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Fireweed Control Research (DAFF 179/10)

Final Report on investigation of potential biological control agents in South Africa, including the KwaZulu-Natal province and surrounding areas.

Andy W Sheppard[1] and Terry Olckers[2]

[1] CSIRO Ecosystems Sciences, GPO Box 1700, Canberra, ACT 2601

[2] University of KwaZulu-Natal (Pietermaritzburg), Faculty of Science & Agriculture, School of Biological & Conservation Sciences, Private Bag X01, Scottsville 3209, South Africa

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Executive summary

This final report describes achievements and ongoing progress on fireweed biological control activities undertaken under the Department of Agriculture, Fisheries and Forestry (DAFF) funded project 179/10 with the University of New England (UNE). UNE subcontracted these activities to CSIRO, who in turn subcontracted the majority of the research to the University of KwaZulu-Natal (UKZN) at Pietermarizburg in South Africa. These activities relate to Milestones 3-5 in the head contract, which included the proposed appointment of a post doctoral fellow. Delays in contract negotiations between CSIRO and UKZN and a failure to attract a suitable candidate to the post doctoral fellow position have in turn delayed the delivery of Milestone 5. Following a proposal from CSIRO and UKZN and written agreement from UNE and DAFF, project funding has been redirected towards post graduate fellowships that will continue for two to three years beyond the end of this contract. Results of this research will be reported in future annual progress reports to both parties.

Project investment in South Africa has nonetheless led to significant progress and parallel investments by the UKZN. An MSc student started on the project in South Africa in January 2011 and a post graduate PhD student was appointed to the project in early 2012. Both students are focussing on the invertebrate natural enemies of fireweed in South Africa. Remaining funding is considered sufficient to appoint a second PhD student to study the pathogens of fireweed in South Africa. Also, in recognition of the international importance of native *Senecio* spp. in this region of South Africa, the UKZN is providing a PhD scholarship through the University's John Bews Herbarium to study the taxonomy, genetics and chemistry of native species in this genus in the KwaZulu-Natal region.

This project has so far completed two of three project milestones. The completed Milestones are:

3. Understanding the status of regulations in South Africa that might affect the capacity of Australia to import native South African species for the potential biological control of fireweed.
4. Developing the collaborative capacity with South African research agencies (in particular the UKZN) to undertake the required research of the project.

Activities around Milestone 5; the research into the biological control of fireweed in South Africa, has also led to significant progress.

There is now a clearer understanding of the taxonomic status and ecology of fireweed in South Africa. The taxonomy remains complex and there is a continuum of morphological variation in the region between the native species *Senecio madagascariensis* and *Senecio inaequidens.* Clear separation in the field in South Africa may require genetic approaches. There is, however, an altitudinal divide in the distribution of these two species (based on herbarium specimens and literature records) in the KwaZulu-Natal region. *Senecio madagascariensis* is only found from the coast to sites in the midlands below 1000m asl. While greater clarity will be sought through further taxonomic studies at UKZN, for the purposes of this biological control program, studies have focussed on sampling plants and populations of the relevant *Senecio* morphotypes only below 1000m asl.

Information of the ecological drivers of fireweed abundance in the native range has also been obtained. Fireweed is much less abundant in South Africa than in Australia. In South Africa it is largely a roadside plant with very few paddock populations and mostly associated with agricultural activities (cropping and pastoral). We concluded that the main ecological drivers determining the quite low fireweed abundance in South Africa were: a) disturbance – plants are most commonly seen along roadsides; b) rainfall and fire management regimes – winter drought promotes the use of fire to rejuvenate grasslands and opens up space for fireweed recruitment; and c) a warm summer wet season promotes strong perennial grass growth suppressing fireweed by the end of the summer. There was little observational evidence that natural enemies are regulating fireweed populations in South Africa.

Studies on the natural enemies in South Africa under this project have built on historical (for Australia) and ongoing studies (for Hawaii conducted by the Hawaiian Department of Agriculture), which targeted a range of related *Senecio* species and genotypes in Africa and Madagascar beyond *S. madagascariensis* sensu stricto and its currently known native range. We now have a clearer understanding of the invertebrate natural enemy community found feeding on *S. madagascariensis* in the KwaZulu-Natal region. We are also starting to acquire clearer information on the identity and on the levels of specificity of some of these natural enemies by studying their occurrence on other sympatric native *Senecio* species. The project currently has a list of at least 18 invertebrates and three fungi on fireweed in South Africa that are considered likely to be *Senecio* specialists, by quantitatively sampling fireweed populations in space and time across more than 20 sites.

Future research this project will undertake based on current funding includes:

- studies in more depth of the community of plant pathogens on fireweed in South Africa
- multi-year field observations at three sites on the population dynamics of *S. madagascariensis,* including data on the associated pasture competition and the presence of any natural enemies.
- experiments on the impacts of augmenting *S. madagascariensis* density on the abundance of specific natural enemies in the field as an assessment of their impacts.
- experiments on the impacts of natural enemies by exclusion using the controlled use of insecticides and fungicides

Only once one or more potential biological control agents have been identified and considered to be both specific enough for introduction and have the capacity to control fireweed in Australia, will an application be made to import this agent into Australia for further risk assessment studies.

Research for the Biological Control of Fireweed (*Senecio madagascariensis*) for Australia

1 Background and Introduction

1.1 Background

Fireweed (*Senecio madagascariensis* Poir., Family Asterceae) was declared a target for biological control by the Australian Weeds Committee in 1991. Early on it was recognised that what makes this plant a difficult target for weed biological control in Australia is the taxonomic close proximity of fireweed to a group of Australian native species in the *Senecio pinnatifolious* A.Rich. (= *S. lautus*) group (Scott et al. 1998; Pelser et al. 2002). Hybridization can also occur between these native species and fireweed, even if the progeny are sterile (Prentis et al. 2007). Initial studies were focussed on a) surveys of the native range and b) understanding the natural enemies of fireweed already in Australia.

The first surveys for biological control agents of fireweed in its native range were undertaken by Jennifer Marohasy (1989) in Madagascar with funding support from Meat and Livestock Australia. This country was considered, at the time, to be within the native range of fireweed. Marohasy (1991) also made a short trip to South Africa in the KwaZulu-Natal region and found 22 species of insects on fireweed of which 11 were considered quite specific. The results of all early surveys, including surveys made by Dr Mohsen Ramadan for Hawaii, are presented in **Appendix A**.

In Australia, surveys were undertaken by Dr John Hosking and Dr Royce Holtkamp of NSW Agriculture in 1992-1993. Surveys included fireweed and closely related and associated *Senecio* spp. in the *S. pinnatifolious* group. Holtkamp and Hosking (1993) found 30 insects common to *S. lautus* group and fireweed in SE Australia, including the chrysomelid beetle *Chalcolampra* sp., the arctiid moth *Nyctemera amica* (White), the pyralid moth *Patagoniodes farianara*, two agromyzid and two tephritid flies. They also found two fungal pathogens, the cosmopolitan rust *Puccinia lagenophorae* Cooke and the smut *Albugo tragopogonis* (Pers.) S.F. Gray. They argued this shared community of natural enemies was further evidence of close taxonomic proximity between *S. madagascariensis* and the *S. pinnatifolious* group.

Two moths, a flower feeding pyralid (*Phycitodes* sp.) and a root-feeding tortricid (*Lobesia* sp.) were imported from Madagascar into quarantine in Australia in the early 1990's and tested for their specificity to fireweed. Neither was found to be specific enough for release into Australia (McFayden and Sparks 1996). No further work was undertaken in Australia on insect biological control agents prior to this project.

From genetic studies in Australia (Scott et al. 1998, Radford et al. 2000) and for the management of the closely related species *Senecio inaequidens* DC. in Europe (Lafuma et al. 2003) it was realised that the native range of *S. madagascariensis* is confined to the KwaZulu-Natal region of South Africa.

In 2002-2003, Dr Louise Morin undertook a short project funded by the Shoalhaven City Council (Morin 2003). The aim of the project was to provide an initial assessment of accessions of a rust fungus from South Africa for the biological control of fireweed in Australia in order, if appropriate, to justify longer-term funding for extensive host-specificity testing. Populations of fireweed from around KwaZulu-Natal were sampled and seven isolates of the rust were collected. Taxonomic studies and sequencing evidence confirmed these rust accessions were a mix of *P. lagenophorae* and interspecific hybrids with *P. lagenophorae* as one of its parents (Morin et al. 2009). These rust accessions infected Australian fireweed plants and some failed to penetrate *S. pinnatifolious* subsp. *lanceolatus* (Benth.) I.Thomps. in trials. However, in the trials the South African rust accessions were found to be less virulent than Australian accessions of *P. lagenophorae* suggesting that their introduction would be unlikely to bring about greater impact on fireweed than the accessions already naturally present.

Based on this information and the continued lack of known candidate agents specific enough for use against fireweed in Australia, a review of the potential for the biological control of fireweed was presented at the National Fireweed Conference at Bega in May 2008 (Bega Valley Fireweed Assoc. 2008). The scientific case for a continuing biological control program against fireweed in Australia has been quite challenging, driven by the need for both monospecific to *S. madagascariensis* and effective agents. Although more than 50–85% of weed biological control programs have led to significant or permanent weed control (Myers and Bazely, 2003), these constraints and the high associated chance of non-target impacts, suggested a very much lower chance of success for the Australian fireweed biological control program. To be conservative, the view was presented to the stakeholders at the conference that the chances of success might be in the order of 20%. The arguments in favour of continuing the biological control program were as follows:

a) There have been at least six weed biological control programs in Australia where there are native species in the same genus as the target weed. At least two of these have been successful at controlling the target weed to some degree. These programs were against *Rumex pulcher* L. and *Jacobaea vulgaris* Gaertn (= *Senecio jacobaea* L.) (Ireson and McLaren 2012).

b) Monospecific agents are not hard to find in weed biological control programs. Most targets that are widespread in their native range have at least some natural enemies that are monospecific. Also most plant pathogens used as biological control agents are monospecific and indeed many are weed-genotype or biotype-specific pathotypes. Researchers have also found biotype-specific arthropod agents (e.g. two strains of *Dactylopius opuntiae* (Cockerell) on *Opuntia ficus-indica* (L.) Mill. or *O.stricta* (Haw.) Haw. in South Africa).

c) No in-depth studies of fireweed have been completed in the native range of fireweed in the KwaZulu-Natal region of South Africa.

Based on these arguments and on the outcomes of a strategic planning workshop to at the first National Fireweed Conference in Bega in 2008, the continuation of the fireweed biological control program was supported by the stakeholders. The Australian Government Department of Agriculture, Fisheries and Forestry made funding available for this project in 2009. Also in 2012 fireweed was approved as one of Australia's 32 Weeds of National Significance.

1.2 Introduction

This project is an investigation of potential biological control agents for fireweed in South Africa. CSIRO is the subcontractor of University of New England and CSIRO has in turn subcontracted the majority of these activities to the University of KwaZulu-Natal (UKZN) in South Africa. The biological control project addresses three of the milestones of the head contract with the detail from the sub-contract in parentheses:

Milestone 3: *Agreement with the South African government.* [Negotiate agreement with the South African government under the Convention on Biological Diversity for the export and use of any South African biological resources for the benefit of biological control of fireweed in Australia]

Milestone 4: *Collaborative agreement with South African research agencies*. [Negotiate agreement with the South African research agencies to assist in undertaking South Africa based components of this research]

Milestone 5: *Investigation of biological control agents in South Africa, identification of promising agents, permission to import and, if necessary, testing permit.* [Undertake initial investigation of potential biological control agents in South Africa and if appropriate host specificity testing in contained use in Australia or South Africa]

Following discussions with South African colleagues, the research into the biological control agents in South Africa was divided into six separate activities:

1) Evaluation of the taxonomic distinctiveness of *S. madagascariensis* and closely related species in and around Pietermaritzburg and existence of hybrids and the likelihood of any taxonomic impediments to focussing research on this species.
2) Proposed further taxonomic/genetic studies of the target if required.
3) 18 months field observation data on the population dynamics of *S. madagascariensis* including data also on the associated pasture competition and the presence of any natural enemies at three sites.
4) Surveys of natural enemies on *S. madagascariensis* and related species in KwaZulu-Natal based on current knowledge (Table 1 & Morin et al. 2009).
5) Experiments to augment the density of *S. madagascariensis* in the field to see the impacts on natural enemy abundance.
6) Experiments on the impacts of natural enemies through the controlled use of insecticides and fungicides.

This research was to be undertaken with the recruitment of a post doctoral research fellow at UKZN.

Due to delays in agreements and appointments and agreed changes in the implementation of this project, Milestones 3 and 4 have been completed but Milestone 5 is still in progress. This final report reports on the project milestones in relation to the "performances standards" and "completion dates" outlined in the contract and describes the progress made under Milestone 5 and the planned activities and their time frames that will continue on existing funds. Future activities will be reported via annual progress reports after the end of the contract.

2 Regulatory status of Australia's capacity to import potential biocontrol agents of Fireweed from South Africa

Milestone 3: *Agreement with the South African government.*

Performance Standard: Negotiations commenced concerning the permission to export South African native species as potential biological control agents in Australia. Note: if an agreement cannot be reached then the budget for the biocontrol component as outlined in the Consultant's tender would need to be renegotiated with the Department.

Completion Date: within one week of signing this Contract and concluded by 31 October 2010.

CSIRO discussed the state of South African biodiversity legislation and the potential for this as an impediment to Australia exporting South African native organisms for the purposes of fireweed biological control with Dr Andrew McConnachie, head of the biological control team at the South African Plant Protection Research Institute (ARC-PPRI) at Cedara in KwaZuku-Natal. Dr McConnachie said that ARC-PPRI had historically regularly assisted with shipping South African insects to other countries; however they had not undertaken this in about the last 5 years. Dr McConnachie said there had been changes to the legislation since that time, however, he did not consider the changes would affect their capacity to carry out this service in the future if required. He urged CSIRO not to delay the project on these grounds. They did not, however, have legislative details relevant to the request. Dr McConnachie said he would seek a suitable contact in government who could advise CSIRO and UKZN on the current state of such legislation in relation to our requirements. This has not yet happened.

Subsequent discussions with Dr Terry Olckers from UKZN also led CSIRO to believe that there was little likelihood of a legislative impediment for exporting South African species to Australia as biological control agents. He accepted that handling such matters would be part of the UKZN's responsibilities, when the time came, should suitable organisms be found and considered worth shipping to quarantine in Australia. It was on this basis that UKZN accepted this sub contract from CSIRO and the project was able to progress.

Based on this, CSIRO developed the agreement with UKZN and assessed that risk around this aspect of the future continuation of the biological control program for fireweed was now low.

3 Status of collaborative research arrangements with UKZN

Milestone 4. *Collaborative agreement with South African research agencies*.

Performance Standard: Negotiations concerning the appointment, supervision and bench costs of a research scientist in South Africa to undertake biological control. It is assumed that the supervisor working on this project in South Africa would have significant experience in the field of classical biocontrol and have a minimum qualification of Doctor of Philosophy in a relevant field. Note: if an agreement cannot be reached then the budget for the biocontrol component would need to be renegotiated with DAFF.

Completion date: Collaborative negotiations concluded by 31 October 2010, and the research commenced within one week of signing of the agreed contract.

The original agreement with UKZN was that the University would employ a post doctoral fellow to undertake the sub-contracted studies aimed at identifying and selecting potential biological control agents. The DAFF project started in June 2010 and Drs Sheppard and Olckers first met in South Africa at UKZN in September 2010 to discuss the activities being based at the UKZN. Dr Terry Olckers, an entomologist, agreed to undertake the work in collaboration with CSIRO through the research laboratory of Prof Steve Johnson.

A second visit was made in November 2010, when a research agreement to subcontract these activities was completed and submitted to the UKZN business office. A detailed research plan was also developed with Dr Olckers and the University offered to initiate a two year MSc scholarship in advance to ensure some activities could start immediately. The appointed Masters student, Daniella Egli, initiated her studies in January 2011.

During the third visit in March 2011, UKZN business office agreed that the contract was acceptable and it was finally signed by both parties in April 2011. This led to the advertisement for the post doctoral fellow within South Africa and Australia and then globally a few weeks later. There were few applicants for the position and their CV's were not of sufficient standard to consider these candidates further.

By the fourth visit in October 2011 a suitable applicant had applied from Australia, with PhD experience on the natural enemies of fireweed in Australia. The position was offered to this applicant in November, however they turned it down for personal reasons.

During the same visit, the UKZN considered that the global importance of this group of native South Africa *Senecio* spp. as weeds merited further understanding of their taxonomy, genetics and chemical ecology. A PhD scholarship on the systematics (morphological, genetic and chemical) of *Senecio* in the KwaZulu-Natal region was proposed funded by UKZN through the University's John Bews Herbarium. Dr Paul Rymer from the University of Western Sydney, a specialist in *Senecio* genetics in Australia, agreed to co-supervise the student.

By March 2012 no further suitable candidates were found for a post doctoral level appointment, however Dr Olckers had found a local candidate he considered could do the work at a post graduate level. Following consultation with UNE and DAFF it was agreed that this PhD candidate, Matabaro Ziganira, be appointed to the role and supported for three years on this project with the funding already provided under the subcontract to UKZN. The remaining funding is also being considered to support a second PhD position at the university on the pathogens of fireweed through another UKZN faculty member, plant pathologist Dr Kwasi-Yobo.

It was agreed with Peter Langdon at DAFF that this was an acceptable outcome and that CSIRO should keep DAFF and UNE informed of developments after the contractual end to this project in June 2012. CSIRO will provide annual progress reports on this work as the research progresses. CSIRO will continue to assist with the delivery of the ongoing activities in South Africa within the capacity of the current budget.

4 Investigation of biological control agents in South Africa, identification of promising agents, permission to import and, if necessary, testing permit

Milestone 5: *Investigation of biological control agents in South Africa, identification of promising agents, permission to import and, if necessary, testing permit*

Performance standard: This research should include liaison with South African agencies to consider the biological and environmental factors limiting the weediness of fireweed in its native range aimed at defining a biological control strategy for Australia. This should include the identification, based on current taxonomic knowledge, of all native South African invertebrates or pathogens that offer potential as biological control agents from the KwaZulu Natal South African native range, including preliminary risk assessment in South Africa based on host specificity. Taxonomic validation of species found may be required. Should one such natural enemy population or pathogen isolate have good enough potential and therefore merit the investment an application for import for future research will be made to the Australian Quarantine and Inspection Service (AQIS). At least one application will also be made to the Department of the Environment, Water, Heritage and the Arts (DEWHA) for a testing permit for experimental work in Australia according to the Environment Protection and Biodiversity Conservation Act 1999.

Completion date: If negotiations successful research commenced by 1 November 2010 and results available by 31 May 2012.

4.1 Introduction

Given the delays outlined in Section 3, this milestone has not yet been completed, but progress has been made and will continue on the funding beyond the current end date of this project.

The remainder of this section outlines the progress that has been made as "achieved deliverables" and the planned future work as "planned deliverables". Some of these elements are outside the "performance standard" but considered necessary after discussions in South Africa.

4.2 Achieved deliverables

4.2.1 BIOLOGICAL AND ENVIRONMENTAL FACTORS LIMITING THE WEEDINESS OF FIREWEED IN ITS NATIVE RANGE AIMED AT DEFINING A BIOLOGICAL CONTROL STRATEGY FOR AUSTRALIA

The native range of fireweed is typified by dry winters and wet summers in a warm temperate to sub-tropical climate. Local land management consists of burning off perennial grass cover over winter. During this project CSIRO and UKZN made four exploratory trips to help understand the general levels of abundance of fireweed (*S. madagascariensis*) in the native range. The first spring trip in October 2010 sought field populations of fireweed with the potential to disrupt agriculture in the context found in Australia. As October was still in extended winter drought, only quite isolated overwintered mature individual plants were found. A second trip was made in November after the late spring rains fell and fresh cohorts of seedlings were seen. While fireweed was widespread along roadsides only five true field populations were found between Pietermaritzburg and the coast after four days of searching. Three of these were in a pasture situation and two in a post harvest cropping situation (Figure 1). We collected plant samples to look for evidence of natural enemies from these sites, however little was found as this was the start of the growing season. These sites were revisited in March 2011 to see how they had developed over the South African wet summer. Both cropping populations had disappeared under cultivation and resowing. The pasture populations were present but overtopped by dense perennial grass cover. A return to these sites in spring 2011 showed that the populations were resident but did not increase in abundance, rather just varying based on local and seasonal conditions from year to year.

Figure 1. Fireweed populations in South Africa a) in maize stubble at Cedara -29.526530lat/30.268634long 1063m asl Nov 2010, b) in sugarcane stubble nr Vernon Crookes Nature Reserve -30.304016lat/ 30.538116long 425m asl Nov 2010 c) pasture population at Cedara -29.540534lat/30.275765long 1060m asl Nov 2010 and d) same as c) in Mar 2011.

From these observations we concluded that the main ecological drivers determining fireweed abundance in South Africa were: a) disturbance – plants are most commonly seen along roadsides; b) rainfall and fire management regimes – winter drought promotes the use of fire to rejuvenate grasslands and opens up space for fireweed recruitment; and c) a warm summer wet season promotes strong perennial grass growth suppressing fireweed by the end of the summer – such growth appears largely beyond the capacity of the grazing livestock to suppress in favour of fireweed (Figure 2). The movement of fireweed to Australian coastal regions with warmth and reasonable rainfall and the recurring droughts in summer that can break up the perennial grass cover may assist it to be invasive. It appears therefore that fireweed may be pre-adapted to the Australian climate in affected regions. Furthermore there was little observational evidence from natural enemy damage levels in South Africa to suggest that fireweed populations are limited primarily by natural enemies in their native range.

Figure 2. Fireweed populations in South Africa a) grazed pasture population at Cedara (see Fig 1) close up spring, b) ditto close up autumn, c) in horse paddock in Australia

4.2.2 TAXONOMIC STATUS OF *S. MADAGASCARIENSIS* AND CLOSELY RELATED SPECIES IN THE KWAZULU-NATAL REGION OF SOUTH AFRICA

This group of *Senecio* species has not been well studied in South Africa, and the degree to which there is hybridisation with related taxa in a species complex is poorly understood. Time spent in the extensive *Senecio* collection at the University's John Bews Herbarium at Pietermaritzburg suggested that the morphological differences between native *Senecio* spp. in this region were quite obvious except for separating *S. madagascariensis* from *Senecio inaequidens*. There are distinct differences in leaf shape and capitulum structure amongst the closely related *S. skirrhodon* DC. Prodr*, S. burchellii* DC.*, S. harveianus* Mac Owan and *S. madagascariensis*. There is a also a marked overlap in the distribution of *S. burchellii* and *S. madagascariensis*, making rapid differentiation of the two species difficult, however *S. burchellii* commonly has narrow thin pinnate leaves and when flowering, typically 12-13 involucral bracts, while *S. madagascariensis* has large variable, often auriculate leaves and 19-21 involucral bracts. With a little training, separation in the field is not difficult. In the herbarium, specimens of *S. inaequidens, S. harvelanus* and *S. madagascariensis* appear to be somewhat mixed up with many specimens of each having moved at least once between taxa. The morphological similarities between *S. madagascariensis* and *S. inaequidens* in the herbarium specimens make these species pretty inseparable. The last treatise on the Asteraceae in the Natal region (Hilliard 1977) distinguished these species only on *S. madagascariensis* being an annual and *S. inaequidens* being a perennial, which in reality is an unreliable distinction as mature *S. madagascariensis* individuals were found in spring that had clearly survived the winter. Herbarium specimens of *S. inaequidens* had more linear primary and cauline leaves, while *S. madagascariensis* has broader more lanceolate leaves with more prominent serrations, however this distinction is not always obvious in mature individuals and in reality a full continuum of differences is observed, suggesting hybridization may also occur. In the field mature *S. inaequidens* plants appear to grow larger and bushier than *S. madagascariensis* plants. Careful reading of the specimen labels in the herbarium at UKZN with reference to the only paper that has separated specimens genetically from confirmed known locations (Lafuma et al. 2003) suggested that all material collected below 1000m asl and in the coastal region was *S. madagascariensis.* With Pietermaritzburg at c.800m asl populations with 19-21 involucral bracts near this town or in the midlands between the Pietermaritzburg and Durban and coastal regions around Durban were unlikely to be anything other than *S. madagascariensis*. The studies of the natural enemies focussed on this region.

In recognition of the complexity of variation in native *Senecio* spp. in the KwaZulu-Natal region and the need to clarify this for the Australian fireweed biological control program, a PhD project on the systematics (morphological, genetic and chemical) of *Senecio* in the region is now being funded by UKZN through the university herbarium.

4.2.3 QUANTITATIVE SURVEYS OF ARTHROPOD NATURAL ENEMIES ON *S. MADAGASCARIENSIS* AND RELATED SPECIES IN KWAZULU-NATAL

To understand the natural enemy community on *S. madagascariensis* in South Africa and the degrees of likely specificity of the species found, surveys were undertaken, mostly as part of an MSc project by Daniella Egli. These surveys aimed to identify the species present and quantify their abundance on *S. madagascariensis* in comparison to other co-occurring native *Senecio* spp. across the KwaZulu-Natal region and throughout the growing season. *Senecio polyanthemoides* Sch.Bip. is by far the most abundant native congener that grows in its close proximity to *S. madagascariensis,* so it was selected as a comparative native species. When *S. madagascariensis* populations were selected for sampling, searches were carried out at the sites for other *Senecio* species and these nearly always turned out to be *S. polyanthemoides*. These studies focused primarily on insects and as a basis for selecting potential biological control agents.

4.2.3.1 Survey methods

4.2.3.1.1 Pilot surveys.

As a precursor to structured surveys, a pilot survey in March 2010 collected 10 plants each from five *S. madagascariensis* sites across in the midlands around and south of Pietermaritzburg. Plants were dissected fresh and the number of individuals of each natural enemy species that could be identified from historical information (Table 5 and Appendix A) counted per plant.

4.2.3.1.2 Quantitative surveys.

Structured quantitative surveys were carried out on *S. madagascariensis* and *S. polyanthemoides* in KwaZulu-Natal province during 2011-2012 ranging from the midlands around Pietermaritzburg to the coastal region. To obviate the risk of sampling populations of the closely related *Senecio inaequidens* (see earlier comment), surveys did not include the uplands (high altitude) region and were mostly carried out in areas below an altitude of 1000m asl. Whenever possible, *S. polyanthemoides* was sampled at the same site as *S. madagascariensis*. Two approaches were adopted as follows:

Random sampling: Several populations of the two plant species were sampled at various times and at different sites in the province (Table 1) to augment data on the insect faunas. On each occasion, five flowering plants of *S. madagascariensis* were uprooted, placed into brown paper packets and then frozen to allow later dissection and recording of all ectophagous and endophagous insects. Because *S. polyanthemoides* is considerably taller (up to 1.8 m vs. up to 0.5 m), whole plant samples were not carried out and five branches containing inflorescences were sampled instead. In the laboratory, ectophagous insect species were recorded from each plant which was then separated into flowers, leaves, stems and roots (the latter for *S. madagascariensis* only) and then dissected to record the endophagous immature stages inside these tissues. Plant height and the numbers of leaves and flowers were recorded prior to each plant dissection. Voucher specimens of the two *Senecio* species were also collected from each site for reference and subsequent storage in the University's John Bews Herbarium. Most of the samples were collected along roadsides where the plants were most frequently encountered. Indeed, following the onset of the summer rainy season plants became more difficult to locate in undisturbed areas and from then on roadsides provided the best opportunities. In total, 21 sites (185 plants) have so far been sampled for *S. madagascariensis* and 9 sites (80 plants) for *S. polyanthemoides* (Table 1).

Seasonal sampling: Three benchmark populations, two of *S. madagascariensis* and one of *S. polyanthemoides*, were monitored on the University's Research Farm (Ukulinga) on the outskirts of Pietermaritzburg, in order to provide seasonal data on insect presence and abundance. The populations were sampled during the summer (February), autumn (May), winter (August) and spring (November) of 2011. On each sampling occasion, five plants were sampled (uprooted in the case of *S. madagascariensis*) and analysed as before. In order to rear the immature stages to adulthood, additional plants from each site were taken back to the laboratory, separated into the different tissues (see above) and placed into emergence containers.

Table 1. Details on the sites in KwaZulu-Natal where *Senecio madagascariensis* and *Senecio polyanthemoides* were sampled.

Site #	***Date(s)***	***Location****	***Grid reference Coordinates***	***Altitude (m)***	***Habitat***	***Plants***
			Senecio madagascariensis			
1	17/02/2011 26/05/2011 17/08/2011 18/11/2011	Ukulinga farm; Pietermaritzburg (M)	29° 40' 09.72" 30° 24' 44.24"	810	Cropland	10 10 10 10
2	17/02/2011 26/05/2011 17/08/2011 18/11/2011	Ukulinga farm; Pietermaritzburg (M)	29° 39' 46.54" 30° 24' 11.91"	833	Paddock	10 10 10 10
3	05/07/2011 27/09/2011	Emanzini; Nr Albert Falls (M)	29° 28' 41.05" 30° 22' 34.80"	698	Roadside	5 5
4	08/07/2011 15/09/2011	Emanzini; Nr Albert Falls (M)	29° 28' 49.70" 30° 22' 19.57"	733	Garden	5 5
5	16/07/2011	Ashburton; along old road (M)	29° 39' 26" 30° 26' 23"	ca 750	Roadside	5

6	16/07/2011	Ashburton; along old road (M)	29° 40' 53" 30° 28' 04"	ca 750	Roadside	5
7	16/07/2011	Ashburton; along old road (M)	29° 41' 06" 30° 30' 14"	ca 750	Roadside	5
8	20/10/2011	Outside Tala Game Reserve; Nr Camperdown (M)	29° 50' 09.73" 30° 31' 29.30"	712	Roadside	5
9	20/10/2011	Illovo Beach (C)	30° 08' 53.88" 30° 49' 48.79"	45	Roadside	5
10	20/10/2011	Nr Unzinto/Park Rhynie; road to caravan park (C)	30° 19' 34.22" 30° 44' 03.17"	43	Roadside	5
11	19/01/2012	Nr Hilton (Cedara); St Joseph's Road (M)	29° 31' 21.75" 30° 16' 10.77"	1109	Roadside	5
12	19/01/2012	Nr Nottingham Road; on Dargle road (M)	29° 30' 07.75" 30° 02' 08.68"	937	Roadside	5
13	09/02/2012	New Hanover (M)	29° 18' 36.10" 30° 32' 57.12"	1069	Plantation	5
14	09/02/2012	Nr Greytown (M)	29° 05' 40.08" 30° 35' 11.23"	1028	Roadside	5
15	09/02/2012	Nr Wartburg (M)	29° 29' 17.69" 30° 26' 06.39"	642	Roadside	5
16	23/02/2012	Nr Richmond (M)	29° 48' 17.11" 30° 20' 35.60"	872	Roadside	5
17	23/02/2012	Nr Richmond; Byrne Valley road (M)	29° 51' 55.09" 30° 14' 55.09"	887	Roadside	5
18	08/03/2012	Gilletts; along railway line (C)	29° 47' 35.79" 30° 48' 00.89"	625	Roadside	5
19	22/03/2012	Tongaat; along R102 (C)	29° 36' 48.32" 30° 05' 11.17"	125	Roadside	5
20	22/03/2012	Road between Tongaat and Wartburg (C)	29° 25' 09.64" 30° 47' 29.67"	41	Roadside	5
21	22/03/2012	Nr Wartburg (M)	29° 26' 30.83" 30° 36' 20.90"	912	Roadside	5
Senecio polyanthemoides						
1	17/02/2011 26/05/2011 17/08/2011 20/11/2011	Ukulinga farm; Pietermaritzburg (M)	29° 40' 21.01" 30° 24' 07.46"	840	Roadside	10 10 10 10
2	11/05/2012	Emanzini; Nr Albert Falls (M)	29° 28' 41.05" 30° 22' 34.80"	698	Roadside	5

3	20/10/2011	Outside Tala Game Reserve; Nr Camperdown (M)	29° 50' 09.73" 30° 31' 29.30"	712	Roadside	5
4	19/01/2012	Hilton (M)	29° 32' 37.85" 30° 17' 48.36"	1158	Roadside	5
5	09/02/2012	New Hanover (M)	29° 18' 36.10" 30° 32' 57.12"	1069	Plantation	5
6	23/02/2012	Nr Richmond; Byrne Valley road (M)	29° 51' 55.09" 30° 14' 55.09"	887	Roadside	5
7	23/02/2012	Nr Richmond; Nr Byrne Valley turnoff (M)	29° 51' 16.53" 30° 11' 17.88"	ca 900	Roadside	5
8	08/03/2012	Nr Camperdown	29° 43' 44.37" 30° 32' 53.56"	781	Roadside	5
9	08/03/2012	Botha's Hill; along railway line	29° 45' 11.59" 30° 43' 43.95"	758	Roadside	5

* Where M = midlands (inland) and C = coastal regions.

4.2.3.2 Results

4.2.3.2.1 Pilot surveys

The pilot survey in March 2010 (late summer) included two paddock populations (at Cedara Fig 1 c,d and at Ukulinga) and three roadside populations within 100 km south of Pietermartizburg. This survey revealed a significant number of phytophagous insect species and plant pathogens (Table 2), some of which were known from earlier opportunistic collections by Australian and Hawaiian colleagues (Table 5 and Appendix A). In particular, several endophagous (e.g. stem-boring and capitulum-boring) insect species were easily found demonstrating that plenty of natural enemies and potential biocontrol agents were present.

4.2.3.2.2 Quantitative surveys

During the quantitative surveys several insect taxa, comprising species of Coleoptera, Diptera, Hemiptera and Lepidoptera were collected on *S. madagascariensis*. Species that were obviously predatory or considered to be generalist phytophages or causal associates were excluded from the assessment, as were those that were recorded only on single occasions. Some 38 particularly endophagous taxa were regarded as having a significant association with *S. madagascariensis* (Table 3). Taxa found on *S. polyanthemoides* are presented in Table 4. Several of the most important taxa are likely to have been positively identified as a result of earlier collections during the 1990s (Table 5 and Appendix A).

Of the species that fed internally in the flowers, larvae of Agromyzidae (Diptera) were most commonly encountered, followed by larvae of Tephritidae (Diptera), Nitidulidae (Coleoptera) and unidentified Lepidoptera. While Agromyzidae and Nitidulidae were not previously reported from the flowers (see Table 5), some five species of Tephritidae and two species of Pyralidae (Lepidoptera) were previously collected from these tissues. Similarly, of the species that fed internally in the stems, larvae of other Agromyzidae and Tephritidae followed by those of Lepidoptera and Curculionidae (Coleoptera) were most commonly encountered (Table 3). Other stem-boring larvae encountered at lower incidences (i.e. % samples in which recovered) included Cecidomyiidae (Diptera), unidentified Coleoptera and Cerambycidae (Coleoptera). One or more species of Agromyzidae, Tephritidae, Curculionidae and Pterophoridae (Lepidoptera) were previously reared from the stems (Table 5). Agromyzidae were well represented on *S. madagascariensis*, having also been observed in leaf mines on the plant.

Several ectophagous species, mostly Coleoptera and Hemiptera, but also some Lepidoptera larvae, were collected from the foliage of the plant. Many of these were considered to be unimportant because of casual associations, low recoveries and predatory behaviour. Pending confirmation of identity, some are considered to be species with endophagous larval stages (e.g. stem-boring Curculionidae). The incidence of most of these species was low (recovered in <5% of samples). The most commonly encountered ectophages included sap-sucking Hemiptera like Aphididae (presumably generalist species) and a species of Tettigometridae (prob. *Hilda elegantula*) which may well be more specific than suspected given its low recovery on *S. polyanthemoides* (Table 4). Despite their low recovery rates, there are two species, a flea beetle (Chrysomelidae: Alticinae) and a moth (Arctiidae), that warrant further consideration, because they may well comprise analogues of agents that have previously been used in the successful biological control program against ragwort, *Jacobaea vulgaris*, a closely related weed in the Asteraceae in Australia (Ireson and McLaren 2012).

While no root-feeding immature stages were recorded during dissections of the roots of *S. madagascariensis*, it is possible that root-feeding species (e.g. the flea beetle) may feed externally on these tissues below the ground and thus avoided detection.

Table 2. Natural enemies found on five sites of *Senecio madagascariensis* sampled in KwaZulu-Natal in March 2011. Species names remain to be verified but are the "best guess" based on current literature.

Nature of attack	***Natural enemy type (family)***	***Scientific name (current knowledge)***	***No. sites where found***	***Average % plants attacked at sites where present***	***No. (max) individuals per plant***
Stem-borers	Weevil (Curculionidae) Resembles *Lixus* sp.	*Gasteroclisus* nr. *tricostalis* Thunberg	5	80	10
	Plume moth (Pterophoridae)	*Platyptilia?* sp.	5	50	2
	Fly (Agromyzidae)	*Melanagromyza* spp.?	5	70	5
Flower-feeders	Moth (Pyralidae)	*Homeosoma stenotea*?	3	20	2
	Fly (Tephritidae) large	*Cryptophorellia peringueyi*?	3	10	2
	Fly (Tephritidae) small	?	5	50	5
	Fly (Cecidomyiidae)	?	1	10	10
Sap suckers	Leaf hopper (Tettigometridae)	*Hilda* prob. *elegantula*	2	20	Many
	Plant bug (Miridae)	*Ellenia* sp.?	2	20	Many
Plant pathogens	Stem rust	*Puccinia lagenophorae* (assumed)	3	20	n/a
	Flower smut	*Ustilago* sp.	5	100	n/a
	Stem blotch fungus	Not yet isolated	1	10	n/a

Table 3. Incidence of phytophagous insect species associated with *Senecio madagascariensis* in KwaZulu-Natal, South Africa.

Feeding guild	***Insect species***	***Reference***	***Incidence****
Flowerbud-feeders (endophages)	Coleoptera		
	Prob. Nitidulidae (larvae)	FCol01	18.4
	Diptera		
	Agromyzidae (larvae)	FDip01/02	56.8
	Tephritidae (larvae)	FDip05	20.0
	Lepidoptera		
	Unidentified larvae	FLep01-05	10.8
Stem-borers	Coleoptera		
	Cerambycidae (larvae)	SDip04	1.1
	Curculionidae (larvae)	SCol02	10.3
	Unidentified larvae	SCol01	5.9
	Diptera		
	Agromyzidae (larvae)	SDip01	35.1
	Cecidomyiidae (larvae)	SDip02	9.7
	Tephritidae (larvae)	SDip03	30.8
	Lepidoptera		
	Unidentified larvae	SLep01	13.5
Leaf-miners	Agromyzidae (larvae)	LDip01	17.3
Foliage-feeders (ectophages)	Coleoptera		
	Chrysomelidae: Alticinae (possible root-feeder)	Col02	2.7
	Curculionidae 1	Col10	3.2
	Curculionidae 2	Col11	2.2
	Curculionidae 3	Col12	1.6
	Curculionidae 4	Col14	1.1
	Curculionidae 5	Col17	1.6
	Hemiptera		
	Aphididae	Aphid	69.7
	Cicadellidae 1	Hem11	1.6
	Cicadellidae 2	Hem28	1.6
	Coreidae 1 (nymphs)	Hem03	8.6
	Coreidae 2 (nymphs)	Hem17	3.7
	Miridae 1	Hem01	1.1
	Miridae 2	Hem14	1.1
	Miridae 3	Hem15	5.4
	Miridae 4 (nymphs)	Hem25	4.3
	Tettigometridae (*Hilda* prob. *elegantula*)	Hilda	29.7

	Tingidae 1	Hem17	1.6
	Tingidae 2 (nymphs)	Hem18	2.2
	Unknown 1 (nymphs)	Hem21	6.5
	Unknown 2 (nymphs)	Hem24	2.2
	Unknown 3 (nymphs)	Hem04	10.8
	Unknown 4 (nymphs)	Hem05	4.3
	Lepidoptera		
	Arctiidae (larvae)	Lep10	1.1
	Tortricidae 1 (larvae)	Lep02	1.6
	Tortricidae 2 (larvae)	Lep08	1.1
	Unknown (larvae)	Lep12	1.1

* % of samples (n = 185 plants) in which the species was recovered.

Similarly, several species of Coleoptera, Diptera, Hemiptera and Lepidoptera were collected on the related *S. polyanthemoides*. Some 26 taxa were regarded as having a significant association with the plant (Table 4). Similar taxa were recorded inside the flowerbuds (Agromyzidae, Tephritidae, Nitidulidae, and Lepidoptera larvae), stems (Cerambycidae, Agromyzidae, Curculionidae) and leaves (Agromyzidae) of this plant compared to *S. madagascariensis* (Table 3). However, the identity of these species needs to be confirmed to understand whether they are the same species as those recorded on *S. madagascariensis*.

Table 4. Incidence of phytophagous insect species associated with *Senecio polyanthemoides* in KwaZulu-Natal, South Africa.

Feeding guild	***Insect species***	***Reference***	***Incidence****
Flowerbud-feeders (endophages)	Coleoptera		
	Prob. Nitidulidae (larvae)	FCol04	15.0
	Diptera		
	Agromyzidae (larvae)	FDip08	53.8
	Tephritidae (larvae)	FDip10	16.3
	Lepidoptera		
	Unidentified larvae	FLep07-09	12.5
Stem-borers	Coleoptera		
	Cerambycidae (larvae)	SCol06	21.3
	Curculionidae (larvae)	SCol09	8.8
	Unidentified larvae	SCol05-07	22.5
	Diptera		
	Agromyzidae (larvae)	SDip11-13	18.8
	Unknown larvae (Tephritidae?)	SDip14	5.0
	Lepidoptera		
	Unidentified larvae	SLep02	7.5
Leaf-miners	Agromyzidae (larvae)	LDip10	40.0
Foliage-feeders (ectophages)	Coleoptera		
	Chrysomelidae	Col49	3.8
	Curculionidae	Col17	2.5

	Unknown	Col46	7.5
	Hemiptera		
	Aphididae	Aphid	62.5
	Cicadellidae 1 (nymphs)	Hem11	23.8
	Cicadellidae 2 (nymphs)	Hem37	2.5
	Coreidae (nymphs)	Hem13	6.3
	Miridae 1	Hem01	6.3
	Miridae 2	Hem25	21.3
	Psyllidae	Hem47	2.5
	Tettigometridae (*Hilda* prob. *elegantula*)	Hilda	2.5
	Tingidae	Hem38	2.5
	Unknown 1 (nymphs)	Hem04	8.8
	Unknown 2 (nymphs)	Hem42	16.3
	Lepidoptera		
	Unknown (larvae)	Lep6/12/19	3.8

* % of samples (n = 80 plants) in which the species was recovered.

Indeed all collected insects in Tables 3 and 4 require formal identification to obtain a clear picture of the natural enemy community of S. *madagascariensis* in South Africa. This is the next stage of the MSc project with the help of South African taxonomists. Similarly the results of the season sampling have not yet been analysed and will be presented in future progress reports.

4.2.3.3. Discussion and conclusions

Based on these surveys and historical surveys made by Marohasy in 1991 and by Mohsen Ramadan from the Hawaiian Department of Agriculture (Appendix A), Table 5 provides a provisional list of natural enemies from the native range of *S. madagascariensis* in South Africa that may have potential as biocontrol agents of fireweed in Australia. Some of these species are illustrated in Figures 3-5. Although confirmation of identity is still pending, most of these species (at least at the level of their feeding guild) were found to be common at the sites surveyed. While the present study did not focus on pathogens, four species have so far been recovered on *S. madagascariensis*.

A number of activities remain to be completed to finish the quantitative surveys:

1. Additional rearing to adulthood of the immature stages of important phytophagous species to provide sufficient voucher specimens that will be lodged in the Natal Museum (Pietermaritzburg) and/or National Collection of Insects (Pretoria).
2. Confirmation of the identity of the most important phytophagous species.
3. Processing of the quantitative data to determine the seasonal abundance of the most important phytophagous species.
4. Additional collections to fill in any ‘gaps’, particularly for *S. polyanthemoides* where sampling has been less intensive.

When compared to the successful biological control program in Australia against ragwort (*J. vulgaris*), the agents found during these surveys look quite promising. *Senecio madagascariensis* populations in KwaZulu-Natal support agent taxa and feeding damage (i.e. insect guilds) similar to those that have successfully controlled ragwort (i.e. arctiid moths and chrysomelid flea beetles; Ireson and McLaren 2012). The presence of foliage-feeding (Arctiidae), flower-feeding (Pyralidae, Pterophoridae, Tephritidae), stem-boring (Agromyzidae, Curculionidae, Tephritidae, Tortricidae) and root-feeding taxa (Chrysomelidae (Alticinae), Curculionidae) in quite high levels of abundance, further supports a conclusion that there are a variety of potentially suitable candidate biocontrol agents in South Africa.

Table 5. List of known natural enemies of *Senecio madagascariensis* in South Africa that are most likely to be restricted to the genus *Senecio* and that possibly warrant further consideration as biological control agents.

Nature of attack	***Natural enemy type (family)***	***Scientific name (current knowledge)***
Stem-borers	Weevil (Curculionidae)	*Gasteroclisus tricostalis* (Thunberg)
	Moth (Tortricidae)	*Lobesia* sp.
	Fly (Tephritidae)	*Coelopacidia strigata* Bezzi
	Fly (Agromyzidae)	*Melanagromyza* spp.
Flower-feeders	Moth (Pyralidae)	*Homeosoma stenotea* Hampson
	Moth (Pyralidae)	*Phycitodes* sp.
	Moth (Pterophoridae)	Undetermined
	Fly (Tephritidae)	*Cryptophorellia peringueyi* (Bezzi)
	Fly (Tephritidae)	*Trupanea inscia* Munro
	Fly (Tephritidae)	*Sphenella austrina* Munro
	Fly (Tephritidae)	*Telaletes ochraceus* (Loew)
	Fly (Tephritidae) small	Undetermined
	Fly (Cecidomyiidae)	Undetermined
Root feeders	Weevil (Curculionidae)	*Proictes longehirtus* Fairemaire
	Leaf beetle (Chrysomelidae)	Undetermined
Sap suckers	Leaf hopper (Tettigometridae)	*Hilda elegantula* Gerstaecker
	Plant bug (Miridae)	*Ellenia* sp.?
	Lace bug (Tingidae)	Undetermined
Plant pathogens	Yellow rust (Pucciniaceae)	*Puccinia lagenophorae* Cooke & hybrids
	White rust (Albuginaceae)	*Albugo* sp. (*tragopogonis*?)
	Flower smut (Ustilaginaceae)	*Ustilago* sp.

Despite the diversity of phytophagous insects in KwaZulu-Natal, however, none of the populations surveyed had plants clearly stressed by insect (or pathogen) damage. This supports the earlier observation that other factors (i.e. disturbance, rainfall and fire management regimes and perennial grass competition) drive fireweed abundances in South Africa. This observation does not reduce the likelihood of future successful biological control in Australia. First, insect herbivore populations in South Africa are exposed to their own natural enemies; freedom from these, following introduction into Australia, could lead to considerably higher population densities and hence higher impact on the target. Second, the current lack of natural enemies in Australia is likely to render the plants far more competitive than their counterparts in South Africa where all plant tissues are attacked to some degree. Reducing the competitiveness of plants in Australia by the introduction of biological control agents may thus allow other ecological stressors to reduce plant populations. The impending field trials in South Africa where populations of *S. madagascariensis* will be subjected to varying levels of plant competition and moisture, under conditions of insect and pathogen (or both) exclusion should quantify the impact of natural enemies on the plant and reveal whether biological control is likely to deliver the desired outcomes.

The particular challenge for this fireweed biological control program remains to find agents that are sufficiently specific to attack fireweed but not species in the Australian native *S. pinnatifolious* complex or other native species in Australia.

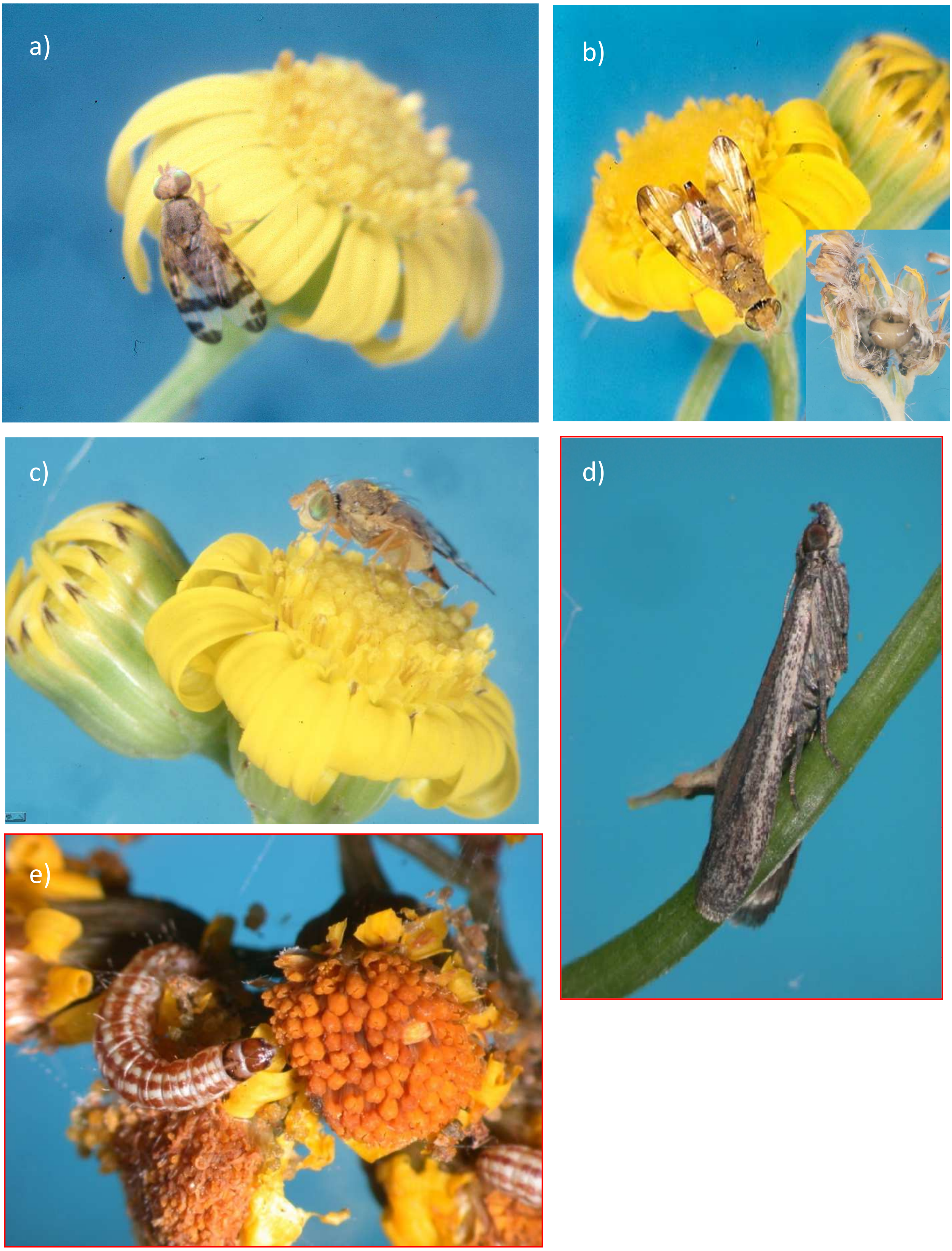

Figure 3. Fireweed potential biological control agents – captiulum feeders (Photos provided by M Ramadan); the tephritid seed flies a) *Sphenella austrina*, b) *Cryptophorellia peringueyi*, c) *Thaletes ochraceus*, and d) adult and e) larvae of the Pyralid moth *Phycitodes* sp.

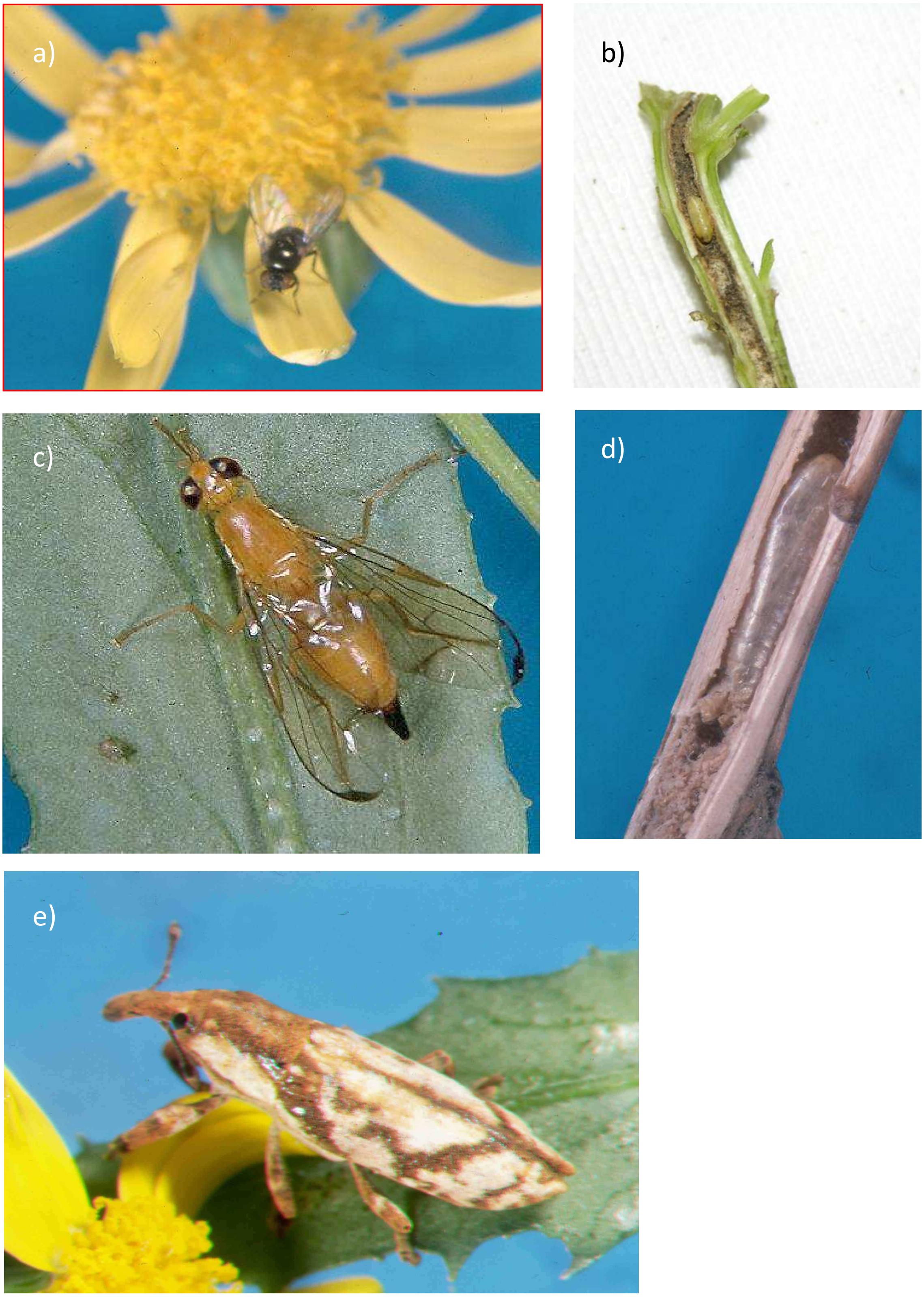

Figure 4. Fireweed potential biological control agents – stem borers (Photos provided by M Ramadan); a) & b) the agromyziid fly, *Melanoagromyza* sp., c) & d) the tephritid fly *Coelopacidia strigata*, e) the weevil, *Gasteroclisus tricostalis*

Figure 5. Fireweed potential biological control agents – other guilds (Photos provided by M Ramadan); a) the tortricid moth, *Lobesia* sp. (stem borer), b) the tettigometrid, *Hilda elegantula* (sap sucker), c) the weevil, *Proictes longehirtus* (root feeder).

4.3 Planned deliverables

4.3.1 FIELD STUDIES AND OBSERVATIONS OF *S. MADAGASCARIENSIS* IN SOUTH AFRICA

Outputs:

- Multi-year field observation data at 3 sites on the population dynamics of *S. madagascariensis,* including data on the associated pasture competition and the presence of any natural enemies.
- Experimental results on the impacts of augmenting *S. madagascariensis* density on the abundance of specific natural enemies in the field as an assessment of their impacts.
- Experimental results on the impacts of natural enemies through the controlled use of insecticides and fungicides

The ecological research components of this project are just starting and consist of setting up permanent research plots in 2-3 populations of fireweed in the KwaZulu-Natal region of South Africa. At these sites fireweed populations will be:

- monitored for the demographic parameters of fireweed in situ at each site using permanent quadrats and recognised sampling protocols including the estimation of the impacts of natural enemies; and
- subjected to experimental plots in which the density of fireweed will be manipulated to levels above the natural field densities (to attract natural enemies) and for the impacts of natural enemies to be quantified through the controlled use of insecticides and fungicides.

The plots and experiments will be set up and monitored on a regular basis for the duration of the project at least over two summers to measure and identify the impacts of natural enemies. This is a recognised protocol for determining and detecting effective biological control agents applied by CSIRO since the mid-1980s, and is required for fireweed because of the known lack of existing candidate agents (insects or pathogens) specific enough for use against fireweed in Australia.

A post graduate research student recently appointed in South Africa will undertake this research over two growing seasons. Experiments will be set up at Ukulinga the UKZN research farm for long-term monitoring to quantify the impacts of natural enemies (by 31 Jan 2013). First year field work will be completed, including analysis of data, and a progress report completed by 30 June 2013. Second year field work, including analysis of data, will be completed and a final report submitted by 30 June 2014.

4.3.2 SURVEYS OF PATHOGENS ON *S. MADAGASCARIENSIS* IN SOUTH AFRICA AND THEIR LIKELY SPECIFICITY AND EFFICACY

Previous research on the pathogens of fireweed in South Africa has shown the potential for such pathogens to be sufficiently specific to exploit *S. madagascariensis,* but not Australian native *Senecio* spp. (Morin et al. 2009). Remaining funding will be used to appoint a second post graduate student to study the pathogens of South African *Senecio* spp., their specificity and impacts. At least five pathogens have already been found on *Senecio* spp. in South Africa during this and previous studies, including the rust fungi *Puccinia lagenophorae* and *Albugo* nr *tragopogonis*, a flower smut, *Ustilago* sp. and some unknown leaf and stem pathogens (Figure 6). Future work will be undertaken with the assistance of South African pathologists at UKZN and the ARC-PPRI.

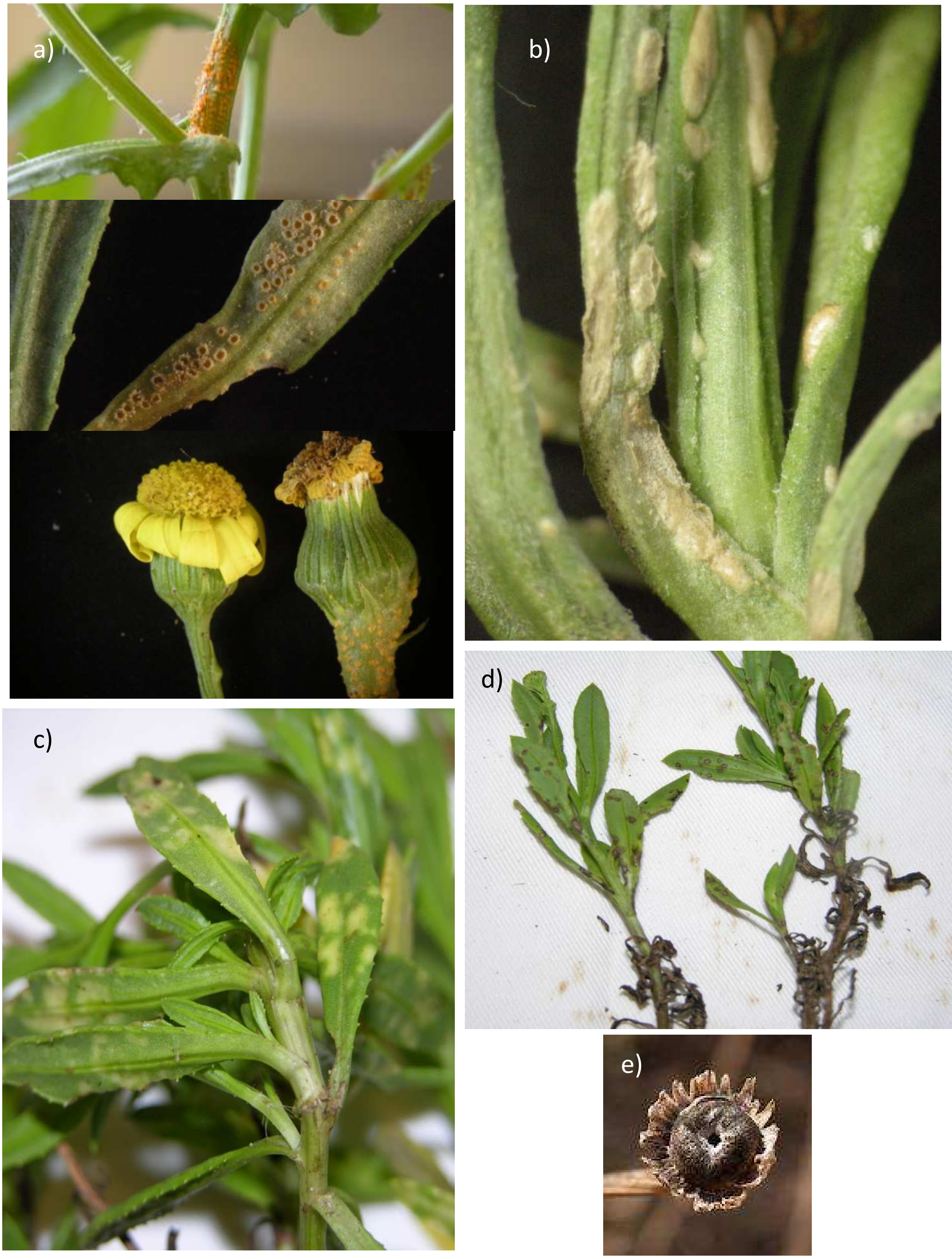

Figure 6. Fireweed potential biological control agents – plant pathogens in the native range (some photos provided by M Ramadan); a) *Puccinia lagenophorae* in native range, b) *Albugo tragopogonis,* c) unknown leaf-shoot pathogen, d) unknown leaf/stem blotch fungus, e) flower smut *Ustilago* sp.?

4.3.3 SELECTION AND PRIORITIZATION OF BIOLOGICAL CONTROL AGENTS FOR *S. MADAGASCARIENSIS* IN SOUTH AFRICA

Native South African invertebrates or pathogens that offer potential as biological control agents will be listed and prioritised for further consideration. This will be based on the information being collected from ongoing studies, including information on agent specificity from field comparisons in the KwaZulu-Natal South African native range through the observation of attack on related *Senecio* species in the same region. This prioritisation process will be dynamic such that the list will change as more information is obtained. This process will include identification, based on current taxonomic knowledge. Taxonomic validation of species found may be required using genetic approaches similar to that which has already taken place (Morin et al. 2009). Following this preliminary risk assessment in South Africa, based on host specificity, should an insect of pathogen appear to have good enough potential as a biocontrol agent for fireweed, an application for importing this agent into Australia for future research will be made to the Australian Quarantine and Inspection Service (AQIS). An application would also be made to the Department of the Environment, Water, Heritage and the Arts (DEWHA) for a testing permit for experimental work in Australia, according to the Environment Protection and Biodiversity Conservation Act 1999.

5 Conclusions and recommendations

The project activities undertaken and outlined in this report set out to deliver on three milestones in the main DAFF contract on fireweed management relating to the setting up of a biological control program for fireweed in Australia.

Milestone 3: *Agreement with the South African government.* Negotiations commenced concerning the permission to export South African native species as potential biological control agents in Australia.

Milestone 4: *Collaborative agreement with South African research agencies.* Negotiations concerning the appointment, supervision and bench costs of a research scientist in South Africa to undertake biological control completed and research staff appointed.

Milestone 5: *Investigation of biological control agents in South Africa, identification of promising agents, permission to import and, if necessary, testing permit.* Liaison with South African agencies to undertake research to understand the biological and environmental factors limiting the weediness of fireweed in its native range aimed at defining a biological control strategy for Australia. Identification, based on current taxonomic knowledge, of all native South African invertebrates or pathogens that offer potential as biological control agents from the KwaZulu-Natal South African native range, including preliminary risk assessment in South Africa based on field host specificity. Taxonomic validation of species found. Application for an import permit for future research should a suitable agent be found.

The project has achieved Milestones 3 and 4 and has made significant progress on Milestone 5.

Information on the ecological drivers of fireweed abundance in the native range has also been obtained. Fireweed is much less abundant in South Africa than in Australia. In South Africa it is largely a roadside plant with very few paddock populations and mostly associated with agricultural activities (cropping and pastoral). We conclude that the main ecological drivers determining fireweed abundance in South Africa were: a) disturbance – plants are most commonly seen along roadsides; b) rainfall and fire management regimes – winter drought promotes to use of fire to rejuvenate grasslands and opens up space for fireweed recruitment; and c) a warm summer wet season promotes strong perennial grass growth suppressing fireweed by the end of the summer.

There is now also a clearer understanding of the taxonomic status and ecology of fireweed in South Africa. The taxonomy remains complex and there appears to be a continuum of morphological variation in the region between the known species of *Senecio madagascariensis* and *S. inaequidens* to the point where clear separation may require existing genetic approaches. However, there does appear to be an altitudinal divide in that *S. madagascariensis* (based on herbarium specimens and previous records in the literature) is only found from the coast to sites below 1000m asl. While greater clarity will be sought through genetic studies at UKZN, for the purposes of the biological control work, studies have focussed on sampling plants and populations of *Senecio* morpho-types below 1000m asl.

Studies on the natural enemies in South Africa under this project have built on historical for Australia and ongoing studies for Hawaii conducted by the Hawaiian Department of Agriculture (Appendix A), which have targeted related *Senecio* species genotypes beyond *S. madagascariensis* sensu stricto and its currently known native range. We now obtaining a clearer understanding of the invertebrate natural enemy community found on *S. madagascariensis* sensu stricto in the KwaZulu-Natal region. The project currently has a list of 18 invertebrates and three fungi that appear to be *Senecio* specialists on fireweed in South Africa by quantitatively sampling fireweed populations and throughout the year (Table 5).

Future research, based on the current funding for this project, will involve:

- studies in more depth of the community of plant pathogens on fireweed in South Africa;

- multi-year field observations at three sites on the population dynamics of *S. madagascariensis,* including data on the associated pasture competition and the presence of any natural enemies;
- experiments on the impacts of augmenting *S. madagascariensis* density on the abundance of specific natural enemies in the field as an assessment of their impacts; and
- experiments on the impacts of natural enemies through the controlled use of insecticides and fungicides.

The investment made towards these activities through this project should now be enough to complete sufficient research in South Africa to define if agents (arthropods and/or pathogens) exist there that are potentially specific enough for consideration as biological control agents for fireweed in Australia. This has not yet been achieved because of delays in setting up the necessary collaborative arrangements around this project in South Africa, but sufficient funding remains to complete Milestone 5.

The project team will continue the research now being undertaken in South Africa beyond the end of this contract on the existing funding. The project staff will keep all parties informed through annual progress reports. Once the existing funding has been spent, an assessment can be made on final achievements and further recommendations made on whether to continue this biological control program into the future.

Appendix A

Insects collected on *S. madagascariensis* in Madagascar and South Africa as part of the Australian biological control effort prior to this project (from Marohasy 1989,1991: identifications from CIE)

INSECTS	Country	Plant part attacked	Other information
LEPIDOPTERA			
Noctuidae:			
Thysanoplusia orichalcea (Fab.)	Madagascar	Leaves	Known polyphagous pest species
Condica conducta Walker	Madagascar	Leaves	Known generalist on Asteraceae
Geometridae:			
Indet. genus and sp.	Madagascar	Leaves	No other information
Pyralidae:			
Homoeosoma stenotea Hampson	South Africa	Flowers	Damaging - potential agent
Phycitodes new sp.	Madagascar	Flowers & stems	Imported and tested in quarantine
Crambidae:			
Udea ferrugalis (Hübner)	South Africa	Leaves	
Tortricidae:			
Indet. genus and sp.	South Africa	Stem-boring in pith	Not very damaging
Epichorestodes acerbella Walker	South Africa	Leaves	
Lobesia new sp.	Madagascar	Stems	Imported and tested in quarantine
Platyptilia ?molopias Meyrick	South Africa	Stems and flowers	Damaging - potential agent
DIPTERA			
Tephritidae:			
Sphenella marginata (Fallen)	Madagascar	Flowers	Cosmopolitan species present in Australia
Cryptophorellia peringueyi (Bezzi)	South Africa	Flowers	Also from other *Senecio* spp.

Agromyzidae:			
Liriomyza trifolii (Burgess)	Madagascar	Leaves	Known polyphagous pest species
Melanagromyza sp.	South Africa	Stem boring	Damaging but similar to *M. seneciophila* in Australia
Cecidomyiidae:			
Indet. genus and sp.	South Africa	Flowers	Host range unknown
Sciaridae:			
Indet. genus and sp.	South Africa	Boring in pith of stem & root	Host range unknown
HOMOPTERA			
Pseudococcidae:			
Tylococcus ?harongae Mamet	Madagascar	Phloem feeding	Host range unknown
Coccidae:			
Pulvinaria sp.	South Africa	Phloem feeding	Host range unknown
Cicadellidae:			
Indet. genus and sp.	South Africa	Phloem feeding	Host range unknown
Tettigometridae:			
Hilda sp.	South Africa	Phloem feeding	Host range unknown
Aphididae:			
Aphis fabae ssp. *solanella* Theobald	South Africa	Phloem feeding	Known polyphagous pest species
Aphis gossypii Glover	Madagascar	Phloem feeding	Known polyphagous pest species
Brachycaudus helichrysi (Kaltenbach)	South Africa	Phloem feeding	Known polyphagous pest species
Macrosiphum euphorbiae (Thomas)	South Africa	Phloem feeding	Known polyphagous pest species
Myzus ornatus Laing	South Africa	Phloem feeding	Known polyphagous pest species
HETEROPTERA			
Lygaeidae:			
Nysius albipennis Distant	Madagascar	Seed heads	Host range unknown: other *Nysius* spp. attacking *Senecio* spp. in Australia

Nysius ericae (Schilling)	Madagascar and South Africa	Seed heads	Host range unknown
Nysius ?graminicola (Kolenati)	South Africa	Seed heads	Host range unknown
Nysius ?senecionis Schilling	South Africa	Seed heads	Host range unknown
Rhopalidae:			
Stictopleurus scutellaris coquerelli (Signoret)	Madagascar	Phloem feeding	Host range unknown
Miridae:			
Ellenia obscuricornis (Poppius)	South Africa	Flowers	Host range unknown
HYMENOPTERA			
Eucoilidae:			
Diglyphosema sp.	South Africa	Stem boring	Host range unknown; may be parasite of agromyzid
COLEOPTERA			
Curculionidae:			
? Throgonius sp.	Madagascar	Adults at flowers	Larval host unknown
Gasteroclisus tricostalis (Thunberg)	South Africa	Boring in stem pith	Common but not very damaging
THYSANOPTERA			
Phlaeothripidae:			
Haplothrips nigricornis (Bagnall)	Madagascar	Seed heads	Pest of sunflower?

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

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CSIRO Ecosystem Sciences
Dr Andy Sheppard
t +61 2 6246 4198
e Andy.Sheppard@csiro.au
w www.csiro.au/en/Organisation-Structure/Divisions/Ecosystem-Sciences.aspx