Forest Protection SSIF research on species other than radiata pine 2018/19

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FOREST GROWERS RESEARCH

EXECUTIVE SUMMARY

Plantation species other than *Pinus radiata* (radiata pine), in particular Douglas-fir and eucalypts, form an important part of a diversified forest estate. Douglas-fir is planted over approx. 105,000 ha. and is the most widely planted tree species after radiata pine. *Eucalyptus species* are planted over approximately 27,000 ha and contribute ~$40 million pa in hardwood chip exports. Throughout New Zealand the biggest threat to *E. nitens* plantations is from the eucalyptus tortoise beetle, *Paropsis charybdis* (Bain and Kay 1989). SWP has been supporting the project team that is working to introduce a new biocontrol agent from Australia to suppress damage from this beetle. The culmination of five years of research saw the EPA application submitted (for the release of the new biocontrol agent), a hearing held, and a final approval for release made (in Q3).

Forest Protection undertook SSIF funded research on the health of plantation species aligned to the Specialty Wood Products Partnership. This year the $150K pa of aligned research focused on research within the post-border entomology area. The work aims to improve sustainable management of *Eucalyptus* plantation pests in order to permit on-going confidence in the sector and show that *Eucalyptus* can continue to be grown in New Zealand, even the pest-prone Symphyomyrtus species (Millen et al. 2018).

Firstly, economic modellers assessed the economic impact of *Paropsis charybdis* and defined the cost and the benefit of its control to New Zealand. This report proved invaluable for industry, and for the application in support of the biological control agent to be proposed for release against *P. charybdis*. Secondly, the EPA application to release a new biocontrol agent was successful, both the staff assessment report, and the final decision document agreed that the likely benefits outweighed any risks for New Zealand of introducing a new agent. Thirdly, the prospects of locating a suitable biological control agent for the recently introduced pest *Paropsisterna variicollis* was strengthened through collaboration with international entomologists. Masters student Ryan Ridenbaugh, University of Central Florida, USA, has shown a high proportion of *P. variicollis* larvae infesting *Eucalyptus globulus* plantations throughout November and early December in Victoria, Australia, are infested with a species of *Eadya* (Braconidae). At least half the sites revealed successful parasitism. We await the molecular results to reveal whether or not the *Eadya* specimens are in fact all the expected species, *Eadya annleckii*, or whether they might be a combination of the *Eadya* species identified to date. The only work not completed to the stage expected was submission of a collaborative publication that shows the likely geographic origin of *P. variicollis* based on sequences from two gene regions of beetles from throughout Australia and New Zealand. The analyses are not complete and therefore we can’t release the results for public dissemination at this time.

BACKGROUND

Plantation species other than *Pinus radiata* (radiata pine), specifically Douglas-fir (*Pseudotsuga menziesii)* and eucalypts (*Eucalyptus* spp.), form an important part of a diversified forest estate. Douglas-fir is planted over approx. 105,000 ha. and is the most widely planted tree species after radiata pine. *Eucalyptus nitens* is planted over approximately 14,000 ha (NZ Forest Owners Association 2017) and contributes ~$40 million pa in hardwood chip exports. Throughout New Zealand the biggest threat to *E. nitens* plantations is from the eucalyptus tortoise beetle, *Paropsis charybdis* (Withers and Peters 2017). In addition, the recent arrival of myrtle rust *Austropuccinia psidii* and *Eucalyptus* variegated beetle *Paropsisterna variicollis* may pose further challenges to the *Eucalyptus* forestry industry (Millen et al. 2018).

Eucalyptus and Paropsis
To manage populations of *P. charybdis*, chemical control by aerial spraying of insecticides occurs in up to a quarter of large plantations annually (Rolando et al. 2016). However, the costs associated with aerial spraying are prohibitive for many growers and a major barrier to increasing eucalypt plantations. Other undesirable outcomes, such as environmental and ecological harm and risking FSC certification could also result from long-term use of chemical insecticides. An alternative approach to insecticides is using classical biological control (Rolando et al. 2016).

In the case of *Paropsis charybdis*, four potential biological control agents have been introduced already in previous decades, but only two of these have been helpful, so a more effective control is needed (Withers and Peters 2017). A promising new agent is the Australian parasitoid *Eadya daenerys* (Hymenoptera: Braconidae). Host-testing of non-target species against this parasitoid in a quarantine facility at Scion has been completed and this year Scion sought to obtain permission from the New Zealand government to release this new parasitoid *Eadya* in New Zealand.

Research was also continued on investigating options for future control of the *Eucalyptus* variegated beetle *Pst. variicollis,* in particular the origin and identity of the population in New Zealand was investigated by molecular methods. Field work was also begun in Australia to identify and assess prospective biological control agents of the pest within its area of origin.

RESULTS

Milestone 1: Economic Analysis of *Paropsis charybdis* control

The standing *Eucalyptus* crop in New Zealand was valued in terms of projected yield and other ecosystem services. Also, the cost of *Paropsis charybdis* damage to *Eucalyptus* forests was estimated along with the costs and benefits of chemical and biological control of this pest.

Key results

The total planted area of *Eucalyptus* species in New Zealand was estimated to be 27,598 ha with a standing volume of 8.1 million m^3, with a conservative asset value of $671 million. This could be increased in the future if higher value products (e.g. wood flooring or ground-durable poles) are produced from the existing *Eucalyptus* estate and future plantings. *Paropsis charybdis* shows a strong feeding preference for *Eucalyptus nitens*, which is the major species grown for the production of wood chips for paper making. *Paropsis charybdis* finds many species in the eucalypt sub-genus *Symphyomyrtus* palatable but all show different susceptibility to the pest. We know the proportion of susceptible species in different stands will differ between regions. Regional forest inventory data from the Ministry for Primary Industries (MPI 2016) was examined and combined with Scion in-house species-site matching knowledge to estimate the proportion of *Eucalyptus* species in each region that might be palatable to *P. charybdis*. From this exercise, the weighted average across New Zealand of *Eucalyptus* plantations susceptible to *P. charybdis* was estimated at 60-75%. Therefore, $402-$503 million worth of *Eucalyptus* stands have a high potential of being damaged by *P. charybdis*.

***Benefit : Cost of managing* Paropsis charybdis**

Damage caused by *P. charybdis* in terms of yield loss can reach $10,000 ha^{-1} in the case of low-severity, $30,000 ha^{-1} for medium-severity and $60,000 ha^{-1} following high-severity attack at the end of a 40-year rotation. The value of the damage is lower ($1,600 ha^{-1} low-severity, $4,800 ha^{-1} medium-severity, and $9,700 ha^{-1} high-severity) for shorter (15-year) rotation pulpwood plantations. However, in the absence of effective chemical control, the rotation period of a severely damaged stand will need to be extended to obtain the same volume at harvest as an unaffected stand.

There are approximately 15,300 ha of vulnerable *E. nitens* within short-rotation pulpwood plantations in New Zealand and the potential yield loss due to *P. charybdis* damage is estimated at $10 million per year. The current management method involves chemical control by aerial spraying with insecticides once or twice per year. This costs $160 ha^{-1} per year for plantations >40 ha. Chemical treatment was found to be uneconomical for small plantations or woodlots (<10 ha) at an estimated $340 ha^{-1} per year. The current chemical control costs an estimated $1.0–$2.6 million/year and the Net Present Value of the pest control of all susceptible *Eucalyptus* species is $30-$38 million in New Zealand over a 40-year rotation.

Comparison of biological control with chemical control

Effective biological control would reduce damage caused by *P. charybdis* with no on-going costs once the agent is established. In contrast, chemical control involves on-going costs that vary based on the size of the plantation. In most situations, biological control was found to be more cost effective than chemical control. Large plantations (>40 ha) will need to be protected by chemical control when damage is severe but this is an uneconomic method for plantations <10 ha, and not economically justifiable yearly when damage is light to moderate. Thus, small growers are reliant on biological control to realise the value of their woodlots. Effective biological control will prevent an average yield loss of 4.1 m^3 ha^{-1} per year in susceptible *Eucalyptus* stands, which is equivalent to \$417 ha^{-1} per year in value. Effective biological control with *Eadya daenerys* could prevent \$5.8-\$7.2 million in losses per year for the current *Eucalyptus* spp. stands established in New Zealand.

Report title	Economic impact of eucalyptus tortoise beetle (*Paropsis charybdis*) in New Zealand (attached as APPENDIX ONE to this report)
Authors	Robert I Radics, Toni M. Withers, Dean F. Meason, Toby Stovold, and Richard Yao
Client	Scion internal
SIDNEY output number	61256
Signed off by	Lindsay Bulman
Date completed	30 August 2018
Confidentiality requirement	Non-confidential

Proposed future work:
Robert Radics, Toni Withers and Dean Meason are preparing this research into a publication.

Milestone 2: Decision on EPA application to release *Eadya daenerys* from containment as a biocontrol agent for *Paropsis charybdis*

In 2015, a laboratory colony of the parasitoid identified in Tasmania, *E. daenerys*, was established n containment in New Zealand. Laboratory mortality was high due to incompletely-spun pupal cocoons and it proved difficult to break pupal diapause. As a result, we abandoned our initial plan to mass rear a laboratory colony for the duration of the project. Instead, multiple field collections of adults of unknown age were made from *E. nitens* plantations in Tasmania by in-kind contributors, collaborators, and Scion staff in December 2015, 2016 and 2017. Adult female wasps were shipped in chilled boxes to the containment facility in Rotorua and maintained for experiments. Nine species of non-target beetles were chosen for host testing after first using two different risk assessment approaches to understand the best host testing list. Non-target beetles were collected and reared in the laboratory over three years 2015-2017 to obtain numerous larvae of the stage suitable for experiments. All host species with spring-active, external leaf-feeding larvae, were tested against the parasitoid using three different methods: no-choice physiological assays, sequential no-choice behavioural assays, and two-choice behavioural assays. Development to emergence only occurred within eucalypt-feeding species in the tribe Paropsina; the target *P. charybdis* and another pest *Trachymela sloanei*. Unsuccessful internal parasitism occurred in four less closely related non-target Chrysomelinae; *Dicranosterna semipunctata*, *Allocharis nr. tarsalis*, *Chrysolina abchasica* and *Gonioctena olivacea*. Considering the different feeding niches of non-target Chrysomelinae, we concluded the likelihood that *E. daenerys* would cause non-target impacts beyond the Paropsina was very low.

In-depth research was also undertaken in Tasmania as part of the project. Most significantly, over six years Paropsina larval specimens were collected from throughout Tasmania and reared to document the *Eadya* species' host interactions. These *Eadya* species were analysed morphologically and three gene regions were analysed using a molecular phylogenetic approach (Peixoto et al. 2018). It was this work that revealed the presence of a complex of four similar parasitoid species in the genus *Eadya* (Ridenbaugh et al. 2018). This work allowed us to define the parasitoid complex and assure the EPA that we were researching and proposing to import the species that targeted *P. charybdis*.

Key results

Pre-release community engagement and consultation was undertaken widely in New Zealand. Engagement with Maori increased as the project progressed, and included multiple mail outs, face to face meetings, attendance at hui and appropriate iwi komiti meetings. The Application to release *Eadya daenerys* into the New Zealand environment was sent to the EPA in September 2018, and the Hearing undertaken in January 2019 (Staff assessment report Attached Appendix Two). The approval for full release in New Zealand was obtained on 25 February 2019 (Appendix Three):

Date	25 February 2019
Application code	APP203631
Application type	To import for release and/or release from containment any new organism under section 34 of the Hazardous Substances and New Organisms Act 1996
Applicant	Scion
Date application received	18 September 2018
Date of Hearing	22 January 2019
Date of Consideration	22 January 2019
Considered by	A decision-making committee of the Environmental Protection Authority (the Committee)1: Dr Louise Malone (Chair) Dr Kerry Laing Dr Ngaire Phillips

Purpose of the application	To release a parasitoid wasp, *Eadya daenerys*, as a biological control agent for the Eucalyptus tortoise beetle (*Paropsis charybdis*)
The new organisms approved	*Eadya daenerys* (Ridenbaugh, 2018)

EPA staff assessment report is attached as Appendix Two.
EPA Decision report attached Appendix Three

Proposed future work:
Toni Withers has requested SWP and the NZ Farm Forestry Association assist with co-funding to recollect *Eadya daenerys* from Tasmania in December 2019. These will be imported into Scion containment for mass rearing through one generation prior to MPI issuing approval for their release (Withers and Harnett 2019). In future years (we propose three seasons) commercial eucalypt growers will fund the mass rearing outside of containment for release into New Zealand forests. We will request MPI through the Sustainable Food Fibre Futures fund to co-fund this to ensure farm foresters can also benefit from nation-wide releases of *Eadya daenerys*. The sooner *E. daenerys* can be established to control the spring generation of *P. charybdis*, the better for tree health and for the environment.

Milestone 3: Investigating the origin of and potential biocontrol agents for EVB *Paropsisterna variicollis*

The prospects of locating a suitable biological control agent for the recently invaded *Eucalyptus* pest *Pst. variicollis* was strengthened through successful collaborations with international entomologists. Firstly, a collaboration agreement was drawn up between Scion and Australian entomologists Helen Nahrung and Geoff Allen. Co-funding was received from the University of the Sunshine Coast. Adult beetles superficially resembling *Pst. variicollis* were collected from the Hawke's Bay region in New Zealand, and from several sites throughout Tasmania and mainland Australia. *Paropsis charybdis* from New Zealand were collected and used as an outgroup for molecular analysis. DNA was extracted from one leg each from each of the 130 beetles. Forward and reverse target primers were used for sequencing PCR products from two mitochondrial gene regions cytochrome c oxidase subunit 1 gene (COI), and cytochrome b (*Cyt b*). Male and female adult specimens of a subsample of a number of species of beetles were identified blind by Dr Chris Reid (who is one of the authors) to species where possible, based on external morphology, especially pronotal and elytral punctures. Analysis of 96% of the samples from both COI and *Cyt b* trees gave rise to distinct clades, named mainland Australia, Tasmania, Western Australia and New Zealand. However there is low separation between clades. The final conclusions of the work can't yet be released until data analysis is completed. The work will shortly be submitted to an international journal.

Secondly, a Masterate of Science student Ryan Ridenbaugh was financially supported by Scion SSIF to conduct field work for two successive years in the Australian Capital Territory, New South Wales, and Victoria. He first undertook collections during December 2017, with little success. This season he arrived earlier and undertook collections between 31 October and 10 December 2018. Both *Paropsis* and *Paropsisterna* spp. larvae and adults were collected from at 36 sites and reared at the Australian National University. From this material 101 wasps were reared, with the majority of these emergences arising from *Pst. variicollis* larvae from Victoria. The distinctive black stripe down the dorsal surface of the yellow *Pst. variicollis* larvae greatly assists with locating the correct species of larvae in the field. Based on the size of the wasp larvae, the coloration of the cocoon, and the time of the emergences Ryan believes all were species of *Eadya*. All *Eadya* emergences were from beetles collected around Hamilton, Victoria and from juvenile *Eucalyptus globulus* plantations. This suggests that in New Zealand it is likely *E. nitens* will be a host for EVB, as *E. nitens* and *E. globulus* are extremely closely related within the sub-genus Symphyomyrtus. This is the first time any *Eadya* have been recorded in Victoria west of Melbourne and will likely result in several new distribution and host records.

Of the 101 emergences, roughly half successfully spun cocoons and can be used for both morphological and molecular analyses. In addition to the wasps, roughly 50-60 Tachinidae flies were reared from material collected in Hamilton, VIC and Canberra, ACT. Species identifications for all wasps, flies, and beetles will be determined once the specimens are successfully imported to the University of Central Florida and molecular analyses can be performed. Ryan's first and second progress reports are attached as Appendices Four and Five "Field work to identify natural enemies of *Paropsisterna variicollis* (Chrysomelidae) Eucalyptus Variegated Beetle, in Australia".

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Economics: Thanks to the contributions from DF. Meason, T Stovold, and R Yao (Scion). Contributors included Oji Fibre Solutions NZ Ltd and Southwood Exports.

Eadya: The successful EPA hearing was made possible thanks to David Fox, Grant Wilcock, Graeme Manley, Chris Reid, Carl Wardhaugh and Robert Radics, not to mention all the submitters in support of the application and Scion staff behind the scenes such as Vicky Hodder, Michelle Harnett, Juan Monge, Ramona Radford, Steve Pawson and Andrew Pugh.
In terms of the science, many thanks to Scion staff including Andrew Dunningham, Justin Nairn, Matt Scott, Pam Taylor, Carl Wardhaugh, Andrew Pugh and Belinda Gresham and University of Tasmania, Institute of Agriculture staff members Geoff Allen, Vin Patel and Steve Quarrell. Dean Satchell, New Zealand Farm Forestry Association has also been an invaluable contributor to this research.
Students including Stephanie Kirk, Mike Davy, Sean Gatenby, Katherine Moors, Elise Peters and Amy Yasutake-Watson, in New Zealand, and Ray Ali, Hui Law, Meng Lim, Allanna Russell, and Rebekah Smart, in Australia.
Thanks to Landcare Research scientists Ronny Groenteman, Hugh Gourlay, Chris Winks, Paul Peterson and Richard Leschen and AgResearch scientist Mike Cripps for their invaluable assistance with non-target beetles. *Allocharis* nr *tarsalis* were collected under New Zealand Department of Conservation research authority 54216RES.
Funding was from the New Zealand Ministry for Primary Industries Sustainable Farming Fund contracts 12-039 and 407964, and New Zealand Ministry of Business Innovation and Employment Strategic Science Investment Funding contract to Scion. Industry funding co-partners Southwood Exports Limited and Oji Fibre Solutions NZ Ltd, are gratefully acknowledged, as are the Speciality Wood Products Partnership, and the New Zealand Farm Forestry Association.

EVB: Co-authors of the paper in preparation (alphabetically) include G.R. Allen (UTAS) A. Lewis and R. McDougal (Scion), H.F. Nahrung (USC), R. Ridenbaugh (UCF), C.A.M. Reid (Museum of Sydney), and T.M. Withers (Scion). Furthermore Dongmei Li (MPI Plant Health Environment Laboratory) contributed additional sequences from a March 2016 collection in New Zealand. New Zealand collections were undertaken by SPS Biosecurity and Colin Ferguson (AgResearch). We are grateful for the additional collections in Australia conducted by A. Garcia, M. Schroder, N.M. de Souza, and Megan Head.
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APPENDICES

Appendix One: Economic impact of eucalyptus tortoise beetle (*Paropsis charybdis*) in New Zealand. Scion internal report number 61256

Economic impact of eucalyptus tortoise beetle (*Paropsis charybdis*) in New Zealand

Robert I. Radics, Toni M. Withers, Dean F. Meason, Toby Stovold, and Richard Yao

An adult *Paropsis charybdis* on *Eucalyptus* foliage. Photo: Scion.

Report information sheet

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Date	30 August 2018
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Intellectual property	
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Executive summary

Economic impact of eucalyptus tortoise beetle (*Paropsis charybdis*) in New Zealand

The problem

A number of tree species in the genus *Eucalyptus* L'Her are grown in New Zealand on a small scale. However, the economic value of this resource is not known. The economic impact of damage caused by a pest, the eucalyptus tortoise beetle (*Paropsis charybdis*), to *Eucalyptus* species in grown in New Zealand is also not defined.

The current approach

The standing *Eucalyptus* crop in New Zealand was valued in terms of projected yield and other ecosystem services. Also, the cost of *Paropsis charybdis* damage to *Eucalyptus* forests was estimated along with the costs and benefits of chemical and biological control of this pest.

Key results

The total planted area of *Eucalyptus* species in New Zealand was estimated to be 27,598 ha with a standing volume of 8.1 million m^3, with a conservative asset value of $671 million. This could be increased in the future if higher value products (e.g. wood flooring or ground-durable poles) are produced from the existing *Eucalyptus* estate and future plantings. *Paropsis charybdis* shows a strong feeding preference for *Eucalyptus nitens*, which is the major species grown for the production of wood chips for paper making. *Paropsis charybdis* finds many species in the eucalypt sub-genus *Symphyomyrtus* palatable but all show different susceptibility to the pest. We know the proportion of susceptible species in different stands will differ between regions. Regional forest inventory data from the Ministry for Primary Industries (MPI 2016) was examined and combined with Scion in-house species-site matching knowledge to estimate the proportion of *Eucalyptus* species in each region that might be palatable to *P. charybdis*. From this exercise, the weighted average across New Zealand of *Eucalyptus* plantations susceptible to *P. charybdis* was estimated at 60-75%. Therefore, $402-$503 million worth of *Eucalyptus* stands have a high potential of being damaged by *P. charybdis*.

***Benefit : Cost of managing* Paropsis charybdis**

Damage caused by *P. charybdis* in terms of yield loss can reach $10,000 ha^{-1} in the case of low-severity, $30,000 ha^{-1} for medium-severity and $60,000 ha^{-1} following high-severity attack at the end of a 40-year rotation. The value of the damage is lower ($1,600 ha^{-1} low-severity, $4,800 ha^{-1} medium-severity, and $9,700 ha^{-1} high-severity) for shorter (15-year) rotation pulpwood plantations. However, in the absence of effective chemical control, the rotation period of a severely damaged stand will need to be extended to obtain the same volume at harvest as an unaffected stand.

There are approximately 15,300 ha of vulnerable *E. nitens* within short-rotation pulpwood plantations in New Zealand and the potential yield loss due to *P. charybdis* damage is estimated at $10 million per year. The current management method involves chemical control by aerial spraying with insecticides once or twice per year. This costs $160 ha^{-1} per year for plantations >40 ha. Chemical treatment was found to be uneconomical for small plantations or woodlots (<10 ha) at an estimated $340 ha^{-1} per year. The current chemical control costs an estimated $1.0–$2.6 million/year and the Net Present Value of the pest control of all susceptible *Eucalyptus* species is $30-$38 million in New Zealand over a 40-year rotation.

Comparison of biological control with chemical control

Effective biological control would reduce damage caused by *P. charybdis* with no on-going costs once the agent is established. In contrast, chemical control involves on-going costs that vary based on the size of the plantation. In most situations, biological control was found to be more cost effective than chemical control. Large plantations (>40 ha) will need to be protected by chemical control when damage is severe but this is an uneconomic method for plantations <10 ha, and not economically justifiable yearly when damage is light to moderate. Thus, small growers are reliant on biological control to realise the value of their woodlots. Effective biological control will prevent an average yield loss of 4.1 m^3 ha^{-1} per year in susceptible *Eucalyptus* stands, which is equivalent to $417 ha^{-1} per year in value. Effective biological control with *Eadya daenerys* could prevent $5.8-$7.2 million in losses per year for the current *Eucalyptus* spp. stands established in New Zealand.

Eucalyptus *in the context of ecosystem services*

Exotic planted forests in New Zealand (including *Eucalyptus* forests) provide important environmental benefits. These include carbon sequestration, habitats for taonga species, shelter, shading and avoided nitrate leaching. Such benefits are not considered in market transactions but their values can be approximated using environmental economic valuation techniques. The quantifiable environmental value of existing *Eucalyptus* plantings was estimated to be about $11 million per year. However, these environmental values should be considered as indicative only as the value of these ecosystem services can vary substantially across space and time, as well as across tree ages and forest management practices.

Economic impact of eucalyptus tortoise beetle (*Paropsis charybdis*) in New Zealand

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Introduction

Planted forests cover approximately 7% of the land area in New Zealand. The forestry sector is valued at approximately NZ$5.6 billion per year, which makes it New Zealand's third largest export earner (NZ Forest Owners Association, 2017). Protection of this resource from biosecurity threats as well as biotic and abiotic risks is, therefore, a high priority for forest growers (NZ Forest Owners Association, 2017).

New Zealand's commercial plantation forests are dominated by two softwood species: radiata pine (*Pinus radiata* D.Don; 89%) followed by Douglas-fir (*Pseudotsuga menziesii*; 5%). The remaining 6% of the planted estate is comprised of various other species that have the potential to be grown commercially at a large scale. Having a diversified forest estate is important for New Zealand in terms of spreading risk should a biosecurity incursion devastate one major plantation species. A number of species of gum trees in the genus *Eucalyptus* are grown in New Zealand on a small scale and have potential to be an expanded and valuable plantation resource (Wilcox, 1993).

Eucalyptus species are native to Australia and produce hardwood rather than softwood. Some species are very fast growing (Candy, 1997) and contain high-quality wood (Miller, et al., 1992). The wood fibre also has excellent characteristics for pulp and paper making so high value is placed on hardwood chips for manufacturing specialised high-strength packaging products both in New Zealand and overseas. In 2014, the total value of chip exports originating from *Eucalyptus nitens* (H.Deane & Maiden) Maiden plantations was estimated to be approximately NZ$44 million (J. Monge, Scion, unpublished data). The timber from some *Eucalyptus* species is attractively coloured and is suitable for flooring and specialised timber applications (Bootle, 1983). Also, the wood from some species is naturally durable so does not require treatment with toxic chemicals to make it rot resistant (Millen, 2011). A regional value chain is being developed by the New Zealand Dryland Forests Initiative (NZDFI) to grow naturally durable timber on a short rotation for use directly as poles and also for the production of Laminated Veneer Lumber (LVL). Timber from these forests should be available by 2035 (Millen, et al., 2018). One integrated forestry and processing company (Juken NZ Ltd) has already identified eucalypt LVL as a promising product and is actively planting *Eucalyptus* species on the East Coast (currently several hundred hectares). Several other East Coast forest growers and farm foresters, including Landcorp Farming and the Hawke's Bay Regional Council, are also actively planting *Eucalyptus* species (Millen, et al., 2018). It is important to note that wood from some species require specialised processing to prevent growth-stress-related characteristics and/or drying distortion in sawn timber that would otherwise reduce the value of the end product (McKinley, et al., 2002).

Eucalyptus species are beneficial to New Zealand's forestry sector but there is no current consensus on their economic value. Uncertainty exists because some trees have been damaged by a number of specialist pests and pathogens that have occasionally resulted in woodlots being so unhealthy that they have had no commercial value except as firewood. Therefore, the overall objective of this study was to estimate the current economic value to New Zealand of the standing *Eucalyptus* crop.

Many eucalypt pests have invaded New Zealand from Australia, presumably due to the close proximity of the two countries (Withers, 2001). A secondary objective of this study was to determine the loss in economic value caused by defoliation of trees by the most serious pest of *Eucalyptus* species, the eucalyptus tortoise beetle, *Paropsis charybdis* Stål. (Col.: Chrysomelidae) (Bain, et al., 1989; Withers & Peters, 2017). This beetle has been a pest of eucalypt trees in New Zealand since it invaded the South Island in 1916. It causes substantial damage to *Eucalyptus* species, especially *E. nitens*. This pest is considered a high risk to the future profitability of plantations, and this concern may be limiting the development of new plantings. For instance, a similar invasive leaf-feeding pest, *Paropsisterna beata* (Newman) was subjected to an eradication campaign by the Ministry for Primary Industries (MPI) following a cost-benefit analysis that estimated it could cause $23 million in lost pulp wood production over 20 years (Yamoah, et al., 2016).

For the last two decades, forest managers growing *E. nitens* have dealt with outbreaks of *P. charybdis* in their plantations by aerial spraying with the pesticide alpha-cypermethrin (Rolando, et al., 2016). This type of operation is expensive and may also produce incidental spray drift to adjacent plantations that may invalidate spray-free certification, for example by the Forest Stewardship Council (FSC) (Withers, et al., 2013). Biological-control approaches are more environmentally sustainable alternative methods of managing pests such as *P. charybdis.* A number of biological-control agents have been introduced into New Zealand in the past with some success (Bain, et al., 1989; Withers & Peters, 2017). Scion is currently investigating the introduction of a parasitoid *Eadya daenerys* Ridenbaugh (Hym.: Braconidae) from Australia that shows excellent potential to reduce the spring generation of *P. charybdis* by attacking larvae (Ridenbaugh, et al., 2018). However, it may not be possible to establish this beneficial parasitoid if chemical control continues to be the most favoured pest-management technique. This is because broad-spectrum pesticides (such as alpha-cypermethrin) will kill the biological-control agent as well as the pest so are likely to reduce the population size and effectiveness of the beneficial insect (Loch, 2005). Furthermore, managing *P. charybdis* by chemical control is probably not economically feasible for small growers, and they need a sustainable way of ensuring they can grow their *Eucalyptus* crop for long enough to extract the full value from the timber. This would require a sustainable and cost-effective protection from pests for a much longer rotation length.

Paropsis charybdis *biology*

Paropsis charybdis is a chrysomelid leaf-feeding beetle, one of a group of “paropsines” that have evolved to feed on the foliage of the genus *Eucalyptus* from Australia. Feeding by adult beetles is largely restricted to species in the sub-genus *Symphyomyrtus*, Section Maidenaria (Pryor, et al., 1971). For instance, they prefer *Eucalyptus viminalis* La Billardière, *Eucalyptus globulus* La Billardière, *E. nitens,* and many other closely related species. These preferred species support both adult and larval feeding and are prone to severe defoliation every year. *Paropsis charybdis* lay fewer eggs on other species of *Eucalyptus* and the resultant larvae take longer to develop. They also exhibit high mortality (for instance on the monocalypt *Eucalyptus fastigata* Deane & Maiden) (Bain, et al., 1989). Both adults and larvae of *P. charybdis* are voracious feeders. Young larvae feed on new expanding fresh foliage tips, older larvae feed on fresh (but fully expanded) adult leaves and adults can feed on older leaves as long as they are not fully hardened. Trees less than two years old have glaucous (waxy), simple-shaped juvenile leaves that are not palatable. From the age of two years to five years, a transition to glossy, sickle-shaped adult leaves occurs (Brennan, et al., 2001), after which the growing tips and young adult leaves become highly palatable to *P. charybdis*. The pest completes at least two generations per year in New Zealand (A. Pugh et al., unpublished data) so damage can occur between September and May (McGregor, 1984), but peaks in January (Murphy, et al., 2000).

Heavy defoliation of *E. nitens* results in a crown devoid of current foliage and a proliferation of juvenile foliage on the main stem and larger branches (called epicormic growth). Repeated defoliation results in crown die-back and a complete lack of stem growth or height increase. Such trees are commonly referred to as “witches’ brooms”. Complete defoliation over two consecutive years can cause the death of young trees (Bain, et al., 1989). Heavily defoliated older trees may survive indefinitely in a moribund condition without producing any additional stem growth (Figure 1). A field research project in Tasmania has modelled the impact of a range of levels of defoliation on growth of *E. nitens* over a 15-year rotation for pulp logs (Elek, et al., 2017). Their findings mirror observations made in New Zealand, particularly regarding young trees suffering repeated heavy defoliation late in the season for two consecutive years. These trees had a 17% smaller MAI (mean annual increment) and their diameter was at least 21% lower compared with untreated trees over one rotation. Defoliated trees would need to grow for three to four more years to reach the same stand volume as undefoliated trees at harvest (Elek, et al., 2017).

A

B

Figure 1. (A). A *Eucalyptus nitens* plantation in the central North Island following more than 12 years of repeated defoliation from *Paropsis charybdis*. (B). A *Eucalyptus nitens* plantation in the Southland region of the South Island that is free of any insect damage. Note that the Southland trees are half the age of the central North Island trees. Photos T. Withers & S. Gous, Scion.

Methods

The approach used here involved the collection of data on the size and age class distribution of the *Eucalyptus* spp. resource in New Zealand, and the likely costs of managing *Paropsis charybdis.* These data were then analysed using appropriate models to determine the economic value of the resource and the benefit : cost of managing *Paropsis charybdis* using various types of control.

Data collection

Eucalyptus *asset value in New Zealand*

Data on size and age class of the standing *Eucalyptus* spp. resource by region in New Zealand was collected from the National Exotic Forest Description (NEFD), websites (MPI and Forest Owners Association) and industry (Southwood Export Ltd, Oji Fibre Solutions Ltd.) to inform the asset evaluation of New Zealand *Eucalyptus* stands.

Benefit : cost of managing Paropsis charybdis

Researchers at Scion and plantations managers at Timberlands Ltd, Southwood Export Ltd, Oji Fibre Solutions NZ Ltd. were asked to provide details of the costs of forest management practices in their *Eucalyptus* plantations within the last 3–8 years, especially the methods, efficacy, and expenses they have undertaken to control *P. charybdis*. This information was broken down into: application; forest surveillance; and monitoring costs.

The aerial chemical control cost of spraying eucalypt plantations against *Paropsis charybdis* has a strong negative correlation with the plantation size, and ranges from \$22–\$140 ha^{-1} because of fixed minimum aircraft costs to initiate an operation. The pesticide cost is generally lower than the cost of application but shows a positive correlation with plantation size. An almost identical spray boom set-up and flying operation is conducted for spraying pine plantations against Dothistroma needle blight caused by the anamorph form of the pathogen *Dothistroma pini* Hulbary (Ascomycota: Dothideomycetes) so relevant variable costs for 2017 were obtained from the New Zealand Dothistroma Committee (L. Bulman unpublished data) as well compared to the data obtained from plantation managers. The sensitivity of changes in chemical control cost based on plantation size was also explored.

Previously published results for the growth of *E. nitens* under various artificial defoliation treatments (Elek, 1997; Elek, et al., 2017) were used to calculate the impact of *P. charybdis* on growth loss of susceptible eucalypts in New Zealand. The 'heavy damage' treatment was selected to represent the current situation for *P. charybdis* damage in New Zealand (Withers & Peters, 2017) (Table 1). Damage from *P. charybdis* was set to begin at age four when susceptible species of tree exhibiting heteroblasty initiate the transition from resistant juvenile to susceptible adult foliage (Brennan, et al., 2001).

Eucalyptus *in the context of ecosystem services*

The Environmental Valuation Reference Inventory database was searched in July 2018 for available literature on the contribution of *Eucalyptus* species to other ecosystem services besides economic value in New Zealand. The search topic “"economic valuation of biological control for eucalyptus" was used. In addition, published works by Yao et al. (2013) and by Yao and Velarde (2014) that estimate market and non-market values of ecosystem services for existing and proposed forests were also consulted.

Data analysis

Eucalyptus *asset value in New Zealand*

Various *Eucalyptus* species are grown in the existing forest estate and these differ in the land area and stand volume. The 2016 National Exotic Forest Description (NEFD) was used to quantify the number of hectares in each 5- or 10-year NEFD age class by region (NZ Forest Owners Association, 2016). Scion expert opinion was used to estimate the proportion of *E. nitens* and other species per region and the yield tables produced by Berrill, et al. (2006) were applied accordingly. The NEFD does not provide estimates of stands smaller than 40 ha; thus, it does not capture standing area of small woodlots. Expert opinion was obtained from the NZ Farm Forestry Association to enable the total area of small woodlots in New Zealand to be estimated. Then, recovery rate and an average stumpage price were allocated using values from Satchell (2015) to estimate *Eucalyptus* stand asset value by age class and region. The inventory age of the forests was used to discount the end of rotation value.

The *E. nitens* growth model (Candy, 1997) and the *E. fastigata* yield model were used to calculate stand volumes for this study (Berrill, et al., 2005). Both models were used to generate average New Zealand stand yield tables for both typical pulp and sawlog regimes for these two species by age class (Berrill, et al., 2006).The assumption was made that the *E. fastigata* yield model is adequate for approximating the standing volume of all other *Eucalyptus* species growing for sawlog regimes.

Benefit : cost of controlling Paropsis charybdis *using chemical methods*

Previously published results for the growth of *E. nitens* under various artificial defoliation treatments (Elek 1997; Elek & Baker 2017) were used to calculate the impact of *P. charybdis* on growth loss of susceptible eucalypts in New Zealand. The 'heavy damage' treatment was selected to represent the current situation for *P. charybdis* damage in New Zealand (Withers & Peters, 2017). The assumptions used in the model of *P. charybdis* impact on *E. nitens* are shown in Table 1. Damage from *P. charybdis* was set to begin at age four years when susceptible species of tree exhibiting heteroblasty initiate the transition from resistant juvenile foliage to susceptible adult foliage (Brennan et al., 2001).

The calculated volume loss at age 15 years was applied to an *E. nitens* production model for short-rotation plantations (Pérez-Cruzado et al., 2011). The loss of MAI at age 40 years was applied to an *E. fastigata* production model for long-rotation plantations (Berrill, et al., 2005).

Table 1. Assumptions used to model/simulate growth and impact of *P. charybdis* on *E. nitens*

Parameter	Assumption	Implications
Growth models	For short-rotation plantations (15 years), the *E. nitens* growth model was used (Pérez-Cruzado, et al., 2011). For long-rotation plantations (40 years), the *E. fastigata* growth model was used (Berrill, et al., 2005).	*E. nitens* grows faster initially than *E. fastigata.*
Rotation length	15 years minimum for *E. nitens* for pulp; 40 years for solid wood.	Only two types of end use were modelled.
Stocking density	Assumed even initial stocking rate of 1100 stems ha^{-1}.	Solid wood regimes have a lower final stocking density after thinning.
Susceptibility	Assumed *E. nitens* is 100% susceptible to *P. charybdis* attack while *E. fastigata* is 0% susceptible.	Other *Eucalyptus* species would likely have a range of values of susceptibility between these two extremes.
Weighted stumpage price	Assumed a weighted stumpage price of \$101 m^{-3} of a *E. nitens* green log.	Depending on the end product, this is conservative.
Plantation size	Cut off between a small and large plantation was set at 40 ha.	Assumed 16% of *Eucalyptus* forests are smaller than this cut-

		off when calculating total value to NZ.
Transition to adult foliage	*E. nitens* transitions to adult foliage at a mean age of 3 years, so only is impacted by *P. charybdis* from 4 years on.	In fact, transition to adult foliage occurs at a range of ages from 2–5 years.
Light damage	50% of new season's foliage removed twice, early in December in two consecutive years, just after having transitioned to adult foliage, LE2 or HE2 (Elek, et al., 2017).	(Assume this damage level once *Paropsis charybdis* is under effective biocontrol in NZ). Stimulates height growth in the short term. At a harvest age of 15 years, trees damaged early assumed to have 2 cm lower DBH than undamaged trees, about 12% reduction in MAI or the rotation age extended by 1 year.
Moderate damage	50% of new season's foliage removed once as well as all growth buds, late in February LDLa1 (Elek & Baker, 2017).	At 15 years old, late disbud once damaged trees were 3 cm lower DBH than undamaged trees, about 14% reduction in MAI, or extended rotation by 2 years.
Heavy damage	100% of new seasons foliage removed in February, in two consecutive years, just after having transitioned to adult foliage, HLa2 (Elek, et al., 2017).	(Assume this damage is currently experienced due to *Paropsis charybdis* feeding in NZ). Over 15 years, either wood volume loss of 20% or rotation extended by another 4 years.
Control cost	\$100–\$400 ha^{-1} per year control cost was applied in the economic model to show the break-even points of chemical applications by severity.	The estimated chemical control cost relied on industry data and expert opinion.
Inflation rate	1.75% inflation in the Net Present Value (NPV) calculation based on New Zealand Treasury data (Statistics NZ, 2013).	
Discount rate	8% discount rate was considered in the NPV calculation.	The discount rate is the choice of the entity that calculates the NPV. Lower discount rates improve the economics of chemical control.

A spreadsheet model was developed to evaluate the effect of three levels of insect damage (low, moderate, or heavy) and the aerial spray application costs needed to control *P. charybdis/*prevent insect damage in plantations. The model represented one hectare of a large (defined as >40 ha) *E. nitens* plantation from age four until harvesting (for pulp at age 15 years, or alternatively for solid wood at age 40 years). A Net Present Value (NPV) calculation was applied to obtain a more realistic estimate of the future costs and effects on income from plantations.

One or two applications per year and a variable scale of aerial spraying expense (\$100–\$400 ha^{-1} per year) and control efficacy (0–100%) were applied to explore the sensitivity of changes in control cost to *P. charybdis* attack severity (light, moderate or heavy). The estimated control cost per hectare per year includes the pest-related forest management efforts such as the cost of staff time to monitor plantation health status, and chemical application costs. In all cases, break-even points were defined and noted. A benefit : cost table was generated and used as a decision-support tool to summarise all the scenarios tested.

Comparison of biological control with chemical control

Biological control is costly to implement, but when successful can create a long-term sustainable method of supressing pest populations, that require no additional costs. The successful biological control project against the gum leaf skeletoniser pest, *Uraba lugens* Walker (Lep.: Nolidae) using *Cotesia urabae* (Austin & Allen) (Hymenoptera: Braconidae) (Berndt, 2011) cost approximately NZ$1.3 million (L. Bulman, Scion, pers. comm). The current proposal to investigate the potential of releasing a new biocontrol agent against *P. charybdis* began in 2013 and is likely to cost over $1 million by the time mass rearing and releases have been completed (L. Bulman, Scion, pers. comm). The cost was not included in the benefit : cost analyses because the full costs are not yet known and the project was funded by a combination of government public-good research funding and industry co-funding. However, the return on investment for successful biological control is generally high. For instance, the return derived from using biological control against insect pests to protect the value of urban *Eucalyptus* trees in California, USA, ranged from US$428 to US$1070 per dollar expended (Paine, et al., 2015).

Biological control was considered as an alternative to chemical control for managing populations *P. charybdis* to below ‘outbreak’ level. An insect outbreak can be defined as 'an explosive increase in the abundance of a particular species that occurs over a relatively short period of time'. This was done by determining the reduction in yield loss that could be achieved by controlling *P. charybdis* populations using biological methods. Laboratory trials have shown that a proposed new larval biological control agent (*Eadya daenerys* Ridenbaugh*,* Hymenoptera: Braconidae) (Ridenbaugh, et al., 2018; Withers, Allen, et al., 2017) can reduce survival of attacked *P. charybdis* larvae from 90% to 9%, although not all pest larvae will ever be located by this natural enemy (T. Withers, unpublished data 2018). Furthermore, in Tasmania, parasitism of spring-generation *P. charybdis* larvae from *E. daenerys* ranges from 0 to 13% per site, but this is in the presence of strong competition from tachinid flies that are not present in New Zealand (Peixoto, et al., 2018). If pest population sizes in any one region are too low then the biological-control agent will either not establish or will become locally extinct. Therefore, in the long term, *P. charybdis* and *Eadya daenerys* are likely to reach a population equilibrium, i.e. the biological-control agent will never drive the pest to extinction. However, levels of the pest should settle eventually at a lower abundance than would occur without biological control.

For this study, it was assumed that, in the future, the presence of effective biological control from *Eadya daenerys* would reduce *Eucalyptus nitens* damage severity from *P. charybdis* from “heavy late season damage” to “light early damage” (see Table 1 above for assumptions) (Elek, et al., 2017). The biological reason for this is that the parasitoid attacks the first-generation of larvae that are present during spring (A. Pugh et al, unpublished data). However, those individuals continue to feed while the parasitoid develops within them. Also, the parents of the infested larvae will persist in the plantation and cause foliar damage so light, spring-season damage will still occur. However, none of the larvae parasitised by *E. daenerys* will reach adulthood so will not emerge from the ground in summer; thus late-season damage should become rarer. This benefit was compared to the on-going costs of one chemical application per year (see above). Results were summarised in a decision-support table to show under what scenarios biological control versus chemical control was the most economically viable option in relation to plantation size.

Results and Discussion

Eucalyptus spp. asset value in New Zealand

Forest inventory data obtained from MPI showed the total area of standing *Eucalyptus* spp. in New Zealand as at April 2016 was 23,182 ha out of a total exotic forest estate of 1,704,707 ha (NZ Forest Owners Association, 2017). However, these MPI data include only owners who have at least 40 hectares of forest. Smaller areas of eucalypts are known to occur as shelterbelts, small woodlots, in small groups or individual trees. MPI (2016) estimated that 16% of New Zealand forests are less than 40 ha so the **total planted *Eucalyptus* area was estimated to be 27,598 ha**. This information plus 2016 data for *Eucalyptus* spp. forest area by age class were used as inputs into the *Eucalyptus fastigata* yield model (Berrill, et al., 2005). The resulting volume of the total *Eucalyptus* estate was 8.1 million m^3. A Net Present Value calculation by age class was applied to this volume and **total asset value** of the 27,598 ha of *Eucalyptus* spp. forests currently in New Zealand was estimated to be **NZ$671 million** (land value excluded).

End products ranging from firewood to high-value timber can be produced from *Eucalyptus* species so the stumpage value can vary. The types of end use depend on the species grown, site conditions and management regime applied. There is potential for the standing *Eucalyptus* estate and future planting of *Eucalyptus* forests to produce high-value products (e.g. wood flooring or ground durable poles). The potential increase in asset value of this resource was estimated to be up to NZ$2 billion based on data from Statistics New Zealand (Statistics NZ, 2013).

Value of eucalypt wood products

Eucalypt wood has a wide range of potential end uses (Millen, et al., 2018). Prices vary from \$20 m^{-3} to \$1200 m^{-3} depending on the quality of the wood, the level of processing, and the place in the supply chain (Satchell, 2015). The weighted stumpage price was used in the current study (Table 2) except where noted otherwise. The reason for this was to provide a conservative estimate of asset value estimate for *Eucalyptus* spp. plantations in New Zealand and to focus on the benefits of pest control.

Table 2. Eucalypt wood product stumpage value from Satchell (2015)

Weighted stumpage price	$/m^3
Solid wood (40-year rotation)	101
Pulp wood (15-year rotation)	50

Benefit : cost of controlling *Paropsis charybdis* using chemical methods

According to MPI, the largest areas of *Eucalyptus* species are in Otago and Southland (12,594 ha) and central North Island (6,534 ha). The total for these two regions is 19,128 ha. These plantations are grown for wood chips for export (Southwood Export Ltd) and for manufacture of packaging products (Oji Fibre Solutions NZ Ltd). Data obtained from plantation managers were used to estimate the average stocking densities for different species: 75-80% for *E. nitens* and 20-25% for *E. fastigata* or *E. regnans*. Only the *E. nitens* plantations (i.e. 15,300 ha) are susceptible to attack by *P. charybdis.*

Eucalypt plantings have started to increase in the Marlborough, Wairarapa, Gisborne and Hawkes Bay regions, reflecting the efforts of the NZDFI (Millen, et al., 2018). Research has begun to evaluate which of the species being developed by the NZDFI are susceptible to *P. charybdis* (Lin, et al., 2017). Although this research is still preliminary, it is known that half of most promising species in terms of end use (i.e. *E. bosistoana* F. Muell., *E. quadrangulata* Deane & Maiden, *E. camaldulensis* Denhardt, and *E. argophloia* Blakely) are showing moderate to high damage caused by *P. charybdis* and other paropsine pests (Lin, et al., 2017). The NZDFI have implemented a research programme that includes selection for pest resistance within the most promising seedlots for future plantings(Millen, et al., 2018). At the present time however damage susceptibility of these species to attack by *P. charybdis* remains highly variable. To reflect this variability within these regions, it was estimated that a range of between 50-70% of the 1900 hectares of plantations would be susceptible to damage, and 30-50% resistant. These data were combined with data from the pulp-growing regions. In addition, all the remaining regions where the composition mixes of species was unknown were assigned a range of between 50% and 70% susceptibility. These data were combined to produce a range of estimated weighted averages across New Zealand of *Eucalyptus* species susceptible to *P. charybdis* of 60-75%. **Therefore, existing *Eucalyptus* stands, worth approximately $402-$503 million are currently vulnerable to yield loss caused by *P. charybdis*.**

A range of scenarios involving one of three levels of insect damage (low, moderate, or heavy) was assessed using the spreadsheet model to determine the cost of *P. charybdis* control for one hectare of a large (defined as >40 ha) *E. nitens* plantation from age four until harvesting (for pulp at age 15 years, or alternatively for solid wood at age 40 years). The current management method of chemical control (Rolando, et al., 2016) **costs an estimated $1.0–$2.6 million/year and the Net Present Value of the pest control of all susceptible *Eucalyptus*** species **is $30-$38 million in New Zealand over a 40-year rotation**. An average application cost of $160 ha^{-1} per year was used. However, the cost of chemical control, if applied, would be at least $340 ha^{-1} per year for small plantations (<10 ha).

Short rotation

In large (>40 ha) eucalypt plantations managed under a short (15-year) rotation for a pulpwood end use, damage caused by *P. charybdis* can reach a NPV $1,600 ha^{-1} in the case of a low-severity attack, $4,800 ha^{-1} from a moderate-severity attack and $9,700 ha^{-1} after high-severity attacks at the end of a 15-year rotation. The benefit : cost ratios of chemical control are summarised in Table 3 and Figure 2. The green cells in the tables indicate those situations where the present values of the avoided yield loss are higher than the present values of chemical application, i.e. it is profitable to apply chemical control. The red cells indicate those situations where using chemical control will not provide enough benefit (i.e. won't reduce growth yield loss sufficiently) to justify application.

Table 3. Benefit : cost ratios of chemical control to reduce yield loss in an *E. nitens* plantation grown for pulpwood on a 15-year rotation under various scenarios. A. one insecticide application per year, and B. two insecticide applications per year

A. One application per year

Plantation type	Size (ha)	Cost (NZ$/ha/application)	Benefit : cost ratio for a given *P. charybdis* damage severity		
			Heavy	Moderate	Low
Large plantation	>40	100	3.4	1.8	0.7
Large wood lot	30-40	200	2.1	1.1	0.4
Medium wood lot	10-20	300	1.1	0.6	0.2
Very small wood lot	<10	400	0.9	0.4	0.2

B. Two applications per year

Plantation type	Size (ha)	Cost (NZ$/ha/application)	Benefit : cost ratio for a given *P. charybdis* damage severity		
			Heavy	Moderate	Low
Large plantation	>40	100	1.7	0.9	0.3
Large wood lot	30-40	200	1.1	0.6	0.2
Medium wood lot	10-20	300	0.6	0.3	0.1
Very small wood lot	<10	400	0.4	0.2	0.1

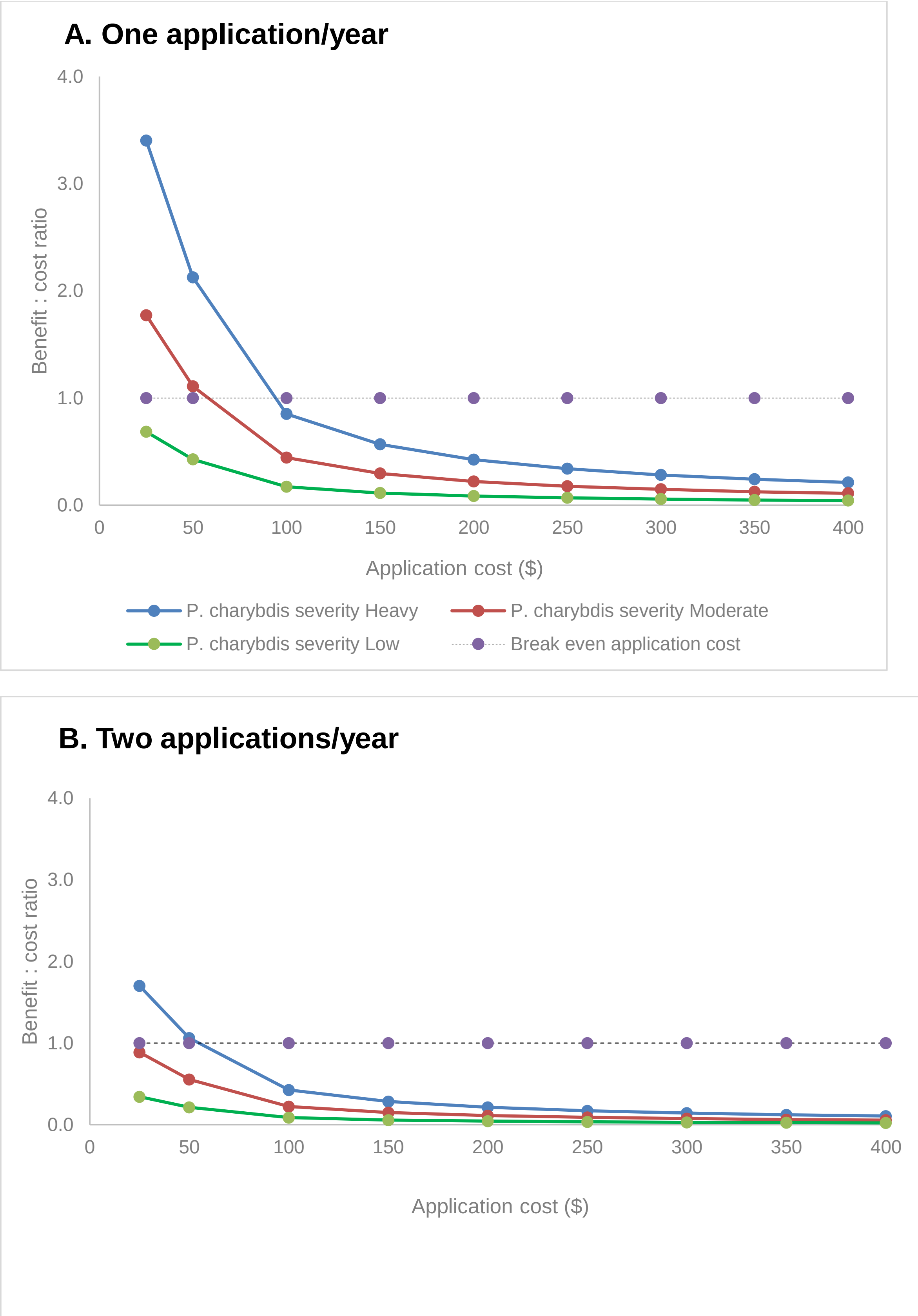


Figure 2. Impact of aerial chemical application cost against *P. charybdis* on the benefit : cost ratio for an *E. nitens* plantation (>40 ha) grown for pulpwood on a 15-year rotation (A. one application per year; B. two applications per year)

Long rotation

Some eucalypt plantations are managed under a long (40-year) rotation for solid wood end uses. No studies on the effect of *P. charybdis* over this time frame are available so it is not known whether chemical control would be needed every year, or whether the loss of MAI that is modelled up to 15 years old would continue to be realised up to 40 years old (Elek, et al., 2017). Candy (1999) made the assumption that all trees stabilise to the same growth rate as undefoliated trees within four years of defoliation ceasing. Applying this assumption means that smaller trees never regain the growth that they had lost in previous years. However, Elek and Baker (2017) found that more heavily defoliated trees continued to show reduced growth rates compared to undefoliated trees at harvest, which suggests they continue to generate a lower MAI, and the variation between treatments increases over time. The benefit : cost ratios of chemical control for a long rotation are summarised in Table 4 and Figure 3.

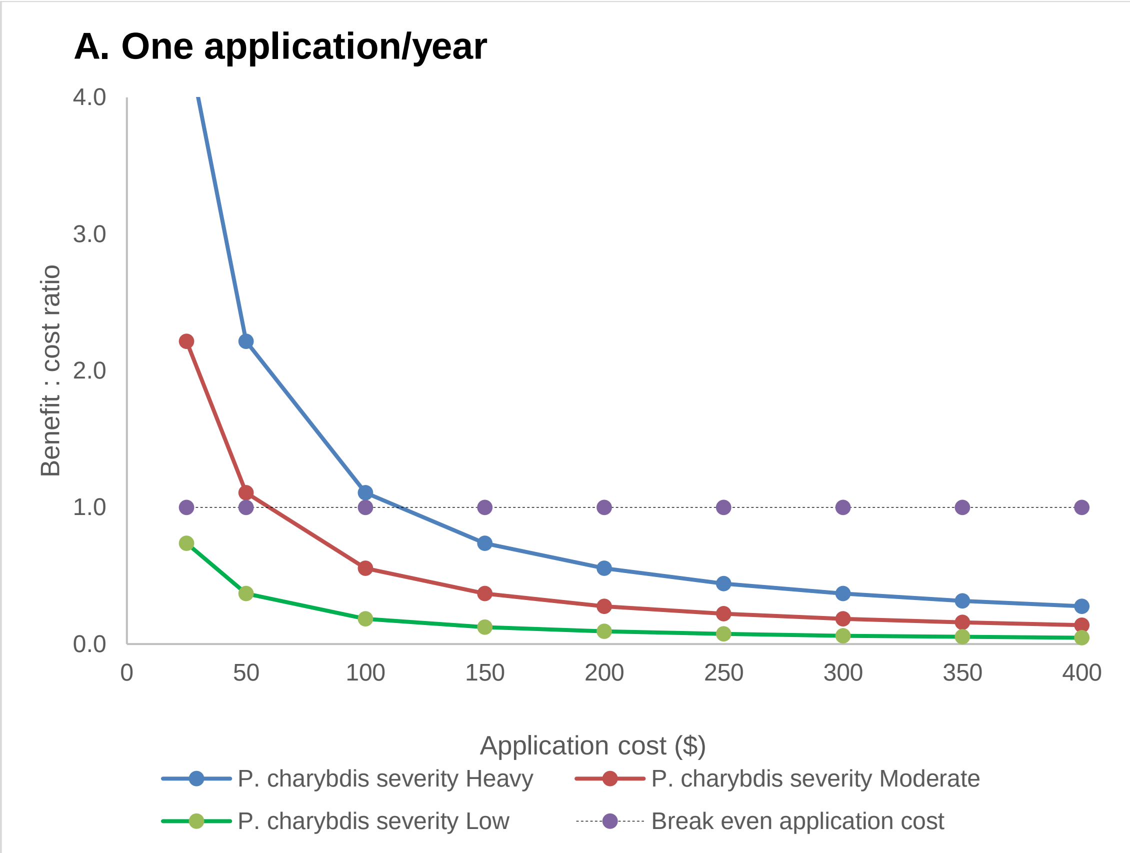
Table 4: Benefit : cost ratio of chemical control to reduce yield loss in a solid wood 40-year rotation plantation according to damage severity caused by *Paropsis charybdis*, and plantation size, when undertaking: A. one insecticide application per year; and B. two insecticide applications per year

A. One application per year

Plantation type	Size (ha)	Cost (NZ$/ha/application)	Benefit : cost ratio for a given *P. charybdis* damage severity		
			Heavy	Moderate	Low
Large plantation	>40	100	4.1	2.0	0.7
Large wood lot	30-40	200	2.6	1.3	0.4
Medium wood lot	10-20	300	1.4	0.7	0.2
Very small wood lot	<10	400	1.0	0.5	0.2

B. Two applications per year

Plantation type	Size (ha)	Cost (NZ$/ha/application)	Benefit : cost ratio for a given *P. charybdis* damage severity		
			Heavy	Moderate	Low
Large plantation	>40	100	2.0	1.0	0.3
Large wood lot	30-40	200	1.3	0.6	0.2
Medium wood lot	10-20	300	0.7	0.3	0.1
Very small wood lot	<10	400	0.5	0.3	0.1



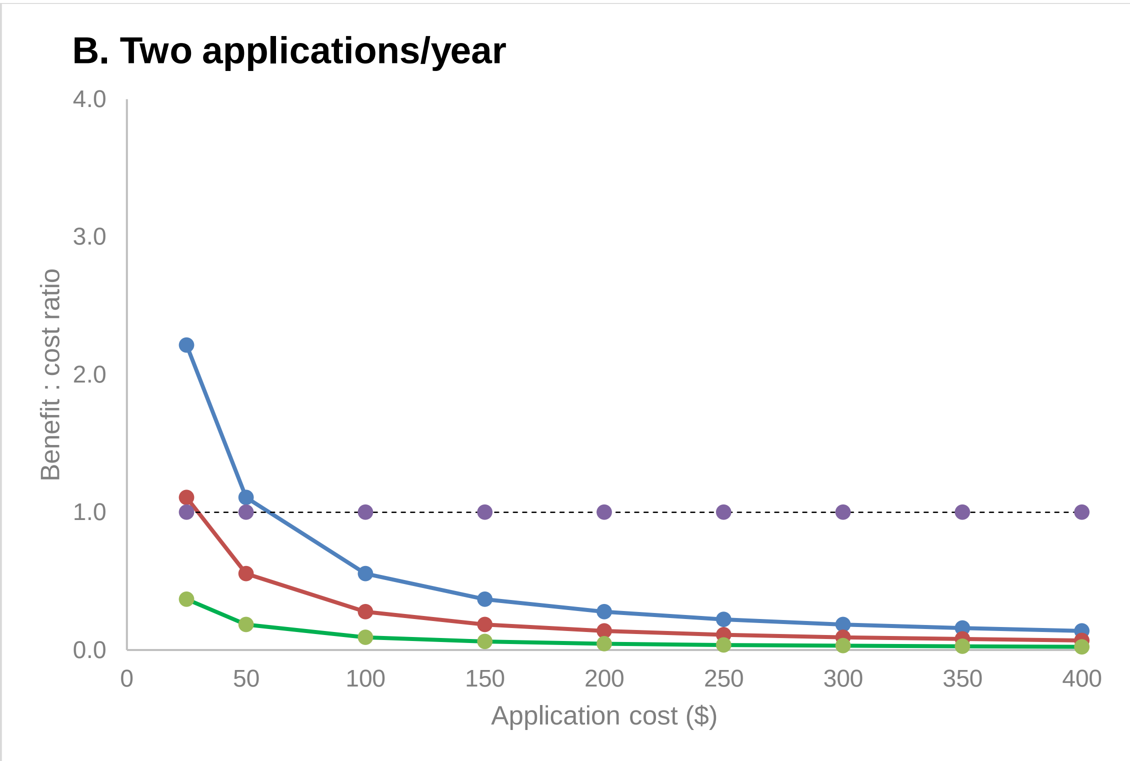


Figure 3. Impact of aerial chemical application cost against *P. charybdis* on the benefit : cost ratio for an *E. nitens* plantation grown for solid wood in a 40-year rotation (>40ha). (A: one application per year; B two applications per year).

Damage caused by *P. charybdis* in terms of yield loss can reach \$10,000 ha^{-1} in the case of low-severity, \$30,000 ha^{-1} for medium-severity and \$60,000 ha^{-1} following high-severity attack at the end of a 40-year rotation. With the cost of chemical control for plantations >10 ha found to be NZ\$160 ha^{-1} per year, chemical pest control is **not economically viable when damage severity is low**. For medium-severity damage, chemical pest control is economical only if the prevented yield loss is >65%. In the case of high severity, chemical control is viable if the avoided yield loss is >34% (Figure 4).

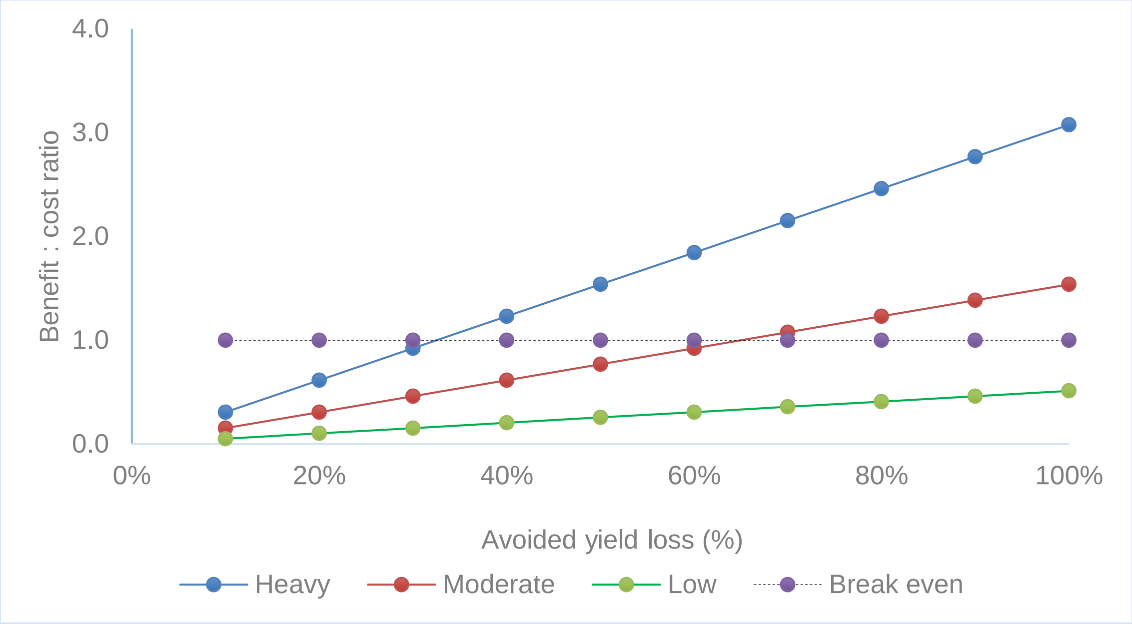


Figure 4. Benefit : cost ratio of the percent avoided yield loss in *E. nitens* plantations from *P. charybdis* damage at various degrees of severity assuming an average total chemical application cost of $160/ha in large plantations (>40ha).

The chemical control cost for very small plantations (≤10 ha) is NZ$340 ha^{-1} per year due to higher fixed costs of operating aircraft over smaller areas. At this cost, chemical pest control is not economically viable when damage from *P. charybdis* is of low or medium severity. For high-severity damage, chemical control is beneficial only if the avoided yield loss is more than 70% (Figure 5).

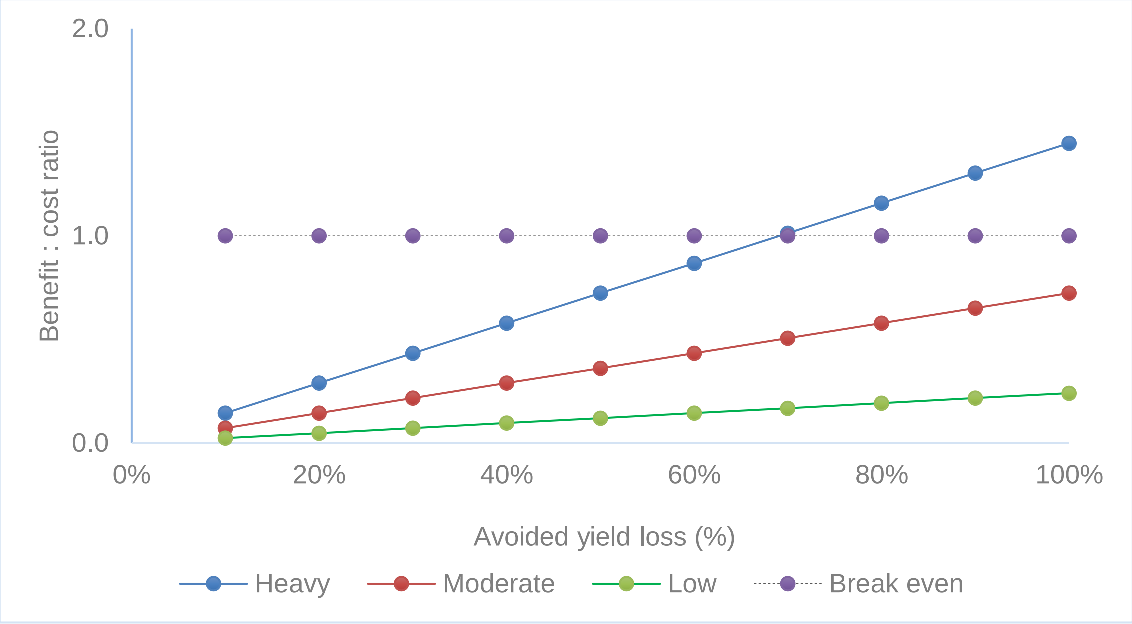


Figure 5. Benefit : cost ratio of percent avoided yield loss from *P. charybdis* at various severities according to average chemical application costs of $340 ha^{-1} in very small plantations (≤10 ha)

Comparison of biological control with chemical control

The economic benefit of preventable yield loss by reducing *P. charybdis* populations using biological control was estimated. It was assumed that, in the future, the presence of effective biological control from *Eadya daenerys* would reduce *Eucalyptus nitens* damage severity from *P. charybdis* from "heavy late-season damage" to "light early-season damage" (Table 1). The analyses were conducted in relation to plantation size. The following assumptions were applied:

- zero chemical application cost when the biological-control agent was used in all years
- first pest attack occurs at year 3,
- 95% avoided yield loss by aerial chemical control insecticide application
- 45% yield loss prevented by effective biological control (Table 1)
- one chemical application per year

The results of the analysis are shown in Table 5.

Table 5. Benefit : cost ratios of utilising biological control compared to chemical control on *Eucalyptus nitens* yield loss under either: A. short rotation of 15 years; or B. long rotation of 40 years.

A. Short rotation

Plantation type	Size (ha)	Benefit : cost ratio for a given *P. charybdis* damage severity		
		Heavy	Moderate	Low
Large plantation	>40	0.69	1.11	X
Large wood lot	30-40	0.89	3.64	X
Medium wood lot	10-20	3.04	X	X
Very small wood lot	<10	X	X	X

B. Long rotation

Plantation type	Size (ha)	Benefit : cost ratio for a given *P. charybdis* damage severity		
		Heavy	Moderate	Low
Large plantation	>40	0.74	0.83	X
Large wood lot	30-40	0.88	1.50	X
Medium wood lot	10-20	1.62	X	X
Very small wood lot	<10	4.01	X	X

X= chemical control costs exceed the prevented yield loss benefits based on Table 3 A and B even without using a biological-control agent

The green cells in Table 5A and B show the situations when the net present values of the avoided yield loss from biological control are higher than those of chemical application, i.e. it is profitable to rely on biological control. The red cells indicate that biological control will not provide sufficient benefit (i.e. reduce growth yield loss) so application of chemical control will be required to maintain the profitable growth of the plantation. *Eadya daenerys* will be more economically beneficial for small and medium wood lots, which would require unrealistically costly chemical control applications. No clear net monetary benefit of biological control would occur compared to chemical control in the case of large plantations experiencing very high- or medium-severity of defoliation by *Paropsis charybdis*. The advantage of biological control is greater for a short, 15-year rotation than for a long, 40-year rotation.

Using *Eadya daenerys* to reduce damage from *Paropsis charybdis* provides an average NPV of \$1,245 ha^{-1} over a 40-year rotation period of a *Eucalyptus* spp. stand. Assuming a 60-75% susceptibility rate across New Zealand of eucalypt woodlots and plantations, the total NPV of using biological control instead of chemical control is \$17.4-\$21.8 million.

Effective biological control will prevent an average yield loss of 4.1 m^3 ha^{-1} per year in susceptible *Eucalyptus* stands, which is equivalent to \$417 ha^{-1} per year in value. Effective biological control with *Eadya daenerys* could prevent \$5.8-\$7.2 million in losses per year for the current *Eucalyptus* spp. stands established in New Zealand.

Eucalyptus in the context of ecosystem services

The Millennium Ecosystem Assessment (MEA, 2005) provides a framework for demonstrating the full range of direct and indirect benefits provided by an ecosystem (e.g. a *Eucalyptus* forest ecosystem) to society. This framework enables the assessment and accounting of market (e.g. timber) and non-market (e.g. biological control, recreation and habitat provision) values in policy discussions. Under this framework, the *biological control* service is classified as one of the regulating services (i.e. an ecosystem process usually mostly taken for granted as it indirectly benefits society). However, this section focuses on describing the potential benefits of using biological control as an eco-friendly pest control method over chemical control of *P. charybdis* in New Zealand's *Eucalyptus* forests based on related economic valuation studies.

New Zealand's 1.7 million hectare exotic planted forest estate is mainly recognised for timber values but it is also being increasingly regarded for the provision of non-market ecosystem services such as carbon sequestration, avoided erosion, recreation, biodiversity conservation and improved water quality (Yao, et al., 2013). Timber has a market value and, therefore, it is easily accounted for in decision making. Non-market ecosystem services are also important and they can be estimated using economic valuation techniques based on actual behaviour of forest users (e.g. travel cost), hypothetical behaviour under simulated market scenarios (e.g. stated preference) and other environmental economic valuation approaches (Barry, et al., 2014; Yao, Scarpa, et al., 2014) (Dhakal, et al., 2012). In the estimation of non-market benefits, a monetary value is assigned based on the fact that the benefit is defined as a change in human well-being generated by the change in provision of an environmental good (Bateman, et al., 2011). For example, in the estimation of willingness to pay for species conservation in planted forests, respondents of a stated preference survey are asked if they would be willing to financially support a proposed programme that would increase the abundance of iconic species in planted forests (Yao, Scarpa, et al., 2014). Bateman, et al. (2011) described the major non-market valuation techniques and recommended practices (e.g. avoiding double counting, reducing biases) used to ensure that estimated values are robust and that such values can be aggregated accordingly.

Chemical control reduces numbers of many insect species in a forest but biological control only reduces populations of the target insect. Therefore, there should be more food for insect-eating birds (e.g. piwakawaka (fantail), riroriro (grey warbler) and tui) in *Eucalyptus* stands under biological control. Yao, et al. (2010) used a survey-based stated-preference approach called 'contingent valuation' to test how a sample of more than 700 New Zealand households would value the enhancement of biodiversity on private land. Their results showed that a typical household would be willing to financially support the planting and growing of native trees on private land to provide habitats for native birds at the rate of NZ\$42 per household per year for a five-year programme. Similarly, a stated preference study by Yao, Scarpa, et al. (2014) found that a sample of 209 New Zealand households would pay for a five-year programme that would conserve key native species (e.g. North Island brown kiwi, a taonga species) in planted forests (Holzapfel, et al., 2008). An older study by Jetter, et al. (2004) also used the contingent valuation method to estimate the willingness to pay of a sample of 522 households in Southern California for proposed biological control of an insect pest of *Eucalyptus* in the urban landscape. They found the release of natural enemies was overwhelmingly the most preferred option while chemical insecticide was least preferred. All pest control options were valued by a typical household respondent and each would be prepared to pay on an annual basis US\$485 for natural enemy, US\$131 for bacterial spray and US\$23 for the chemical pesticide option.

Use of chemical pesticides in plantation forests can pollute or contaminate waterways, which can negatively impact on human health and freshwater-related recreational activities (e.g. fishing, swimming, and boating). Clinch (1999) estimated the reduction on angling value due to water pollution from forestry in the UK to be approximately £20 ha^{-1}. In 2016, a large majority (73%) of New Zealand's planted forests had environmental certification (i.e. FSC) (NZ Forest Owners Association, 2017). *FSC Criterion 6.6* states that "Management systems shall promote the development and adoption of environmentally-friendly non-chemical methods of pest management and strive to avoid the use of chemical pesticides" (FSC (Forest Stewardship Council), 2013). These examples provide a strong case for the use of biological control to ensure that waterways are safe for recreation while ensuring the forest itself is compliant with environmental certification requirements.

Various ecosystem services such as timber, recreation, avoided erosion, carbon sequestration and avoided nitrate leaching have already been quantified in New Zealand forests using the Forest Investment Framework and economic valuation techniques (Barry, et al., 2014; Yao, et al., 2013; Yao, et al., 2016; Yao & Velarde, 2014)). Yao and Velarde (2014) approximated the value of ecosystem services provided by planted forests in the Ōhiwa catchment in the Bay of Plenty (on a per hectare basis; Table 6). Not all of the non-market ecosystem service values identified for Ōhiwa would be applicable for the existing 27,598 hectares of *Eucalyptus* plantings estimated above nor for any new plantings. For example, the recreation value described in Yao and Velarde (2014) only applies to publicly accessible planted forests. The NZDFI have stated their aim is to increase the area of *Eucalyptus* forest by 100,000 ha by 2030, which is five times more than the current *Eucalyptus* estate (Millen, February 2018). These new *Eucalyptus* plantings would likely be set on private farmlands; therefore, recreational access will be limited. In terms of species conservation value, the study by Yao, Scarpa, et al. (2014) specifically applies to planted forests that are sufficiently large i.e. at least 5000 hectares in a contiguous area so may not be applicable to new *Eucalyptus* plantings. Also, it is not possible to apply values for nutrient cycling and soil formation as those services fall under supporting services (which underpin the provision of the final ecosystem services), which could lead to double counting (Fu, et al., 2011). However, approximate values for carbon sequestration, avoided erosion and some of the other services listed in Table 6 can be applied to these new plantings if they fit the conditions stated in New Zealand's Emissions Trading Scheme (ETS). The ETS defines a forest as an area covering at least one hectare of forest species and has more than 30% tree crown-cover on each hectare, and an average crown-cover width of at least 30 metres. In this exercise, it was assumed that half of the new plantings will have the characteristics that allow them to be classified as 'forests'.

It was assumed that half of the identified 27,598 ha of existing eucalypt plantings could be classified as forests, i.e. 13,799 ha. This latter value was multiplied by the average annual value of applicable ecosystem services of \$812 ha^{-1}. This results in a conservative, aggregate non-market ecosystem service value estimate of approximately NZ\$11 million per year or a total of approximately \$NZ440 million for a 40-year rotation. These values should be considered as indicative only and should be treated with caution as the value of these services can significantly vary across space and time as well as across tree ages and forest management practices.

Table 6. Forest ecosystem services quantified on a per-hectare basis.

Ecosystem service	**Ecosystem service value of exotic forestry in Bay of Plenty's Ōhiwa catchment ($/ha/year)**	**Applicable values for existing *Eucalyptus* plantings in New Zealand ($/ha/year)**
Recreation	900	na
Species conservation	257	na
Carbon sequestration	48	48
Avoided sedimentation	121	121
Avoided nitrate leaching	168	168
Pollination	206	206
Water regulation	6	6
Waste treatment	244	244
Pest and disease regulation	11	11
Water supply	8	8
Nutrient cycling	994	na
Soil formation	14	na
TOTAL	2,977	812

Source: Yao and Velarde (2014). na means this particular value is not applicable to *Eucalyptus* forests that are closed to public access, or no data exists.

Eucalyptus forests also provide other important services such as shelter, shading, amenity trees, floral resources, species-diverse plantations, wind breaks and firewood (Paine, et al., 2015; Taranaki Regional Council, undated) in addition to those listed above. New Zealand city dwellers and residents (as well as local councils) have recognised the importance of the establishment and maintenance of street and park trees (Meurisse, et al., 2016), which do potentially include certain species of *Eucalyptus*. For example, Vesely (2007) found that New Zealand urban households would be willing to financially support a proposed programme that would increase the number of amenity trees in urban areas. Since biological control of would effectively and efficiently control *P. charybdis*, it could help in maintaining and sustaining the environmental and social benefits provide by *Eucalyptus* species in both rural and urban settings.

The NZDFI is also encouraging the creation of smaller-size durable eucalypt plantations (woodlots and shelterbelts) due to the diversity of benefits these species offer if planted in farm environments, including:

- On-farm production of posts, poles and timber for farm infrastructure with no treatment required
- Excellent firewood
- Nectar and pollen production
- Shelter and shade for stock
- Remediation of waste water (Some eucalypt species have been proven to remediate waste water through the use of spray irrigation in plantations and could have the potential to strip nitrates from ground water if planted and harvested with care in riparian margins).
- Erosion control and carbon sequestration (*Eucalyptus* spp. can live hundreds of years so could also be established as permanent forests on steep unproductive land for erosion control and to sequester carbon. The trees could be spaced widely to allow native planting or regeneration to also form a long-term forest canopy. Forest ecosystem services such as avoided erosion and carbon sequestration have already been quantified using the Forest Investment Framework (Yao, et al., 2016)).

These benefits are likely to extend to the billion-tree programme announced recently by the Labour government (Millen, et al., 2018)

The above values of biological control in planted forests provide some positive non-market values for planted forests in New Zealand. However, these values were generated for different locations and were undertaken at a different scale to the current study so were not to incorporate into the economic evaluation conducted here. Little published literature exists that compares valuation studies on conservation biological control. One review paper by (Naranjo, et al., 2015) included two New Zealand based economic valuation studies but focused on agricultural crops such as tomato, soybeans and cacao rather than forest. Therefore, estimating the economic value of introduced biological control in forestry is an area for future study. Also, there are insufficient data at present to show how the provision of ecosystem services vary between a biologically controlled versus chemically controlled *Eucalyptus* forests.

Conclusion

Existing plantings of *Eucalyptus* species in New Zealand have a substantial economic asset value. This value is expected to increase in the next decade with additional investment in new plantings. Forest growers need to invest in pest management to prevent yield loss from *P. charybdis*. The economic analysis undertaken here shows that either chemical- or biological-control methods can be the most cost effective in different situations depending on the severity of the pest outbreak, plantation size, (and associated aerial spraying cost) and rotation length.

The following trade-offs exist:

1.) Biological control of *P. charybdis* becomes more cost effective as the cost of chemical control increases. This information is most relevant for small (<10 ha) *Eucalyptus* woodlots where the cost of aerial spraying is unjustifiable when higher than \$300 ha^{-1}.

2.) The average value of the harvested timber is lower for short-rotation pulp plantations than for long-rotation solid wood plantations. Biological control of *P. charybdis* is more cost effective than chemical control for short rotations.

3.) Only long-term yield losses following severe damage to large plantations are sufficiently high to justify chemical treatment rather than biological control.

Chemical control can be disadvantageous to the environment, society and sustainability certification, and could reduce the value of the wood or product. *Eucalyptus* trees grown in New Zealand may provide a range of direct and indirect ecosystem service benefits. The aggregate non-market ecosystem service value of 13,799 ha of existing *Eucalyptus* forest was estimated to be approximately NZ$11 million per year.

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Appendix Two: Staff Assessment report APP203631: An application to release from containment a parasitoid wasp, *Eadya daenerys*, for biological control of eucalyptus tortoise beetle (*Paropsis charybdis*), a pest of eucalyptus trees in New Zealand.

Staff Assessment Report

APP203631: An application to release from containment a parasitoid wasp, *Eadya daenerys*, for biological control of eucalyptus tortoise beetle (*Paropsis charybdis*), a pest of eucalyptus trees in New Zealand.

Purpose	To introduce a parasitoid wasp (*Eadya daenerys*) to control eucalyptus tortoise beetle (*Paropsis charybdis*)
Application number	APP203631
Application type	Notified, Full Release
Applicant	Scion
Date formally received	18 September 2018

Executive Summary and Recommendation

In September 2018, Scion submitted an application to the Environmental Protection Authority (EPA) seeking to introduce the parasitoid wasp, *Eadya daenerys,* as biological control agents (BCA) for the pest eucalyptus tortoise beetle (ETB), *Paropsis charybdis*.

The EPA assessed the risks, costs and benefits of the release of *E. daenerys* in the context of the environment, market economy, people and communities, public health and on the relationship of Māori and their culture and traditions. The EPA considered that there are no direct or tangible benefits or risks to public health from the release of the parasitoid wasp and this aspect was not considered in the assessment.

The EPA assessed the environmental benefits and considered that despite the reduction of broad-spectrum pesticide use in eucalypts plantations, the BCA is likely to have a minor impact on biodiversity values due to eucalypt monoculture plantations and short rotation rates. Besides, the impact would be minimal on ecosystem services due to the small areas planted with eucalyptus at the national scale. We also noted that these benefits are not specific to eucalyptus and would apply to other forest species. We concluded that the parasitoid wasp would have **low** environmental benefits.

The EPA assessed the economic benefits and considered that *E. daenerys* is highly likely to reduce the cost of pesticides and help growers to maintain their Forest Stewardship Council (FSC) certification. However, its impact on the economic value of ecosystem services are not specific to eucalyptus and apply to other forest species. We concluded that the parasitoid wasp would have **low** economic benefits at the national scale but **medium** benefits for some regions in New Zealand where large ETB-susceptible plantations are grown.

The EPA assessed the benefits of the release of *E. daenerys* on people and communities and considered that through the improvement of eucalyptus tree health and the reduction of pesticide use, recreational activities could improve locally. However, we concluded that the impact on the community would be **low** due to the small areas impacted and identical benefits available from other species of trees.

The EPA then assessed the risk and costs of *E. daenerys* to the environment. Host range experiments showed that the most closely related native beetles and beneficial BCA species to the target host found in New Zealand are not susceptible to the parasitoid wasp. We noted that there are no specific ETB predators that could be affected by the reduction of ETB populations, and no native parasitoid wasps in the *Eadya* genus in New Zealand that could interbreed with the BCA. Therefore, we assessed the adverse effects on the environment to be **negligible**.

The only economic risk the EPA considered is the potential attack of beneficial BCA by *E. daenerys*. We concluded that this risk is **negligible** as the six weed BCA were tested in host range experiments were not shown to be physiological hosts.

The EPA assessed the application against the minimum standards in the HSNO Act and concluded that *E. daenerys* meets the minimum standards. The potential risks to Māori interests from the release of *E. daenerys* are likely to be acceptable in terms of Māori culture beliefs and environmental frameworks.

We found the benefits of the release of *E. daenerys* outweigh the risks and costs. We recommend the decision-making committee approve the release of *E. daenerys* as a biocontrol agent for eucalyptus tortoise beetle.

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Purpose of this document

1. Scion applied to the Environmental Protection Authority (EPA) seeking approval to release the parasitoid wasp *Eadya daenerys* as a biological control agent (BCA) for eucalyptus tortoise beetle (ETB) *Paropsis charybdis* in New Zealand.

2. This document has been prepared by EPA staff to advise the Decision-making Committee on our assessment of the risks and benefits of the release of *E. daenerys*. The document discusses the information provided in the application, information readily available in scientific literature, and information submitted to the EPA during the public notification process.

Application process

3. Scion lodged an application with the EPA on 18 September 2018 seeking approval to release the parasitoid wasp *Eadya daenerys* under section 34 of the Hazardous Substances and New Organisms (HSNO) Act (the Act).

4. The application was publicly notified, and open for submissions for 30 working days on 2 October 2018 as required by section 53(1)(b) of the Act. The submission period ended on 14 November 2018.

Submissions

5. The EPA received 27 submissions on this application. The submissions are summarised in Appendix 1.Twenty-one submitters supported the application and six submitters opposed the application.

6. We received submissions from Ngāi Tahu and five individuals who oppose the application, and 15 representatives from the forest industry, regional councils, the Department of Conservation (DOC) and two individuals in support of the application. Eight of the submitters explicitly requested to be heard at a public hearing. Since submitters requested that a hearing be held to speak to their submissions, a hearing will take place for this application.

Submissions from DOC and MPI

7. As required by the Act and the Hazardous Substances and New Organisms (Methodology) Order 1998, the Ministry for Primary Industries (MPI) and DOC were notified of the application and provided with the opportunity to comment.

8. MPI did not make any comments on the application.

9. DOC has no objection to the release of this biocontrol agent *E. daenerys*. Rod Hitchmough (Scientific Officer, Biosecurity) noted that the host testing showed that adverse impacts on native beetles would be limited. The full submission is included in Appendix 2.

Eucalyptus tortoise beetle as the target pest

The biology and ecology of *Paropsis charybdis*

10. *Paropsis charybdis* is a large (8-11 mm long) species of beetle. The insect is part of the family Chrysomelidae (Table 1) and is represented by more than 150 species in New Zealand.

11. *Paropsis charybdis* is commonly named eucalyptus tortoise beetle (ETB) due to its back resembling a tiny tortoise shell varying from straw-coloured to reddish-brown with darker marks.

12. Native to south-eastern Australia and Tasmania, it was first recorded in the Christchurch Port Hills in 1916 (Thompson 1922). It is thought to have been accidentally introduced and has spread rapidly through New Zealand due to its efficient mode of dispersal. The beetle pest is a strong flyer and has been observed on motors vehicles and trains (White 1973). It is now well established in eucalyptus plantations and shelter-belts across New Zealand (Styles 1970).

Taxonomic Unit	Classification
Phylum/Division	Arthropoda
Class	Insecta
Order	Coleoptera
Family	Chrysomelidae
Subfamily	Chrysomelinae
Genus	*Paropsis*
Species	*Charybdis* (Stål, 1860)
Common name	Eucalyptus tortoise beetle

Table 1: Complete taxonomic description of eucalyptus tortoise beetle

13. *Paropsis charybdis* produces two generations each summer with a one-year lifespan (Figure 1). Overwintered adults emerge as early as September in spring and start feeding on eucalyptus foliage. Females begin oviposition about two weeks after emergence, starting before the males are ready to mate on occasion. This can result in a large number of unfertilised eggs at the beginning of the season (Bain et al. Revised 2009).

14. Females lay 20 to 30 eggs in batches under the leaves and can produce up to 2000 eggs over a period of two to three months. Eggs take between 14 and 21 days to hatch depending on the temperature, and larvae go through four stages (instars). A new generation of adults will emerge 7 to 9 weeks after oviposition. Mature larvae are less selective and, like adults, feed on both young shoots and old foliage before dropping into the leaf litter to pupate (Styles 1970). When disturbed, larvae can eject a strong-smelling spray. Young adults of the first generation feed on eucalyptus until they reach maturity and then repeat the cycle. However, the second generation feeds extensively on old and new foliage to store up fat reserves for their hibernation in the leaf litter or under loose bark, until the next spring (Styles 1970; Jones & Withers 2003).

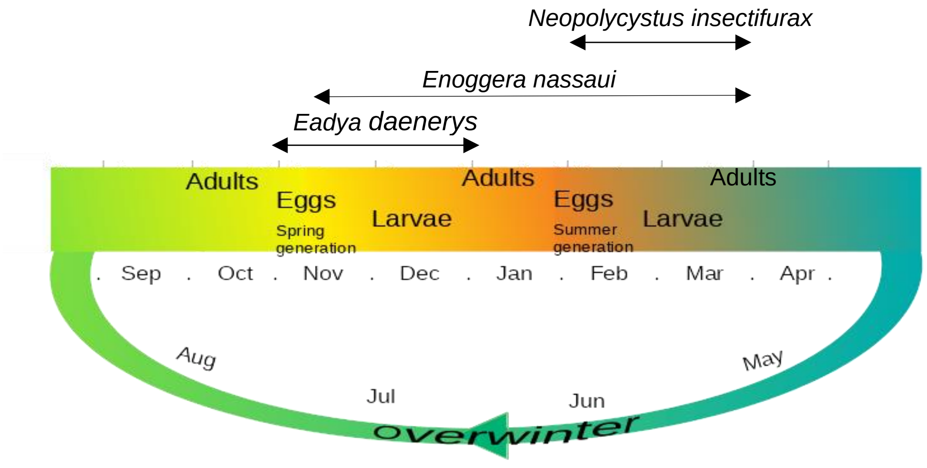


Figure 1: Life cycle and phenological[1] synchrony of *Paropsis charybdis* in relation with the parasitoid species present in New Zealand and the proposed parasitoid wasp *Eadya daenerys*.

Distribution

15. ETB originates from Australia where it is considered a rare species. It is mainly found in coastal areas and adjacent tablelands of south-eastern Australia and Tasmania (Styles 1970).

16. In New Zealand, this pest beetle is found throughout the country wherever eucalyptus is grown. It disseminated through the South Island before reaching the North Island in the mid-1950s, becoming a major pest of eucalypts plantations. However, in Australia, ETB populations remain low, potentially due to the presence of other *Paropsis* species, which increases competition, as well as the presence of natural enemies (Bain et al. Revised 2009).

Current strategies to control eucalyptus tortoise beetle

17. Natural predators (native and exotic) of the beetle are present in New Zealand. Nevertheless, their impact is considered negligible on the pest population as ETB continues to cause damage to eucalyptus trees (Styles 1970; Bain & Kay 1989). The interest in biological control agents was motivated by the development of the timber industry. The industry suggests that to efficiently control ETB populations, biological control agents, pesticides or biopesticides can be used.

Biocontrol agents

18. In the 1970s and 1980s, to reduce the severity of defoliation caused by *P. charybdis* on eucalypt trees, four natural enemies of the beetle were released in New Zealand. Only two of them, the parasitoid wasp *Enoggera nassaui* and the ladybird *Cleobora mellyi*, established self-sustaining populations (Figure 2). The egg parasitoid wasp is now found throughout eucalypt growing regions of the country whereas the ladybird, which feeds on soft-bodied insects and their eggs, is only found in the Marlborough Sounds (Withers et al. 2013). The failure of the ladybird to disperse and establish widely is attributed to the absence of psyllid prey required by the adults to successfully reproduce. Despite their impact on the pest beetle, *P. charybdis* remains New Zealand's most serious eucalyptus defoliator (Murray et al. 2008).

[1] The study of cyclic and seasonal natural phenomena, especially in relation to climate, plant, and animal life

19. In 2002, two self-introduced species, the parasitoid wasps *Neopolycystus insectifurax* and the hyperparasitoid *Baeoanusia albifunicle*, were found in the Bay of Plenty (Withers et al. 2013). These two wasps are now widespread in New Zealand with the exception of Southland. *Baeoanusia albifunicle*, which was identified as an obligate hyperparasitoid (parasitoid on another parasitoid) of *E. nassaui*, has the potential to prevent the reproduction of the introduced BCA. This could reduce the impact of *E. nassaui* on the ETB. Populations of *N. insectifurax* are immune to the hyperparasitoid wasp (Murray et al. 2008).

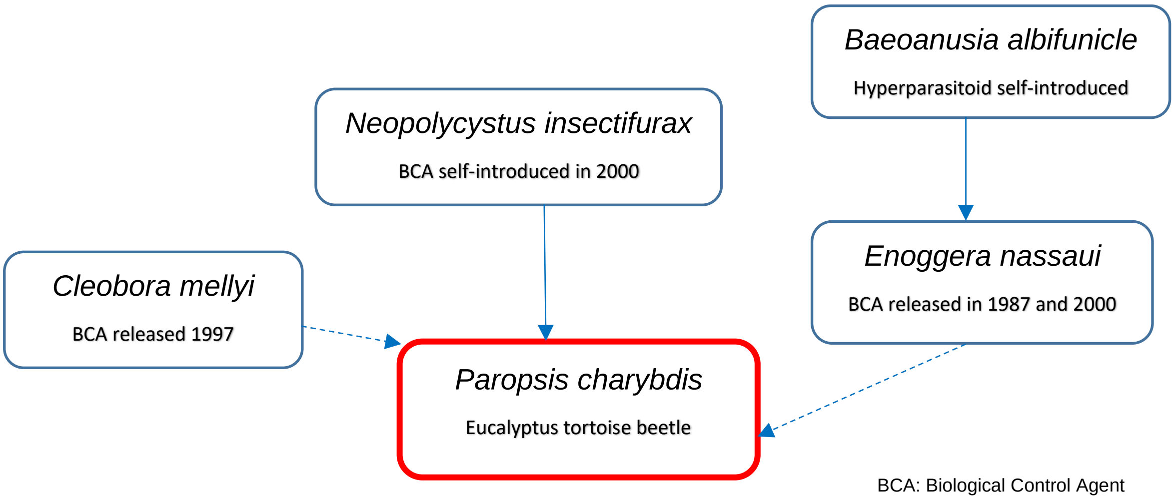


Figure 2: Current biological control relationships of *Paropsis charybdis* in New Zealand.

20. The new BCA proposed, *Eadya daenerys*, active in Tasmania from November to December (Withers et al. 2018a), will be the first larval parasitoid targeting the spring generation of ETB as *E. nassaui*, present from November to March, impacts mainly the summer generation. So does *N. insectifurax* which appears late in summer from February to March (Figure 1).

Chemicals

21. An alternative to biocontrol is the use of pesticides via aerial spraying. However, broad-spectrum chemicals, e.g. alpha-cypermethrin, are likely to kill many species including natural enemies and are particularly toxic to bees and aquatic species (Chambers 2015). Furthermore, pesticides are not efficient in the long term as re-infestation may occur from outside areas or from second generations (Styles 1970; Bain et al. Revised 2009).

22. Other chemical control options are less damaging to fauna. For example, clothianidin is a systemic insecticide applied to the roots of trees. One application provides up to two years of protection against most herbivorous insects. It poses lower risks to mammals and bees but takes several weeks for the application to be effective, therefore, is not an effective treatment when a rapid response is required (Chambers 2015).

23. Alternative biologically derived chemical control solutions exist. Success Neo, for example, is a fermentation product based on a bacterium used in Australia for the control of two chrysomelid species (*Paropsisterna bimaculata* and *P. agricola*). However, biopesticides remain costly for the forestry industry and are not as effective as broad-spectrum chemicals (Chambers 2015).

Eucalyptus forest in New Zealand

History and background

24. There are no native species of *Eucalyptus* in New Zealand. All *Eucalyptus* species (around 700) originate from Australia, New Guinea and Indonesia. There are four main sub-genera: *Monocalyptus, Symphyomyrtus, Corymbia* and *Nothocalyptus*, each with different siting and wood properties. With almost one species for every climate niche, from swamps to arid, tropical to mountain summits (Judd & Menefy 2002), eucalyptus are the most cultivated hardwood trees planted around the world.

25. The first eucalyptus were brought as early as 1836 to New Zealand by missionaries. Shortly after, in the 1860s, eucalyptus plantations were established in Canterbury to provide building supplies and firewood. Thanks to their ability to dry up swamps, they were also planted to keep mosquitoes and malaria at bay. Moreover, Māori were using them for their medicinal properties to treat asthma and prevent haemorrhaging after childbirth. (Judd & Menefy 2002).

26. At the beginning of the 20th century, eucalyptus trees dominated plantations before the industry collapsed due to the lack of phenological studies to determine optimum growing conditions in New Zealand (e.g. seed imported from Australian wetlands was inappropriately planted in dry areas) and the arrival of more competitive forestry species. From the mid-1950s, planted forests started to be dominated by two pine species, Monterey pine (*Pinus radiata*) and Douglas-fir (*Pseudotsuga menziesii*). These species now represent 96% of all planted areas in New Zealand. The remaining 4% represent other exotic species mainly *Eucalyptus* species.

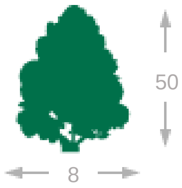
Distribution and economy

27. There are about 160 introduced *Eucalyptus* species in New Zealand. Different species are used for different purposes (e.g. windbreaks, erosion control and plantations). *Eucalyptus nitens,* mainly found in the South Island, is the dominant *Eucalyptus* species in New Zealand (Murray et al. 2008). *Eucalyptus nitens* is replaced by *E. fastigata* and *E. regnans* in the North Island as the dominant species (Nicholas & Hall 2010). Other species also used are *E. saligna, E. maidenii, E. obliqua, E. botryoides, E. pilularis,* and *E. globoidea* (Forest Owners Association 2017).

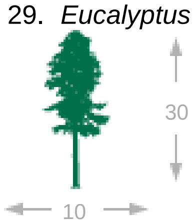
	Temperature (ºC)	Rainfall (mm year^{-1})	Elevation (m)
E. nitens	-3 ºC – 24	750 - 1750	800 – 1300
E. fastigata	-4 ºC – 28	>700	650 – 1400
E. regnans	7 ºC – 20	650 - 2000	0 – 1100

Table 2: Ecology of the three main *Eucalyptus* species grown in New Zealand.

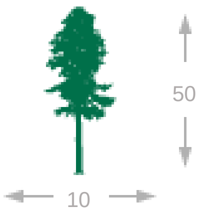
28. *Eucalyptus nitens* naturally grows between 800 and 1300 m but can be found from 640 m in Victoria to 1600 m in New South Wales. The species is resistant to cold and sensitive to hot dry winds with mean temperatures varying from 21 to 24ºC in summer to -3ºC to 2ºC in winter. It establishes easily and tolerates wet sites with rainfall between 750 and 1750 mm per annum in heavy, fertile soils (Murphy & Payn 1996) (Table 2). It is extremely fast growing (up to 10 m after five years) and can reach up to 50 m at maturity. It flowers from January to March. The diagram on the left shows the shape and dimensions (m) of an adult *E. nitens* tree.



29. *Eucalyptus fastigata* is found in low to mid-elevation mountain of New South Wales at altitudes between 650 and 1400 m. It favours cool to warm, sub-humid to humid climates with temperatures range between 23 and 28ºC and -4 ºC to 3ºC, and rainfall superior to 700 mm (Schulze & Maharaj 2007). *Eucalyptus fastigata* has a rapid growth rate and reaches 7 m after five years and 30 m when mature. It flowers from December to February (Table 2).



30. *Eucalyptus regnans* is native to Victoria and Tasmania where it occurs from sea level up to 1100m altitude. It grows well on windy erodible hill country and tolerates moderately fertile soils with reasonable drainage (Satchell 2018). It prefers cool mountainous climate with a mean annual temperature of 7ºC to 20ºC and an average annual rainfall of 650 to 2000 mm (Murphy & Payn 1996; Vaughan 2011). *Eucalyptus regnans* has also a rapid growth rate (6 m after five years) and can reach 50 m at maturity. It flowers from December to May (Table 2).



31. In 2017, eucalypt forests represented 13,283 ha in the South Island and 9,023 ha in the North Island (Clough et al. 2017). More than 80% of these plantations are concentrated in four regions (Figure 3) with at least 14,000 ha of *E. nitens* (Withers 2018b).

32. Although *Eucalyptus* species are a minor component of the forest industry in New Zealand, they represented $41 million of the New Zealand gross domestic product in 2016 (Forest Owners Association 2017). Scion economists have valuated the eucalyptus forests asset at $671 million. However, the survival and expansion of eucalypt plantations in New Zealand and worldwide are under threat from insect defoliators, including the ETB (Peixoto et al. 2018).

33. A number of eucalypt plantations in New Zealand are certified by the Forest Stewardship Council (FSC). This certification helps to access international markets and add value to the products made from sustainable forests. In order to become and remain certified, plantations need to follow guidelines and must find alternatives to chemical control (Williams et al. 2013).

34. *Eucalyptus* species are the most efficient producers of high-quality fibre (an ingredient of high-quality paper) and firewood. In New Zealand, the eucalypt timber market is starting to emerge but the major consumer of eucalypt wood fibre remains pulp and chip markets (Davies-Colley 2006). In addition to their commercial value, eucalyptus trees benefit soil conservation and provide shelter and shade to livestock (Ministry for Primary Industries 2014).

Figure 3: Eucalyptus plantations are found in four main regions in New Zealand. The percentage represents area planted in eucalypt species by region as at 1 April 2017 (Clough et al. 2017).

Impact of the eucalyptus tortoise beetle on eucalyptus forests

35. Most species of eucalyptus can be defoliated by the pest beetle but some species are more palatable than others. ETB is mainly restricted to trees in the sub-genus *Symphyomyrtus* (Bain et al. Revised 2009) such as *E. nitens*, *E. saligna* and *E. botryoides*. Adults and larvae feed on eucalyptus leaves which give the tree a tattered appearance. Repeated defoliation can stop the growth of the tree and, in severe cases, may cause death.

36. The adverse impact of the pest beetle to New Zealand's forestry industry might be explained by the absence of competition and natural enemies in our eucalypt forests (Withers 2018b). Less than 1% of the invertebrate species feeding on eucalyptus in Australia are present in New Zealand (Judd & Menefy 2002). The adverse impacts of the beetle could be controlled by the release of new biological control agents e.g. *Eadya daenerys*, the use of pesticides, or planting unpalatable species of *Eucalyptus* such as *E. fastigata*, *E. delegatensis*, and *E. regnans* (Bain et al. Revised 2009). Mr Millen, project manager for New Zealand Dryland Forests Initiative (NZDFI), noted in his submission that NZDFI is looking to develop genetic resistance to reduce insect threats and the use of chemical controls (Appendix 1).

37. When under attack by the ETB, FSC authorises, under derogation, the use of 'highly hazardous chemicals' such as alpha-cypermethrin to minimise damage to forests. In New Zealand, despite the introduction of biological control agents, ETB is still considered a major pest for the forest industry. Scion noted in its application that 60 to 75% of the eucalyptus forests are potentially at risk from ETB damage.

38. Margaret Hicks submitted that elevated fire risk could be one indirect adverse effect of the biocontrol programme against ETB. Foresters may be inclined to plant more eucalyptus trees to grow their businesses as a result of the release of *E. daenerys.* The oil produced by *Eucalyptus* species is extremely flammable which, added to leaves and bark peels on the ground, makes eucalyptus a high fire hazard. Ms Hicks advises against the planting of more eucalyptus trees in the interest of public safety and the environment,

39. Despite the potential impact of fire on the environment (it could spread to native forests), community (loss of homes and livelihoods) and economy (destruction of plantations), we did not include fire hazard in our assessment because we do not consider that increasing fire risk would be a direct result from the release of the BCA. The proposed harm from elevated fire risk is too far removed from the biocontrol programme against ETB.

The proposed biological control agent *Eadya daenerys*

The biology and ecology of the *Eadya daenerys*

40. *Eadya daenerys* (Table 3) is a medium-sized (6-10 mm long) solitary black braconid wasp with a bright orange head. The Braconidae is a very large family of parasitoid wasps divided into 47 subfamilies. The subfamily Euphorinae is often used for biological pest control and is represented by 36 genera. Many parasitoids within the family Braconidae have been imported into New Zealand as BCA but there are no native parasitoids in the genus *Eadya*.

Taxonomic Unit	Classification
Class	Insecta
Order	Hymenoptera
Family	Braconidae
Subfamily	Euphorinae
Genus	*Eadya*
Species	*Eadya daenerys,* Ridenbaugh, 2018
Common name	None

Table 3: Taxonomic description of *Eadya daenerys*

41. *Eadya daenerys* originates from Australia where it is known to almost exclusively use either *Paropsisterna agricola* or *P. charybdis* that both feed on eucalyptus leaves (Peixoto et al. 2018). *Eadya daenerys* has a high fecundity with an average of 975 eggs per female for a longevity of up to 44 days.

42. Once a host has been located the parasitoid wasp lays one small (0.3 mm) hydropic[2] egg directly into the haemocoel of its host. The larva develops in the host by absorbing water and nutrients. After around twenty-five days at 18°C it reaches maturity and emerges to spin a brown silk cocoon where *E. daenerys* larva undergoes a ten month obligate pupal diapause period until the following summer (Peixoto et al. 2018; Withers 2018a).

2 Absorbing water and watery fluid

43. *Eadya daenerys* is univoltine[3] in Tasmania, with adults present from November to December. The similarity of Tasmania's climate to the New Zealand climate predicts an abundance peak of *E. daenerys* in December which would coincide with the spring generation of *P. charybdis* (Figure 1).

44. The absence of other parasitoid species, e.g. tachinids in New Zealand, would limit the competition for host larvae in spring and allow *E. daenerys* populations to grow quickly. Furthermore, the impact of *E. daenerys* on ETB could be much higher than in Australia with the absence of its preferred host *Pst. agricola*. In their application, Scion noted that laboratory results showed a 90% decrease of the survival rate of *P. charybdis* larvae with the presence of *E. daenerys*.

Climate favourable for Eadya daenerys establishment in New Zealand

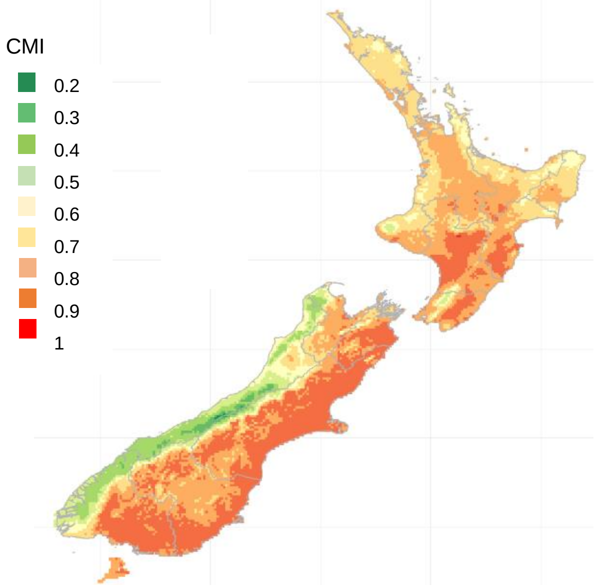


Figure 4: Climate match between *Eadya daenerys* distribution in Tasmania compared to all of New Zealand. The algorithm calculates a 'composite match index' (CMI) for each New Zealand location, which can range from zero (no match) to one (perfect match). The colour gradient indicates CMI values. CMIs >0.7 are generally interpreted as an indication that the two climates are sufficiently similar for a species to persist at that location (Pugh et al. 2018).

45. *Eadya daenerys* is found in southeast Australia (Australian Capital Territory, New South Wales and Tasmania) (Ridenbaugh et al. 2018). Scion analysed the climatic similarities between Tasmania and New Zealand to evaluate the probability for the parasitoid wasp to establish in New Zealand where populations of *P. charybdis* are found. The results obtained by a Match Climates Regional model show that the majority of the country is climatically suitable with a Composite Match Index (CMI) greater than 0.7 (Figure 4).

3 A species that has one brood of offspring per year

Selection for host range testing

46. Scion seeks to release the parasitoid wasp *Eadya daenerys* to control ETB. The parasitoid wasp was previously identified as *Eadya paropsidis* based on morphological identification. However, molecular taxonomy investigations revealed the existence of a new cryptic (morphologically indistinguishable) species identified in 2018 by Ridenbaugh as *E. daenerys* (Peixoto et al. 2018; Ridenbaugh et al. 2018). In 2015, *E. paropsidis* was imported into containment for host range testing under EPA approval APP202154, but all species imported under that approval were later identified as *E. daenerys* (Withers et al. 2018a).

47. *Eadya daenerys* is active in Tasmania for a short period of time, from late spring to early summer. It attacks diurnal larvae, therefore, nocturnal or beetle larvae that live internally within vegetation and which are not present in November and December have been excluded as potential non-target hosts.

48. To identify test species for host range experiments Scion used a traditional phylogenetic approach where the relationship between the target host and other beetles is determined. A shortlist of nine beetles was selected according to their similarities to the pest target. They were chosen due to their close genetic relationship to the pest and their ecological characteristics (e.g. spatial and temporal similarities to ETB), similar biological attributes, as well as the feasibility to collect and rear the species in containment for testing.

49. The traditional approach was later supported by a computer-based model PRONTI (Priority Ranking Of Non-Target Invertebrates) developed by Better Border Biosecurity (B3) researchers. Seven of the nine traditionally selected species were in the top 20 PRONTI selection (Withers et al. 2018a). The two species which were not included (*Agasicles hygrophila* and *Cassida rubiginosa*) were kept as test organisms as they are two valuable BCA in the same family as *P. charybdis*. The 13 extra species in the top 20 were not included in the final list due to either the lack of information available on them, they are root-feeding larvae, or are difficult to collect and test (Withers et al. 2018a).

50. PRONTI analysed an initial list of 153 potential beetles, including the 40 native species in the Chrysomelinae subfamily, the 100 species in the phylogenetic sister group Galerucinae and the 13 species of Chrysomelid BCA introduced to New Zealand (Withers et al. 2018a). Different criteria and weightings were applied to rank the beetles that could be exposed to *E. daenerys* in New Zealand. Compared to the traditional approach of selecting non-target test species, the model provides a transparent ecologically based ranking of non-target species (Withers et al. 2018a). We consider that PRONTI provided additional confidence in the selection process.

51. The host specificity testing for *E. daenerys* was also reviewed by biological control expert, Dr Ronny Groenteman, from Manaaki Whenua Landcare Research (Appendix 3). She considered that the testing was completed in accordance with best practice, including test host and plant selection, methods and replication. The conclusions drawn in the report provided in Appendix 5 of the application are supported by the results from the host range experiments according to Dr Groenteman.

52. Submitters Margaret Hicks and Dr Cliff Mason considered the host testing to be inadequate and noted the difficulty to fully assess the impacts of the introduction of a new species on the ecosystem. Dr Mason added that the host range tests on native beetles failed due to the inability to locate them (Appendix 1).

Risk assessment

53. Our assessment of the benefits and risks associated with the release of *E. daenerys* to control ETB is based on the assumption that this parasitoid wasp successfully establishes in the New Zealand environment and develops self-sustaining populations.

54. If *E. daenerys* does not establish in New Zealand there is no risk. Conversely, if the parasitoid wasp establishes large populations, the frequency of risks, discussed in our assessment below, increases. At the same time, the benefits will also increase with larger populations since the parasitoid wasp would need to reach high numbers to cause optimum damage to ETB populations in order to be beneficial. Therefore, an assessment made on full establishment makes it easier for us to determine if the benefits truly outweigh the risks, or *vice versa*.

55. We further noted that the parasitoid wasp may take time to establish and build self-sustaining populations; therefore, the effects of the biocontrol agent on ETB populations will be gradual at first.

56. We consider that the potential benefits, risks and costs which could result from the release of *E. daenerys* would remain limited and have local to regional implications due to the small surface areas occupied by eucalyptus forests presently. However, in the future, the impact might increase with the development of more eucalyptus plantations on private land.

Assessment of risks and benefits

57. We assessed the risks and benefits of the release of *E. daenerys* to the environment, market economy, human health, people and communities and on Māori and their relationship to the environment. We only discuss the effects that we consider to have a significant result, therefore, those effects where the magnitude of the effect and likelihood of that effect occurring is improbable or speculative are not included in our assessment.

58. We consider that there are no benefits or risks to human health from the intent of this application. Figure 5 presents the beneficial and adverse effects we assessed. The beneficial effects on the environment, people and communities and the market economy are discussed next. Effects on Māori are discussed in paragraphs 147 to 153.

Potential benefits from the release of *E. daenerys*

Environment

59. The applicant identified the following environmental benefits of releasing *E. daenerys* in the New Zealand environment:
    - Improving biodiversity in eucalypt forests
    - Reduction of pesticide usage in the environment
    - Enhancement of ecosystem services

60. We consider that the establishment of *E. daenerys* in New Zealand will limit the impact of ETB populations in eucalyptus plantations and therefore reduce the use of damaging pesticides, and improve biodiversity in eucalyptus forests as well as ecosystem services.

61. *Eadya daenerys* is a natural predator of *P. charybdis* found in Tasmania. To date, it is considered as the best candidate for biological control of ETB in New Zealand due to its synchrony with the first larvae generation of ETB. It would complement existing BCA, *E. nassaui* and *N. insectifurax*, already present in New Zealand. Figure 1 presents the synchronic relationship *E. daenerys* has with other BCA.

62. In its native environment, *E. daenerys* is found to almost exclusively parasitise *Paropsisterna agricola* and *P. charybdis*. In the Peixoto and co-authors study, 87% of the wasps were reared from *Pst. agricola* and 8.8% from *P. charybdis.* The remaining represented larvae emerging from *Pst. nobilitata* and *Pst. bimaculata* but neither have crossed over from Australia (Peixoto et al. 2018). Although the principal host of *E. daenerys* appears to be *Pst. agricola*, it is absent in New Zealand and it is likely that *E. daenerys* would focus its attacks on ETB.

Impact of E. daenerys on pesticides usage

63. Up till now, the only rapid, effective and economic control option available to limit the damage from severe outbreaks of the ETB is to spray a broad spectrum chemical (see section 21). Despite its negative impacts on non-target fauna, alpha-cypermethrin is widely used in Australia and New Zealand (Loch 2005; Bain et al. Revised 2009). Immediately after spraying this insecticide, nearly all beneficial arthropods, including existing BCA, died with limited residual activity (Loch 2005). In spite of its efficiency, it only provides short-term protection as nearby populations which have not been sprayed can rapidly re-colonize plantations (Styles 1970).

64. Less broad-spectrum insecticides, such as products containing spinetoram (e.g. Sparta) are also available in New Zealand. Despite being less damaging and declared by the manufacturer as compatible with integrated pest management practice due to highly selective chemistry (Dow AgroScience), spinetoram products are less commonly used as they are more expensive than alpha-cypermethrin (Withers et al. 2013).

65. In 2013, eucalyptus plantations certified by the Forest Stewardship Council have obtained a derogation to spray alpha-cypermethrin as an emergency pest management measure. The derogation is expected to run until 2018, requiring the forest industry to look for alternative sustainable solutions to control the pest beetle (Duffy 2007).

66. Alternative methods include bio-insecticides and biological control agents. In 2013, Scion and AgResearch were unable to identify suitable biopesticides targeting larvae and adults simultaneously. Moreover, microbial pesticides require more work (e.g. surveillance and multiple applications on a tight management schedule to spray the trees before the larvae drop to the ground to pupate) and are less effective than synthetic chemicals (Withers et al. 2013).

67. Therefore, biological control agents remain the only effective option for long-term sustainable management. Both the two egg parasitoids already established in New Zealand (*E. nassaui* and *N. insectifurax*) target the second generation of ETB eggs but do not provide sufficient control to limit the impact of the pest beetle. By attacking the spring generation *E. daenerys* would improve overall control of the ETB across its lifecycle.

68. We consider that, with the control of the first generation of ETB, severe outbreaks occurring later in the season would decrease, therefore, it is **highly likely** to reduce the need to use broad-spectrum pesticides in eucalyptus plantations decreasing collateral environmental damage. The magnitude of these beneficial effects would be **moderate** given the severity of the non-target impact of alpha-cypermethrin. We conclude that the level of benefits resulting from the reduction in pesticide use is **medium**.

Impact of E. daenerys on biodiversity

69. We did not identify direct benefits from the release of *E. daenerys* on biodiversity values, however, it could have indirect beneficial effects on biodiversity through a decrease in ETB populations. In their application, Scion noted that eucalyptus trees less subject to attack from the ETB would provide more habitats and food for other species.

70. Monocultures, like eucalyptus plantations where the *E. daenerys* target host is found, are known to support less diverse communities of insects than native forests (Majer & Recher 1999; Cunningham et al. 2005). Where the replacement of native ecosystems by plantation forests could be damaging to biodiversity, the impact on species richness is not always negative when planted on abandoned pastures or degraded land with poor biodiversity (Brockerhoff et al. 2001).

71. The decrease in ETB populations would allow eucalyptus trees to produce more flowers that would attract bees and nectar feeders e.g. tuis and bellbirds seeking food, shade, and a suitable place to nest. The proliferation of insects would also attract insectivorous birds like fantails (Satchell 2018). As the trees grow older more holes, fissures and hollow branches will provide ideal nesting for other native birds like tomtits (Lindenmayer et al. 1993).

72. Pawson et al. (2010) noted that, in New Zealand, exotic plantation forests are used by threatened indigenous species. A total of 54 threatened species were recorded to benefit from exotic forest stands. Insectivore and nectar-feeding birds were the most common in plantations during flowering periods of eucalyptus. Long-tailed bats, classified as vulnerable on the IUCN Red List[4], were also found feeding and roosting in stands of *Eucalyptus* spp. (Clout & Gaze 1984; Pawson et al. 2010).

73. However, we note that successive short rotations on eucalyptus plantations (10 to 15 years) could contribute to the decline in biodiversity with habitat destruction and seed bank depletion. We note that young eucalyptus stands appear to support low diversity fauna (Clout & Gaze 1984), whereas flora diversity appears not affected by the short rotation (Allen et al. 1995; Brockerhoff et al. 2001).

74. Taking the available information into consideration, we find that *E. daenerys* is **likely** to have a **minor** impact on biodiversity values in eucalyptus plantations despite healthier eucalyptus stands able to support higher fauna diversity. Indeed, short rotation rates would continue to put pressure on eucalypt ecosystems and their ability to support biodiversity. Furthermore, we note that these biodiversity benefits are not specific to eucalyptus and would apply to other forest species. We conclude that the level of benefits to biodiversity values is **low**.

Impact of E. daenerys on ecosystem services and other indirect environmental benefits

75. The potential benefits obtained from improved ecosystem services considered here are indirect effects from the release of the BCA and are attributed to healthier plantations. Planted and natural forests provide habitats that support biodiversity values which are closely linked to ecosystem services. Scion noted that *E. daenerys* would have multiple impacts on the environment through ecosystem services. We acknowledge the indirect impacts that healthy eucalyptus forests would have on our environment through carbon sequestration[5], nitrate leaching[6], improvement of water quality, and provision of more habitats.

76. Planted forests help to reduce greenhouse gases present in the atmosphere. Carbon sequestration in an eucalyptus plantation reaches 22.75 tonnes of CO_2 per ha per year which is four times higher than in pine plantations (Lopes 2013). This is attributed to faster growing rates of eucalyptus trees that allow them to sequester greater amounts of CO_2. However, we note that deforestation is the second main source of CO_2 emissions as the carbon stored in the trees is released into the atmosphere as CO_2 when the wood is burned or left to rot (Yao et al. 2013).

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[4] International Union for Conservation of Nature (IUCN) Red List is an inventory of the global conservation status of biological species.

[5] A natural or artificial process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form.

[6] Natural process occurring when nitrate leaves the soil in drainage water.

77. Nitrate leaching can be limited by plants when nutrients present in the soil are absorbed by roots before it reaches the ground water where it becomes an environmental pollutant. Therefore, trees planted on pastures reduce the pollution of waterways by absorbing nutrients discharged by livestock. This practice known as agroforestry is well developed in Australia and New Zealand where it is recognised as a profitable and desirable land management system, improving the environment and increasing the viability of many rural communities (Bray 1995).

78. In New Zealand, research confirmed that *Eucalyptus* species can play a role in wastewater treatment (Murphy 1996). Eucalypt plantations can improve water quality by absorbing nitrates and toxic metals (Minhas et al. 2014).

79. Healthier eucalyptus forests would provide better habitats, as well as more nectar and pollen for honey bees and native birds (see sections 71 and 72). It would also help the establishment of permanent forests on steep unproductive land and on gullies for erosion control (Hawke's Bay Regional Council, 2002).

80. We note that these ecosystem services are not specific to eucalyptus plantations and could apply to other tree species. However, eucalyptus forests are estimated to have higher non-market value than pine forests mainly due to the amount of carbon sequestered (Lopes 2013).

81. We consider that *E. daenerys* is **likely** to have a **minimal** impact on ecosystem services and indirect benefits due to the small areas planted with eucalyptus at the national scale. We note that the impacts would be more important at regional scales where large eucalypt plantations susceptible to ETB exists, e.g. in Southland. We conclude that the level of benefits to ecosystem services is **low**.

Conclusion to the potential environmental benefits of Eadya daenerys

82. We took into consideration the potential environmental benefits that may occur following the release of *E. daenerys* in New Zealand and found that it is **highly likely** that biological control of ETB would reduce the use of damaging broad-spectrum pesticides. It is **likely** to have a low impact on biodiversity and ecosystem services, however these benefits are not specific to eucalypt forests. We consider the overall level of benefits to be **low to medium** with localised and contained benefits to regions where large eucalypt ecosystems exist.

People and communities

83. The release of *E. daenerys* could indirectly impact the community through the improvement of eucalyptus tree health and the increase of eucalyptus plantations.

84. Scion noted that less pesticide could decrease the contamination of waterways and potentially benefit the community through freshwater-related recreational activities. Healthier trees, as well as the potential increase of trees on farms, could reduce the pollution of the environment via waterway (see section 77).

85. David and Chloe Blackley, from the Bay of Plenty, mentioned in an interview with the NZ Farm Forestry Association (Blackley et al. 2014) that some of their plantations share a boundary with regional parks that are used by the public for recreational activities such as mountain biking, walking or horse riding in exchange for a small donation. The trees also provide shade from the sun and protection from the wind for people and animals as well as a pleasant environment for farmers to work and live in.

86. The benefits on communities will vary across the country. Southland and Waikato regions, which represent more than 70% of the eucalyptus plantations in New Zealand, would be the most affected by the release of *E. daenerys* where access to clean air and water could potentially improve due to better tree health. The improvement of eucalypt plantations in these regions could also create more employment opportunities in the forestry industry and in the sectors that support wood processing and associated businesses (Yao et al. 2013). Mr Millen stated in his submission that NZDFI plans to plant 100,000 ha of eucalypt forests by 2030 which could create 1700 jobs by 2050 (Appendix 1).

Conclusion to the potential benefits of Eadya daenerys on people and communities

87. We consider that *E. daenerys* would have **minimal** beneficial effects on people and communities at the national scale due to small areas planted with eucalyptus trees and identical benefits available from other species of trees. However, it is **likely** to have **minor to moderate** impacts at the regional scale where larger ETB-susceptible eucalyptus plantations exist or could be developed in the future. We conclude that the overall level of benefits from the release of the parasitoid wasp would be **low to medium**.

Economy

88. The applicant noted that successful biocontrol of ETB may benefit the market economy by:
    - Increase yield of ETB-susceptible Eucalyptus species
    - Reduced pesticide costs
    - Continuation of FSC certification

89. Our assessment of the economic benefits of *Eadya daenerys* took into consideration the increase in productivity of plantations, the reduction in pesticide costs and the benefits derived from the continuation of FSC certification.

Impact of E. daenerys on eucalyptus forests productivity

90. Despite the growth in popularity of eucalyptus trees worldwide, due to the demand for ornamental landscapes and timber, the development of eucalyptus forests in New Zealand is slowing down. This is due to the effects of insect defoliators such as ETB, the slow establishment of new specialised processing facilities that would reduce the costs associated with eucalypt wood products (Satchell & Turner 2010), and limited bigger scale operations that would reduce the costs of production (Satchell 2015).

91. In New Zealand, the most serious invasive pest to eucalyptus plantations is the ETB. Its favourite eucalyptus host is the dominant species in South Island plantations, *E. nitens*, (Ohmart 1991; Murray et al. 2008). The ETB also targets a large number of other *Eucalyptus* species, including species used in plantations such as *E. saligna, E. maidenii,* and *E. botryoides* (Satchell 2010). In their economic assessment, Scion noted that with 60 to 75% of the eucalyptus forests at risk, the ETB could cost the industry $402 to $503 million.

92. Compared to more traditional pine forests, eucalyptus forests have faster growth rates, 15 to 45 m^3 compared to 20 to 35 m^3 per ha per year, and shorter rotation lengths, 10 to15 years compared to 28 to 32 years (Judd & Menefy 2002). With the decrease in ETB pressures from biocontrol by *E. daenerys,* the pressures on trees due to the voracious leaf feeding habits of adults and larvae would reduce. The growth of trees, in size and height, would improve and healthier forests would provide opportunities for faster harvesting. Furthermore, the death of trees attributed to consecutive attacks by the ETB would also be avoided. More eucalyptus trees would be ready for harvesting, increasing the production output of plantations and profits.

93. In his submission, Mr Satchell, of Sustainable Forest Solutions, noted that the control of ETB could create new opportunities for growers, e.g. plantations of red mahogany (*E. scias*) with superior timber properties, previously abandoned due to its susceptibility to ETB. He also noted that the market value of eucalyptus timber is approximately five times greater than *Pinus radiata*, ensuring a better return on investment for growers than traditional pine plantations (Appendix 1).

94. Healthier trees planted on farmland would improve shelter and shade for livestock, decreasing environmental stresses and consequently improving welfare and productivity (Ministry for Primary Industries 2014). The NZ Farm Forestry Association interviewed some farmers on the value of eucalyptus to their operations and livelihoods. Ian Jackson in South Canterbury claimed that trees on pastures protect sheep after shearing and during lambing, increasing the survival rates of the livestock (Jackson 2012). Similarly, John and Christine Pedersen from Whangarei added that eucalypts and pine trees planted on less productive land improved the productivity of pastures by providing more grass and shelter in hot and cold weather for their stock (Pedersen & Pedersen 2012).

95. Economic benefits would be more important at the regional scale. With almost half of the ETB-susceptible plantations, Southland would be the most economically impacted by the release of the BCA. The forest and logging industries would further contribute significantly to the region where healthy forests are grown and harvested.

96. We consider that *E. daenerys* is **likely** to have a **minor** impact on the market economy at a national scale but a **moderate** impact at the regional scale on forest production by improving commercial value to eucalyptus plantations where ETB-susceptible plantations are grown. Furthermore, we note that in the future, the potential impact on the economy may increase with the development of eucalyptus stands by the forestry industry. We conclude that the level of benefits to eucalyptus forests productivity is **low to medium**.

Impact of E. daenerys on pesticide costs

97. Pesticides are currently sprayed once or twice annually on eucalyptus plantations to limit the impact of ETB. According to Scion's report on the 'Economic impacts of ETB in New Zealand' (Appendix 1 of the application), chemical control costs between $1.0 and $2.6 million/year. Aerial spraying costs double for small plantations (< 10 ha).

98. *Eadya daenerys* could reduce the adverse impacts of ETB, therefore, reducing the need for highly hazardous chemicals and, in turn, reducing the costs of pesticides. Furthermore, the assumption is that the parasitoid wasp would establish self-sustaining populations in eucalyptus plantations. Therefore, no ongoing costs would be required to control the pest.

99. We conclude that it is **highly likely** that *E. daenerys* would reduce the costs of pesticide usage due to the reduction in ETB populations. Again, the impact would be **moderate** at the regional scale but **minimal** at a national scale. We conclude that the level of benefits resulting from the reduction in pesticide costs is **low to medium**.

Impact of E. daenerys on ecosystem services

100. The parasitoid wasp improves eucalypt tree health by attacking ETB, therefore, improving the indirect and direct effects of eucalypt trees in the environment. However, the market value of the ecosystem services provided by the release of the BCA is difficult to estimate. In their application, Scion estimated the non-market value of *Eucalyptus* species to the environment at $11 million per year through carbon sequestration, habitats for taonga species, shelter, shading and limiting nitrate leaching.

101. Since the release of the Kyoto protocol, the Emissions Trading Scheme (ETS) has put a price on greenhouse gases including CO_2, to encourage landowners to grow forests that increase carbon storage. By earning carbon credits through the ETS forest owners help the country to meet its international obligations for reducing greenhouse gas emissions.

102. We note that healthy eucalyptus forests can limit flooding of some areas, increasing forest infiltration capacity as well as higher water consumption, therefore, limiting surface runoff (Yao et al. 2013).

103. In 2001, Krausse et al. provided an estimate of the economic impacts of soil erosion in New Zealand at approximately NZ$127 million per year (Krausse et al. 2001).

104. We conclude that the release of *E. daenerys* is **likely** to have a **minimal** impact on the economy through increase in ecosystem services due to small areas planted with eucalyptus at the national scale. The impact would be more important at regional scales, e.g. for the Southland region, where large eucalypt plantations that are susceptible to ETB exists, however, we note that some of these indirect benefits are not specific to eucalyptus and would apply to other forest species too. We conclude that the level of benefits to ecosystem services is **low**.

Impact of E. daenerys on FSC certification

105. FSC certification is internationally recognised as a rigorous environmental and social standard for responsible forest management and is supported by environmental groups such as the World Wildlife Fund and Greenpeace.

106. The emergence of green building markets increases the demand for products from certified forests which improves their market access. Furthermore, it increases grower profits as prices are generally higher than traditional hardwood products made of uncertified wood (Counsell et al. 2017).

107. The derogation to spray alpha-cypermethrin runs until 2018. If *E. daenerys* is approved for release, it is likely that foresters would be able to maintain their FSC certification as sprays of alpha-cypermethrin are expected to no longer be required. The continuation of their certification could have a moderate impact on New Zealand economy as it could help to promote products made from responsibly managed forests on the international market.

108. We conclude that with the release of the BCA, the forestry industry would not continue to rely on broad-scale chemicals to control ETB infestations and is **highly likely** to keep their certification. The impact would be **minor** nationally and **moderate** regionally. We conclude that the level of benefits of maintaining FSC certification is **medium**.

Conclusion of the potential economic benefits of biological control of ETB by E. daenerys

109. We consider that there are **likely** to be economic benefits from the release of the BCA with an increase in production and increase in ecosystem services and then is **highly likely** to be a reduction in pesticide costs and continuation of FSC certification. The magnitude of all these benefits is considered to be **minimal** to **minor** at the national scale but **minor** to **moderate** at the regional scale, e.g. the Southland region would benefit more than other regions where less Eucalyptus are grown. We consider the overall level of benefits on New Zealand's market economy from the release of *E. daenerys* to be **low** at the national scale but **low to medium** for some regions.

Potential risks from the release of *E. daenerys*

110. We have assessed all the risks but only discuss the effects that we consider to be significant. Effects, where the magnitude of the effect and likelihood of that effect occurring is improbable or speculative, are not included in our risk assessment.

Environment

111. The applicant identified the following risks of releasing *E. daenerys* to the New Zealand environment:
   - *Eadya daenerys* could attack the larvae of native sub-alpine Chrysomelinae beetles.
   - *Eadya daenerys* could attack beneficial non-native Chrysomelinae beetles.
   - *Eadya daenerys* could cause indirect adverse effects to other organisms caused by a reduction in ETB populations.
   - The BCA is unpalatable to predators and increases nectar competition.

112. In our assessment, we looked at the potential impact of *E. daenerys* on native, beneficial and pest species as well as indirect effects on ecosystems. We consider that people and communities would not be affected by the parasitoid wasp as it is solitary species living in the canopy of eucalyptus trees and cannot sting.

113. Biological control appears to be a less damaging approach to manage invasive species compared to chemical control, although the actions of the BCA could also negatively affect native or valued exotic flora and fauna. Therefore, the potential for the parasitoid wasp to have non-target effects must be carefully assessed to limit the risk. In order to identify test species for host range experiments, Scion combined the traditional phylogenetic approach with the PRONTI model (see sections 46 to 52).

114. As a result, the applicant generated a list of nine species considered potentially at risk from the introduction of *E. daenerys*. It includes one native, six exotic beneficial, and two pest species with physiological or phylogenetic similarities with the target host ETB (Table 4).

115. Between 2014 and 2017, Scion undertook three types of experiments on the nine selected species for laboratory host range testing (Appendix 5 of the application):
   - Physiological assays with 24-hour no-choice exposure where eight second instar beetle larvae of a non-target species on a sprig of their host foliage were confined with one female *E. daenerys* for 24 hours. The test was replicated 12 times except for the pest beetle *Trachymela sloanei* which was replicated five times and for the native species *Allocharis* nr *tarsalis* (replicated eight times) due to a limited supply of larvae for these two species. After exposure, all larvae were kept for up to four weeks before counting the number of larvae parasitized by *E. daenerys*.
   - Behavioural observation tests with two 10-minute consecutive no-choice experiments where eight second instar non-target (A) or eight target beetle larvae (B) on their host foliage were confined with one female parasitoid wasp for 10 minutes. The wasp was then removed and quickly placed in a different petri dish, alternating first contact with either ETB larvae (B) or non-target larvae (A) for 10 more minutes. The fate of each larva was recorded.
   - Second behavioural observation tests with a 25-minute two-choice test where eight non-target beetle larvae and eight ETB larvae on their appropriate host foliage sprig were kept on the same petri dish with one female parasitoid wasp for 25 minutes. The test was replicated 12 times with the exception of *T. sloanei* which was not tested due to insufficient larvae. The timing of each behaviour as well as time spent on each host plant was recorded.

116. The results of the physiological test showed that the wasp was only able to develop and emerge once as a fully formed adult from one non-target species, the pest beetle *T. sloanei*. Internal parasitism was found in four other non-target larvae species, *D. semipunctata, A.* nr *tarsalis*, *C. abchasica* and *G. olivacea*, but the BCA larvae never reached maturity.

117. The results of the behavioural tests showed that when *E. daenerys* was in contact with foliage other than eucalyptus, the majority of the time, it adopted a resting or grooming behaviour and did not attempt to attack non-target beetle larvae. The applicant noted that apart from *T. sloanei*, all other non-target species were significantly less likely to be targeted by *E. daenerys* compared to *P. charybdis*.

Impact of E. daenerys on native beetles

118. *Paropsis* and the closely related *Paropsisterna* genera are endemic to Australia. In New Zealand, the closest native genera in the subfamily Chrysomelinae comprise of approximately 40 species. These species are uncommon and little is known about their behaviour (Withers et al. 2017). Most publicly available information relating to New Zealand's Chrysomelid fauna is recorded and published by invertebrate systematists at Manaaki Whenua Landcare Research (Leschen & Reid 2004).

119. The most closely related endemic beetles are Chrysomelinae in the genera *Allocharis, Aphilon, Caccomolpus, Chalcolampra* and *Cyrtonogetus (*Withers et al. 2015*)*. Only one species, *Allocharis* near *tarsalis*, was located for testing. However, most of the other closely related native species are believed to be nocturnal (Withers et al. 2015). This ruled them out as potential hosts that are synchronised to the host searching behaviour of *E. daenerys*. The only native Chrysomelid beetles occasionally observed in Eucalyptus are in the genus *Eucolaspis*. Nevertheless, females lay their eggs in the soil and are not closely related to ETB, therefore they are not considered at risk with the release of *E. daenerys*.

120. *Allocharis* near *tarsalis* was collected in Kahurangi National Park on the subalpine shrub, *Veronica* spp*,* between 1200 and 1400 metres above sea level where no eucalyptus are currently found. Beetles in this genus have only been found in subalpine regions where its preferred host vegetation grows. Its habitat does not overlap with the habitat of the parasitoid wasp which is eucalyptus forests where its host is found, therefore, we consider that encounters between *A.* nr *tarsalis* and *E. daenerys* are very unlikely to occur.

121. Despite the results showing that *A*. nr *tarsalis* is not a physiological host for the parasitoid, the attack rates[7] on the host plant of *A*. nr *tarsalis* was not significantly different than for ETB during the two-choice tests. The applicant explained these results due to the presence of two female wasps which showed outlier behaviour compared to the other 6 of wasps tested. In both cases, the number of attack-insertions on the target host ETB was greater than on the native beetle species. We concluded that in the wild *E. daenerys* is unlikely to encounter *A*. nr *tarsalis* due to its different feeding niche and habitats compared to ETB, therefore, the risk to native beetle species is low (Table 4).

122. In its submission, DOC did not raise any concerns for native beetles from the release of the parasitoid wasp as a biocontrol agent. DOC considered that the host testing done by Scion was adequate and showed limited impact on native beetles with population-level impacts very unlikely to result from the release of the parasitoid (Appendix 2).

[7] Attack rate on the plant was calculated as: No. attack-insertions / total spent on that host's plant

123. Based on the information available, there are no native species closely related to ETB that would be at risk from the introduction of the parasitoid wasp. Furthermore, most native Chrysomelinae beetles are naturally uncommon, active only at night or spend their larval stages in the soil environment or inside plant tissue where they would not be discoverable by *E. daenerys* during its host searching activities. We conclude that it is **unlikely** that the BCA would attack non-target native beetle species. We consider that if off-target attacks should occur it would be incidental and would cause **minimal** adverse effects on native beetles. We conclude that the level of risks to native beetles is **negligible**.

Impact of E. daenerys on beneficial biological control agents

124. A total of six beneficial weed BCA were selected by Scion. Two in the same subfamily as ETB (Chrysomelinae), two in the sister subfamily (Galerucinae) and two in the same family (Chrysomelidae).

125. The two beneficial BCA species selected in the same subfamily Chrysomelinae were *Gonioctena olivacea* and *Chrysolina abchasica*, introduced in New Zealand to control scotch broom, *Cytisus scoparius,* and the weed tutsan, *Hypericum androsaemum* respectively*.* They were selected for host range tests because their larval stages occur at the same time when *E. daenerys* females are searching for hosts to oviposit in. Scotch broom and tutsan are also found in the same environment as eucalyptus trees. The test results showed that the parasitoid wasp was minimally attracted to *G. olivacea* and *C. abchasica* larvae in the no-choice exposure tests (5.2% and 1.8% of larvae parasitised respectively) but none of the larvae successfully produced adult wasps (Withers et al. 2018b).

126. The two beneficial BCA species selected in the sister group Galerucinae were *Lochmaea suturalis* and *Agasicles hygrophila*, introduced in New Zealand to control heather, *Calluna vulgaris,* and the alligator weed, *Alternanthera philoxeroides*. Their selection was based on the phylogenetic relatedness to the host ETB and biological affinities to the parasitoid wasp (e.g. their larvae are present when *E. daenerys* searches for hosts) (Withers et al. 2015). After 24-hour no-choice exposure to *E. daenerys* neither were parasitised, therefore, Scion concluded that they are not at risk from the release of the parasitoid wasp (Withers et al. 2018b).

127. The two beneficial BCA species selected in the same family as ETB were *Neolema ogloblini* and *Cassida rubiginosa,* introduced in New Zealand to control wandering willie, *Tradescantia fluminensis,* and the creeping thistle, *Cirsium arvense*, respectively*.* Both host plants grow in the same geographical environment of eucalyptus trees and have exposed larvae when *E. daenerys* is active (Withers et al. 2015). The results showed that neither larvae were attacked by the parasitoid wasp during the 24 hour no-choice exposure tests, therefore, Scion concluded that they are not at risk from the release of *E. daenerys* (Withers et al. 2018b).

128. Based on the information available, we consider that it is **highly improbable** that non-target beneficial BCA would be targeted by the parasitoid wasp. If this occurs, any effects would remain **minimal** as no viable adult wasps would emerge. These beetles would thus not support *E. daenerys* populations building up in areas where beneficial beetles live. We conclude that the level of risks to beneficial biological control agents is **negligible**.

Impact of E. daenerys on pest beetles

129. Scion included two pest Chrysomelid beetles in the host test experiments to further demonstrate the potential host range of *E. daenerys*. The two exotic pest beetles, *Trachymela sloanei* and *Dicranosterna semipunctata*, are in the same subfamily as the target and are found in the same niche or in adjacent habitats in *Eucalyptus* trees and *Acacia* trees respectively.

130. During the behavioural no-choice tests no significant difference in attack-insertions and attack rates on plants were observed between the two eucalyptus feeding beetles, ETB and *T. sloanei*. But it was significantly different between ETB and *D. semipunctata* that feeds on Acacia. These observations suggest that the parasitoid wasp use odour cues produced by the plant host or the beetle itself to find its host.

131. The physiological assays demonstrated that *E. daenerys* could only form a completely developed adult in one out of five *T. sloanei* larvae. The other four *T. sloanei* larvae produced tiny non-viable cocoons. Despite being a physiological host to *E. daenerys*, survival rates were low indicating that *T. sloanei* would not increase the propagule size of the wasp. Furthermore, the likelihood of these species encountering each other in the wild is considered to be rare given the diurnal-nocturnal differences between them.

132. There were only minimal attacks on the second exotic pest beetle, *D. semipunctata,* with only 1.6% of larvae parasitised by *E. daenerys*. The pest beetle is not a physiological host as no adults emerged from parasitised larvae (Table 4).

133. Based on the information available, we consider that it is **highly likely** that pest beetles in the same sub-family as ETB, sharing the same habitats and with the same phenology and behaviour would be targeted by the parasitoid wasp. However the adverse effect would be minimal as pest beetles are not protected or valuable to New Zealand. We consider that the reduction of this pest beetle could be a secondary benefit.

Indirect effect of E. daenerys on the ecosystem and food webs

134. The ecosystem may be affected at different trophic levels by the release of *E. daenerys*. We considered three potential impacts. First, the reduction of prey available to ETB predators. Second, reductions in ETB populations could benefit other pest species. Third, the hybridisation of *E. daenerys* with other parasitoid wasps could affect the inherent genetic diversity of native or exotic beneficial wasps in New Zealand.

135. We could not find any records of *Eadya* hyperparasitoids in the literature. Hyperparasitism in the family Braconidae is described as rare (Ghahari et al. 2010), therefore, we did not consider this in our risk assessment.

136. The ETB established in New Zealand more than 100 years ago with the development of eucalyptus plantations. To-date, only two native predators of ETB have been identified, the brown soldier bug, *Cermatulus nasalis,* and the predatory shield bug, *Oechalia schellembergi*. These two bug species attack ETB larvae as well as many other soft free living insects such as caterpillars and should not be affected by the reduction in ETB larvae.

137. The ETB is also a source of food for birds and other insectivores but, similarly to the two native bugs, the pest beetle does not constitute their main or only source of food, therefore, they would not be impacted by reductions in ETB populations. Eucalypt forests in New Zealand do not support populations of specialised or native species that compete with self-introduced insects.

138. From November to December, adult parasitoid wasps feed on nectar, potentially reducing the quantity of food available for other nectar-feeder species. We note that the main *Eucalyptus* species planted in New Zealand are not synchronised to *E. daenerys* biology, suggesting that the parasitoid wasp would feed on nearby flowering vegetation. Nonetheless, the competition between pollinators and parasitoids for nectar is considered to have negligible effects on the availability of nectar (Varennes 2015). We conclude that the presence of *E. daenerys* would not add significant competition for nectar with other species.

139. The reduction in ETB populations could lead to the emergence of sleeper eucalyptus pests that are already present in New Zealand. For example, the newly arrived Australian pest, the bronze bug (*Thaumastocoris peregrinus)*, could benefit from the release of the parasitoid wasp. The bronze bug is a sapsucker that feeds on the leaves of a wide host range and is mainly found on *E. nicholii* in the Auckland region. It is known to attack at least 30 *Eucalyptus* species including some species used by the forestry industry such as *E. nitens, E. globulus*, *E. saligna*, and *E. botryoides* (Sopow & George 2012). However, the occupation of the ETB niche by another eucalyptus pest remains hypothetical. If this occurred, proper control measures for the new pest could be investigated in good time before it becomes a significant pest to the industry.

140. In New Zealand, there are no native or introduced species in the *Eadya* genus. The NZ Arthropod Collection (NZAC) from Manaaki Whenua Landcare Research counts six genera (*Cryptoxilos, Dinocampus, Leiophron, Meteorus, Microctonus, Syntretus*) in the same subfamily as *E. daenerys* as present in New Zealand. Some parasitoid wasps were introduced as biocontrol agents and some are endemic. However, they are not considered closely related enough to be able to interbreed naturally with *E. daenerys*.

141. Based on the information available, we consider it **very unlikely** that the release of *E. daenerys* would have adverse impacts on the ecosystem with no ETB specific predators and no closely related species of parasitoid wasps to adversely affect the inherent genetic diversity of native or beneficial wasps in New Zealand from hybridisation. The indirect effects of *E. daenerys* on the ecosystem and food webs would be **minimal**. We note that it is **unlikely** that the reduction of ETB populations would be profitable for another eucalyptus pest species. We conclude that the level of risks to ecosystem and food webs is **negligible**.

Conclusions of the potential adverse environmental effects of biological control of ETB by E. daenerys

142. We took into consideration the potential adverse environmental effects that may occur following the release of *E. daenerys* in New Zealand and found that it is **highly improbable** that biological control of ETB will impact beneficial BCA and **unlikely** to **very unlikely** that it would impact native species and ecosystem interactions. The impact on pest beetles is not considered a risk but a benefit. The magnitude of the adverse effects would be **minimal** as it would only have localised and contained environmental impacts. We consider the overall level of risks to be **negligible**.

Subfamily	Species	Status	Similarities to ETB	Possible risk(s)
Chrysomelinae	*Paropsis charybdis*	Exotic pest	Target host	High internal parasitism by *E. daenerys* (>30%) in 24 hours no-choice exposure test.
Chrysomelinae	*Trachymela sloanei*	Exotic pests	Phylogenetically close	Low survival rates (12.5%) in 24 hours no-choice exposure tests but nocturnal larvae.
	Dicranosterna semipunctata		Phylogenetically close	Unsuccessful internal parasitism by *E. daenerys* (1.6%) in 24 hours no-choice exposure tests. Different host plant.
	Allocharis nr *tarsalis*	Endemic species	Diurnal external larvae	No geographic overlap with ETB. Low attraction to *E. daenerys* for oviposition. Low internal parasitism by *E. daenerys* (7.5%) in 24 hours no-choice exposure tests.
	Gonioctena olivacea	Beneficial biological control agents	External spring larvae.	Geographic distribution overlap with ETB but found on a different plant host. Not a physiological host. Unsuccessful internal parasitism by *E. daenerys* (5.2%) in no-choice exposure tests.
	Chrysolina abchasica		External spring to summer larvae	Geographic distribution overlap with ETB but it is found on different plant hosts. Unsuccessful internal parasitism by *E. daenerys* (1.8%) in 24 hours no-choice exposure tests.
Galerucinae	*Lochmaea suturalis*		External early summer larvae	Not parasitised by *E. daenerys* in no-choice tests.
	Agasicles hygrophila		External spring to summer larvae	Not parasitised by *E. daenerys* in no-choice tests.
Criocerinae	*Neolema ogloblini*		External spring to summer larvae	Not parasitised by *E. daenerys* in no-choice tests.
Cassidinae	*Cassida rubiginosa*		External spring to summer larvae	Not parasitised by *E. daenerys* in no-choice tests.

Table 4: The target host ETB and the list of nine species tested by Scion as potential hosts for the parasitoid wasp *Eadya daenerys*.

Economy

143. Amongst the risks identified by the applicant, the potential attack of beneficial Chrysomelid beetles by the parasitoid wasp could have an impacts on the economy.

Impact of E. daenerys on introduced BCAs

144. We consider that the main economic risks of the release of *Eadya daenerys* is its potential to target larvae of beneficial agents previously introduced to New Zealand.

145. Among the nine species tested, six are beneficial weed control agents selected by their phylogenetic and ecological affinities to the target host ETB. The results (see sections 125 to 129) showed that it is highly improbable that *E. daenerys* would attack these BCA and if an attack were to occur it will be an isolated case. Consequently, we do not consider that there would be population-level effects on beneficial BCA. We consider the potential adverse effects from the release of the parasitoid wasp on beneficial BCA to be minimal.

Conclusion to the potential economic risks of biological control of ETB

146. We consider **highly improbable** that the release of the BCA would have potential adverse effects on beneficial BCA due to the host specificity of *E. daenerys*. The overall level of risks on New Zealand's market economy from the release of *E. daenerys* is considered to be **negligible**.

Conclusion on benefits and risks assessment

147. After completing our risk assessment and reviewing the available information, we consider that the adverse effects of releasing *E. daenerys* to control ETB are negligible and the environmental and economic benefits as well as benefits to the community are low to medium (Table 5). Therefore, our assessment is that the benefits from the release of the BCA outweigh the risks.

Potential outcomes	Likelihood	Consequence	Conclusion (level or risk/benefit)
Potential beneficial effects to the environment			
Reduce pesticide usage	Highly likely	Moderate	Medium
Improve biodiversity	Likely	Minor	Low
Improve ecosystem services	Likely	Minimal (national) / minor (regional)	Low
Overall level of environmental benefits			Low / medium
Potential beneficial effects to the market economy			
Increase in wood productivity	Likely	Minor (national) / moderate (regional)	Low (national) / medium (regional)
Decrease pesticide costs	Highly likely	Minimal (national) / moderate (regional)	Low (national) / medium (regional)

Improve ecosystem services	Likely	Minimal (national) / minor (regional)	Low
Maintain FSC certification	Highly likely	Minor (national) / moderate (regional)	Medium
Overall level of economic benefits			Low / medium
Potential beneficial effects on the community			
Improve recreational activities, wellbeing and employment.	Likely	Minimal (national) / moderate (regional)	Low / medium
Potential adverse effects on the environment			
Attack on native non-target species	Unlikely	Minimal	Negligible
Attack on beneficial introduced non-target species (weed BCA)	Highly improbable	Minimal	Negligible
Impact of *E. daenerys* on pest beetles (same sub-family, same habitats and same phenology and behaviour than ETB)	Highly likely	Minimal	No risk (considered a secondary benefit)
Risk to ecosystem interactions and food webs (indirect effects)	Very unlikely / unlikely	Minimal (national) / Minor (regional)	Negligible
Overall level of environment risks			Negligible
Potential adverse effects to the market economy			
Decresing populations of beneficial BCA	Highly improbable	Minimal	Negligible

Table 5: Summary of our assessment of the benefits, risks and costs associated with the release of *E. daenerys* to control ETB.

Relationship of Māori to the environment

Summary of the applicant's engagement with Māori

148. During the pre-application stage, the applicant engaged face-to-face at hui or via other forms of engagement (email, post and videoconferencing) with more than twenty Māori and iwi groups across New Zealand between 2013 and 2018. Māori expressed a general concern about the introduction of another exotic organism and its potential impact on people and the environment. They are opposed to the use of harmful chemicals and some Māori would prefer to have native tree plantations instead of Eucalyptus.

Submissions from Māori on this application

149. Te Rūnanga o Ngāi Tahu opposed the release of *Eadya daenerys*. They are recognised as the representative of Ngāi Tahu Whānui, which is the third largest Māori iwi in Aotearoa with almost 60,000 membership representing over 90% of the South Island.

150. Te Rūnanga o Ngāi Tahu acknowledge the Māori consultation done by Scion for this application. However, they perceived the questions that were raised during these meetings to have remained unanswered. They believed that no economic case was made for the introduction of the BCA to control an introduced pest affecting exotic trees which have relatively small economic value. The risks around the introduction of the BCA have not been fully quantified and are not considered highly unlikely.

Kaupapa Kura Taiao cultural risk assessment

151. The potential effects on the relationship of Māori to the environment have been assessed in accordance with section 5(b), 6(d) and 8 of the Act. Under these sections, all persons exercising functions, powers and duties under this Act shall take into account the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, valued flora and fauna and other taonga, and the Treaty of Waitangi.

152. Findings of the cultural risk assessment (CRA) for the parasitoid wasp, *Eadya daenerys*, in relation to the above HSNO provisions are summarised below. A full CRA can be found in Appendix 4 of this report.

153. Based on the information provided, the potential risks to Māori interests appear to be acceptable. However, further work may be needed to better understand the potential indirect impacts of the application and to support on-going engagement between the applicant and Māori.

Assessment against the Minimum Standards

154. Prior to approving the release of a new organism, the EPA is required to determine whether the parasitoid wasp *E. daenerys* meets the minimum standards set out in section 36 of the HSNO Act.

Can E. daenerys cause any significant displacement of any native species within its natural habitat?

155. The applicant provided information from host range testing and studies that indicated that the candidate biocontrol agent is specific to eucalyptus-feeding paropsine beetles (Appendix 5 of the application). Closely related native Chrysomelinae are not known to live in eucalyptus forests in New Zealand. Therefore, we consider it unlikely for the wasp to have adverse effects on native beetle species in their natural habitat as *E. daenerys* would be restricted to the vicinity of eucalyptus.

156. There are eucalyptus trees outside forestry environments, however, they are not found in natural habitats of many of our native Chrysomelid species, e.g. in Kahurangi National Park. Where there is overlap in ETB-susceptible *Eucalyptus* species and native beetle habitats, the vulnerable life stage may not be present or they may be protected from attack inside plant tissue or in soil.

Can E. daenerys cause any significant deterioration of natural habitats?

157. We consider the adverse indirect effects on ecosystem interactions, such as food webs, that could occur following the introduction of *E. daenerys* in paragraphs 136 to 143. We conclude that it is very unlikely the agent would cause excessive pressure on native insect species or natural habitats through interactions such as a lack of prey for native predators or cross-breeding with native wasps in New Zealand.

Can E. daenerys cause any significant adverse effects on human health and safety?

158. There are no mechanisms of interaction between humans and the BCA that may cause adverse effects to human health and safety. The wasp does not sting. Furthermore, it has a preference for the canopy of the tree where ETB larvae are found.

Can E. daenerys cause any significant adverse effect to New Zealand's inherent genetic diversity?

159. There are no native *Eadya* species present in New Zealand, therefore, it is unlikely that the candidate agent could cross-breed naturally with native species thereby adversely affecting New Zealand's inherent genetic diversity.

Can E. daenerys cause disease, be parasitic, or become a vector for human, animal or plant disease?

160. The parasitoid wasp is not known to cause disease or be a vector for animal, plant or human disease in their native range. It is a parasitic organism intended to parasitise its host ETB.

Conclusion on the minimum standards

161. We consider that *E. daenerys* meets the minimum standards as stated in the HSNO Act.

Can E. daenerys establishes undesirable self-sustaining populations?

162. Section 37 of the Act requires EPA staff to have regard to the ability of the organisms to establish undesirable self-sustaining populations and the ease with which the organisms could be eradicated if they established such a population.

163. We note that the purpose of the application is to release the parasitoid wasp and to allow the organism to establish self-sustaining populations and disperse to attack its host, ETB, in our environment. This is the foundation of a classical biological control strategy and therefore we consider that any population of *E. daenerys* will not be undesirable.

164. The potential risks of the organism is assessed above and was found to be negligible (Table 5). In the very unlikely event a population is shown to become undesirable it would be difficult and expensive to eradicate such a population as it would require the application of non-specific insecticides.

Recommendation

165. Our assessment has found that the benefits of releasing *E. daenerys* outweigh any identified risks or costs. We therefore recommend that the application be approved.

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Appendix 1: Summary of submissions

#	Submitters	Position	Summary of submission
127364	Alex Benjiman	Against	Not satisfied with the 'low' risk of the new BCA. Alternatives native species should be looking at.
127368	Cecelia Martin	Against	Object to all imports of BCA. Too many are not host specific. Wasps will threaten our bee populations.
127371	Joseph (Shaf) van Ballekom Proseed New Zealand Limited	Support	Proseed is actively involved in the breeding of durable eucalypt species. *Eucalyptus nitens*, *E. fastigata* and *E. regnans* can be regarded as niche species and add value to the forest sector.
127378	Rod Hitchmough Department of Conservation	Support	No objection. We are happy with the host testing and the limited impacts on native beetles.
127380	Clinton Care	Support	We have Eucalyptus Leaf Skeletoniser moths in North Island.
127381	Maui TePou	Against	Why is EPA protecting Eucalyptus?
127382	Jacalyn Reynolds	Support	BCA is a better option than chemicals. Large quantities of trees dying in the last 12 months. Eucalyptus play an important role for carbon sequestration and support a diverse and thriving ecosystem.
127383	Gary Fleming	Support	ETB target valuable *Eucalyptus* species with environmental benefits (birds, shelter, amenity properties, carbon sequestration, nitrogen leaching).
127384	Marco Lausberg Specialty Wood Products	Support	*Eadya daenerys* will limit the damage and also help save on chemical use. The industry prefers a BCA to a chemical option due to the cost and environmental benefits
127385	Mark Dean Ernslaw Ernslaw One Limited	Support	We are the 4th largest forestry company in New Zealand and are looking to develop fast growing hardwood. As owners of FSC certified forests we are required to minimise the use of chemicals. In order to have the confidence to plant species potentially susceptible to ETB an assurance that *E. daenerys* can be deployed if necessary to our investors.
127386	Mark Forward Nelson Forests Limited	Support	This beetle causes significant damage to this tree species to the point at where it has become uneconomic to grow and the stands of trees are in significant decline.

127387	Paul Millen New Zealand Dryland Forests Initiative (NZDFI)	Support	Eucalypt species are well adapted to New Zealand's dryland eastern regions. Our vision by 2030, is 100,000 ha planted with eucalypt forests that could be worth $2 billion and employ 1700 people by 2050. The NZDFI are developing a durable eucalypt species. The only current option to control ETB is by using insecticides. We want to develop genetic resistance as well as environmental methods to reduce insect threats.
127388	Venise Confort NZ Forest Owners Association	Support	BCA is the only feasible means to reduce chemical use and therefore negative impacts on eucalypt trees on plantations and parks.
127389	Dr J J Dymock Northland Regional Council	Support	Eucalyptus species are suitable for Northland climate but are difficult to grow due to ETB serious damage. Currently, there is 450 ha of eucalyptus plantations in Northland. Eucalyptus trees also provide shade, shelter, erosion control and nectar. Host specificity tests showed that although non-target Chrysomelid beetles were attacked by the parasitoid, *Eadya daenerys*, none of these parasitoids survived to complete development, except in *Trachymela sloanei*, which is also a pest of eucalypts. It is unlikely that the wasp attack native non-target Chrysomelid beetles found in non-eucalyptus habitats.
127390	Dean Satchell Sustainable Forest Solutions	Support	I am a forest grower, Eucalyptus species produce strong, attractive and durable high-quality timbers that are in demand by consumers and provide good returns for growers and a profitable land use. The current price is approximately 5 times what a similar Radiata pine grade and size produce. ETB has been the most destructive and difficult eucalyptus pest to control for over 100 years. This wasp offers new opportunities to grow high-value solid timber such as *Eucalyptus scias* abandoned as a plantation species in the early 1900s due to the damage caused by ETB. Trees and forestry are an important land use for New Zealand, offers public benefits, for producing timber but also erosion control and carbon sequestration. High-value plantation forestry species on relatively short rotations generate economic value and returns to growers.
127391	Dr John A. McLean Gisborne-East Coast Branch NZ Farm Forestry Association	Support	ETB is a pest in some of our plantations. We are a supporter of NZ Dryland Forests Initiative (NZDFI) and their regional strategic plan seeks to establish 100,000 ha of durable eucalyptus forests where the approval of the BCA will be timely.
127392	Peter Berg New Zealand Farm Forestry Assn	Support	Eucalyptus species are a significant commercial resource in New Zealand (some 20, 000ha). They provide higher quality timbers, erosion control and carbon sequestration. Trees grow exposed to such pests for long periods 30-40 years, so any control needs to be robust and effective long-term. Work undertaken by Scion has demonstrated that *Eadya* is a very effective and host-specific predator of *Paropsis*. Planting and growing Eucalyptus is for many fundamental to a successful forestry enterprise.

127393	Scott Andrew Juken NZ	Support	Juken NZ is a forestry company. 350ha of Eucalyptus were planted in the last 1-7 years to support the company's mills in diversifying its product mix. ETB has led to moderately to severe defoliation. Spraying insecticide is not an option for the company. The introduction of *Eadya daenerys* will vastly improve the vigour and health of the eucalyptus estate leading to the final desired timber product.
127394	Graeme Manley Southwood Export	Support	Our company is involved in the forest industry and in the research programme to develop specialty timber species. ETB is our biggest threat. Currently, we have to resort to aerial spraying which it is seen as "environmentally unacceptable" and not favoured by FSC. Effective biocontrol is the obvious path and science shows that *Eadya daenerys* is an effective option with little (if any) risk to NZ's native species.
127395	Gerry Te Kapa Coates Te Rūnanga o Ngāi Tahu	Against	Pre-application attempts at consultation with Māori relating to this biocontrol agent were carried out with Māori questioning several aspects of the application to which Scion seemingly gave little by way of response. Our submission generally opposes the Application on the grounds that neither an economic nor an environmental case has been made for the introduction of such a new exotic biocontrol agent to control an introduced pest that may only affect an introduced exotic forestry tree with relatively small economic value.
127396	Margaret B. Hicks	Against	For the interest of the public safety and the environment, Eucalyptus trees should not be planted. Eucalyptus are exotic and ETB won't be a problem if man did not import the tree in the first place. They are a fire hazard and as monoculture encourage the spread of diseases and pests. Why profits outweigh the conservation of our own valuable native trees? The impact of the BCA on the ecosystem is unpredictable.
127397	Jun Kitamura Southland Plantation Forest Company of New Zealand	Support	We grow *Eucalyptus nitens* for export fibre and future solid wood product. ETB is our biggest threat. Currently, we have to resort to aerial spraying which it is seen as "environmentally unacceptable" and not favoured by FSC. Effective biocontrol is the obvious path and science shows that *Eadya daenerys* is an effective option with little (if any) risk to NZ's native species.
127398	Junichi Nishimura Kodansha Treefarm NZ	Support	We grow *Eucalyptus nitens* for export fibre and future solid wood product. ETB is our biggest threat. Currently, we have to resort to aerial spraying which it is seen as "environmentally unacceptable" and not favoured by FSC. Effective bio control is the obvious path and science shows that *Eadya daenerys* is an effective option with little (if any) risk to NZ's native species.
127399	Dr Cliff Mason	Against	Introduction of an exotic species will have unpredictable effects in the NZ environment. The testing of non-target host has failed due to the inability to locate native beetle species. *Allocharis* near *tarsalis*, an incomplete physiological host, indicates the possibility of related species being complete hosts or evolutionary adaptation. Geographical barriers can be overcome by the BCA. Eucalyptus forests are unsustainable due to pesticides and susceptibility to myrtle rust. The economic 'losses' reported due to ETB are relative to a theoretical optimum growth rate.

127400	Davor Bejakovich Greater Wellington Regional Council (GWRC)	Support	Risks to non-target related native and beneficial beetles in New Zealand has been examined in laboratory tests and appears to be very low. GWRC trusts that due diligence will be followed in the assessment of risk by these agencies and supports the establishment of biocontrol species. An additional BCA will ensure that the eucalyptus sector of the forestry industry remains strong and productive. Biocontrol is a cost-effective and largely publicly acceptable technique. Establishment of *Eadya daenerys* will greatly assist with the long-term, national management and protection of New Zealand's forestry sector.
127401	Philip Millichamp Oji Fibre Solutions	Support	We are a New Zealand-based manufacturer of pulp, paper and cardboard packaging products, earning approximately $1.4B in revenue. We are a substantial employer in New Zealand relying heavily on the supply of wood fibre from *Pinus radiata* and *Eucalyptus*. With the growing demand for sustainable packaging and developments in technology, our industry is considered likely to be central to New Zealand's future low-carbon economy. We support the release of the BCA based on the understanding biosecurity risks will be very well managed. Without such measures, New Zealand risks eroding its competitiveness in the wood, fibre and bio-industries and this will likely lead to reduced investment and lost opportunities to develop a sustainable, circular economy based on renewable inputs.
127402	Stephen Lamb (N. Poutasi) Regional Council - Bay of Plenty	Support	We support plantation forestry as a sustainable land use, and we see the release of this agent resulting in a positive benefit by increasing the growth and yield of Eucalyptus species.

Appendix 2: Submission from Department of Conservation

From: Rod Hitchmough [mailto:rhitchmough@doc.govt.nz]
Sent: Friday, 19 October 2018 2:31 PM
To: submissions <submissions@epa.govt.nz>; Aubanie Raynal <Aubanie.Raynal@epa.govt.nz>; Diane Totton <Diane.Totton@epa.govt.nz>
Cc: Verity Forbes <vforbes@doc.govt.nz>
Subject: RE: APP203631 Eucalyptus tortoise beetle BCA. Open for public submissions

Thank you for the opportunity to comment on the application: APP203631 Eucalyptus tortoise beetle BCA.

The Department of Conservation has no objection to the release of this biocontrol agent. We are happy with the host testing that has been carried out and the conclusion that any impacts on native beetles will be limited to very occasional oviposition which will not result in completion of the parasitoid life-cycle, and that furthermore geographic and habitat separation means that even such unsuccessful parasitism will be a very rare event, so is very unlikely to have population-level impacts.

Regards

Rod Hitchmough
Scientific Officer (Biosecurity)
Department of Conservation—Te Papa Atawhai
National Office, PO Box 10 420, Wellington 6143
18-32 Manners St, Wellington 6011

Appendix 3: Dr Ronny Groenteman review

From: Ronny Groenteman [mailto:GroentemanR@landcareresearch.co.nz]
Sent: Monday, July 30, 2018 9:35 AM
To: Aubanie Raynal <Aubanie.Raynal@epa.govt.nz>
Cc: Toni Withers <Toni.Withers@scionresearch.com>
Subject: Independent expert review of host range tests for Eadya daenerys

Kia ora Aubanie,

I have now reviewed the host specificity testing for *Eadya daenerys* and, following discussion with the author, clarifications were made to the original manuscript. My comments below are based on the corrected version (attached) which I have also reviewed.

I am now satisfied that:

1. The testing was completed in accordance with best practice, including test host & plant selection, methods and replication
2. The conclusions drawn in the report are supported by the results from the host range tests

Ngā mihi nui,

Dr Ronny Groenteman
Biocontrol Scientist
Manaaki Whenua – Landcare Research
T +64 3 321 9904

Appendix 4: Cultural Risk Assessment (CRA) for New Organisms Application

Purpose of CRA

The purpose of this Cultural Risk Assessment (CRA) is to assess the potential risks and impacts on Māori interests associated with releasing from containment the parastoid Eadya wasp (*Eadya daenerys*) as a biological control for the Eucalyptus tortoise beetle (*Paropsis charybdis*) (ETB) incursion in New Zealand. Cultural risk includes any negative impacts to treasured flora and fauna species, the environment, and the general health and well-being of individuals and the community.

Ngā here ture (Statutory obligations)

This CRA has been undertaken in accordance with sections 5(b), 6(d) and 8 of the Hazardous Substance and New Organisms Act 1996 (HSNO) which oblige all persons exercising functions, powers, and duties under the HSNO to:

- Recognise and provide for the maintenance and enhancement of people and communities to provide for their cultural well-being, and
- Take into account the relationship of Māori and their culture and traditions with their ancestral lands, water, taonga and the principles of The Treaty of Waitangi (Te Tiriti o Waitangi).

The Treaty principles most relevant to assessing and deciding this application are:

- The Crown has a duty to actively protect Māori interests.
- The Crown has a duty to be informed and make informed decisions.
- 'Taonga' include all valued resources and intangible cultural assets.

Introduction

The ETB causes significant damage to susceptible species of eucalypts (gum trees) as both the adult beetle and the grubs (larvae) eat the newly produced leaves of host trees. It first arrived in New Zealand in Lyttleton in 1916. Early attempts at biological control were unsuccessful, and recent efforts have had mixed results.

Eucalypts are an important component of our forestry industry with the total value of eucalypt forests estimated at $671 million (land value excluded). Of this total, there is an estimated $402-$503 million worth of vulnerable Eucalyptus stands. Unmanaged, the eucalyptus tortoise beetle presents a significant risk to the productivity of these plantations and to the economic justification for establishing new forests that could expand New Zealand's pulp and paper and solid wood industry in the future.

Māori worldviews of insects, plants and biocontrols

Insects are culturally significant due to the part they play in kōrero o mua (traditional narratives) and Māori environmental lore. Kōrero o mua tell us that insects and other arthropods belong to a group within the domain of Tāne-mahuta (deity of humans, forests and forest dwelling species) known to Māori as Te Aitanga Pepeke (insect relatives) and Te Tini o Hakuturi (the multitude of bow-legged ones). The broad domain of Tāne is sometimes known as Te Marae o Tāne (literally 'the precinct of Tāne'), which can be interpreted loosely from a western point of view as being terrestrial ecosystems. Te Aitanga Pepeke is a sub-group representing arthropods. The Eadya wasp and ETB are both pepeke (insects) and therefore belong to Te Marae o Tāne (terrestrial ecosystems), and specifically Te Aitanga Pepeke.

Māori may also associate the ETB with the domain of Whiro (the deity of darkness, evil, death and disease) due to its potential to devastate plants, crops and livelihoods. Vectors of disease, infestations, and the pestilence and destruction wrought by pests, such as the ETB, also fall within the domain of Whiro.

The interaction between Eadya wasp and ETB reflects the eternal struggle between Tāne and Whiro, where living things are always at risk of being compromised by misfortune and danger – good pitched against bad. This tension is recalled in kōrero o mua which recount that it was Whiro who, on his unending quest to destroy humankind, plants and creatures created by Tāne, sent an army of insects, birds and bats to kill Tāne when the latter climbed to the heavens to fetch the three baskets of sacred knowledge – which Whiro tried to get himself. However, Tāne called the winds to keep them away. As Tāne came back down with the baskets, Whiro sent out a swarm of beetles, but Tāne defeated them too. He took all of Whiro's insects and birds to his forests, where they remain to this day. This story illustrates that good eventually triumphs over evil, and that long lasting change can be inspired by great leaders.

Eucalypts, along with other plants, belong to the domain of Tāne-mahuta, along with the Eadya wasp and ETB. Māori value plants in a multifaceted way that recognises their tangible and intangible uses as well as historical and contemporary importance. Some plants retain special significance even when their uses change or they are no longer used but have 'remembered' cultural value. This worldview respects past and evolving relationships between people and plants, and connects Māori with their culture and history. There is hardly a facet of classical Māori culture that did not somehow connect with plants. Māori regard all native flora and fauna as taonga species and value exotic species for their many beneficial uses. In the latter case, this is sometimes because introduced species have supplanted native ones for particular purposes.

Forestry, and traditional uses of forests, are not only important for sustenance and economic reasons but also for connecting Māori to the land, as the term 'tāngata whenua' suggests – people of the land. This relationship is important to Māori irrespective of the size of the area under cultivation from large scale commercial operations to ngakinga (small domestic plots).

Māori historically used biological control agents, albeit on a domestic scale, to manage pests prior to European contact. For example, Māori are known to have kept karoro (black-backed gulls) as pets which they trained to eat caterpillars that infested kumara crops. Post-contact, introduced animals became prominent in the everyday biosecurity of kāinga (homes and settlements). For example, when Māori began to keep cats their effectiveness in controlling mice and rats was well-known and appreciated by their owners. Similarly, in rural environments, dogs are used to hunt other pests such as mustelids, rabbits and possums. Dogs and cats help to suppress rodents and lower risk to poultry and eggs – valuable home-sourced food for rural whānau. Biological controls are also employed in contemporary gardens where companion planting is used to attract beneficial insects and repel pests.

Eadya wasp, ETB and their New Zealand relatives

The Eadya wasp does not appear to share close whakapapa (genealogy/taxonomy) with any other pepeke in New Zealand suggesting that there is no risk of interbreeding with native pepeke.
The applicant does, however, note the potential for adverse effects on non-target host beetles, for example if the Eadya wasp is blown on wind to sub-alpine habitats that lack eucalypts and ETB. This suggests a potential impact on New Zealand's native leaf beetles. In addition, there could be indirect effects including potential impacts on other organisms via displacement of native species, competition, or other flow-on impacts within food webs.

Issues and concerns for Māori

It appears that eradicating ETB by conventional means alone (i.e. spraying insecticides) would likely be impractical, uneconomic and ultimately unsuccessful. Furthermore, any insecticide that posed risk to native or beneficial species would be regarded as undesirable from a Māori point of view.

In general, Māori favour natural methods for solving environmental issues. Releasing Eadya wasp provides a natural alternative to possibly more harmful interventions. Firstly, not using insecticides to eradicate ETB would avoid potential adverse impacts on culturally significant species from spays. Secondly, use of insecticides would increase chemical loading on the environment.

The proposal to release the Eadya wasp may be reassuring to Māori involved in primary sector industries. Māori economic assets are currently valued at around 50 billion dollars, with a significant portion of this being in plant and biomass production. Agriculture and horticulture are keystones of Māori development with Māori accounting for 36% of New Zealand's forestry.

Many Māori families and households also depend on the forestry industry for their livelihoods and well-being. Into the future, as the Māori economy continues to grow, Māori are likely to be increasingly represented in this sector. The ETB could potentially put these activities at risk and have a substantial adverse economic and social impact on Māori.

Māori will be concerned about the potential for the Eadya wasp to interbreed with native species, resulting in hybridisation and/or decimation of the native species. However, as noted in the application, New Zealand has no native parasitoids in the genus *Eadya*.

Māori need to have confidence that releasing the Eadya wasp would be highly efficacious and not adversely affect Māori interests and the ecological, economic, social and cultural well-being of New Zealand. Potential unintended outcomes and a lack of certainty around various issues in this application raise concern for Māori, particularly in relation to effects on culturally significant and non-target species. Some of the key concerns are:

- Uncertainty about whether the Eadya wasp would die out if the ETB was eradicated.
- It would be practically impossible to eradicate the Eadya wasp once it has been released.
- The possibility that the Eadya wasp could develop self-sustaining populations on other host species.
- The possibility of indirect impacts on birds and other species, and the subsequent impacts of this on the wider ecosystem.

Taha hauora (human health)

No adverse impacts on taha hauora (human health) are anticipated as a result of releasing the Eadya wasp. The application notes that it is not able to sting humans, so will not affect taha tinana (physical health). Keeping the ETB in check could have a positive effect on the dimensions of taha wairua and taha hinengaro, particularly amongst those who have to deal with ETB infestation and its consequences such as horticulturalists, farmers and and home gardeners.

Taha wairua is spiritual health and well-being obtained through the maintenance of a balance with nature and the protection of mauri. Restoring ecological equilibrium by controlling an invasive and damaging insect pest will enhance taha wairua.

Taha hinengaro is mental health and well-being and the capacity to communicate, think and feel. This is about how Māori see themselves in this universe, their interaction with that which is uniquely Māori and the perception that others have of them. Thus, doing what is right in terms of tikanga Māori by suppressing the ETB will engender a sense of validation and respectability.

Summary of commentary from Māori

The application provides detail about pre-application consultation with Māori, including several hui and mail/email correspondence. While no written comment was received, the applicant details the range of concerns expressed verbally during face-to-face meetings. In general, the concerns reflect a level of ambivalence on the part of Māori towards eucalypts as a non-native tree species despite the potential economic benefits. There is also a level of mistrust because of the detrimental impact on New Zealand of past introductions of new species. The feedback suggests a need for on-going engagement between the applicant and Māori beyond the application process.

Dr Toni Withers also presented and discussed the proposal at a Te Herenga (a national Māori network of environmental practitioners) regional hui in Whakatane on 23 May 2018. Information was also circulated by the EPA to the wider Te Herenga network prior to lodgement.

Two submissions were received from Māori; both opposed the application.

Kaitiakitanga (guardianship & stewardship)

Kaitiakitanga seeks to maintain balance and harmony within the environment from a perspective of intergenerational sustainability.

As a general principle, introducing exotic species into the New Zealand environment is culturally undesirable. Approval of the Eadya wasp would address a potentially devastating economic and environmental problem as well as contribute to the social and cultural well-being of people and communities (e.g. those working with, or benefitting from, plants) into the future. However, further information and evidence is needed to definitively determine whether the premise of kaitiakitanga is met.

Conclusion

Based on the information provided, the potential risks to Māori interests appears to be acceptable. However, further work may be needed to better understand the potential indirect impacts of the application and to support on-going engagement between the applicant and Māori.

The HSNO Act

Section 5(b) – recognise and provide for cultural well-being

Further information and evidence is required to determine whether this application is likely to put cultural well-being of Māori at risk or infringe on Māori cultural beliefs and environmental frameworks.

Section 6(d) – take into account Māori relationship to the environment

The EPA's cultural risk assessment considers potential risks and impacts on Māori interests including the relationship of Māori to the environment, culturally significant species and resources, and tikanga (customary values and practices) associated with these taonga. It has identified concerns in relation to uncertainties around potential impacts on culturally significant species and wider ecosystem effects. Concerns around these issues can be addressed by obtaining with further information and evidence. These matters aside, the application is not inconsistent with Māori cultural beliefs and environmental frameworks.

Section 8 – take into account Treaty of Waitangi principles

The active protection principle i.e. the Crown has a duty to actively protect Māori interests.

The EPA has undertaken a cultural risk assessment to consider potential risks and impacts on Māori interests. As noted above, the concerns in relation to culturally significant species and wider ecosystem effects can be addressed by obtaining further information and evidence.

The informed decision making principle i.e. the Crown has a duty to make informed decisions.

The EPA has undertaken a cultural risk assessment to ensure decision making on this application is informed by a Māori perspective. This assessment includes feedback from Māori groups regarding the Eadya wasp proposal.

The taonga principle i.e. 'taonga' include all valued resources and intangible cultural assets.

The scope of the EPA's cultural risk assessment includes tangible and intangible taonga, such as culturally significant species and resources, and the tikanga (customary values and practices) associated with these taonga.

Appendix Three: Decision APP203631 25 February 2019

Environmental Protection Authority
Te Mana Rauhī Taiao

Decision

February 2019

Date	25 February 2019
Application code	APP203631
Application type	To import for release and/or release from containment any new organism under section 34 of the Hazardous Substances and New Organisms Act 1996
Applicant	Scion
Date application received	18 September 2018
Date of Hearing	22 January 2019
Date of Consideration	22 January 2019
Considered by	A decision-making committee of the Environmental Protection Authority (the Committee)[1]: • Dr Louise Malone (Chair) • Dr Kerry Laing • Dr Ngaire Phillips
Purpose of the application	To release a parasitoid wasp, *Eadya daenerys*, as a biological control agent for the Eucalyptus tortoise beetle (*Paropsis charybdis*)
The new organisms approved	*Eadya daenerys* (Ridenbaugh, 2018)

[1] The Committee referred to in this decision is the subcommittee that has made the decision on the application under delegated authority in accordance with section 18A of the Act.

Summary of decision

1. Application APP203631 to import for release the parasitoid wasp, *Eadya daenerys*, was lodged under section 34 of the Hazardous Substances and New Organisms (HSNO) Act 1996 (the Act). The aim of the application is to enable the release of the wasp as a biocontrol agent for the Eucalyptus tortoise beetle, *Paropsis charybdis*.
2. The application was considered in accordance with the relevant provisions of the Act and of the HSNO (Methodology) Order 1998 (the Methodology).
3. The Committee has **approved** the application in accordance with section 38 of the Act.

Application process

Application receipt

4. The application was formally received for processing on 18 September 2018.

Purpose of the application

5. The applicant, Scion, applied to the Environmental Protection Authority to import for release the parasitoid wasp, *Eadya daenerys*, as a biological control agent for the Eucalyptus tortoise beetle (*Paropsis charybdis*).

Public notification

6. Section 53(1)(ab) of the Act requires that an application under section 38 of the Act must be publicly notified by the Environmental Protection Authority (EPA) if the application has not been approved under section 35.
7. The application was publicly notified by placing a notice on the EPA website on 2 October 2018.
8. In accordance with section 53(4) of the Act, letters or emails were sent notifying the Minister for the Environment, the Ministry for Primary Industries (MPI), the Department of Conservation (DOC), and other government departments, crown entities, and local authorities who have expressed an interest in being notified about applications for non-genetically modified new organisms. Māori organisations, non-government organisations and stakeholders who have expressed an interest in being notified about applications for non-genetically modified new organisms were also directly notified. All these parties had an opportunity to comment on the application in accordance with section 58(1)(c) of the Act and clause 5 of the Methodology.
9. Section 59(1)(c) of the Act requires an application to be open for the receipt of submissions for 30 working days from the date of public notification. The submission period closed on 14 November 2018.

Submissions from members of the public

10. The EPA received 27 submissions during the public notification period.
11. Twenty-one submitters supported the application. Five submitters opposed the application and one submitter was neither for nor against the application.

Comments from MPI and DOC

12. In accordance with section 58(1)(c) of the Act, the Ministry for Primary Industries (MPI) and the Department of Conservation (DOC) were advised of, and provided with the opportunity to comment on, the application.

13. MPI did not make any comment or submission on the application.

14. DOC had no objections to the release of *E. daenerys* and noted that host testing showed that adverse impacts on native beetles would be limited.

15. The Committee is satisfied that the submission from DOC has been considered in making this decision.

Reports providing advice to the Committee

16. The EPA Staff Assessment Report was provided under section 58(1)(a) of the Act. It was published on the EPA website and the applicant and submitters were informed of its availability on 2 October 2018.

17. Ngā Kaihautū Tikanga Taiao (NKTT) elected not to prepare a report on the application.

Hearing

18. Section 60(c) of the Act requires that a hearing be held if a person who has made a submission stated in that submission that he or she wishes to be heard. Eight submitters indicated they wished to be heard.

19. Section 59(1)(d) of the Act requires that the hearing commence not more than 30 working days after the closing date for submissions. The hearing was held on 22 January 2019 at the Terrace Conference Centre, 114 The Terrace, Wellington.

20. Mr Gerry Te Kapa Coates (Te Runanga o Ngāi Tahu), Ms Margaret Hicks and Mr Graeme Manley (Southwood Export Limited) appeared at the hearing to speak to their individual submissions. Mr Graeme Manley also represented Southland Plantation Forest Company of New Zealand Limited and Kodansha Treefarm New Zealand Limited.

21. The applicant was represented by Dr Toni Withers, Dr Robert Radics and Dr. Carl Wardhaugh from Scion. Mr Grant Wilcock from Oji Fibre Solutions New Zealand Limited also presented to provide background information on the paper and pulp industry to support the applicant's presentation.

Information available for the consideration

22. The information available for the consideration comprised:

- the application
- the EPA Staff Assessment Report
- submissions
- comments received from DOC
- information obtained during the hearing.

23. The Committee considered that it had sufficient information to assess the application, and waived any further legislative information requirements.

Matters for consideration

24. The Committee considered the application in accordance with section 38 of the Act, taking into account the matters specified in sections 36 and 37, relevant matters in Part 2 of the Act, and the Methodology.

25. Each point is addressed in the following sections of this decision.

26. Specific points raised by submitters (either in their submission or during the hearing) are addressed where appropriate throughout this decision.

Summary of appearances and information discussed at the hearing

Presentations from the applicant party at the hearing

Dr Toni Withers, Scion

27. Dr. Withers expressed that biocontrol is an environmentally sustainable method of pest control with previous biocontrol agents being effective at controlling the second (summertime) generation of *P. charybdis*. She emphasised that one of the key benefits of releasing *E. daenerys* will be that it can have greater impact on *P. charybdis* populations in the first (springtime) generation than existing biocontrol agents. Dr Withers noted that *E. daenerys* appears to be host specific to *Paropsis* and *Paropsisterna* and could prevent $7.2m in losses per annum of damage to New Zealand's eucalypt industry while reducing the reliance on pesticides.

Mr Grant Wilcock, Oji Fibre Solutions NZ Limited

28. Mr Wilcock indicated that Oji Fibre Solutions New Zealand Ltd has been in existence for four and a half years (after buying the previous Carter Holt Harvey operations) and has a number of sites in Australia and New Zealand. The company has three pulp and paper mills located in New Zealand that collect all types of fibre.

29. Mr Wilcock noted that eucalyptus is chipped on site at Kinleith Mill and has a high yield of 70-75% pulp. Eucalyptus pulp complements *Pinus radiata* and recycled pulp when manufacturing high performance papers and is the hardwood species of choice for commercial, technical and operational reasons. In addition, eucalyptus pulp improves compressive strength properties of Kinleith paper which complements the containability achieved with softwood fibre. High yield eucalyptus pulp also contains residual lignin which "sets" during the corrugating process resulting in high strength corrugated board.

30. Mr Wilcock stated that New Zealand is an exporter of a wide range of primary produce from fruit and vegetables to meat and dairy. The supply chains are often long and include significant periods (up to six months) in cool storage with variable humidity. Mr Wilcock emphasised that high performance packaging is critical to the safe and efficient transportation of each product. He noted that virgin pulp-based packaging products are a durable, cost effective and environmentally friendly solution.

31. Mr Wilcock concluded that by using eucalypt-based paper and pulp, New Zealand has a cost effective and durable method of packaging for exporting economically significant primary products. He referred to the apple and kiwifruit industries which rely on eucalypt-based packaging and their current and projected economic values:
    a. Apple: Export revenue of NZ $780m (December 2018) with 21 million cartons that is forecasted to increase in 2019. Planting of apples continues to increase.
    b. Kiwifruit: Export revenue of NZ $2.2bn (March 2019) with $150m worth of single layer eucalypt-based trays. Japan, Europe and China have a 72% share and are primary markets for New Zealand.

Dr Toni Withers, Scion

Benefits of growing Eucalyptus

32. Dr Withers presented on the benefits of eucalypt forestry to New Zealand. She noted that eucalypt trees (of which there are many species) have numerous benefits. Apart from superior quality pulp compared to other trees, eucalypts also produce one of the hardest and most durable woods in the world, and eucalypt poles do not require chemical treatment. Dr Withers mentioned that eucalypts have been imported since the arrival of the first European settlers in New Zealand and are currently used in power poles, cross arms, bridges, wharfs and vineyard posts. She noted other significant environmental benefits such as uses in laminated veneer lumber (LVL) production, firewood, providing a winter flowering food source for bees, and shade and shelter for organisms such as birds. Furthermore, even though the New Zealand eucalypt industry is small compared to pine forestry, it is good to have a diversified plantation forest estate for greater resilience to climatic and environmental challenges. She also noted that nutrient recycling by eucalypt species is superior to that achieved by other plantation tree species, eucalypts can complement native trees in replanting projects, and that eucalypts could play a useful role in plans to plant large numbers of trees throughout New Zealand (such as the New Zealand Government's Billion Trees project).

33. Dr Withers stated that the *Symphomyrtus* sub-genus, which includes most of the fibre and wood producing species and is cool-tolerant, is attacked by the Eucalyptus tortoise beetle. An estimated 15,300 hectares are planted using symphomyrtus species in New Zealand. Species in the *Monocalyptus* sub-genus are slower growing. Both types are being developed by the New Zealand Dryland Forests Initiative which aims to plant 100,000 hectares by 2030.

Risks to industry and environment from insect attack

34. Dr Withers highlighted that aerial applications of insecticide cost between $160-340 per hectare, per spray, have adverse effects on the environment through increasing the overall chemical burden. She noted that the whole industry currently spends $1-2 million per annum for chemical sprays to reduce *P. charybdis* populations. The industry experiences yield losses between $4,800 and $9,700 per hectare per year if chemical spray is not used. Trees that have been repeatedly defoliated by Eucalyptus tortoise beetle attack can stop growing completely. The Net Present Value (NPV) of susceptible eucalyptus plantations in New Zealand is $402-503 m.

35. Dr Withers also noted that Scion estimates eucalyptus species provide additional ecosystem services to New Zealand conservatively estimated at $11m per year.

Dr Robert Radics, Scion

How did we value New Zealand eucalypts?

36. Dr Radics expanded on the methodology used to provide a valuation of New Zealand eucalyptus forests. He noted that Scion used a four-step process:
    a. Ascertaining the size and value of eucalypt plantations.
    b. Completing a cost-benefit risk assessment of chemical treatment.
    c. Completing a cost-benefit risk assessment of existing biocontrol agents.
    d. Comparing the efficacy of chemical treatment and existing biocontrol agents in different hypothetical scenarios.

37. Dr Radics described the use of forest inventory plantation data for eucalypts in 2016, which showed that 23,182 hectares were planted with these species throughout New Zealand. This

data does not include woodlots of less than 40 hectares, so an additional 16% (4,416 ha) was included in Scion's calculations to account for these, giving a total figure of 27,598 ha planted in eucalyptus throughout New Zealand.

38. Dr Radics explained that Scion had used Berill et al (2006)'s yield model to estimate trunk volume. Net Present Value (NPV) was obtained by applying age class data (young plantations currently dominate) with weighted stumpage value applied differentially for solid and pulp wood ($\$101/m^3$ and $\$50/m^3$, respectively). *Symphomyrtus* species (which are susceptible to beetle damage) accounted for 60 to 75% of all eucalyptus plantations, giving a final estimate of NPV of $402-503 million for eucalypts susceptible to *Paropsis charybdis* in New Zealand.

39. Dr Radics showed how estimates of the benefit:cost ratios for using beetle control chemicals varied with increasing application costs for different levels of beetle infestation and for short rotation (15 year) and long rotation (40 year) plantings. These graphs indicated where the economic benefits of chemical application would exceed break even point.

40. Dr Radics concluded that it is estimated that 12,300 hectares of eucalyptus plantations are planted in species resistant to *P. charybdis* but 15,300 ha are susceptible (*Symphomyrtus* species). He noted that economic modelling showed that the cost of spraying chemical pesticides to control *P. charybdis* in small wood lots or when damage is only low can not be justified economically.

Dr Toni Withers, Scion

Economic benefits of Paropsis charybdis control by Eadya daenerys

41. Dr Withers stated that effective biocontrol of *P. charybdis* will reduce damage from heavy to light and reduce the need for pesticide spraying applications. The result would mean a reduction in yield from 20% volume loss to less than 10% (Elek & Baker, 2017). This improvement provides an average NPV of $1,245 per hectare over a long rotation. She stated that for the 15,300 hectares of susceptible eucalypt species in New Zealand, the NPV of using this biocontrol agent instead of chemical control equates to $17.4m to $26.8m saved.

42. Dr Withers highlighted that reduced populations of *P. charybdis* would lead to an improvement in tree health, increased cost savings through reductions in pesticide usage, improvements in acceptability and 'social licence to operate' for those renewable plantations that produce fibre.

43. She concluded that there would be reduced damage to susceptible eucalypt species from the use of *E. daenerys*. This may result in improved growth rates, shorter rotation time, increased wood volumes and yield and, subsequently, increased profitability and increased confidence for small growers to invest in diversified plantings.

P. charybdis biology and biocontrol

44. Dr Withers described the biology of *P. charybdis* and its effects on eucalypt species. She stated that both adult and larval stages of *P. charybdis* damage plants by inhibiting all flush (new growth) from expanding and through the consumption of young leaves. Each adult female lays up to 2,000 eggs. Each year, at least two generations of *P. charybdis* occur with the first generation laying eggs in spring and the next generation in summer. Nearly all eggs that are laid are viable, with first generation eggs having a 95% hatch rate. This results in rapid population expansion and Dr Withers concluded that for any method to be effective in controlling *P. charybdis* and reducing damage to eucalyptus tree growth, the first generation of the beetle needs to be controlled.

45. In relation to existing biocontrol agents, Dr Withers stated that the cooler spring temperatures restrict the ability of current biocontrol agents to reduce first generation populations of *P. charybdis*. She noted that current biocontrol agents (two species of egg parasitoids) are effective in reducing second generation populations of *P. charybdis* with as few as 4% of eggs surviving in this generation. She concluded that the first generation is responsible for all current damage and *E. daenerys* would be the optimal biocontrol agent to target this generation.

46. Furthermore, Dr Withers noted that *P. charybdis* is one of many eucalyptus beetles native to Australia. She stated that Scion had completed field work with Dr Geoff Allen of University of Tasmania to search for parasitoid species which may be suitable for controlling *P. charybdis* in New Zealand. Dr Withers highlighted that Scion's earlier research evaluated all of the parasitoids of *P. charybdis* and concluded that, after five years of field research, *E. daenerys* was the most promising in terms of host specificity. Molecular research confirmed host range and number of species (Sharanowski et al. 2018).

47. Dr Withers stated that in order to be confident that *E. daenerys* has a restricted host range, Scion collaborated with Dr Allen over many years to survey field-collected insects from the parasitoid's home range for parasitism by *E. daenerys*. Thousands of leaf-feeding caterpillars were collected and reared in Australia by Dr Allan and he also hosted international scientists who had reared 2,700 Gonipteran (weevils) larvae for this purpose; there were no observations of parasitism by *E. daenerys* in any of these insects. Dr Withers emphasised that the importance of this observation is that larvae of these weevils are present on the same plantations at exactly the same time as *E. daenerys*. She concluded that Scion is confident that, in conjunction with host testing, these observations consolidate the notion that *E. daenerys* are parasitic specifically to leaf beetles and primarily *P. charybdis*.

The risk of E. daenerys causing direct adverse environmental effects

48. Dr Withers stated that *E. daenerys*, which has a single generation per year (univoltine) in Tasmania, would attack the first generation of *P. charybdis* larvae from November to December. She noted that observations showed female *E. daenerys* lay one egg directly into host larvae of any size, with the juvenile parasitoid larva emerging from (and killing) its host after three weeks. The parasitoid then spins a cocoon in the soil, and overwinters until it emerges as an adult the following November to December.

49. Dr Withers noted that *E. daenerys* has been reared only from four *Paropsis* and *Paropsisterna* beetles in Australia. She emphasised that New Zealand has no native paropsini beetles - only invaded pests. She added that other New Zealand beetle species belonging to the Chrysomelinae subfamily might be at risk if their larvae are medium sized (>5mm), leaf-feeders and active during early summer.

Host testing experiments

50. Dr Withers highlighted that *P. charybdis* is the largest of the invasive paropsine genus in New Zealand. Dr Withers discussed Scion's host testing regime, which featured both choice and no-choice tests. Scion tested the two largest species out of the phylogenetically closest relatives in New Zealand in the subfamily Chrysomelinae. In terms of endemic species in the subfamily Chrysomelinae, Dr Withers identified three potential test genera: *Allocharis*, *Chalcolampra* and *Caccomolpus*. She noted that Scion undertook field surveys to obtain specimens of each of these genera but were successful only in locating one species from the genus *Allocharis*.

51. Dr Withers noted that host testing also included two beneficial weed biocontrol agents in the Chrysomelinae*: Gonioctena olivaceae,* which has been introduced for control of scotch broom

and *Chrysolina abchasica* for the control of tutsan. In addition, Scion also completed host testing on other beneficial weed biocontrol agents in a sister subfamily (Galerucinae)*:* *Agasicles hygrophila* (introduced for alligator weed control) and *Lochmaea suturalis* (heather control). Furthermore, Scion also completed host testing on two other beneficial weed biocontrol agents in unrelated subfamilies: *Neolema oglobini* (Criocerinae) (for tradescantia control) and *Cassida rubiginosa* (Cassidinae) (for Californian thistle control).

52. Dr Withers described a no-choice physiological assay, designed to present the parasitoid with maximum opportunity to attack and parasitise a potential host. In these tests, one female *E. daenerys* wasp was confined with eight beetle larvae on foliage in Petri dishes and observed over 24 hours. During the testing, behavioural observations (number of stings made by the wasps and time spent on the plants) were made. After 24 hours, the beetle larvae were removed and reared on foliage until pupation or death. Numbers of larvae from which parasitoids emerged were counted and dead larvae from which no parasitoid had emerged were dissected to look for evidence of incomplete parasitism (i.e. the parasitoid had attacked the host successfully but failed to develop fully and emerge).

53. Dr Withers discussed the results obtained by Scion which showed viable (complete) parasitism only in the two paropsine beetles tested. *Paropsis charybdis* had a 30 to 34% parasitism rate (n = 240) and the Australian native Chrysomelinae*, Trachymela sloanei*, had a parasitism rate of 12.5% (n = 40). *Eadya daenerys* larvae emerged from each these five parasitized *T. sloanei* beetles, but only three of these larvae went on to spin cocoons and, of these, only one developed successfully to adulthood, producing a viable, but minute, adult. This suggests that *T. sloanei* would not be an optimal host for *E. daenerys*.

54. Compared to other beetles, unsuccessful internal (incomplete) parasitism by *E. daenerys* was discovered upon dissection of four other non-target Chrysomelinae: *Dicranosterna semipunctata* 1.6% (n = 16), *Allocharis nr tarsalis* 7.5% (n = 10), *Chrysolina abchasica* 1.8% (n = 14) and *Gonioctina olivaceae* 5.2% (n = 12). All other species in Galerucinae*,* Cassidinae and Criocerinae had 0% parasitism (n = 11-16).

55. Dr Withers noted that survival of the beetle test species reared in containment ranged from 40% (*Chrysolina*) to 90% (*Allocharis*). Target pest rearing survival dropped from 95% in the absence of parasitism, to 9% after stinging by *E. daenerys*. She noted that physiological host testing is considered the worst case scenario and over-estimates the likely field host range. Dr Withers made reference to Scion's 24 hour testing which allowed for nocturnal and diurnal activity by *E. daenerys* and was long enough for deprivation effects to become extreme.

56. The physiological host testing confirmed the minimum host size of about 35 mg. Of the beetle species tested, only the three exotic pest species were larger than this. The other test species, which could not support complete parasitism, were all smaller than this, suggesting that any non-target beetles that mature to less than 35 mg pupal weight will be unable to support complete development of *E. daenerys* and therefore, that *E. daenerys* would be unable to form populations in habitats occupied by such beetles.

57. Dr Withers stated that the *E. daenerys* attack rate when given a choice was significantly less than against *P. charybdis* (number of stings per minute). She noted that Scion observed an overlap in the attack rate by *E. daenerys* on *T. sloanei* with *P. charybdis* when given no choice.

58. Dr Withers concluded that no non-target beetle feeds on Myrtaceae and that *E. daenerys* shows little interest in non-target beetles except *T. sloanei* and *P. charybdis*, both of which feed on eucalyptus leaves. All beetles that consume eucalyptus leaves in New Zealand are considered pests. The sub-alpine native beetle, *Allocharis nr tarsalis,* was attacked in no-choice 24 hour physiological assay testing but ignored in two-choice Petri dish tests. Dr

Withers concluded that, while Scion cannot rule out that *E. daenerys* will reach sub-alpine areas, without the presence of eucalyptus species or paropsine hosts, there is minimal risk to non-targets. In addition, there is minimal overlap in the potential occurrence of *A. nr tarsalis* and *E. daenerys*, as CLIMEX composite match index modelling showed.

59. When questioned about the CLIMEX modelling results, which showed that *E. daenerys* might be able to survive in some areas where larger native Chrysomelinae beetles are located, Dr Withers explained that the model used Tasmanian data on *E. daenerys*'s distribution based on a 40 x 40 km grid, so the resultant map's granularity was coarse. Dr Withers had recently received new data based on a 5 x 5 km grid and she suggested that this might show less overlap with the sub-alpine native beetles' locations.

60. When questioned about the possibility of eucalyptus being grown in sub-alpine regions, Dr Withers explained that *Eucalyptus nitens* and *Eucalyptus globulans,* which are grown in the South Island, are cold-tolerant but not snow-tolerant. There are no alpine eucalyptus species in New Zealand.

Dr Carl Wardhaugh, Scion

61. Dr Wardhaugh presented on the relatedness between native Chrysomelinae beetles and *P. charybdis*. Scion has co-authored a publication with two beetle experts – Dr Chris Reid from the Australian Museum and Dr Rich Leschen, Landcare Research.

62. Dr Wardhaugh noted that according to DOC's website, native Chrysomelines are all "naturally uncommon" but a more accurate assessment would refer to these native beetles as poorly sampled in their natural habitat, e.g. alpine areas. He noted that all but one species are flightless, very few host plants have been reported and Chrysomelinae beetles can be found in mosses, ferns, leaf litter and tussocks with larvae mainly feeding well hidden on the plant.

63. Dr Wardhaugh noted that a recent study of molecular phylogeny of the subfamily Chrysomelinae has shown that the New Zealand native species are very dissimilar to the Australian paropsines and the species are likely to have diverged from each other 40 million years ago. He also noted that three genera, *Allocharis*, *Cyrtonogetus* and *Chalcolampra* have now been combined into a single genus, *Chalcolampra*.

64. He stated that Scion found and tested one native Chrysomelinae species: *Allocharis nr tarsalis*. Scion searched sub-alpine habitats of the Kahurangi National Park with the blessing of local iwi, Manawhenua Ki Mohua (umbrella entity for three iwi of Golden Bay), and acquired a DOC permit. Dr Wardhaugh noted that the larvae of *A. nr tarsalis* are external leaf feeding and that observations in containment showed the larvae were poor physiological hosts as *E. daenerys* was not attracted to those larvae.

65. Dr Wardhaugh expressed his personal viewpoint that it was highly unlikely that *E. daenerys* would establish in sub-alpine zones. He noted that natural widespread dispersal is unlikely as *E. daenerys* are not strong fliers and instead one or a few *E. daenerys* individuals may be carried by wind to the sub-alpine zone. He stated that in the sub-alpine zone, there are no eucalyptus species or *P. charybdis* larvae to parasitise, therefore, any potential encounter with non-target larvae would be very rare. Even if *E. daenerys* were to encounter non-target larvae, an attack would be unlikely as there are no Paropsine larvae in close proximity to elicit an oviposition response as shown in containment. Dr Wardhaugh concluded that *E. daenerys* would be unable to develop and sustain a population in such an environment.

Presentation by EPA Staff

66. Aubanie Raynal (Advisor, New Organisms) presented a summary of the EPA Staff Assessment Report focussing on the benefits, risks and costs of *E. daenerys* and assessing the parasitoid wasp against the minimum standards in the HSNO Act. The staff assessment discussed the information provided in the application, information readily available in scientific literature, and information submitted to the EPA via public submissions. The EPA staff assessed the potential benefits and positive effects of introducing the wasp, in particular the benefits to the environment and to the market economy. The report also considered potential risks and costs (adverse effects) associated with its introduction. The potential adverse effects assessed included the risk of the wasp attacking non-target insects and adversely affecting food webs. The EPA also assessed the effects of the wasp on the relationship Māori have with their environment. The staff assessment concluded that the benefits of releasing the wasp to control the Eucalyptus tortoise beetle are likely to outweigh any identified risks and costs. The staff assessment also concluded that *E. daenerys* meets the minimum standards for introduction and release as stated in the Act.

Record and summary of presentations from submitters at the hearing

Gerry Te Kapa Coates, Te Runanga O Ngāi Tahu

67. Gerry Te Kapa Coates presented Ngāi Tahu's submission. Mr Coates outlined the Ngāi Tahu value system, which includes whanaungatanga (family), manaakitanga (looking after their people), kaitiakitanga (stewardship), tikanga (appropriate action), tohungatanga (expertise) and rangatiratanga (leadership). Mr Coates discussed the role the Ngāi Tahu HSNO Komiti plays in monitoring EPA applications and expressed that the EPA and MPI must be ever mindful of its task of 'active protection' under the Treaty of Waitangi.

68. Mr Coates stated that Ngāi Tahu were in opposition to the release of *E. daenerys* on the basis that neither the economic or environmental case had been made for the introduction of such a new exotic biocontrol agent to control an introduced pest that may or may not affect an exotic forestry industry with relatively small economic value. Mr Coates noted that Scion estimates *E. daenerys* could prevent approximately $7.2 million in losses per year from eucalypt forests and the total value of such eucalyptus forests is $402 to 503 million. Mr Coates concluded that this was a relatively small benefit when compared with the total value of exotic standing timber of $14 billion.

69. Mr Coates stated that the only perceived benefit from the release of *E. daenerys* would be a reduction in the use of broad spectrum chemical pesticides on the environment.

70. Mr Coates highlighted that consultation with Māori raised questions about the application to which he considered the applicant gave seemingly inadequate responses.

71. Mr Coates concluded that if *E. daenerys* is to be released, monitoring the establishment and the efficacy of the biocontrol agent should be a condition.

Ms Margaret Hicks (by telephone)

72. Ms Hicks expressed concerns with the application relating to the element of risk that she believed should not be ignored and that the disadvantages of eucalyptus forests should be considered too.

73. Ms Hicks stated that the whole point of the application to release *E. daenerys* is not to control the Eucalyptus tortoise beetle, but, is instead a method for the eucalypt industry to expand the

distribution of their plantations. She highlighted that eucalypt plantations are not a suitable and sustainable species of tree for New Zealand for numerous reasons.

74. Firstly, Ms Hicks emphasised the apparent focus on monoculture which won't save nature. She noted that identical species grown closely together facilitates the spread of pests and diseases which, in this example, could result in the proliferation of pathogenic organisms such as myrtle rust through eucalypt plantations. The establishment and spread of self-sustaining populations of myrtle rust via eucalypt plantations could in turn pose an increased risk to native Myrtaceae species such as manuka and pohutukawa. In the case of manuka, Ms Hicks noted that this would have economic ramifications for New Zealand manuka and honey industry.

75. Secondly, Ms Hicks highlighted the potential risk of expanding eucalypt plantations in New Zealand to a potentially greater incidence of forest fires. She noted that eucalyptus species are some of the most flammable trees and that each tree emits quantities of volatile organic compounds that are the equivalent of a can of petrol. She stated that it is therefore unsurprising that as eucalypts are native to Australia, we often hear of forest and bushfires there.

76. Ms Hicks noted that many European countries have cleared native trees and replanted using eucalypt species and New Zealand seems to be following this trend.

77. She noted that the large expansion of eucalyptus forests in Spain and Portugal which have recently had outbreaks of fire due to the high flammability of exotic eucalypt and pine species.

78. Ms Hicks emphasised the importance of learning from international examples as it would appear countries that have planted eucalyptus have had a greater incidence of forest fires. Ms Hicks alluded to research into the 2018 Californian wildfires which concluded that eucalyptus species were among the species involved. She stated that New Zealand needs to learn from international examples where fires had occurred to better understand the risks involved with expanding New Zealand's eucalypt industry and the rising temperatures attributed to climate change.

79. Ms Hicks highlighted that eucalyptus species are part of the myrtle family of plants (*Myrtaceae*) and with the increase in land being converted to eucalypt forests, these trees may act as a biological vector for myrtle rust (*Austropuccinia psidii*). This may have impacts on the many New Zealand myrtle species such as rata, manuka and pohutukawa which are vulnerable to myrtle rust. Ms Hicks noted that any adverse environmental impacts on manuka would cascade and have serious ramifications for New Zealand's apiculture industry.

80. Ms Hicks concluded that *E. daenerys* has not proven to be species specific and she believed that the testing programme conducted by the applicant was inadequate. Ms Hicks strongly believed that the primary purpose of the application was monetary benefit and the potential risks had not been adequately addressed to warrant any release.

Mr Graeme Manley, Southwood Export Limited

81. Mr Manley stated that Southwood Export Limited (SWEL) manages two client companies – Southland Plantation Forest New Zealand Limited and Kodansha Treefarm New Zealand Limited with a combined forest resource of 12,600 hectares over 42 forests that are predominantly *Eucalyptus nitens*. He stated that *E. nitens* became the optimal species for hardwood chip exports in 1987 with over 860 hectares of *E. nitens* established by 1993. Annual production is 340,000 tonnes of export chip with 28,000 to 30,000 tonnes being shipped out of Bluff port each month. He noted that annual sales value was in excess of $36 million and this subsequently injects significant capital into the South Island regions.

82. Mr Manley remarked that the New Zealand eucalypt industry had encountered pests before in the scale insect, *Erioccocus coriaceus*, which had been somewhat controlled by *Rhyzobius ventralis*, a species of ladybird. Broad spectrum insecticides in the form of alpha-cypermethrin had been previously used to control outbreaks of the *P. charybdis* which had become the primary threat to maintaining healthy forest growth. Mr Manley noted that while alpha-cypermethrin has positive outcomes in reducing Eucalyptus tortoise beetle populations in the short term, after three years, significant re-population occurs.

83. Mr Manley advised that the eucalypt industry faces emerging problems with maintaining Forest Stewardship Council (FSC) certification which is essential for exporting to international markets as the continued use of chemical pesticides reduces the ability to maintain certification and therefore, a loss of market access. Mr Manley stated that new methods are required to control the Eucalyptus tortoise beetle and alternative chemical products have yielded inconclusive results and are more expensive. He noted that spraying is not a long-term solution and may affect commercial apiarists.

84. Mr Manley noted that the real benefit from any introduced biocontrol agent will come from any reduction in populations of early larvae before it does significant damage and growth loss and before the adult has an opportunity to reproduce.

85. SWEL is a member of the Government & Industry funded Specialty Wood Products research group concentrating on both non-durable and durable eucalypt species. Mr Manley stated that there is a plethora of potential uses for eucalypt trees including solid timber, veneer, laminated veneer lumber (LVL) and reconstituted products. *E. nitens* in particular has specialty purpose potential and offers a real chance to add value in the South Island given its ability to grow better than other eucalypts in cooler climatic environments.

86. Mr Manley stated that eucalyptus planting may increase significantly in the future with the government's pledge to plant 1 billion trees by 2028. He believed that farmers may seek to plant more eucalypt species as they are more aesthetically pleasing than *Pinus radiata*.

87. Mr Manley concluded that SWEL and its client companies support this five year programme to introduce a new biological control agent to reduce populations of the Eucalyptus tortoise beetle.

Applicant's response to matters raised

88. Dr Withers responded on behalf of Scion and addressed the apparent inadequate consultation with Māori. Dr Withers stated that Scion did speak with the HSNO Komiti of Ngāi Tahu in person on 26 October 2017. She noted that consultation with local iwi began in 2014 and Scion were told that, "host testing would be considered inadequate if even one native species is not tested" because Māori consider all native species as taonga. Dr Withers noted that Scion perhaps did not address Māori questions in the application as well as they should have due to the similarity and repetition of questions and because they were considered to have been addressed in other ways before the application was lodged. To address concerns of Māori, Dr Withers stated that Scion had invited Māori to their containment facility to examine the environment where *Eadya daenerys* would be held. In addition, Scion created a website and a YouTube video with the primary aim of addressing many of the questions and concerns they had received. Scion also created a mailing list of Māori and iwi and contacted the individuals and parties on this list in 2017 and 2018.

89. In response to concerns about the value of introducing an exotic species to control an exotic pest that is consuming an exotic plant, Dr Withers noted that this is what biological control of

pests in New Zealand is always about and stated that much of what New Zealanders consume and grow, from apples to kiwifruit, are exotic.

End summary of hearing

90. The hearing was adjourned and closed on 22 January 2019.

91. The Committee would like to thank all people who submitted the information that was used in making this decision. Public submissions provide a focus for the Committee on points that need clarification, and the Committee found the submissions and the applicant's responses very helpful in its consideration of the application.

Organism description

92. The organism approved for release is:

Taxonomic Unit	Classification
Class	Insecta
Order	Hymenoptera
Family	Braconidae
Genus	*Euphorinae*
Species	*Eadya daenerys* (Ridenbaugh, 2018)
Common name	N/A

Inseparable organisms

93. No inseparable organisms associated with *E. daenerys* were identified.

Assumptions for risk assessment

94. The Committee noted that there is uncertainty about whether or not *E. daenerys* will successfully establish self-sustaining populations and have an impact on *P. charybdis* populations in the New Zealand environment. The Committee considered that if the wasp fails to establish, there will not be any significant effects from its release. Conversely, if *E. daenerys* successfully establishes, any effects would be at their greatest. Therefore, the Committee assessed the benefits and risks and the minimum standards associated with the release of the wasp based on the establishment of self-sustaining populations in the environment.

Identification and assessment of potentially significant adverse effects

95. The Committee considered the potential risks and costs of the release of *E. daenerys* including any potentially significant adverse effects on the environment, public health, people and communities, the market economy, and Māori culture, traditions, and the principles of the Treaty of Waitangi (Te Tiriti o Waitangi).

Potential adverse effects on the environment

96. The Committee considered the potential for *E. daenerys* to cause adverse effects if the actions by the wasp damage and reduce populations of native arthropods and interfere with trophic webs.

Risks to non-target native beetle species

97. The Committee considered the host range experiments that had been undertaken to examine if *E. daenerys* could attack and parasitise non-target native beetle species. The Committee also considered the biophysical characteristics of many of New Zealand's known native Chrysomelid beetles that may be at risk of attack. They are known to live in sub-alpine environments, associate with native plants or complete their vulnerable life stages inside plant hosts. In addition, *Allocharis nr tarsalis* is a diurnal leaf feeder. These factors protect native leaf beetles from potential exposure to and attack by *E. daenerys*. The Committee also noted that most known native members of the subfamily Chrysomelinae are smaller than the minimum size for hosts of *E. daenerys* and that no-choice testing of *Allocharis nr tarsalis* showed that this beetle could not support full development of the parasitoid. In choice tests, *E. daenerys* preferred the target host, *P. charybdis*, over *Allocharis nr tarsalis*.

98. The Committee concluded that native beetle species are not at risk of attack by *E. daenerys* due to poor overlapping of habitats and *E. daenerys* having a strong preference for *P. charybdis* in host testing.

Risks to weed biocontrol agents

99. The Committee considered the potential impact *E. daenerys* would have on existing beneficial weed biocontrol agents belonging to the family Chrysomelidae that have been released in New Zealand.

100. The Committee concluded that existing beneficial biocontrol agents would not be adversely impacted by the release of *E. daenerys* as testing in containment showed that these beetles are not attractive to the parasitoid or are unable to support full development of the paraistoid if attacked. They are not physiological hosts of the parasitoid.

Interference with ecosystem interactions and food webs

101. The Committee considered the potential of *E. daenerys* to elevate pressures on other biocontrol species through a reduction of common prey or hosts.

102. The Committee also considered the potential impact of *E. daenerys* to benefit other pest species, increase competition for nectar and the potential for hybridisation to occur.

103. The Committee noted that while *P. charybdis* has two native predators in the brown soldier bug (*Cermatulus nasalis*) and the predatory shield bug (*Oechalia schellenbergi*), the Eucalyptus tortoise beetle does not constitute sole prey for these two species. Therefore, the Committee concluded that these two species would be unaffected by the reduction in *P. charybdis* larvae.

104. The Committee considered if the reduction of *P. charybdis* populations could lead to an outbreak of sleeper pests on eucalypt trees that are present in New Zealand, such as the bronze bug (*Thaumastocoris peregrinus*).

105. The Committee noted that while potential reductions of *P. charybdis* populations may occur from the release of *E. daenerys*, the occupation of the niche by another eucalyptus pest remains hypothetical. The Committee concluded that if there were to be any occurrence of another eucalyptus pest occupying the niche of *P. charybdis*, proper control measures for the new pest could be investigated prior to the pest becoming significant to the eucalypt industry.

106. The Committee noted that while adult *E. daenerys* individuals feed on nectar, it is highly unlikely that *E. daenerys* would have adverse effects on the availability of nectar for other nectar-feeding species such as birds and other insects.

107. The Committee noted that there are no native or introduced species in the *Eadya* genus and while there are six genera (*Cryptoxilos, Dinocampus, Leiophron, Meteorus, Microctonus* and *Syntretus*) in the same subfamily as *E. daenerys* present in New Zealand, these parasitoid wasps are not considered closely related enough to be able to interbreed naturally with *E. daenerys*.

108. The Committee concluded that the potential for hybridisation to occur between *E. daenerys* and a parasitoid wasp from a related subfamily is unlikely.

109. The Committee concluded that the release of *E. daenerys* is unlikely to have adverse impacts on ecosystem interactions and food webs.

Potential adverse effects on the economy

110. The Committee considered the potential adverse impact on the market economy if *E. daenerys* attacks target larvae of beneficial biocontrol agents previously introduced in New Zealand.

111. The Committee noted that the applicant had nine species host-tested to ascertain the likelihood of *E. daenerys* attack on beneficial biocontrol agents. The Committee noted that host testing showed that it is highly improbable that *E. daenerys* would attack beneficial biocontrol agents and, if an attack were to occur, it would be an isolated case or spill-over effects where weed hosts and susceptible eucalyptus hosts grow in close proximity to each other.

112. The Committee considered that *E. daenerys* could potentially vector viruses that may damage other plants if approved for release. The Committee noted that any potential release of *E. daenerys* specimens in our environment would be dependent on the wasp meeting the strict biosecurity requirements of an import health standard.

113. The Committee concluded that the release of *E. daenerys* is highly improbable to have adverse effects on the New Zealand market economy.

Potential adverse effects on Māori culture, traditions, and Te Tiriti o Waitangi

114. The Committee took into account the possible effects on the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, valued flora and fauna, and other taonga, and the principles of the Treaty of Waitangi (Te Tiriti o Waitangi).

115. The Committee noted that the applicant engaged with Māori during the pre-application stage face-to-face at hui and also through email, post and videoconferencing with more than twenty Māori and iwi groups across New Zealand between 2013 and 2018.

116. The Committee noted Māori concerns about the potential release of another exotic organism and its potential to impact people and the environment. The Committee also noted Māori concerns in relation to the continued use of pesticides and the preference to have native tree plantations instead of eucalyptus.

117. The Committee considered the application to be broadly consistent with the principles of the Treaty of Waitangi (Te Tiriti o Waitangi) including the principle of active protection.

118. The Committee noted that no risks to native or taonga species, ecosystems and traditional Māori values, practices, health and well-being were identified in the application.

119. The Committee considered that it is unlikely that the parasitoid would have adverse effects on taonga species and concluded the risk to be negligible.

120. The Committee noted that any potential risks from the release of *E. daenerys* to Māori interests are likely to be acceptable.

121. The Committee made a recommendation that Māori should be included in the implementation and monitoring of biocontrol programmes, such as this programme, against the Eucalyptus tortoise beetle. The Committee encouraged biocontrol practitioners to engage with local iwi and hapū capability where possible so that they could take into consideration concerns relating to monitoring and efficacy of new biocontrol agents.

122. The Committee further noted that an ongoing relationship between the applicant and Māori should be sustained to ensure that Māori are adequately informed if and when *E. daenerys* is released and if any further work such as research and monitoring is conducted on this species and its potential impacts.

123. After assessing all the information, the Committee did not identify any adverse effects on the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, valued flora and fauna, and other taonga.

Potential adverse effects on public health and people and communities

124. The Committee did not identify any significant adverse effects on public health and people and communities from the application to release *E. daenerys*.

Identification and assessment of potentially significant beneficial effects

125. The Committee considered the potential benefits of the release of *E. daenerys*, including any potentially significant beneficial effects on the environment, public health, people and communities, the market economy, and Māori culture, traditions, and the principles of the Treaty of Waitangi (Te Tiriti o Waitangi).

Potential benefits to the environment

126. The Committee considered whether *E. daenerys* would reduce the abundance of *P. charybdis* populations, which would reduce the ability of the beetle to spread within existing sites and to new habitats.

127. The Committee also considered whether control of the beetle by the biocontrol agent will lead to significant reductions in pesticide use and incidences of non-target damage.

Limiting the risk of the spread of P. charybdis and invasion into new sites will improve biodiversity values

128. The Committee considered that through the action of *E. daenerys* reducing *P. charybdis* populations, the future expansion of *P. charybdis* into unmanaged and natural habitats may be curtailed. The Committee noted that *P. charybdis* has not yet reached its full range in New Zealand and the use of *E. daenerys* is likely to decrease its entry into and rate of invasion of other eucalyptus forests that provide habitats for native and beneficial exotic species.

129. The Committee noted that in host testing, *E. daenerys* had a strong preference for *P. charybdis* over native beetle species.

130. The Committee noted that while eucalyptus forests are known to support less diverse communities of insects than native forests, a decrease in *P. charybdis* populations from *E. daenerys* biocontrol would allow these forests to produce greater numbers of flowers and vegetation. Subsequently, this would attract nectar feeding organisms such as bees and birds e.g. tui and bellbirds. The growth of eucalyptus trees from reduced defoliation would lead to a proliferation of insects that could fill niches in and around trees which would attract insectivorous birds such as fantails.

131. The Committee concluded that it is likely the release of *E. daenerys* would reduce the vigour and abundance of *P. charybdis* in New Zealand, thus reducing its progressive invasion of existing and new eucalypt habitats and sustaining biodiversity which may be at risk from *P. charybdis* in the future. The Committee concluded that it is likely the release of *E. daenerys* would improve biodiversity values through reduced defoliation of eucalyptus trees which, in turn, would attract organisms to these habitats.

Reductions in pesticide use

132. The Committee noted that *P. charybdis* populations are controlled by repeated spraying of pesticides which have potentially adverse effects on native and beneficial arthropods. The Committee noted that reductions in pesticide usage would in turn translate into environmental benefits such as reducing the collateral damage on non-target and beneficial native arthropods along with reducing the undesirable effects of increasing the chemical burden on the environment.

133. The Committee noted that whilst biocontrol by *E. daenerys* is likely to lead to reductions in pesticide applications, they did not consider that it would eliminate the need for broad-spectrum pesticide application. However, they noted that in the absence of a sustainable control method, such as biocontrol, pesticide use would probably increase as a consequence of the expansion of the range of *P. charybdis*.

134. The Committee concluded that the release of *E. daenerys* would have future beneficial environmental effects by reducing collateral damage from the use of pesticides that can kill native or other beneficial arthropods that support ecosystems. The release of *E. daenerys* may also reduce the chemical burden on the environment where it controls or eradicates *P. charybdis*.

Potential benefits to the market economy

135. The Committee considered the economic benefits of the release of *E. daenerys* through the increased yield of *P. charybdis*-susceptible eucalyptus species, reduced pesticide costs and the continuation of Forest Stewardship Council (FSC) certification.

Increased yield of eucalyptus forests

136. The Committee considered the increase in yield of eucalypt forests following the control of *P. charybdis* by the parasitoid. The Committee noted that following the release of *E. daenerys* pressures on eucalyptus trees would reduce and, as a result, the growth of trees in size and height would improve. The improvement of forest health would provide businesses with greater opportunities to harvest and for faster harvest. The Committee also noted that tree deaths attributed to consecutive *P. charybdis* attacks would also be reduced or avoided.

Reductions in costs attributed to pesticide use

137. The Committee considered the financial cost of controlling or eradicating *P. charybdis* through pesticide usage. The Committee noted the release of the wasp is likely to reduce *P. charybdis* in areas designated for management or eradication of the beetle, reducing financial costs to businesses.

Continuation of FSC certification

138. The Committee considered the ability of eucalyptus growers to maintain FSC certification from the reduction of *P. charybdis* populations following the release of *E. daenerys*. The Committee noted that eucalyptus growers rely heavily on pesticide spray to control and eradicate populations of *P. charybdis* which subsequently increases the risks that they are able to maintain FSC certification. That may adversely affect access to key international markets for New Zealand timber exports. The Committee noted that the reduction of chemical reliance by growers would allow them to maintain FSC certification and therefore have continuation of market access.

139. The Committee considered that there are likely to be benefits to the economy in the long term from the control of *P. charybdis* by *E. daenerys*. The Committee however noted these benefits would vary across different areas, based on *P. charybdis* abundance, susceptible eucalyptus plantations and the controls that are being employed.

Potential benefits to people and communities

140. The Committee considered that the release of *E. daenerys* could indirectly improve the community through the improvement of eucalyptus tree health and the increase of eucalyptus plantations.

141. The Committee noted that benefits on communities would vary across New Zealand. The Committee noted that reduced pesticide usage could decrease the contamination of waterways and potentially benefit communities through freshwater-related recreational activities. Improvements to air and water could also lead to improved tree health in eucalypt plantations which could create more employment opportunities in the forestry industry and in sectors that support wood processing and associated businesses.

142. The Committee concluded that whilst there are likely to be benefits to people and communities from the release of *E. daenerys,* the benefits are predicted to be minimal at a national scale.

Potential beneficial effects on public health and on Māori and their relationship with the environment

143. The Committee did not identify direct benefits to public health or benefits that relate to Māori and their relationship with the environment specifically.

Weighing of beneficial and adverse effects

144. The Committee concluded that the potential risks and costs of releasing *E. daenerys* are **negligible** while the potential benefits are **non-negligible**.

145. Therefore, the Committee found the benefits outweighed the risks of releasing *E. daenerys.*

Minimum Standards

146. Under the provisions of Section 38 of the Act, the Committee considered whether *E. daenerys* meets the minimum standards set out in section 36 of the Act; specifically whether *E. daenerys* would not:

(a) cause any significant displacement of any native species within its natural habitat; or

(b) cause any significant deterioration of natural habitats; or

(c) cause any significant adverse effects on human health and safety; or

(d) cause any significant adverse effects to New Zealand's inherent genetic diversity; or

(e) cause disease, be parasitic, or become a vector for human, animal, or plant disease, unless the purpose is to import or release an organism to cause disease, be a parasite, or a vector for disease.

Potential to cause significant displacement of any native species within its natural habitat

147. The Committee considered the potential for *E. daenerys* to cause significant displacement of any native species within their natural habitats.

148. The Committee noted that host range testing and studies in its range indicate that *E. daenerys* is specific to eucalyptus-feeding paropsine beetles. In addition, native Chrysomelinae are not known to live in eucalyptus forests in New Zealand. The Committee considered it unlikely for *E. daenerys* to cause significant displacement of any native beetles in their natural habitat as *E. daenerys* would be restricted to the vicinity of eucalyptus.

149. The Committee concluded that *E. daenerys* is not likely to cause significant displacement of any native species within its natural habitat.

Potential to cause significant deterioration of natural habitats

150. The Committee considered the potential for *E. daenerys* to cause significant deterioration of natural habitats.

151. The Committee noted that *E. daenerys* could potentially cause adverse indirect effects on ecosystem interactions such as food webs. The Committee found that significant adverse indirect effects in the ecosystem are very unlikely since the agent would not cause excessive pressure on native insect species or natural habitats. This could occur through interactions such as reducing prey availability for native predators that may feed on Eucalyptus tortoise beetle but none are dependent on this food source (such as two species of soldier bug and bird species), or hyperparasitism of *E. daenerys* which, in turn, may cause elevated pressures on native parasitoids. The Committee noted that hyperparasitism of wasps in the family Braconidae is rare and none have been reported from *E. daenerys*.

152. The Committee noted that *E. daenerys* may potentially reduce the quantity of nectar available for nectar-feeding species through competition. However, the Committee considered that the presence of *E. daenerys* would not add significant competition for nectar with other species.

153. The Committee concluded that the effects of *E. daenerys* on Eucalyptus tortoise beetle populations are unlikely to cause significant deterioration of natural habitats and that the indirect effects of *E. daenerys* on the ecosystem and food webs would be minimal.

Potential to cause significant adverse effects on human health and safety

154. The Committee considered the potential for *E. daenerys* to cause significant adverse effects on human health and safety. The Committee noted that there are no known mechanisms of interaction between humans and the agents and the wasp does not sting.

155. The Committee concluded that *E. daenerys* is not likely to cause any significant adverse effects on human health and safety.

Potential to cause significant adverse effects on New Zealand's inherent genetic diversity

156. The Committee considered the potential of *E. daenerys* to cause adverse effects on New Zealand's inherent genetic diversity. The Committee considered that this could occur through cross-breeding with other *Eadya* wasp species in New Zealand.

157. The Committee noted that there are no native parasitoid wasps in the *Eadya* genus in New Zealand that could interbreed with *E. daenerys*.

158. The Committee concluded that *E. daenerys* is not likely to cause any significant adverse effect to New Zealand's inherent genetic diversity.

Potential to cause disease, be parasitic, or become a vector for disease

159. The Committee considered the potential for *E. daenerys* to cause disease, be parasitic, or become a vector for human, animal, or plant disease, resulting in damage to species other than *P. charybdis*.

160. The Committee noted that this biocontrol agent is not known to cause disease or become a vector for animal, plant or human disease in their native range.

161. The Committee noted that prior to any potential release of *E. daenerys*, the wasp would need to meet strict biosecurity standards, be free from any pests or diseases and would not be a cause of disease.

162. The Committee concluded that *E. daenerys* is not likely to cause disease, be parasitic, or become a vector for disease.

Conclusion on the minimum standards

163. The Committee was satisfied that *E. daenerys* meets the minimum standards set out in section 36 of the HSNO Act.

Ability of the organisms to establish undesirable self-sustaining populations

164. In accordance with section 37 of the Act and clauses 10(e) and (f) of the Methodology, the Committee took into consideration the ability of *E. daenerys* to form undesirable self-sustaining populations, and the ease of eradication of such populations.

165. The Committee noted that the intention of the importation and release of *E. daenerys* is to establish and develop self-sustaining populations, in order to control *P. charybdis*. Further, they considered that in order for a self-sustaining population of *E. daenerys* to be undesirable, it would need to cause undesirable adverse effects.

166. The Committee considered that any population of *E. daenerys* will be desirable since that is the foundation of a classical biological control strategy, and that this agent is not likely to cause adverse effects in the New Zealand environment.

167. The Committee noted that the potential risks of releasing *E. daenerys* are negligible and that if any population of *E. daenerys* were found to be undesirable, it would be difficult and expensive to eradicate such a population without the application of non-specific insecticides.

168. The Committee concluded that it is highly improbable that *E. daenerys* would form undesirable self-sustaining populations.

Achieving the purpose of the Act

169. The purpose of the Act is to protect the environment, and the health and safety of people and communities, by preventing or managing the adverse effects of hazardous substances and new organisms (section 4 of the Act).

170. In order to achieve the purpose of the Act, when considering the application the Committee recognised and provided for the following principles (section 5) of the Act:

   a. the safeguarding of the life-supporting capacity of air, water, soil and ecosystems

   b. the maintenance and enhancement of the capacity of people and communities to provide for their own economic, social and cultural well-being and for the reasonably foreseeable needs of future generations.

171. The Committee took into account the following matters when considering the application in order to achieve the purpose of the Act (sections 6, 7 and 8 of the Act):

   a. the sustainability of all native and valued introduced flora and fauna

   b. the intrinsic value of ecosystems

   c. public health

   d. the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, valued flora and fauna, and other taonga

   e. the economic and related benefits and costs of using a particular hazardous substance or new organism

   f. New Zealand's international obligations

   g. the need for caution in managing adverse effects where there is scientific and technical uncertainty about those effects

   h. the principles of the Treaty of Waitangi (Te Tiriti o Waitangi).

172. The Committee is satisfied that this decision is consistent with the purpose of the Act and the above principles and matters. Any substantive issues arising from the legislative criteria and issues raised by submitters have been discussed in the preceding sections of this decision.

Decision

173. After reviewing all of the information contained in the application, the Committee was satisfied that the application met the requirements of section 34 of the Act. In any event, in accordance with section 59(3)(a)(ii), the Committee waives any information requirement that has not been met.

174. The Committee considered that the threshold for approval under section 38 of the Act has been met. It is satisfied that the organism meets the minimum standards set out in section 36 of the Act, and that the beneficial effects of the organism outweighs the adverse effects of the organism, taking into account all of the following:

- all the effects of the organism and any inseparable organisms,
- the matters in section 37 of the Act,

- the relevant matters in Part 2 of the Act; and
- the Methodology.

175. The Committee decided to exercise its discretion and **approve** the import for release and/or release from containment of *E. daenerys* under section 38(1)(a) of the Act. The Committee noted that in accordance with section 38(2) of the Act, the approval has been granted **without controls**.

176. The Committee noted that under section 38(3) of the Act, if *E. daenerys* has not been released within five years of the date of this decision, this approval for release will lapse. However, any person may apply before the expiry of the time limit for an extension of that time limit for a further period of up to five years.

177. The Committee has waived the requirement under section 38(4) of the Act, to notify the Authority of the release of *Eadya daenerys*.

Environmental Protection Authority
Te Mana Rauhī Taiao

	25 February 2019
Dr Louise Malone **Chair, Decision Making Committee** **Environmental Protection Authority**	**Date**

Organism	Approval code
Eadya daenerys Ridenbaugh 2018	NOR100169

References

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Appendix Four: 2019 Progress Report Field work to identify natural enemies of Paropsisterna variicollis (Chrysomelidae) Eucalyptus Variegated Beetle, in Australia

Name of Recipient: New Zealand Forest Research Institute Limited (SCION)
Project Title: Field work to identify natural enemies of *Paropsisterna variicollis* (Chrysomelidae) Eucalyptus Variegated Beetle, in Australia
Period Covered by Report: June 30th, 2019 to March 28th, 2019
Author: Ryan D. Ridenbaugh, University of Central Florida

1. Summary of 2018 Collections

Field work was conducted in the Australian Capital Territory, New South Wales, and Victoria between October 31st and December 10th, 2018. Both Paropsis/Paropsisterna spp. larvae and adults were collected from at 36 sites (see Table 1) and reared at the Australian National University. From this material 101 wasps were reared (Figure 2) between November 28th, 2018 and my departure on December 10th, 2018, with the majority of these emergences being from *Pst. variicollis* larvae (Figure 1). Based on the size of the larvae, the coloration of the cocoon, and the time of the emergences, I believe these all to be species of Eadya. All Eadya emergences were from beetles collected around Hamilton, VIC in Eucalyptus globulus plantations (Figure 3). This is the first time any Eadya have been recorded in Victoria west of Melbourne and will likely result in several new distribution and host records. Of the 101 emergences, roughly ½ successfully spun cocoons (Figure 4) and can be used for both morphological and molecular analyses. In addition to the wasps roughly 50-60 Tachinidae flies were reared from collected material in Hamilton, VIC and Canberra, ACT. Species identifications for all wasps, flies, and beetles will be determined once I receive the specimens at The University of Central Florida and can perform the molecular analyses. The process of obtaining export permits for the 2018 material collected has been delayed, and as of the end of March I still do not have my samples collected in November. I expect to receive these samples sometime in April.

There were a few setbacks I encountered during this field season that impacted my results. The initial plan was to sample during the beginning of my trip around Canberra, ACT. However, in the capital region there had not yet been enough rain to produce flush growth in the Eucalypts, and I was unable to find any beetles. I headed further south to the Snowy Mountain region where there was flush vegetation, and my collaborator had collected beetles two weeks before. This too proved fruitless, as a cold front dropped temperatures down to freezing. I was able to find a few egg clusters that survived the freeze in *Eucalyptus nitens* plantations near Delegate, NSW, but no larvae or adult beetles. Without success I headed west to Hamilton, VIC early hoping to find beetles and better weather. This decision paid off, as I found an ample amount of larval and adult beetles. Due to the poor weather conditions during the first two weeks of my trip, all of my *Eadya* rearings were from material collected here.

2. Analyses of 2017 Collections

Dissection of the 2017 specimens has yielded one possible parasitic wasp larvae collected from Hamilton, VIC on January 4th, 2017. A definitive ID to genus and species can be given once the DNA has been sequenced. DNA extractions of the 2017 Beetle/Tachinidae is still ongoing but nearly complete. I anticipate having sequence data for the 2017 by the end of June at the latest.

3. Deliverables/Outputs (per section 4 of Schedule A)

No outputs to report at this time.

Table 1. Summary of Field Sites for the 2018/19 Season

Site Identification Code	Date mm/dd/yr	Latitude Longitude	Eadya Reared
ACT001M	12/08/18	S 35° 16.745' E 149° 09.708'	
NSW002	11/08/18	S 36° 36.515' E 149° 25.733'	
VIC076	11/08/18	S 37° 06.456' E 148° 52.845'	
VIC077	11/08/18	S 37° 06.455' E 148° 52.874'	
VIC078	11/10/18	S 38° 24.501' E 146° 41.806'	
VIC079	11/10/18	S 38° 24.508' E 146° 41.806'	
ACT002M	12/08/18	S 35° 15.700' E149° 05.649'	
ACT003M	12/08/18	S 35° 16.881' E 149° 05.804'	
ACT004	11/12/18	S 35° 19.508' E 149° 01.355'	
ACT005	11/12/18	S 35° 19.514' E 149° 01.368'	
ACT006	11/12/18	S 35° 19.511' E 149° 01.373'	
VIC080	11/14/18	S 38° 04.014' E 141° 37.912'	
VIC081	11/14/18	S 38° 13.999' E 142° 49.658'	X
VIC082	11/15/18	S 38° 14.001' E 142° 49.658'	X
VIC083	11/15/18	S 38° 14.000' E 142° 49.659'	X
VIC084	11/15/18	S 38° 14.002' E 142° 49.655'	
VIC085	11/15/18	S 38° 14.011' E 142° 49.664'	X
VIC086	11/16/18	S 38° 13.988' E 142° 49.620'	
VIC087	11/16/18	S 38° 14.005' E 142° 49.590'	
VIC088	11/16/18	S 38° 04.232' E 142° 41.494'	X
VIC089	11/16/18	S 38° 04.668' E 142° 41.409'	X
VIC090	11/18/18	S 38° 03.078' E 142° 41.039'	X
VIC091	11/18/18	S 38° 03.090' E 142° 41.052'	
VIC092	11/18/18	S 38° 03.081' E 142° 41.066'	
VIC093	11/18/18	S 38° 03.193' E 142° 40.625'	X
VIC094	11/18/19	S 38° 03.195' E 142° 40.628'	X
VIC095	11/19/18	S 38° 04.132' E 141° 36.921'	
VIC096	11/19/18	S 38° 04.129' E 141° 36.918'	
VIC097	11/19/18	S 38° 04.153' E 141° 36.884'	X
VIC098	11/21/18	S 38° 06.245' E 141° 38.109'	X
VIC099	11/21/18	S 38° 06.253' E 141° 38.100'	X
VIC100	11/22/18	S 38° 09.097' E 141° 50.395'	
VIC101	11/22/18	S 38° 09.072' E 141° 50.700'	

ACT007	11/23/18	S 35° 28.783' E 148° 56.505'	
ACT008	11/27/18	S 35° 48.257' E 148° 59.685'	
ACT009	11/27/18	S 35° 48.240' E 148° 59.668'	

Figure 1. *Eadya* emerging from *Pst. variicollis* larva

Figure 2. My field rearing setup, with colony boxes (white boxes) and isolation containers (yellow lids)

Figure 3. *Pst. variicollis* on *Eucalyptus globulus*

Figure 4. Freshly spun *Eadya* cocoon

Appendix Five: 2018 Progress report - Field work to identify natural enemies of *Paropsisterna variicollis* (Chrysomelidae) Eucalyptus Variegated Beetle, in Australia

Name of Recipient: New Zealand Forest Research Institute Limited (SCION)
Project Title: Field work to identify natural enemies of *Paropsisterna variicollis* (Chrysomelidae) Eucalyptus Variegated Beetle, in Australia
Period Covered by Report: December 1st, 2017 to June 30th, 2018
Author: Ryan D. Ridenbaugh, University of Central Florida

1. Summary of 2017 Collections

Specimens were collected from 1 site in New South Wales, 2 sites in the Australian Capital Territory, and 76 sites in Victoria between December 13th, 2017 and January 7th, 2018 (see Table 1). Collection sites span two *Eucalyptus nitens* plantations (Pentarch Forestry [Bendoc, VIC] and HVP Plantations [Churchill, VIC]), one *Eucalyptus globulus* plantation (Australian Bluegum Plantations [Hamilton, VIC)), and one national park (Yarra Ranges National Park). 680 specimens of *Paropsis/*Paropsistera were collected, and from these collection's 112 Tachinidae (spp. unknown) were reared. No *Eadya* spp. were reared from the collected material. Chalcid egg parasitoids (sp. unknown) were reared from two sites (R.001 & R.002). Egg predation by a Hemipteran (Possibly Miridae, sp. unknown) was observed on an unidentified species of *Paropsis/Paropsisterna* from the Australian Bluegum Plantations sites (VIC048 & VIC065).

The majority of the successful parasitoid rearings were from specimens collected at the Australian Bluegum Plantation sites. This is primarily due to difficulties faced in regards to rearing at the beginning of the field season. Initially, paropsine larvae were separated at collection and reared in individual 50mL tubes. This resulted in the death of the specimen before the pre-pupation stage in which parasitoids would emerge. The method for rearing was reevaluated and changed before collection commenced at the ABP sites. Specimens were reared gregariously in 750mL take away containers, and separated at the pre-pupal stage before parasitoid emergence. The period this method was implemented (01/02/18 - 01/07/18) may have too late in the season for *Eadya* spp. to be emerging on the mainland, based upon mainland collections by Huddleston & Short . However, larvae collected earlier in the season may contain the larval stages of *Eadya* spp., and will be dissected for any parasitoids that failed to emerge due to the premature death of the beetle. The gregarious rearing method will be used during my 2018 collection trip, given the successful results of this method during the 2017 season.

2. Deliverables/Outputs (per section 4 of Schedule A)

A paper describing and proposed names for, and a key to all species of *Eadya* discovered in collaboration with the University of Tasmania and SCION has been published in the Journal of Hymenoptera Research, Issue 64, .

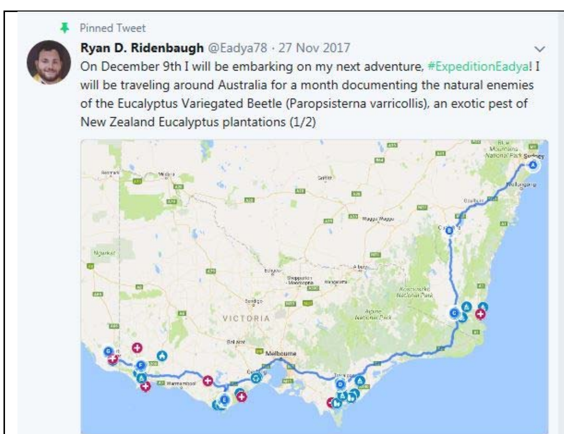

Figure 1. Images from 2017-18 “Expedition Eadya” field trip. Map showing expedition route, picture of *E. nitens* plantations typical of those searched, larval rearing method, prepupal emergence containers. Bottom Ryan in the field, and examining specimens in ANIC, Canberra.

Table 1. Summary of 2017 collection sites

Identification Code	Date mm/dd/yr	State	Plantation	Park	Latitude	Longitude	Tachinidae Reared
R.001	12/15/2017	VIC	Bruce (Pentarch)		S 37° 10' 25.7"	E 148° 56' 23.8"	
R.002	12/14/2017	ACT		ANU	-35.266111	149.123544	
R.003	12/31/2018	ACT		ANU	-35.274459	149.11882	X
NSW001M	12/13/17 - 12/16/17	NSW	Bombala #2		S 37° 05.332'	E 149° 12.177'	
VIC001	12/14/17	VIC	Bruce (Pentarch)		S 37° 09.720'	E 148° 57.096'	
VIC002	12/14/17	VIC	Bruce (Pentarch)		S 37° 09.617'	E 148° 57.047'	
VIC003M	12/14/17 - 12/17/17	VIC	Bruce (Pentarch)		S 37° 10.175'	E 148° 56.559'	
VIC004	12/14/17	VIC	Bruce (Pentarch)		S 37° 09.974'	E 148° 56.782'	
VIC005	12/14/17	VIC	Bruce (Pentarch)		S 37° 09.982'	E 148° 56.765'	
VIC006M	12/14/17 - 12/17/17	VIC	Bruce (Pentarch)		S 37° 09.984'	E 148° 56.769'	
VIC007	12/15/17	VIC	Bruce (Pentarch)		S 37° 09.982'	E 148° 56.760'	
VIC008	12/15/17	VIC	Bruce (Pentarch)		S 37° 09.934'	E 148° 56.767'	
VIC009	12/15/17	VIC	Bruce (Pentarch)		S 37° 09.933'	E 148° 56.775'	
VIC010	12/15/17	VIC	Bruce (Pentarch)		S 37° 09.917'	E 148° 56.761'	
VIC011	12/17/17	VIC	Bruce (Pentarch)		S 37° 09.982'	E 148° 56.765'	
VIC012M	12/19/17 - 12/24/17	VIC	HVP Gipps		S 38° 21.722'	E 146° 33.463'	
VIC013	12/19/17	VIC	HVP Gipps		S 38° 23.251'	E 146° 33.109'	
VIC014	12/19/17	VIC	HVP Gipps		S 38° 23.252'	E 146° 33.122'	
VIC015M	12/19/17 - 12/24/17	VIC	HVP Gipps		S 38° 23.250'	E 146° 33.117'	
VIC016M	12/19/17 - 12/24/17	VIC	HVP Gipps		S 38° 24.790'	E 146° 42.078'	
VIC017M	12/20/17 - 12/24/17	VIC	HVP Gipps		S 38° 24.225'	E 146° 34.059'	
VIC018M	12/20/17 - 12/24/17	VIC	HVP Gipps		S 38° 23.230'	E 146° 33.085'	
VIC019	12/21/17	VIC	HVP Gipps		S 38° 24.484'	E 146° 41.814'	
VIC020	12/21/17	VIC	HVP Gipps		S 38° 24.467'	E 146° 41.824'	

VIC021	12/21/17	VIC	HVP Gipps		S 38° 24.480'	E 146° 41.812'	
VIC022	12/21/17	VIC	HVP Gipps		S 38° 24.480'	E 146° 41.812'	
VIC023	12/21/17	VIC	HVP Gipps		S 38° 24.482'	E 146° 41.816'	
VIC024	12/22/17	VIC	HVP Gipps		S 38° 24.484'	E 146° 41.817'	
VIC025	12/27/17	VIC		Yarra Ranges NP	S 37° 30.056'	E 145° 49.526'	
VIC026	12/28/17	VIC		Yarra Ranges NP	S 37° 30.040'	E 145° 49.582'	
VIC027	12/30/17	VIC		Yarra Ranges NP	S 37° 30.113'	E 145° 49.972'	
VIC028	12/30/17	VIC		Yarra Ranges NP	S 37° 30.104'	E 145° 50.076'	
VIC029	12/31/17	VIC		Yarra Ranges NP	S 37° 30.105'	E 145° 50.366'	
VIC030	12/31/17	VIC		Yarra Ranges NP	S 37° 30.111'	E 145° 50.022'	
VIC031	12/31/17	VIC		Yarra Ranges NP	S 37° 30.111'	E 145° 50.022'	
VIC032	12/31/17	VIC		Yarra Ranges NP	S 37° 30.110'	E 145° 49.969'	
VIC033	12/31/17	VIC		Yarra Ranges NP	S 37° 30.109'	E 145° 49.992'	
VIC034	12/31/17	VIC		Yarra Ranges NP	S 37° 30.108'	E 145° 50.009'	
VIC035	12/31/17	VIC		Yarra Ranges NP	S 37° 30.113'	E 145° 50.023'	
VIC036	12/31/17	VIC		Yarra Ranges NP	S 37° 30.106'	E 145° 50.059'	
VIC037	12/31/17	VIC		Yarra Ranges NP	S 37° 30.107'	E 145° 50.073'	
VIC038	12/31/17	VIC		Yarra Ranges NP	S 37° 30.109'	E 145° 50.053'	
VIC039M	01/02/18 - 01/07/18	VIC	ABG Hamilton		S 37° 48.555'	E 141° 43.236'	
VIC040	01/02/18	VIC	ABG Hamilton		S 37° 50.131'	E 141° 36.992'	X
VIC041	01/02/18	VIC	ABG Hamilton		S 37° 50.131'	E 141° 36.992'	X
VIC042M	01/02/18 - 01/07/18	VIC	ABG Hamilton		S 37° 50.131'	E 141° 36.992'	
VIC043M	01/02/18 - 01/07/18	VIC	ABG Hamilton		S 37° 58.145'	E 141° 51.586'	
VIC044M	01/03/18 - 01/07/18	VIC	ABG Hamilton		S 37° 48.378'	E 141° 42.572'	
VIC045M	01/03/18 - 01/07/18	VIC	ABG Hamilton		S 37° 50.318'	E 141° 36.914'	
VIC046	01/03/18	VIC	ABG Hamilton		S 37° 50.120'	E 141° 37.090'	X

VIC047	01/04/18	VIC	ABG Hamilton		S 37° 48.655'	E 141° 43.911'	X
VIC048	01/04/18	VIC	ABG Hamilton		S 37° 48.647'	E 141° 43.840'	
VIC049	01/04/18	VIC	ABG Hamilton		S 37° 50.107'	E 141° 37.766'	
VIC050	01/04/18	VIC	ABG Hamilton		S 37° 50.218'	E 141° 37.012'	X
VIC051	01/04/18	VIC	ABG Hamilton		S 37° 50.346'	E 141° 36.941'	X
VIC052	01/04/18	VIC	ABG Hamilton		S 37° 58.079'	E 141° 51.047'	X
VIC053	01/05/18	VIC	ABG Hamilton		S 37° 48.533'	E 141° 43.232'	
VIC054	01/05/18	VIC	ABG Hamilton		S 37° 48.547'	E 141° 43.224'	X
VIC055	01/05/18	VIC	ABG Hamilton		S 37° 48.623'	E 141° 43.207'	X
VIC056	01/05/18	VIC	ABG Hamilton		S 37° 50.110'	E 141° 36.934'	X
VIC057	01/05/18	VIC	ABG Hamilton		S 37° 50.112'	E 141° 36.941'	X
VIC058	01/05/18	VIC	ABG Hamilton		S 37° 50.138'	E 141° 37.000'	X
VIC059	01/05/18	VIC	ABG Hamilton		S 37° 50.147'	E 141° 37.000'	X
VIC060	01/05/18	VIC	ABG Hamilton		S 37° 50.160'	E 141° 36.993'	X
VIC061	01/05/18	VIC	ABG Hamilton		S 38° 05.055'	E 141° 39.622'	X
VIC062	01/05/18	VIC	ABG Hamilton		S 38° 05.021'	E 141° 39.323'	X
VIC063	01/05/18	VIC	ABG Hamilton		S 37° 50.119'	E 141° 36.973'	
VIC064	01/05/18	VIC	ABG Hamilton		S 37° 50.114'	E 141° 36.985'	X
VIC065	01/05/18	VIC	ABG Hamilton		S 37° 50.114'	E 141° 36.985'	
VIC066	01/07/18	VIC	ABG Hamilton		S 37° 50.124'	E 141° 36.906'	X
VIC067	01/07/18	VIC	ABG Hamilton		S 37° 50.130'	E 141° 36.903'	
VIC068	01/07/18	VIC	ABG Hamilton		S 37° 50.119'	E 141° 36.909'	X
VIC069	01/07/18	VIC	ABG Hamilton		S 37° 50.211'	E 141° 36.847'	X
VIC070	01/07/18	VIC	ABG Hamilton		S 37° 50.255'	E 141° 36.816'	X
VIC071	01/07/18	VIC	ABG Hamilton		S 37° 50.107'	E 141° 37.083'	X
VIC072	01/07/18	VIC	ABG Hamilton		S 37° 50.315'	E 141° 36.918'	X
VIC073	01/07/18	VIC	ABG Hamilton		S 37° 50.368'	E 141° 36.931'	X
VIC074	01/07/18	VIC	ABG Hamilton		S 37° 50.375'	E 141° 36.927'	X
VIC075	01/07/18	VIC	ABG Hamilton		S 37° 50.123'	E 141° 36.998'	X