). Multichoice tests are about to start, and it will be interesting to see the results of these. However, thus far it seems that *G. tricostalis* may not be as suitable an agent against *S. madagascariensis* as once believed.

Although initially thought to be promising, *Platyptilia* sp., *M. elegans* and *G. tricostalis* have all proven to be, in one form or another, unacceptable as biocontrol agents against *S. madagascariensis* in Australia. *Gasteroclisus tricostalis* still needs to complete multichoice host testing to ascertain whether *S. madagascariensis* is its primary host, but the results of the no-choice tests suggest it is unlikely to be a viable agent in Australia or New Zealand.

This would mean that, with the possible exception of the smut fungus *Ustilago* sp., there are currently no alternative candidates suitable as biocontrol agents against *S. madagascariensis*. Further surveys within the native range would normally be deemed appropriate but extensive surveying has already been conducted in the KwaZulu-Natal region of South Africa, from where introduced populations of *S. madagascariensis* on Hawaii and Australia are believed to have been derived (Le Roux et al. 2006). However, surveys in other parts of South Africa (such as the Eastern and Western Capes) or other countries that *S. madagascariensis* is native to may still be warranted.

Interestingly, genetic analysis performed by Schmidt-Lebuhn, Egli, Grealy et al. (2022) found two subclades of *S. madagascariensis* samples from New Zealand, Australia, and KwaZulu-Natal: one containing New Zealand samples and most Australian samples, and the other containing the KwaZulu-Natal samples and two Australian samples (Figure 4). This sister group relationship between the KwaZulu-Natal samples and almost all introduced samples from Australia and New Zealand does not support the historical assumption that introduced Australasian populations originated from the KwaZulu-Natal region. If the Australasian populations did originate from KwaZulu-Natal, then the Australasian samples would be expected to be nested within the KwaZulu-Natal samples, which is not the case (Schmidt-Lebuhn, Egli, Grealy et al. 2022). This information may warrant the collection of *S. madagascariensis* samples from other native regions beyond KwaZulu-Natal, to help unravel the origin of New Zealand (and Australian) *S. madagascariensis* populations through genetic analysis. That would be an important initial step in a New Zealand biocontrol programme against *S. madagascariensis*.

If a New Zealand biocontrol programme against *S. madagascariensis* were to commence, it would benefit from the host testing of potential biocontrol agents by researchers in Hawaii, South Africa, and Australia. Collaborations with CSIRO and the University of KwaZulu-Natal could help to reduce time and costs involved with a New Zealand programme. Repeat programmes for developing biocontrol agents historically are cheaper than novel programmes, costing on average NZ$203,000 per agent, with two to three agents often being needed for effective control (Paynter et al. 2015).

While the moth *Secusio extensa* has been released against *S. madagascariensis* in Hawaii, it is unlikely to be a suitable biocontrol agent in New Zealand. This is because *S. extensa* was found to feed on other Asteraceae, including other *Senecio* species (Krushelnycky et al. 2018) and New Zealand has many native *Senecio* species. *Secusio extensa* has already been rejected as a potential agent in Australia because of the high number of native *Senecio* species there.

Finally, *S. madagascariensis* has only recently been identified as being present in New Zealand and its known distribution within the country appears limited to Northland.

Given this, and its potential to detrimentally impact pastureland, it is unlikely that there will be strong opposition towards a biocontrol programme targeting *S. madagascariensis*.

7 Recommendations

- Identify whether collaborations and/or data sharing are possible with CSIRO, University of KwaZulu-Natal, Hawaii Department of Agriculture, and other institutions around collecting samples of *S. madagascariensis* for genetic testing and host specificity testing for potential *S. madagascariensis* agents.
  Estimated cost: $500–$2000.
- Conduct a genetic analysis of populations of *S. madagascariensis* in New Zealand, Australia and within the broader native range. **Estimated cost:** $50,000–$100,000.
- Depending on the results of genetic analyses, conduct further native range surveys (outside of KwaZulu-Natal region) of *S. madagascariensis* to identify potential biocontrol candidate agents. **Estimated cost:** $100,000–$150,000.
- Conduct surveys to identify potential natural enemies of *S. madagascariensis* in New Zealand. This will help identify associated invertebrates and pathogens, such as predators and native analogues, that may affect the efficacy of potential biocontrol agents. It will also help identify if there are any potential biocontrol agents already present in New Zealand (thus avoiding wasting time and effort importing an organism that already occurs here). This information is fundamental for subsequent applications to release novel biocontrol agents. **Estimated cost:** $50,000–$60,000.
- Determine if host testing of agents can be conducted by potential collaborators in South Africa, Australia, or Hawaii, or if host testing would need to be conducted in New Zealand.
  - *If host testing can be done by collaborators*: Arrange for shipment of NZ host test plants and organise subcontract for host testing by collaborating researchers overseas. **Estimated cost:** $55,000–$65,000.
  - *If host testing to be done in NZ*: Arrange shipment of agents into containment and establish rearing colony. **Estimated cost:** $30,000–$60,000 per agent. Undertake host specificity testing of potential agents, particularly for native New Zealand *Senecio* spp. **Estimated cost:** $60,000–$100,000 per agent.
- Apply to release agents in New Zealand from containment (once they have been deemed suitable for release). **Estimated cost:** $55,000–$75,000.
- Undertake mass-rearing and release of agents in New Zealand. **Estimated cost:** $50,000–$100,000 per species.
- Monitor establishment success of agents. **Estimated cost:** $10,000–$50,000.
- Evaluate the success of the project. **Estimated cost:** $100,000.

Note: The estimated costs are in NZ dollars, GST exclusive and are based on 2022/2023 figures. Estimates will need to be updated if work is undertaken beyond these dates, or if complicating factors arise (e.g. imported agents are infected with disease).

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Appendix 1 – Steps in a biocontrol project

A classical biocontrol programme typically works through the following steps. Usually, these steps are performed in a sequential manner, but concurrent activities may occur.

- Explore the project's feasibility. If feasibility is confirmed, proceed with the project.
- Survey the target weed in regions where biocontrol is desired. If potential biocontrol agents are located, explore ways to maximise them. Find ways to mitigate any impediments to the project that may arise.
- Perform molecular studies of the weed to help ascertain the best region in the native range to locate natural enemies.
- Survey weed in native range to detect natural enemies (if not already well-known). Identify and study the life cycles of any natural enemies found.
- Identify the host range for potential biocontrol agents. Cease further work on any species that appear to be unsafe or ineffective.
- Apply to the necessary agencies for permission to release agents.
- Once permission is granted, import the agent(s) and clear through containment. Following this, develop rearing techniques for the agent(s) (if not already known).
- Mass-rear and release agents over several years.
- Monitor the establishment success and dispersal of agents over several years.
- Harvest and redistribute agents.
- Evaluate the success of the project. Decide whether further agents are needed to help control the target weed.

Appendix 2 – Record of arthropods feeding on *Senecio madagascariensis*

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
COLEOPTERA					
Bupestridae	Undetermined jewel beetle	Jewel beetle	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as occasional/rare with very scarce abundance (Egli & Olckers 2020).	Unknown if present in NZ. Damage in South Africa reported as slight (Egli & Olckers 2020). Stem borer.
Cerambycidae	Undetermined longhorn beetle	Longhorn beetle	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as rare with very scarce abundance (Egli & Olckers 2020).	Unknown if present in NZ. Damage in South Africa reported as high (Egli & Olckers 2020). Stem borer.
Chrysomelidae	*Ageniosa badenii* Vogel	Leaf beetle	Native to South Africa (Ramadan et al. 2023)	Specific to Senecioneae species. Considered as a biocontrol agent for *Delairea odorata*. Neonate larvae completed development on *D. odorata*, *Senecio tamoides, S. skirrhodon* and *Gynura procumbens* (Olckers et al. 2021).	Not known from NZ. Adults can cause significant damage to *D. odorata* leaves and larvae are leaf and suspected root-feeders (Grobbelaar et al. 2000).
	Chalcolampra sp. Blanchard, 1853	Leaf beetle	Native to Australia and found feeding on *S. madagascariensis* there (Holtkamp & Hosking 1993).	Possibly specific to *Senecio* spp. Reported as feeding on subspecies of the *Senecio lautus* species complex (Holtkamp & Hosking 1993).	Unknown if present in NZ. Severity of damage high, resulting in significant leaf defoliation (Holtkamp & Hosking 1993).
	Longitarsus basutoensis Bechyné	Leaf beetle	Native to South Africa (Ramadan et al. 2023).	Looks to be specific to Senecioneae. Development during host testing on *S. inaequidens*, *S. skirrhodon*, *S. pinnatifolius* var. *latilobus*, *S. polyanthemoides*, *D. odorata*, and *G. procumbens* (Zuma et al. 2021). Unlikely to be suitable as a biocontrol agent in NZ due to its development on other *Senecio* species.	Not known from NZ. Severity of damage likely to be high. Larvae are root feeders and the adults feed on foliage and flowers (Ramadan et al. 2023).

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
	Undetermined chrysomelid beetle	Chrysomelid beetle	Found in South Africa and Eswatini (Sheppard et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown. Feeds on the roots of plants (Sheppard et al. 2013).
Curculionidae	*Gasteroclisus tricostalis* (Thunberg)	Weevil	Native to Eswatini, Lesotho and South Africa (Ramadan et al. 2023).	Mixed information. Reported as specific to *Senecio inaequidens* species complex during native range surveys in KwaZulu-Natal region between 2011 and 2017 (Gooden et al. 2021). However, no-choice host range specificity testing in Australia has shown it to complete development on several native *Senecio* species (Ben Gooden, CSIRO Senior Research Scientist, pers. comm., August 2023).	Not known from NZ. Damage is high. The adults feed on the leaves but most significant damage is from the stem-boring larvae (Egli & Olckers 2020).
	Proictes longehirtus Fairemaire, 1902	Weevil	Native to Madagascar (Ramadan et al. 2023).	Unknown. Was imported to Hawaii for host testing but colony failed to establish (Ramadan et al. 2023).	Not known from NZ. Severity of damage unknown. The larvae are root borers and the adults feed on foliage and petals (Ramadan et al. 2023).
	?Throgonius sp. L. Fairmaire, 1901	Weevil	Found on *S. madagascariensis* in Madagascar (Sheppard & Olckers 2012).	Unknown.	Not known from NZ. Severity of damage unknown. Stem borer.
Nitidulidae	Undetermined sap beetle	Sap beetle	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as being common/occasional with scarce abundance (Egli & Olckers 2020).	Unknown if present in NZ. Severity of damage recorded as slight in South Africa (Egli & Olckers 2020). Capitulum feeder.

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
DIPTERA					
Agromyzidae	*Liriomyza trifolii* (Burgess, 1880)	Leaf mining fly	Native to North America. Found on *S. madagascariensis* in Madagascar (Sheppard & Olckers 2012).	No. Polyphagous on many different plant species (GBIF 2023c).	Not known from NZ. Damage output can be high and is known as a pest species of plant products (Sheppard & Olckers 2012). Feeds on leaves.
	Melanagromyza seneciophila Spencer, 1963	Stem mining fly	Native to Australia and found on *S. madagascariensis* there (Holtkamp & Hosking 1993).	Likely to be specific to Senecioneae (Spencer 1977).	Not present in NZ. Severity of damage unknown.
	Melanagromyza sp.	Fly	Found in Eswatini, Lesotho, Madagascar, and South Africa (Ramadan et al. 2023).	Unknown.	Not known from NZ. Severity of damage unknown. Larvae are stem borers (Ramadan et al. 2023).
	Undetermined fly 1	Fly	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as very common and abundant (Elgi & Olckers 2020).	Unknown if present in NZ. Severity of damage reported as low in South Africa (Egli & Olckers 2020). Capitulum feeder.
	Undetermined fly 2	Fly	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as very common with scarce abundance (Egli & Olckers 2020).	Unknown if present in NZ. Damage in South Africa reported as slight (Egli & Olckers 2020). Stem borer.
	Undetermined fly 3	Fly	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as very common/occasional with very scarce abundance (Egli & Olckers 2020).	Unknown if present in NZ. Damage in South Africa reported as slight (Egli & Olckers 2020). Leaf miner.
	Phytomyza syngenesiae (Hardy, 1849)	Leaf mining fly	Palaearctic native distribution. Found on *S. madagascariensis* in Australia (Holtkamp & Hosking 1993).	No. Feeds on species of the daisy family, as well as *Senecio* spp. (Manaaki Whenua – Landcare Research 2023).	Present in NZ. Damage severity can be high.

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
Cecidomyiidae	Undetermined gall midge 1	Gall midge	Found in South Africa (Sheppard et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown. Feeds on flowers (Sheppard et al. 2013).
	Undetermined gall midge 2	Gall midge	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as occasional with very scarce abundance (Egli & Olckers 2020).	Unknown if present in NZ. Damage in South Africa reported as slight (Egli & Olckers 2020). Stem borer.
Sciaridae	Undetermined dark-winged fungus gnat	Dark-winged fungus gnat	Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unknown.	Unknown if present in NZ. Damage severity unknown. Bores into pith of stems and roots (Sheppard & Olckers 2012).
Tephritidae	*Coelopacidia strigata* Bezz	Tephritid fly	Native to Ghana, Uganda, Kenya, Malawi, Zimbabwe, South Africa (Hancock 2019).	Specific to *Senecio* species in KwaZulu-Natal and reared for one generation on *S. madagascariensis* (Ramadan et al. 2023). *S. scoparius* a reported host (Hancock 2019).	Not known from NZ. Damage severity unknown. Larvae are stem borers (Ramadan et al. 2023).
	Cryptophorellia peringueyi (Bezzi, 1924)	Tephritid fly	Native to Uganda, Kenya, Zimbabwe, and South Africa (Wikipedia 2023b).	Unknown.	Not known from NZ. Severity of damage unknown. Larvae are flower feeders.
	Sphenella marginata Munro, 1957 Synonym = *S. austrina*	Tephritid fly	Naturally occurs in the Palearctic from Europe to Afghanistan (GBIF 2023d). Found in South Africa and Madagascar in association with *S. madagascariensis*.	Specific to tribe Senecioneae (Ramadan et al. 2023). Host specificity testing completed in Hawaii and awaiting release permits (Ramadan et al. 2023).	Not known from NZ. Damage rate high. Larvae feed on flowers, with a preference for unopened flowers (Ramadan et al. 2023).
	Sphenella ruficeps (Macquart, 1851)	Tephritid fly	Native to Australia. Found on *S. madagascariensis* in Northland.	Possibly specific to *Senecio* species (Holtkamp & Hosking 1993).	Present in NZ. Severity of damage unknown. The larvae form galls in the flowers (Hardy & Drew 1996).

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
	Telaletes ochraceus (Loew, 1861)	Tephritid fly	Native to Kenya, Zimbabwe, and South Africa (Wikipedia 2023c).	Unknown.	Not known from NZ. Larvae are flower feeders (Ramadan et al. 2023).
	Trupanea inscia Munro, 1961	Tephritid fly	Native to South Africa (Ramadan et al. 2023).	Unknown. Died out on *S. madagascariensis* after four generations in limited Hawaii host range testing (Ramadan et al. 2023).	Not known from NZ. Severity of damage unknown. Larvae feed on flowers, preferring mature flowers (Ramadan et al. 2023).
	Trupanea sp. 1	Tephritid fly	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported common/occasional with very scarce abundance (Egli & Olckers 2020).	Not known from NZ. Severity of damage in South Africa reported as high (Egli & Olckers 2020). Capitulum feeder.
	Trupanea sp. 2	Tephritid fly	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported common/occasional with very scarce abundance (Egli & Olckers 2020).	Not known from NZ. Severity of damage in South Africa reported as high (Egli & Olckers 2020). Capitulum feeder.
	Undetermined tephritid fly	Tephritid fly	Found in South Africa and Eswatini (Sheppard et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown. Feeds on flowers (Sheppard et al. 2013).
HEMIPTERA					
Aphidae	*Aphis clerodendri* subsp. *clerodendri* Matsumura, 1917 Synonym = *Aphis gossypii*	Aphid	Cosmopolitan species. Found on *S. madagascariensis* in Madagascar (Sheppard & Olckers 2012).	No. Polyphagous pest species.	Present in NZ. Can be a highly damaging pest species. Phloem feeder.
	Aphis solanella Theobold, 1914 Synonym = *Aphis fabae* subsp. *solanella*	Aphid	Found throughout most of Europe, and in Asia, Africa, and South America. Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Known polyphagous pest species.	Not known from NZ. Severity of damage can be high. Phloem feeder.

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
	Brachycaudus helichrysi (Kaltenbach, 1843)	Aphid	Cosmopolitan species. Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Known polyphagous pest species.	Present in NZ. Severity of damage can be high. Phloem feeder.
	Undetermined aphid 1	Aphid	Found on *S. madagascariensis* in Australia (Harvey et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown.
	Undetermined aphid 2	Aphid	Found on *S. madagascariensis* in Australia (Harvey et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown.
	Macrosiphum euphorbiae (Thomas & C., 1878)	Aphid	Native to North America but is now a highly invasive species with a global distribution (CABI 2023b). Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Known polyphagous pest species.	Present in NZ. Likely to be severely damaging. It is a major pest of both greenhouse crops and field crops. Large outbreaks can lead to leaf and stem distortion, leaf roll, necrotic spots on leaves, stunted growth, and ineffective photosynthetic capacity (CABI 2023a).
	Myzus ornatus Doncaster, 1946	Aphid	This species has a global distribution. Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Known polyphagous pest species.	Present in NZ. Damage is likely to be high, as this species is a pest of many crop plants. Phloem feeder.
Cicadellidae	Undetermined leafhopper	Leafhopper	Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unknown.	Unknown if present in NZ. Severity of damage unknown. Phloem feeder.
Coccidae	*Pulvinaria* sp.	Scale insect	Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unknown.	Not known from NZ. Severity of damage unknown.
Lygaeidae	*Nysius albipennis* Distant, 1913	Seed bug	Native to Africa, Reunion Island, Madagascar, Seychelles? Found on *S. madagascariensis* in Madagascar (Sheppard & Olckers 2012).	Unknown. Other *Nysius* spp. Attack *Senecio* spp. In Australia (Sheppard & Olckers 2012).	Not known from NZ. Severity of damage unknown. Attacks seed heads.

Order and Family	**Species**	**Type of organism**	**Geographic range on *S. madagascariensis***	**Likely to be sufficiently host specific?**	**Present in NZ? Likely to be highly damaging?**
	Nysius ?graminicola (Kolenati, 1845)	Seed bug	Mainly found in southeastern Europe and the Mediterranean (Wikipedia 2023d). Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Reported as polyphagous (Ellis 2023).	Not known from NZ. Severity of damage unknown. Attacks seed heads
	Nysius scutellatus Dallas, 1852 Synonym = *Nysius ericae*	Seed bug	Holartic distribution. Found on *S. madagascariensis* in South Africa and Madagascar (Sheppard & Olckers 2012).	Unknown.	Not known from NZ. Severity of damage unknown. Attacks seed heads.
	Nysius ?senecionis (Schilling, 1829)	Seed bug	Found in Asia, Europe and southern Africa. Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unknown.	Not known from NZ. Severity of damage unknown. Attacks seed heads
	Nysius vinitor Bergoth, 1891 Synonym = *Nysius clevelandensis*	Seed bug	Native to Australia. Found on *S. madagascariensis* in Australia (Harvey et al. 2013).	Unlikely. Develops on a range of native and weed hosts and is a pest of numerous crops (Cesar Australia 2023).	Not known from NZ. Severity of damage can be high. Sap sucker that feeds on seed pods.
Miridae	*Ellenia* sp.?	Plant bug	Found in South Africa and Eswatini (Sheppard et al. 2013).	Unknown.	Not known from NZ. Severity of damage unknown. Sap sucking bug.
	Undetermined mirid bug	Plant bug	Found on *S. madagascariensis* in Australia (Harvey et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown.
	Moissonia punctata (Fieber, 1861) Synonym = *Ellenia obscuriconris*	Plant bug	Native to East Africa, from South Africa to Ethiopia to Yemen (Linnavuori & Al-Safadi 1993). Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unlikely. Known pest of potato (Arce 2023).	Not known from NZ. Severity of damage unknown. Sap sucking bug that also attacks flowers.

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
Pentatomidae	*Dictyotus caenosus* (Westwood, 1837)	Shield bug	Native to Australia. Found on *S. madagascariensis* in Northland.	No. Polyphagous on many plants such as *Plantago* species and lucerne.	Present in NZ in both North and South Islands. Sap sucking bug that feeds on developing seeds. Can cause significant damage.
	Nezara viridula (Linnaeus, 1758)	Stink bug	Cosmopolitan, but thought to have originated from Ethiopia (Squitier 1997). Found on *S. madagascariensis* in Northland.	No. Polyphagous on many plants and is a pest of crops.	Present in NZ and widespread. Sap sucking bug that can cause significant damage.
Pseudococcidae	*Tylococcus ?harongae* Mamet, 1950	Mealybug	Found on *S. madagascariensis* in Madagascar (Sheppard & Olckers 2012).	Unknown.	Not known from NZ. Severity of damage unknown. Phloem feeder.
Tettigometridae	*Hilda elegantula* Melichar, 1905	Leafhopper	Found in South Africa (Ramadan et al. 2023).	Unknown. Reared for one generation (Ramadan et al. 2023).	Not known from NZ. Severity of damage unknown. Sap sucker.
	Nototettigometra patruelis (Stål, 1855) Synonym = *Hilda patruelis*	Leafhopper	Found in South Africa (Egli & Olckers 2020). Also reported from Botswana and Zimbabwe (iNaturalist 2023).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as common and very abundant (Egli & Olckers 2020).	Not known from NZ. Damage in South Africa reported as slight (Egli & Olckers 2020). Sap sucker.
Tingidae	*Ammianus* sp.	Lace bug	Found in South Africa (Egli & Olckers 2020).	Unknown. Incidence on *S. madagascariensis* in South Africa reported as rare with scarce/very scarce abundance (Egli & Olckers 2020).	Not known from NZ. Damage in South Africa reported as slight (Egli & Olckers 2020). Sap sucker.
	Undetermined lace bug	Lace bug	Found in South Africa (Ramadan et al. 2023).	Unknown. Colony died out in Hawaii in containment (Ramadan et al. 2023).	Unknown if present in NZ. Severity of damage unknown. Sap suckers with nymphs and adults on foliage.

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
HYMENOPTERA					
Eucoilidae	*Diglyphosema* sp. Förster, 1869	Parasitoid	Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unknown.	Not known from NZ. Severity of damage unknown. Stem borer that likely parasitises agromyzids (Sheppard & Olckers 2012).
LEPIDOPTERA					
Crambidae	*Udea ferrugalis* Hübner, 1796	Grass moth	Native to Central Europe. Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Polyphagous on a variety of plants and sometimes considered a pest.	Not known from NZ. Damage likely to be high. Feeds on leaves.
Erebidae	*Nyctemera amica* Meyrick, 1886	Magpie moth	Native to Australia. Found on *S. madagascariensis* in Australia (White et al. 2008).	Unlikely. Restricted to *Senecio* species but feeds on native Australian *Senecio* species (White et al. 2008).	Present in NZ. Severity of damage can be high (Holtkamp & Hosking 1993).
	Nyctemera annulata Boisduval	Tiger moth	Endemic to NZ. Found on *S. madagascariensis* in Northland.	No. Polyphagous, feeding on plants of Asteraceae such as ragwort and *Cineraria* (Manaaki Whenua – Landcare Research 2023).	Widespread in NZ. Severity of damage unknown. Caterpillars feed on foliage.
	Podomachla apicalis Walker, 1854	Erebid moth	Native to South Africa and Tanzania (Ramadan et al. 2023).	No. Polyphagous on tribes of Senecionae and Helanthae (Ramadan et al. 2023).	Not known from NZ. Severity of damage unclear. Partial no choice specificity tests undertaken but colony died out (Ramadan et al. 2023).
	Secusio extensa (Butler)	Erebid moth	Native to Madagascar (Ramadan et al. 2023)	Specific to tribe Senicioneae (Ramadan et al. 2023). Deemed unsuitable as a biocontrol agent in Australia due to the number of native *Senecio* species there.	Not known from NZ. Severity of damage substantial. Larvae are defoliators and may sever capitula (Reimer 2008). Released in 2013 in Hawaii as biocontrol agent.
Geometridae	Undetermined geometer moth	Geometer moth	Found on Madagascar (Sheppard & Olckers 2012).	Unknown.	Unknown if present in NZ. Severity of damage unknown. Attacks leaves.

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
Noctuidae	*Condica conducta* Walker, 1857	Owlet moth	Native to Africa (South Africa, Congo, Madagascar, Réunion Island (Wikipedia 2023e). Recorded on *S. madagascariensis* from Madagascar (Sheppard & Olckers 2012).	No. Known generalist of Asteraceae (Sheppard & Olckers 2012).	Not known from NZ. Severity of damage unknown. Attacks leaves.
	Thysanoplusia orichalcea (Fabricius, 1775)	Owlet moth	Native to Indonesia. Recorded on *S. madagascariensis* from Madagascar (Sheppard & Olckers 2012).	No. Known polyphagous pest species (Sheppard & Olckers 2012).	Present in NZ (recorded in Auckland; Manaaki Whenua – Landcare Research 2023). Damage output high. Attacks leaves.
Pterophoridae	*Platyptilia* sp.	Plume moth	Found in Eswatini, Lesotho, Madagascar, and South Africa (Ramadan et al. 2023).	Specific to *Senecio* spp. Found to be associated with *S. harveianus* (a member of the *S. inaequidens* species complex) and *S. polyodon* (Mhkize et al. 2023).	Not known from NZ. Can cause significant damage to capitula and stems, despite low abundance in its native range of KwaZulu-Natal (Mkhize et al. 2023).
	Undetermined plume moth	Plume moth	Found in South Africa (Sheppard et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown. Feeds on flower (Sheppard et al. 2013).
Pyralidae	*Homoeosoma stenotea* Hampson, 1926	Snout moth	Native to South Africa and Zimbabwe (Wikipedia 2023f).	Associated with six non-target *Senecio* species, some of which are more distantly-related to *S. madagascariensis* than native Australian *Senecio* species (Mkhize et al. 2023). Disregarded as an agent for Australia (Ramadan et al. 2023).	Not known from NZ. Larvae highly damaging to capitula (Mkhize et al. 2023).
	Undetermined pyralid moth	Pyralid moth	Found on *S. madagascariensis* in Australia (Harvey et al. 2013).	Unknown.	Unknown if present in NZ. Severity of damage unknown.
	Patagoniodes farinaria (Turner, 1904)	Pyralid moth	Native to Australia and New Zealand. Found on *S. madagascariensis* in Australia (Holtkamp & Hosking 1993).	Specific to Senecioneae (Manaaki Whenua – Landcare Research 2023).	Present in NZ. Damage can be high, with larvae ringbarking stems and killing many plants (Holtkamp & Hosking 1993).

Order and Family	Species	Type of organism	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
	Phycitodes sp.	Pyralid moth	Found in South Africa and Eswatini (Sheppard et al. 2013).	Unknown.	Not known from NZ. Severity of damage unknown. Feeds on flowers (Sheppard et al. 2013).
Tortricidae	*Epichoristodes acerbella* (Walker, 1864)	Tortrix moth	Native to Africa. Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	No. Polyphagous on a variety of plants and a pest of carnations and other floral crops (Gilligan & Epstein 2014).	Not known from NZ. Can cause serious damage to floral crops. Larvae feed in rolled leaves, flower buds, flower petals, fruit surfaces and stems (Gilligan & Epstein 2014).
	Undetermined tortrix moth	Tortrix moth	Found on *S. madagascariensis* in South Africa (Sheppard & Olckers 2012).	Unknown.	Unknown if present in NZ. Not very damaging. Stem-boring in pith (Sheppard & Olckers 2012).
	Lobesia sp.	Tortrix moth	Found in Eswatini, Lesotho, Madagascar, and South Africa (Ramadan et al. 2023).	No. Host testing showed it was not host specific (Sheppard et al. 2013).	Not known from NZ. Severity of damage unknown. Reared in Australia with limited testing, but colony died out. Larvae are stem, tip, and rot borers (Sheppard et al. 2013; Ramadan et al. 2023).
	Metamesia elegans (Walsingham, 1881)	Tortrix moth	Native to South Africa (GBIF 2023b).	Yes. Associated with species of the *S. inaequidens* species complex, but not more distantly-related *Senecio* species (Egli et al. 2020).	Not known from NZ. Severity of damage reported as high (Egli & Olckers 2020). Stem borer.
THYSANOPTERA					
Phlaeothripidae	*Haplothrips nigricornis* (Bagnall, 1910)	Thrip	Native to southeast Africa and also recorded in Yemen and India. Found on *S. madagascariensis* in Madagascar (Sheppard & Olckers 2012).	Unlikely. Potential pest of sunflower (Sheppard & Olckers 2012).	Not known from NZ. Severity of damage unknown. Attacks seed heads.
Thripidae	*Pseudanaphothrips achaetus* (Bagnall, 1916)	Thrip	Native to Australia.	No. Highly polyphagous (OzThrips 2023).	Present in NZ. Severity of damage unknown.

Appendix 3 – Records of fungal pathogens associated with *Senecio madagascariensis*

Phylum/ Order/ Family	Species[1]	Symptoms or lifestyle	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
ASCOMYCOTA					
Pleosporales					
Pleosporaceae	*Phoma herbarum* Westend.	Plant pathogen; saprophyte	South Africa	No. Common on various plant species (Hallgrímsson & Eyjólfsdóttir 2004).	Yes. Unlikely to be highly damaging. Not commonly isolated in NZ but occurs as a saprophyte on a wide range of plants (Johnston 1981).
	Alternaria sp.	Saprophytic on *S. madagascariensis*; plant pathogen	South Africa	No. *Alternaria* species are known major plant pathogens (Kirk et al. 2008).	Unknown. Unlikely to be highly damaging. Isolated from dead plant material in South Africa (Bega Valley Fireweed Association 2008).
Didymellaceae	*Leptosphaerulina* sp.	Weakly pathogenic; saprophytic	South Africa	No. Species of *Leptosphaerulina* are reported as saprobic or parasitic on leaves or stems of various plants including important crop plants (Phookamsak et al. 2013)	Unknown. Unlikely to be highly damaging. Weakly pathogenic and only associated with *S. madagascariensis* in South Africa (Bega Valley Fireweed Association 2008).
BASIDIOMYCOTA					
Entylomatales					
Entylomataceae	*Entyloma calendulae* (Oudem.) de Bary	Leaf smut fungus; leaf spot	South Africa	No. Leaf smut on *Calendula* occurs throughout New Zealand (Dingley 1969). Cunningham (1945) noted that it is sometimes serious and reduces their ornamental value.	Yes. However, only associated with *S. madagascariensis* in South Africa (Sheppard et al. 2015).

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[1] Synonyms (old, invalid names for a taxon) are only given here where that (old) name is the one reported in the literature.

Phylum/ Order/ Family	Species[1]	Symptoms or lifestyle	Geographic range on *S. madagascariensis*	Likely to be sufficiently host specific?	Present in NZ? Likely to be highly damaging?
Pucciniales					
Pucciniaceae	*Puccinia lagenophorae* Cooke	Stem and leaf rust fungus	South Africa, Australia, New Zealand	No. Infects other host species including *Bellis perennis, Calendula officinalis, Senecio cruentus* and *S. vulgaris* (Dingley 1969).	Yes. Common throughout NZ. Can be very destructive under certain condition (Dingley 1969).
Incertae sedis	*Aecidium* sp.	Rust fungus	South Africa	Yes. Only found on *S. madagascariensis* in South Africa. Putative interspecific hybrid between *P. lagenophorae* and unknown parent in South Africa (Morin et al. 2009).	Unknown. Only found on the host plant in South Africa (Morin et al. 2009).
Ustilaginales					
Ustilaginaceae	*Ustilago* sp.	Flower smut fungus	South Africa	Yes. Only identified from infected *S. madagascariensis* flowers in South Africa (Sheppard et al. 2015).	Unknown. Only found on the host plant in South Africa (Sheppard et al. 2015).
OOMYCOTA					
Albuginales					
Albuginaceae	*Pustula tragopogonis* (Pers.) Thines (syn. *Albugo tragopogonis* (Pers.) Gray)	Oomycete; soil borne plant pathogen	South Africa	No. On members of Compositae only.	Yes. Common on a number of indigenous and introduced herbaceous host plants of the Compositae primarily *Gerbera* spp. in NZ. Of minor importance (Dingley 1969).