Manaaki Whenua
Landcare Research

Review of a draft prioritisation tool for National Biocontrol Collective funded work in New Zealand

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Contents

Summary

Project and Client

- On behalf of the National Biocontrol Collective, councils have created a draft prioritisation tool, in the form of an Excel spreadsheet that ranks prospective weed biocontrol targets and candidate biocontrol agents. The aim is to assist councils in making biocontrol decisions nationally and within their regions.

Objectives

- The aim of this report is to review the draft prioritisation tool and recommend if changes should be made to enhance the selection of target weeds and candidate biocontrol agents so that the cost-effectiveness of weed biocontrol can be enhanced in New Zealand.

Methods

A literature review on factors affecting biocontrol success was conducted and a gap analysis of factors already considered in the NBC Prioritisation Tool against factors identified in the literature was performed.

The relative quantitative weighting score given to factors included in the NBC Prioritisation Tool was also reviewed against the evidence collected in the literature review.

Results

- The review identified several ways the tool could be simplified and reorganised to quantify factors that can be used to rank potential target weeds by their impacts (importance), the predicted feasibility of biocontrol, and the estimated cost of implementing biocontrol.
- A review of the factors associated with the success rate of individual weed biocontrol agents indicated that, with the current state of knowledge, it is unlikely that a points-based scoring system can be developed to assist agent selection that will reliably prioritise the best agent. However, a relatively simple approach that prioritises candidate agents according to their potential host specificity and capacity to damage the target weed (including the presence or absence of ecological analogues, and information of weed biotypes) should formalise how an initial ‘triage’ is usually done to eliminate the least suitable candidates and develop a pool of species that are worth further investigation.

Recommendations

- In addition to this review, we have edited the excel spreadsheet developed by the NBC to reflect our recommended scoring systems for prioritising weed targets and candidate agents and supplied them to relevant council staff.

1 Introduction

Biological control of weeds in New Zealand (NZ) is performing well. The number of agents released each decade has increased against a backdrop of declining or stagnating releases overseas (Schwarzländer et al. 2018b). The average cost per agent approved for release has declined by ~$53,000 from ~$442,000 in the decade 2000–2009 to ~$389,000 for agents approved in 2011–2020 (using data updated from Paynter et al. 2015).

We anticipate that the success rate of biocontrol releases should also increase because of recent research into selecting more effective agents (e.g. Paynter et al. 2010, 2018; Lam et al. 2021). However, it is too soon to attempt to accurately quantify this because there is an unavoidable lag between an agent being released and becoming sufficiently abundant and widespread to control the target weed. For example, the heather beetle was released in 1997 and has only recently begun killing large tracts of heather on the Central Plateau (Peterson et al. 2020). Nevertheless, the encouraging signs that agents released within that last decade, or so, against weeds such as *Cirsium arvense, Cytisus scoparius, Lantana camara, Marrubium vulgare, Solanum mauritianum* (in shaded sites) and *Tradescantia fluminensis*, are beginning to have major impacts augers well.

This success is recognised internationally: Schwarzländer et al. (2018a) noted that 'New Zealand, in contrast to the regressions in the USA, Hawaii, Canada and Australia, continues to set the standard for cooperative and effective weed biocontrol' and that 'Two new quarantine facilities have recently been built – one for pathogens and an impressive range of weeds has been targeted, and reported in a series of high-quality publications'.

Nevertheless, there is always room for improvement. The National Biocontrol Collective (NBC) is an effective mechanism for councils to collaborate on biocontrol agent development, and funding the NBC is one of the Biomanagers' on-going priorities. However, it is widely recognised that there are several areas of the NBC's function which require improvements.

The NBC have identified weaknesses in the current process of biocontrol prioritisation and associated processes such as risk management. To address these issues, councils have created a draft prioritisation tool (henceforth "NBC Prioritisation Tool"), in the form of an Excel spreadsheet that ranks prospective biocontrol agents based on information on a range of factors that contribute to their relative importance and feasibility. The aim is to assist councils in making biocontrol decisions nationally and within their regions. This work supports step-change system improvements in pest plant biocontrol prioritisation by the regional sector, to address issues identified in a previous report commissioned by the regional sector (McKenzie 2015).

2 Objectives

The deliverables from this Envirolink grant is a report that summarises the results from the following activities:

1. Literature review on factors affecting biocontrol success.
2. Gap analysis of factors already considered in the NBC Prioritisation Tool against factors identified in the literature.
3. Review of the relative quantitative weighting score given to factors included in the NBC Prioritisation Tool against the evidence collected in the literature review.
4. Recommendations of any factors that should be added, removed, or up/down weighted, considering steps 1–3.

Note the project does not involve making changes to the NBC Prioritisation Tool itself. It will simply recommend changes that could be made by regional councils.

3 Literature review: weed prioritisation and factors affecting biocontrol success

In New Zealand (NZ) 2,430 naturalised, alien, vascular plant species (1,780 fully naturalised and 650 casual; Howell & Sawyer 2006) outnumber the 2,414 native vascular plants (De Lange & Rolfe 2010). Given such a high diversity of invasive plant species, the limited resources for tackling weed invasions must be prioritised effectively.

Paynter et al. (2009) reviewed past prioritisation tools used to select weed biocontrol targets, noting that classical weed biocontrol tends to be a public, community-level activity carried out by institutions and public departments rather than private enterprise (Van Driesche & Hoddle 2002). The need to account for this public investment should demand robust decision-making processes to select biocontrol targets that are not only important and have broad social support but are also biologically and ecologically feasible.

Since then, several other attempts to produce decision support tools to rank weed biocontrol targets have been developed (Lefoe & Ainsworth 2012; Paynter & Dodd 2012; Morin et al. 2013; van Klinken et al. 2016; Raghu & Morin 2018).

All these approaches have followed rationales for the prioritisation of weed control that were proposed by Hiebert (1997), who advocated the development of decision-making tools to rank weeds according to: current impacts, future threat, and the cost and feasibility of control.

Many national schemes for setting weed management priorities have emphasised weed impacts (e.g. Thorp & Lynch 2000; Moran et al. 2005) more than the cost or feasibility of control because the latter may be hard to estimate prior to the commencement of a control programme. This deficiency is particularly pertinent to classical biocontrol, which can have significant development costs (Fowler et al. 2000) and does not always succeed.

Indeed, complete successes, where biocontrol is so dramatic that other control methods are no longer required, only account for approximately one-third of all completed programs (McFadyen 1998). Approximately one in six programmes fail to have any tangible impact (Hoffmann 1995; Fowler et al. 2000). Recent and on-going research into success factors is likely to see this rate improve, for example by avoiding the introduction of biocontrol agents that are likely to be subject to high levels of parasitism or predation in the introduced range (Paynter et al. 2010, 2018; Lam et al. 2021). Nevertheless, success is still not guaranteed.

3.1 Prioritising target weeds

3.1.1 Is biocontrol appropriate?

When contemplating biocontrol of an invasive plant species, the first consideration should be whether the use of biocontrol is appropriate. For example, biocontrol of native weeds that are growing within their natural range is no longer considered appropriate, even though such biocontrol programmes have been conducted in the past (Paynter et al. 2009). For example, one of the earliest weed biocontrol programmes conducted in NZ targeted a native weed *Acaena anserinifolia* using a sawfly *Ucona acaenae* collected in Chile, where it feeds on *Acaena* spp. that are native to Chile (Harman et al. 1996). Thankfully, this introduction failed: as Pemberton (2002) noted, it is impossible to limit biocontrol agents only to situations where the target native weeds are problems and such programmes would no longer be sanctioned by regulatory authorities in many countries that utilise biocontrol as a weed management option, including New Zealand (Barratt & Moeed 2005).

Some recent prioritisation frameworks (e.g. Morin et al. 2013; van Klinken et al. 2016; Raghu & Morin 2018) have been used to prioritise lists of invasive non-native plant species. However, biocontrol of weeds that are native (indigenous) to a country but growing outside of their natural range can be appropriate. For example, the grass *Spartina alterniflora* is native to the Atlantic coast of the USA and an introduced weed on the Pacific coast of the USA. A delphacid bug, *Prokelisia marginata*, also native to the Atlantic coast of the USA, has been used as a biocontrol agent for *S. alterniflora* on the Pacific coast (Grevstad et al. 2003).

Weeds can have value in many ways, including as food crops, pasture plants, for forestry, as garden plants, or as a resource for honeybees or other desirable fauna. When there are objections to biocontrol of a weed species a cost–benefit analysis may be required to determine whether a programme should proceed. Unrestricted biocontrol programmes are unlikely to be sanctioned for economically important crops. However, programmes that are 'restricted' to using introduced agents that attack plant reproductive structures to reduce seed set and therefore the ability to disperse and invade may be approved (e.g. agents that attack plant reprodictive parts have been released against *Acacia* spp. that are valued for timber, tannin and firewood production in South Africa; Moseley et al. 2009). In the past, programmes have been allowed to proceed against weeds that are valued by beekeepers, such as Scotch broom *Cytisus scoparius* in NZ (Jarvis et al. 2006) or valued as garden ornamentals (e.g. *Lantana* spp.) because alternative pollen and nectar sources or non-weedy alternative ornamental species are usually available.

To avoid costly delays due to potential objections to biocontrol we recommend asking two stop/go questions regarding whether a plant is native and whether opposition to biocontrol is likely (Table 1).

Table 1. Stop/go question relating to the native range of a candidate target weed and to potential opposition to the use of biological control against a candidate target weed. Adapted from Paynter et al. (2009)

Question	Outcome
1. Is the weed species native?	
a. Yes, and in its natural range	Biological control is undesirable; do not proceed
b. Yes, but growing outside its natural range	Biological control may be ecologically feasible (although unlikely to be a priority)
c. No	Proceed to Question 2
2. Is opposition to biocontrol likely? Does the weed species have socioeconomic value?	
a. Yes, and value of weed demonstrably >cost of control/detrimental impacts	Biological control is undesirable; do not proceed.
b. Yes, but cost–benefit analysis data do not exist	Cost–benefit data will be required for permission to release biocontrol agents, delaying biocontrol, adding to cost and uncertainty of success. Do not proceed until cost–benefit analysis has been conducted
c. Yes, and value of weed demonstrably < cost of control/detrimental impacts	Proceed with prioritisation
d. No, the weed has no documented redeeming features	Proceed with prioritisation

3.1.2 Weed impacts and future threat

Weed impacts

Most systems that have attempted to prioritise weed impacts have followed the assumption made by Parker et al. (1999) that the overall impact is a product of the geographic distribution of the weed and the abundance and impacts of the weed (such as reduced crop production or the modification of natural habitats).

The NBC currently employs a simple voting system to rank potential projects each year, where the desirability of biocontrol work on each weed species is categorised by a delegate from each contributing organisation as 'hot', 'warm' or 'cold' (where hot = the most important, and cold = least important) on an annual basis. The votes in each category are then tallied and a total score, based on each hot, warm, and cold vote scoring 10, 5, and 1 point(s), respectively is then calculated. This total is therefore a rough and ready measure of weed distribution (the more regions affected, the more votes a weed will get) as well as the perceived importance of a weed within each region (where delegates tend to rank weeds as hot, warm, or cold according to their perceived invasiveness and their intractability as regards conventional control options).

Undoubtedly, improvements could be made to this system by providing a more formal framework to quantify the impacts of candidate biocontrol targets. However, comparing and ranking the impacts of weeds that affect many different stakeholders remains problematic. For example, the impacts of weeds of primary industries tend to be measured in economic terms, according to the cost of control and lost production, but the impacts of environmental weeds are measured by their negative impacts on biodiversity. Although there are excellent quantitative data on the biodiversity impacts of some weed species (e.g. dense mats of *Tradescantia fluminensis* prevent seedlings of native plants establishing; Standish et al. 2001), data on the impacts of weeds on biodiversity is commonly lacking (e.g. Sheppard et al. 2006b). The lack of information to assess the impact of most weed species makes it extremely difficult to conduct multi-species comparisons.

Potential projects considered by the NBC include continuation of work already underway alongside novel work on new target weeds. There is no formal system for ranking novel target weeds to be included in the annual voting: when a new species is nominated by a delegate, voting to work on it occurs on an *ad hoc* basis. Potential future targets could be formally prioritised, so that when work on one target weed is complete work on an agreed novel target should commence next.

Future threat

Biocontrol may ultimately be required for many emerging weed species because eradication programmes rarely succeed against weeds, even when they are established over relatively small areas (> 100 ha; Rejmánek & Pitcairn 2002). Biocontrol of emerging weeds is rarely undertaken but it has been investigated on an ad hoc basis in South Africa: Olckers (2004) provided examples where South African researchers conducting survey work looking for agents against high-priority weeds simultaneously collected natural enemies of low-priority weeds in the same region. A similar approach has been undertaken to survey for candidate agents of lesser calamint *Calamintha nepeta*, which is a localised weed in New Zealand, where biocontrol is considered warranted because control is difficult and eradication is considered to be impossible. Nevertheless, future threat is normally a minor consideration when ranking weed biocontrol targets. Limited budgets for biological control programmes are understandably directed at current priorities rather than species that are potentially important future weeds. Moreover, potentially serious weeds with restricted distributions are often eradication targets, or under some form of intensive management to contain infestations that can be incompatible with establishing biocontrol agents.

There is strong evidence that the threats posed by invasive weeds will increase due to global change (Ziska & George 2004; Liu et al. 2017). This is because it has been found that elevated temperature and CO_2 enrichment increase the performance of invasive alien plants more strongly than native plants, and disturbances caused by extreme weather events, such as stronger cyclones, will also favour weed invasions. The most pragmatic prediction regarding an invasive weed species is that it is likely to become even more invasive if, as seems inevitable, CO_2 enrichment continues to increase.

Computer-based climate modelling was used to predict the potential distribution of weed species in Australia and used as one of the criteria to determine twenty Weeds of National Significance (WoNS; Thorp & Lynch 2000). A similar approach could be used to assist identification of emerging weeds in New Zealand that have the potential to become widespread. However, only 71 already problematic weed species were nominated for consideration as Weeds of National Significance and it would be a huge undertaking to predict the potential distributions of all the non-native plant species that have naturalized in NZ. Until such an undertaking is completed it is impossible to consider potential distribution as part of the prioritisation process.

An existing system for ranking environmental weeds

Downey et al. (2010) proposed a model to rank environmental weeds in NSW, Australia, that could be undertaken in the absence of quantitative data on actual impacts. We recommend that a ranking system should follow a similar approach, with modifications, where necessary, to suit the needs of the NBC.

Due to the large number of weed species in NSW, Downey et al. (2010) conducted an initial triage to reduce the number of weeds under consideration by investigating the 'degree of naturalization' and excluding species with small distributions or not widely naturalized, along with species for which there was insufficient information to make an accurate determination). As noted in the *Future threat* section above, biocontrol is normally directed at the most pressing current priorities rather than species that are potentially important future weeds and a similar 'triage process' could be used in NZ unless considerable additional funding for biocontrol is made available.

Downey et al. (2010) also excluded agricultural weeds and species primarily associated with wastelands and disturbed areas. In NZ, biocontrol programmes that target weeds that predominantly affect primary industries have mainly been funded by the MPI Sustainable Farming Fund (SFF) (which was recently superseded by the Sustainable Food & Fibre Futures; SFF Futures). To counterbalance emphasis of SFF funding on weeds of primary industries, the NBC has focussed on biocontrol of environmental weeds, while contributing co-funding in support of SFF projects. However, because NBC Funding can now be used to leverage SFF Futures funding, there is strong justification for prioritising cross-sector weeds (i.e. weed species that affect both primary industry and the conservation estate) ahead of plants that are purely environmental weeds.

The model used by Downey et al. (2010) used five attributes to assess the likely threat and ability of the remaining weed species (after the initial triage) to impact upon biodiversity, namely:

A. Weighted spatial threat: Downey at al. (2010) scored the number of regions (botanical divisions) affected/potentially affected by a weed and threat scored according to Table 2.

Table 2. Scoring system to assess spatial threat (from Downey at al. 2010)

Score	Weighted spatial threat (A) for each of the 11 botanical divisions in NSW
0	no threat – species not present and unlikely to invade the division,
0.5	potential threat only – species not present in the division, but has been assessed as having the potential to invade the division in the future,
1	present, threat unlikely – species only known from a few very small infestations in the division (e.g. <5),
3	low threat – species suspected of posing a threat in the division, with no assumption or evidence of impacts,
7.5	medium threat – species acknowledged as posing a threat to native species in part or all the division and impacts suspected but not observed, or
16.5	high threat – species known to threaten and impact upon native species in the division.

B. Native species impact: Downey at al. 2010 scored a weed species 1–4 on the basis that impacts were low or a limited degree of threat or impact was observed to date (1 point); moderate degree of impact (e.g. impact is to specific individuals of a native species, rather than to populations or ecosystems) (2 points); high degree of impact (e.g. where a weed species has a significant negative impact on populations of native species, but not to the level of 4) (3 points); or transformer species (e.g. weed species that are considered capable of, or are presently modifying the invaded ecosystem to such an extent that they alter ecosystem processes), for example, fire regimes, nutrients, water flows, physical habitat modification, facilitation of other weed species (4 points).

C. Invasive ability: scored as: invasive ability restricted (e.g. to the edges of vegetation communities only) (1 point); invasive with limitations (e.g. while the weed species can invade intact or undisturbed vegetation communities, it typically does not do well in such situations, invasion is often aided by other factors like disturbance) (2 points); or ability to invade without limitations (e.g. invasion is not subject to biotic barriers or invasion constraints, or requires a disturbance event) (3 points).

D. Number of native plant species potentially at risk: Downey et al. (2010) used herbarium records to determine the number of plant species in each region (botanical division).

E. Habitat type: This is equivalent to the **'Ecosystems impacted'** question in the tool. Downey et al. (2010) listed 11 habitat types (e.g. Wetland, heath, woodlands) and calculated the proportion of habitats invaded by each weed dividing the number of habitat types (E) invaded by the maximum number of habitats present (Emax).

Downey et al. (2010) assessed each habitat type on a regional basis (i.e. the botanical regions in NSW) and then summed to give a state-wide value which is then weighted based on the threat potential (A1).

Downey at al. (2010) calculated the Priority rank for each weed was as follows:

$$\sum \begin{array}{c} \text{botanical divisions} \times \text{threat potential [A1]} \\ \text{(weighted spatial threat [A]} \times \text{species impact [B]} \\ \times \text{ invasive ability [C])} \times \text{(biodiversity at risk [D]} \\ \times \text{ habitat type [E] / maximum habitat type [Emax])} \end{array}$$

3.1.3 Cost of implementing biocontrol

It could be argued that the potential cost of a biocontrol programme should be a minor consideration when prioritising biocontrol targets because the benefit–cost ratio of successful programmes can be so high that the implementation cost is trivial in comparison with the benefits (e.g. van Wilgen et al. 2004; Page & Lacey 2006; Hayes et al. 2013; Fowler et al. 2016). However, in NZ, this is only likely to be true for biocontrol programmes that target weeds of primary industries. This is because relatively low sums of money are spent controlling environmental weeds in NZ compared with weeds of primary industries. The economic benefits of a successful biocontrol programme against an environmental weed, in terms of reduced control costs, will therefore be relatively low and monetizing biodiversity benefits is notoriously difficult, resulting in much lower benefit: cost ratios. Moreover, a high-cost programme can absorb a large chunk of available funds for several years – perhaps leading to high expectations and risk to reputations – of both the research provider and the funding bodies (S.V. Fowler, pers. comm.).

The cost of implementing biocontrol in NZ was reviewed by Paynter et al. (2015). Only two factors explained virtually all the variance in programme cost: programme type (repeat programmes were cheaper than novel/pioneering programmes); and the number of agents released. Typically, multiple agent species are released on a target weed but often only one species is responsible for successful control (Denoth et al. 2002). Paynter et al. (2015) argued that efficiencies in future programmes are therefore most likely to be gained by releasing fewer agents due to improved agent selection. For novel/pioneering programmes, recent scientific advances may assist with selecting the most efficacious agents (see section 5.2.2, below). For repeat programmes, this could be achieved by waiting until monitoring has been conducted overseas, so that the best agents or combination of agents can be selected. For example, four agent species were originally introduced into Hawai'i to control mistflower *Ageratina riparia*, but it was recommended that only two of these species should be released into NZ (Morin et al. 1997) and the programme was a major success (Barton et al. 2007; Winston et al. 2020).

Paynter et al. (2015) revealed that, on average, novel programmes cost about four times as much as repeat programmes, so a scoring scheme should reflect this.

Some weed species are invasive in other countries, allowing a consortium approach with overseas agencies, so that costs of developing biocontrol agents can sometimes be shared. For such targets we assumed that the cost of a shared programme would be intermediate between repeat and novel programmes, nuanced according to whether overseas exploration has already been conducted by an overseas agency and if host-specificity testing of prioritised agents is already underway (see section 3.6.1).

Although hypothesized to be an important factor, taxonomic isolation of the target weed, relative to commercially important plants and native flora, did not significantly influence cost of past programmes in NZ (Paynter et al. 2015). However, the importance of taxonomic isolation has changed over time. For example, Hinz et al. (2014) noted that several successful agents in the USA would not be approved for release under the current more risk-averse regulatory system due to the potential for them to damage congeneric non-target plants. The same is likely to be true for NZ (Groenteman et al. 2011). This implies that had these agents been considered for release under current regulations, either additional costly testing would have been required to demonstrate these agents are safe, or further expenditure would have been required to search for other less risky candidate agents, significantly adding to the cost of a programme and the risk of failure. We suggest that taxonomic isolation of the target weed should therefore be included as a factor when estimating the cost of implementing biocontrol, although, in the absence of quantitative data, the adjusted score that we have suggested for weeds that have a valued congeneric plant in NZ (see section 3.6.1) will likely need to be revised in the future when the impact of this factor has been assessed.

Opposition to biocontrol has caused delays, but has not had a major influence on the cost of biocontrol in NZ, probably because weed species with the greatest potential for opposition were immediately identified during feasibility studies and avoided, or because conflicts were resolved by conducting cost–benefit analyses that were relatively minor components of the total programme costs (Paynter et al. 2015).

A recent factor that can increase the cost of implementing biocontrol concerns new 'Access and Benefit Sharing' (ABS) procedures under the Convention on Biological Diversity (CBD). Under the CBD, countries have sovereign rights over their genetic resources. Agreements governing the access to these resources and the sharing of the benefits arising from their use need to be established between involved parties (i.e. ABS). This also applies to species collected for potential use in biological control. Recent applications of CBD principles have already made it difficult or impossible to collect and export natural enemies for biological control research in several countries. (Cock et al. 2010). This has only affected programmes that were already well underway. For example, a biocontrol agent *Freudeita cupripennis* was approved for release in NZ to control moth plant *Araujia hortorum* but, following lengthy delays obtaining permits to export it from Argentina, it was decided to source *F. cupripennis* from Uruguay instead, as obtaining export permits from Uruguay is much easier. However, because the Uruguayan population of *F. cupripennis* was a different population to the one that was originally tested and approved for release, the host specificity testing had to be repeated. The other option would have been to wait for our contact in Argentina to negotiate an export permit (essentially little extra cost, but likely to take years).

It is not clear what steps can be taken to avoid this happening in future. For example, for many weeds of South American origin, we can avoid problems with obtaining permits in Argentina by surveying in Uruguay or Chile, but we do not know if the Uruguayan or Chilean governments are planning to change their permitting procedures. Therefore, although this is a risk, we do not consider it to be predictable in advance.

Another factor that influences cost to stakeholders is whether co-investment is likely. In a decision support (prioritisation) system for Victoria that was largely based on that of Paynter et al. (2009), Lefoe and Ainsworth (2012) included a factor 'Industry Contribution' that asked 'Is industry co-investment likely and is it proportional to industry benefit?' This recognises the fact that weeds that are likely to garner co-investment are likely to cost the Victorian Government less to target. However, weed species that are likely to attract industry co-investment are likely to be weeds of primary industry, while the NBC has focussed on biocontrol of environmental weeds, largely because it is the only means of funding biocontrol of environmental weeds in NZ (see section 3.1.2). Nevertheless, this is a factor that could be incorporated into a system for the NBC. For example, by reducing the potential cost of targeting cross-sector weeds that have both environmental impacts and affect primary industry.

3.1.4 Efficacy (impact) of biocontrol

It is not easy to predict the impact of biocontrol although recent studies indicate that well-resourced programmes do have a high success rate with the majority of programmes resulting in complete or substantial control. Paynter et al. (2012) investigated a range of plant traits that have been assumed to influence weed biocontrol success by calculating an 'impact index', defined as the proportional reduction in weed density due to biocontrol (e.g., if biocontrol reduced a weed's density from 33 to 3.8 stems m^{-2}, then the reduction in stem density = 33-3.8 = 29.2 and impact index = 29.2/33 = 0.885). They found that three factors were predictors of impact:

Ecosystem: where the average impact of biocontrol on wetland and aquatic weeds is greater than for terrestrial weeds.

Mode of reproduction: where the average impact of biocontrol is higher on clonal and apomict weeds, compared to weeds that reproduce sexually. This factor may be a surrogate measure of genetic diversity of an invading weed (clonal weeds tend to have low genetic diversity, compared to outcrossing sexual weeds).

Major weed in native range: Biocontrol programmes targeting plants that are regarded as weeds in the native range tend to have lower impacts, compared to programmes that target weeds that are not regarded as weedy in the native range. This factor may be a surrogate measure of relative abundance. For example, if a target plant is uncommon or a minor component of the native flora, it is unlikely to be considered a weed. Species that are not abundant in the native range but become abundant in the introduced range may do so because they benefit from the absence of specialist natural enemies in the introduced range. Species that are abundant enough to be considered weeds in the native range may be less regulated by natural enemies. For example, spatial models indicate that under certain disturbance regimes, Scotch broom *Cytisus scoparius* can be invasive in the native range, despite the known chronic impacts of natural enemies on growth and fecundity (Rees & Paynter 1997).

Paynter et al. (2012) also demonstrated that the success of pioneering programmes predicts the success of repeat programmes against the same target weed in other regions.

In other words, if a pioneering programme against a weed was successful, then there is a good chance that this success can be repeated in other regions.

3.1.5 Multi-targeting

Releasing agents developed for one weed species on other closely related weed species has been attempted in weed biocontrol programmes overseas. For example, agents released on *Centaurea diffusa* and *C. stoebe* in the USA were released on other *Centaurea* spp. with inconsistent results. Releases failed to establish against some secondary target weeds (e.g. *C. iberica, C. calcitrapa*). Nevertheless, they brought about a dramatic decline in squarrose knapweed *Centaurea virgata* populations in Lassen County, California (Woods & Villegas 2006). Surveys in the native range of *C. virgata* had not been conducted (Woods & Villegas 2006), so this successful biocontrol programme was essentially cost-free. The biological control programmes against thistles in the USA also provided opportunities to release agents on multiple thistle species, again with mixed results (Winston et al. 2020), and resulted in non-target impacts on native thistles (Louda et al. 2003). This illustrates the heightened risk of serious non-target attack when releasing oligophagous insects to control multiple weed species that are closely related to native plants.

Groenteman et al. (2008) discussed how 'multi-targeting' could expanding the benefits of a biocontrol programme in NZ by selecting agents that could simultaneously affect major weeds and related, less-abundant plants with potential to become weeds in the future, noting that this approach could potentially be applied to thistles in NZ (which, unlike the USA, has no native thistle species). Indeed, the green thistle beetle *Cassida rubiginosa* (first released in 2007) can attack multiple thistle species. Nevertheless, we assume that because of the potential for non-target effects and the mixed results from overseas programmes, opportunities for successful multi-targeting are likely to be rather limited for most weed complexes in NZ, but a review of the potential for multi-targeting might be warranted to confirm whether or not this should be included as a factor.

3.2 Prioritisation of candidate agents

Potential projects voted on by the NBC include continuation of work already underway. As noted in Section 3.1.3 above, typically more agent species are released than are necessary to achieve control of a weed. The cost-effectiveness of weed biocontrol could potentially be enhanced if work on candidate agents is prioritised more effectively (resulting in fewer, more effective agents being released) and if prudent decisions are made to decide when work on a target weed should be suspended or ceased altogether.

An advantage of the NBC funding system compared with funding systems in some other countries is that it is possible to suspend work on a target weed so that the impacts of biocontrol can be monitored, before deciding whether control is adequate or if another agent is required and survey work should resume. This allows resources to be utilised more strategically and should ensure that the number of agents released is minimised, improving the cost-effectiveness of weed biocontrol in NZ. The downside of this approach is that if additional agents are required it takes longer to achieve control using this approach.

Candidate biocontrol agents are prioritized for further study according to their perceived potential host specificity and ability to damage the target weed as outlined below.

3.2.1 Predicting potential host specificity

Promising candidate agents for further investigation can be prioritised by predicting their host-specificity. This relies on knowledge of agent biology and taxonomy, and published host-records. Agent feeding niche and taxonomy can often infer potential host specificity. For example, gall-formers, eriophyid mites and rust fungi are commonly highly host specific (Zwölfer & Harris 1971; Smith et al. 2010; Barton 2012). Published host records are also very helpful, although they can sometimes be misleading. For example, erroneous host-records do occur and the presence of cryptic species can result in potentially host-specific agents being overlooked (Smith et al. 2018). Moreover, the host-range of some species can vary between populations. For example, most populations of the broom seed beetle *Bruchidius villosus* use only one host species, even though *B. villosus* has been reared from 12 plant genera across its entire range (Sheppard et al. 2006a). Therefore, although host records can help prioritisation, it may be prudent not to rule out a candidate agent completely based on host records. Some decisions may have to be made on a case-by-case basis depending on expert knowledge, rather than be dictated solely by a scoring system.

3.2.2 Ability to damage the target weed

Surveying the right weed in the right place

Crawley (1986) noted that host plant incompatibility can be a cause of failure and it has been shown that some agents are restricted to host biotypes so that it can be crucial to match the correct candidate agent with the correct weed biotype. A good example in New Zealand is lantana, which has varieties that can differ in their susceptibility to biocontrol agents (Mukwevho et al. 2017). Molecular techniques have been developed so that invasive weed populations can be compared with the populations in the native range to narrow down where to search for natural enemies that are adapted to attack the invasive biotype (e.g. Sobhian et al. 2003; Paterson & Zachariades 2013). If genetic matching is required, it could potentially add to the cost of a programme (although the cost of genetic analyses has plummeted over time, there can be a considerable cost associated with obtaining samples to analyse). However, for novel programmes, it is generally unknown whether genetic matching is likely to be necessary in advance. For repeat programmes, where the importance of genetic matching is known, it will generally be straightforward to check that the biotype present in NZ is a good match to the available agent(s) as genetic markers will have already been developed. Therefore, although genetic matching can be an important factor influencing biocontrol success, it has limited ability to help prioritisation of novel biocontrol targets.

Predicting ability to damage the target weed

The ability of a candidate agent to damage the target weed can sometimes be obvious during the exploratory phase of a weed biocontrol programme or from published literature, prior to any exploration. For example, the heather beetle *Lochmaea suturalis* is a well-known pest of heather *Calluna vulgaris* in Europe and was an obvious candidate to prioritise for biological control of heather in NZ (Syrett et al. 2000). However, damage by some agents can be cryptic (e.g. root-feeders) or highly transient and easy to miss if exploration does not coincide with an outbreak (e.g. plant pathogens can outbreak following favourable climatic conditions and become difficult to detect between outbreaks). Some species (e.g. Sydney golden wattle gall wasp *Trichilogaster acaciaelongifoliae*) may be relatively uncommon and not particularly damaging in the native range, but become abundant and damaging when introduced into a country where their natural enemies are absent or where the host plant population density is much higher (Crawley 1988). Given the difficulties identifying potentially effective agents, a range of approaches have been suggested to assist prioritisation.

Wapshere (1970) proposed 'ecoclimatic' studies to make continuous comparisons between ecological factors, such as target weed density and habitat breadth in the native range and the range invaded by a plant species to get a reasonable indication of the potential impact of biocontrol.

The long-term studies recommended by Wapshere (1970) are expensive, time consuming, and have a number of potential pitfalls: Harris (1973) noted that: (a) the multiplicity of species attacking a weed within its native range makes it difficult to distinguish the effects of each; (b) plant density often varies between the native and introduced range and agents that are prevalent at low densities may not be the most effective at reducing high densities of the weed; and (c) the effects of parasites must be discounted as the agent will be introduced without them.

To simplify agent selection, Harris (1973) proposed a scoring system based on criteria that he hypothesised should assist the selection of the most effective agents. Twelve hypothetical attributes of a successful agent were listed (Appendix 1). This system was updated by Goeden (1983). However, Wapshere (1985) critiqued the approach and concluded that few of the criteria selected by Harris (1973) are helpful predictors and argued that an ecoclimatic method should be superior.

Demographic attributes have also been correlated with agent success (Crawley 1986, 1988, 1989). For example, Crawley (1986) noted that for many target weeds, the insects with the greatest probability of establishing exhibit higher fecundity and smaller body size and pass through more generations per year, and that the insects most likely to depress weed abundance to low levels show precisely the same combination of traits. This contrasted with Wapshere's (1985) assertion that it is rare to find an agent that is very damaging and that produces a prolonged attack on a weed, and that agents that cause critical damage over a limited time can be highly effective.

The various approaches to agent selection (Wapshere 1970; Harris 1973; Goeden 1983; Wapshere 1985; Crawley 1986, 1988, 1989) were compared by Blossey (1995) who concluded that none of the protocols for selecting the most promising candidates was satisfactory.

Despite the failure of previous systems, it has been argued that some form of pre-release efficacy assessments should be performed, to aid the selection of agents and improve overall success by avoiding the use of agents that are not sufficiently damaging (McClay & Balciunas 2005). Such studies can be undertaken in containment or shade houses but can potentially be misleading: for example, it is difficult to predict the population densities that agents will reach in the introduced range and therefore set up realistic levels of herbivory; and laboratory experiments may underestimate damage potential because plants in containment are not subject to additional stressors that would occur in the field, such as drought or competition with other plants, that might exacerbate the impact of herbivory.

Field studies, such as the Wapshere (1970) ecoclimatic approach, may be more informative, but are expensive and, therefore, may not be cost-effective: Sheppard (2003) noted that even if there is some degree of acceptance that ecological studies can assist agent selection, the level to which such studies can be carried out will be largely determined by available resources: whether each activity is worth the resource cost will depend on the importance of the weed and the complexity of the selection process, i.e. the number of agents to choose from. Such research in NZ could potentially be funded through MBIE core funding but funding is only sufficient to research the population dynamics of a handful of weed species. Moreover, MBIE funding is intended to test scientific hypotheses over relatively short timeframes and not cover the operational cost of biocontrol programmes indefinitely, so ultimately the NBC would have to cover the cost of such studies.

Given the cost (and questionable cost-effectiveness) of long-term ecological studies, identifying correlates of agent success remains an attractive approach for prioritising candidate agents. Reviews have indicated that some taxonomic groups, such as chrysomelid and curculionid beetles, appear to make better biocontrol agents than others (e.g. Syrett et al. 1996; Clewley et al. 2012) and that some feeding niches tend to be more damaging than others. For example, ~54% of root feeders contribute to control versus 34% of aboveground herbivores (Blossey & Hunt-Joshi 2003). Few seed-feeders are thought to have reduced plant fecundity sufficiently to reduce target weed populations, although some have (Sheppard 2003). Moreover, as noted in Section 3.4, agents that reduce seed set can enhance overall control in combination with other agents (Hoffmann & Moran 1998), reduce the rate that a weed invades (Paynter et al. 1996; Norambuena & Piper 2000), and assist in integrated control by reducing the amount or reinvasion after control by conventional means (e.g. Rees & Paynter 1997; Rees & Hill 2001).

Despite these advances, Sheppard's (2003) statement that 'universal criteria for agent selection still appear unlikely' is still largely true. This is because the traits of successful agents are likely to vary according to the traits of the target weed. For example, rosette feeders might be the best agents for biennial thistles but have no relevance to biocontrol of woody shrubs or invasive grasses. Root-feeders may be effective agents against perennial terrestrial weeds but have no relevance to aquatic weeds, etc. We strongly suspect that there are insufficient completed weed biocontrol programmes worldwide for an analysis that includes both plant and agent traits to identify 'tailored' selection criteria that matches the ideal agent with the type of target weed. It is, therefore, unlikely that a points-based scoring system to assist agent selection can capture the intricacies of these relationships using the current knowledge available.

Despite the general lack of progress in predicting biocontrol impact, there is one potential predictor of agent effectiveness where there was agreement between Wapshere (1985) and Harris (1973) and where progress has been made: the importance of predators and parasites. Wapshere (1985) considered this to be a strong criterion because if predators or parasites occurring in the native habitat are absent from the new habitat, there will be a corresponding increase in reproductive capacity of the agent available to be employed in controlling the weed.

Wapshere (1985) considered that the risk of an agent being subject to high levels of parasitism and/or predation could not be estimated. However, an 'ecological analogue' approach was subsequently developed by Paynter et al. (2010) to estimate this risk. Their study indicated that native herbivorous arthropods that feed on the target weed in NZ are a predictable source of native parasitoids (or for some agents, specialist predators; Paynter et al. 2018) that are likely to be capable of attacking a closely related biocontrol agent that shares a similar feeding niche. Paynter et al. (2010) argued that the chance of selecting a successful agent should be increased by avoiding agents that have ecological analogues awaiting them in the introduced range. For example, a potentially host specific moth, *Lobesia coccophaga* Falkovitch, was recently given low priority for biocontrol of Japanese honeysuckle *Lonicera japonica*, due to the presence of native analogues (native tortricid moths) feeding on *L. japonica* in NZ. These native tortricid moths are likely to be hosts of specialist parasitoids that are capable of attacking and potentially reducing the impact of *L. coccophaga* (Paynter et al. 2017). Paynter et al. (2018) also noted that there is evidence that the presence of a parasitized 'introduced analogue' (defined as an introduced herbivore that is taxonomically related to the subsequent agent and has a similar lifestyle niche and feeds on the target weed or a congeneric plant) indicates the risk of any subsequent introductions being parasitized.

Finally, although evidence is lacking, we suspect that agents that are observed to be severely damaging the host plant in the native range are highly likely to be effective in the introduced range. For example, Paynter et al. (2018) compared the fortunes of two phytophagous mite biocontrol agents in NZ and noted that, in the native range, the status of both agents is similar to the situation in NZ: the gorse spider mite *Tetranychus lintearius* is uncommon and rarely damaging in Europe, whereas the broom gall mite *Aceria genistae* is common in the Cévennes region of France, where it appears to be one of the few natural enemies capable of killing Scotch broom *Cytisus scoparius* plants.

For many biocontrol programmes the most cost-effective approach may be to prioritise by accounting for the presence or absence of ecological analogues, observations of damage in the native range, and being prepared to release more than one agent species until an agent is found that successfully controls the target weed.

4 Review of the NBC Prioritisation tool

The NBC prioritisation tool is an excel file with two worksheets for prioritisation: a 'plant research prioritisation' worksheet and an 'agent prioritisation' worksheet. These worksheets link to plant and agent 'scoring worksheets' so that scores are automatically calculated according to responses to questions in the prioritisation worksheets.

In this section we discuss which questions should be included in a scoring system and which questions should be excluded. We also discuss how the scores should be weighted according to current knowledge.

4.1 Weed prioritisation ('plant research prioritisation')

As noted in the review of past prioritisation schemes, weed prioritisation is usually assessed by considering three criteria: weed impacts (current and potential future impacts); the cost of implementing biocontrol; and the predicted efficacy (impact) of control.

We have indicated which 'plant research prioritisation' questions are pertinent to each of these criteria (Appendix 1). We recommend that the plant research prioritisation questions and scores are arranged so that these three criteria are scored separately. This will enable overall rankings to be adjusted depending on the relative importance assigned to these criteria, according to input from stakeholders to ensure ranking suits their needs. For example, when prioritising target weeds for Australia, Paynter et al. (2009) calculated an overall ranking based on:

$$\textit{Total Score} = \textit{Weed impacts \& future threat score} \times \textit{Efficacy (impact) of biocontrol score} \times \textit{1/Cost of implementing biocontrol score}$$

At a stakeholder workshop for prioritising weed targets for the Cook Islands, the ranking calculation was adjusted as follows (Paynter & Dodd 2012):

$$\textit{Total Score} = \textit{Weed impacts \& future threat score} + \textit{Efficacy (impact) of biocontrol score} - \textit{Cost of implementing biocontrol score}$$

However, stakeholders expressed concern that the total score favoured the best biocontrol targets and underemphasised the most important weeds. A table was therefore prepared to assist prioritisation, arranged as a matrix of weed species grouped according to their importance and the predicted impact of biocontrol (Table 3) (see also Paynter et al. 2009). The weed species eventually selected as targets for biocontrol were all species with high importance scores and high and medium efficacy (impact) of biocontrol scores. Species that had only medium importance scores but high efficacy (impact) of biocontrol scores resulting in similar overall scores were not targeted as stakeholders expressed a preference to target the most important weeds.

Using matrices to assist the determination of priority taxa has also been used in other prioritisation systems (e.g. Morin et al. 2013; van Klinken et al. 2016; Raghu & Morin 2018).

The matrix approach taken by Paynter and Dodd (2012) included Weed impacts & future threat score and the Efficacy (impact) of biocontrol score. An improvement to this approach might be to calculate a total biocontrol score, where:

Total biocontrol score	=	Efficacy (impact) of biocontrol score	×	1/Cost of implementing biocontrol score

A table could then be prepared to assist prioritisation, arranged as a matrix of weed species grouped according to their importance and the total biocontrol score.

Table 3. Matrix of weed species in the Cook Islands grouped according to their importance and the predicted impact of biocontrol from Paynter and Dodd (2012). Suitability of targets range from the best targets (high importance and high predicted impact; green shading) in the top left-hand cell to the worst targets (low importance and low predicted impact; red shading) in the bottom right cell. Cells with the same shading should have similar suitability as targets for biocontrol. Species that were eventually targeted for biocontrol are typed in a red font

		Weed importance		
		High	**Medium**	**Low**
Impact of biocontrol	**High**	*Arundo donax* *Xanthium pungens*	*Clerodendrum chinense* *Ludwigia octovalvis*	*Sida rhombifolia*
	Medium	*Cardiospermum grandiflorum* *Mikania micrantha* *Spathodea campanulata* *Passiflora rubra* *Psidium cattleianum*	*Phyllostachys bissetii* *Sorghum bicolor* subsp. *drummondii* *Hedychium coronarium* *Calopogonium mucunoides* *Centrosema pubescens* *Ceropia pachystachya* *Pueraria phaseoloides* *Syzigium jambos* *Tithonia diversifolia* *Cestrum noturnum*	*Tecoma stans* *Elephantopus* spp. *Ardisia ellipta* *Hyptis pectinata* *Adenanthera pavonia*
	Low	*Merremia peltata (Decalobanthus peltatus)* *Cenchrus echinatus* *Nephrolepis saligna* *Pennisetum pupureum* *Cuscuta campestris* *Senna obtusifolia*	*Acacia* spp. *Brachiaria mutica* *Mimosa pudica* *Indigophora suffruticosa*	*Stachytarpheta urticifolia* *Bidens pilosa* *Desmodium incanum* *Passiflora malformis* *Triumfetta rhomboidea*

4.1.1 Weed impacts and future threat

We recommend ranking weeds by their impacts and threat and also by the efficacy and cost of existing control options (with the assumption that species that can be effectively managed with existing tools are a lower priority than weeds that cannot be easily or cheaply managed).

As noted in section 3.1.2, Downey et al. (2010) proposed a model to rank environmental weeds in NSW, Australia, that could be undertaken in the absence of quantitative data on actual impacts. Given the general lack of quantitative data on the impacts of environmental weeds in New Zealand, we recommend that a ranking system should follow a similar approach, with modifications, where necessary, to suit the needs of the NBC.

Due to the large number of weed species in NSW, Downey et al. (2010) conducted an initial triage to reduce the number of weeds under consideration by investigating the 'degree of naturalization' and excluding species with small distributions or not widely naturalized, along with species for which there was insufficient information to make an accurate determination). As noted in section 3.1.2, biocontrol is normally directed at the most pressing current priorities rather than species that are potentially important future weeds. A similar 'triage process' could be used in NZ, to reduce the number of weed species under consideration although this may not be necessary if the NBC provides a manageable shortlist of weed species for prioritisation.

Downey et al. (2010) also excluded agricultural weeds and species primarily associated with wastelands and disturbed areas. In NZ, biocontrol programmes that target weeds that predominantly affect primary industries have mainly been funded by the MPI Sustainable Farming Fund (SFF) (which was recently superseded by the Sustainable Food & Fibre Futures; SFF Futures). To counterbalance the emphasis of SFF funding on weeds of primary industries, the NBC has focussed on biocontrol of environmental weeds. However, because NBC funding now can be used to leverage SFF Futures funding, there is strong motivation for making cross-sector weeds (i.e. weed species that affect both primary industry and the conservation estate) a high priority, as well as plants that are purely environmental weeds. We therefore suggest that **weed type** (equivalent to **Primary impact** in the tool) is classified as follows:

- Mainly agricultural: e.g. almost entirely within pasture and cropping systems (exclude from further consideration)
- Mainly environmental: i.e. mainly affecting native habitats (include in ranking)
- Cross-sector: i.e. causing significant issues in both natural habitats and for primary industries (include in ranking)
- Mainly social/cultural impacts: e.g. not significant environmental or agricultural weeds but impacts to human health, reduced recreational use, loss of cultural value, aesthetic qualities, etc. (include in ranking)
- Wasteland/ruderal weeds: e.g. neither important agricultural nor environmental weeds with no significant social/cultural impacts, being a species primarily of wastelands, roadsides, and disturbed areas (exclude from further consideration)

Note here we have expanded *Human health impacts* from the tool to *"social/cultural impacts* to include not only impacts to human health but also to other socio-cultural impacts, such as reduced recreational use, loss of cultural value, aesthetic qualities, etc.

The model used by Downey et al. (2010) used five attributes to assess the likely threat and ability of the remaining weed species (after the initial triage) to impact upon biodiversity, namely:

A. Spatial threat: Downey at al. (2010) scored the threat a weed posed within each region (botanical divisions) and then summed the scores for each division to produce a **weighted spatial threat**. This is therefore equivalent to the **Regional distribution** part of the tool, which also scores local distribution within each region and then sums the totals. In the tool, **Regional distribution'** has four levels (insignificant, minor, moderate, major). We recommend increasing this to six levels to account for perceived future threat:

- No threat: absent & unlikely to invade the region.
- Potential threat: absent but considered to have the potential to invade the region.

- Minor threat: known from a few very small infestations in the region (e.g. <5).
- Low threat: present but not widely distributed.
- Moderate threat: localised impacts.
- High threat: widespread impacts in the region.

Including potential threat albeit with a rather low weighting, reduces the need to include **No. of regions: potential under current without management** or **potential distribution under climate change,** which are listed as separate questions in the tool. Predicting potential distributions (with or without climate change) requires extensive climatic modelling that is time-consuming and relies on adequate distribution data of the weed species being modelled. Modelling the potential distribution of multiple weeds is likely to be an expensive and time-consuming endeavour, and accurate models may not be produced for certain weeds if distribution data is inadequate. If a question cannot be answered reliably, which is currently the case, then any ranking based on that question is also unreliable. We therefore agree with Conser et al. (2015) who, when developing a scoring system for ranking weed risk, argued that questions that cannot be reliably answered should be excluded. Therefore, although potential distribution is a desirable factor to consider when ranking weeds, we think this attribute should be included only if these obstacles can be overcome. It could be incorporated into the tool in the future, if the relevant modelling is done, but it is worth bearing in mind that current models are not highly reliably predictors of weed impacts (e.g. Peltzer et al. 2008; Jones et al. 2010; Bradley 2013).

Other relevant factors included in the tool (**no. RPMPs listed** and **Socio-political pressure to control per region**) could easily be incorporated onto a spatial threat score, based on the Downey et al. (2010) approach.

B. Native species impact: This equates to the **Ecosystems impacted/impact level** score in the tool. Downey at al. 2010 scored a weed species 1–4. We recommend updating this to incorporate scoring based on the Environmental Impact Classification of Alien Taxa (EICAT) definitions for assessing the magnitude of environmental impacts of alien species as follows:

- Data deficient or of only minimal or minor concern (i.e. low, or limited degree of threat or impact observed to date
- Moderate degree of impact (e.g. impact is to specific individuals of a native species, rather than to populations or ecosystems)
- Major impact (e.g. where a weed species has a significant negative impact on populations of native species, but not to the level of 4), or
- Massive impact (e.g. transformer species that are considered capable of; or are presently modifying the invaded ecosystem to such an extent that they alter ecosystem processes). For example, fire regimes, nutrients, water flows, physical habitat modification, facilitation of other weed species.

The tool scores impact between zero (none or data deficient) and 3 for major (transformative) weeds. We recommend using Downey et al.'s (2010) 1–4 score scale on the basis that by taking up space that could potentially be occupied by a native plant, a weed is unlikely to have zero impact unless it is only ever present in heavily modified ecosystems where native plants are totally absent. This also avoids the problem of having a zero score when multiplying scores for all the factors together to create an overall weed importance score.

C. Invasive ability: Downey et al. (2010) scored this as:

- Invasive ability restricted (e.g. to the edges of vegetation communities only).
- Invasive with limitations (e.g. while the weed species can invade intact or undisturbed vegetation communities, it typically does not do well in such situations, invasion is often aided by other factors like disturbance), or
- Ability to invade without limitations (e.g. invasion is not subject to biotic barriers or invasion constraints or requires a disturbance event).

Due to stakeholder concerns during the development of this review, the wording of the scoring was changed as it was felt the approach taken by Downey et al. (2010) would overemphasise weeds of native forest at the expense of many very important weeds that are often associated with disturbance. We therefore suggest altering the scoring to reflect the speed of invasion:

- Relatively slow to invade or reinvade following control.
- Invades moderately rapidly and infested sites require repeated control every few years, or
- Invades/reinvades very rapidly and is very difficult to contain/and infested sites require control annually or even more frequently.

Ability to invade was included within the **Ecosystems impacted** score of the tool, rather than treated separately. For example, 'disturbed/open native forest' was listed as well as 'intact native forest' and 'native forest margins'. We think that the Downey et al. (2010) approach of listing habitats affected and then scoring a weed according to its ability to invade is better as it minimises the number of ecosystems that need to be listed (see section E, below).

D. Number of native plant species potentially at risk: This factor is not included in the tool and we do not consider that it would be useful to include it without further refinement. Downey et al. (2010) used herbarium records to determine the total number of native plant species in each region (botanical division). Although a national vascular plant checklist exists (De Lange & Rolfe 2010), we were unable to find regional checklists. If regional checklists do not exist, it would be a major undertaking to determine the number of native plant species in each of the regions provided in the 'list of regions' heading in the tool. Moreover, the total number of species in a region might not be the best measure of the threat a weed poses to native biodiversity. For example, aquatic weeds will only ever be a threat to other aquatic plants, regardless how diverse the terrestrial flora within a region. Some regions might have a relatively low diversity of native plants but nevertheless have high conservation value due to the presence of critically endangered species. Moreover, the total number of species does not give a measure of urgency. Millar et al. (2017) examined regional patterns in endemism in the vascular flora of New Zealand and noted that many areas of high endemism are often poorly protected. It may be desirable to determine which weed species threaten these regions and prioritise accordingly, but this is beyond the scope of this report and we think that there is currently insufficient information to include this criterion.

E. Habitat type: This is equivalent to the **Ecosystems impacted** question in the tool. Downey et al. (2010) listed 11 habitat types and calculated the proportion of habitats invaded by each weed dividing the number of habitat types (E) invaded by the maximum number of habitats present (Emax). Some of the habitats listed are not relevant to NZ (e.g. Mallee and Arid / desert) and some habitats that are relevant to the NBC were not included (e.g. geothermal). We recommend listing 11 habitats broadly based on terrestrial habitat types identified by Singers and Rogers (2014) (namely: native forest, native scrub, Alpine/subantarctic, wetland/riparian, coastal dunes, cliffs, scree/boulder field, braided rivers, saline, geothermal) plus 'aquatic' (which could potentially be split into two: 'aquatic: rivers' and 'aquatic: lakes').

The Plant Research Prioritisation worksheet of the tool has additional questions that are included in the plant scoring module that were not included in the Downey et al. (2010) system. Most of these questions pertain to the physiological and reproductive outputs of the target weed that are assumed to be correlated with invasiveness (namely, Reproductive ability; Plant fecundity; Seed bank persistence; Growth rate, Primary dispersal type and Other invasive traits). There is also a question that asks if the weed is invasive in climatically similar countries elsewhere.

Many of these traits are correlated with invasiveness and included in weed risk assessment models (WRA; e.g. Virtue et al. 2006). We suspect that some questions, though, cannot be answered reliably. For example, the number of seeds per plant and seed bank persistence are unlikely to have been accurately quantified for many weed species. Moreover, this approach is potentially highly misleading and could therefore result in unnecessary expenditure if applied to post-border weed prioritisation. Although reproductive ability, plant fecundity, and seed bank persistence are correlated with weed impacts, there are major exceptions, e.g. *Tradescantia fluminensis* is a serious weed of native forest remnants that reproduces vegetatively (Standish et al., 2004), but Plant fecundity and seed bank persistence are likely to underestimate the severity of this species (and other weeds that rely on vegetative reproduction). Including these factors might result in worse prioritisation compared with prioritisation based on impacts alone.

Primary dispersal type is potentially misleading because human-mediated dispersal (e.g. dumping garden waste, seeds and vegetative fragments stuck to clothing, mowing machines, etc.) is of overriding importance for many weeds in NZ, so the mode of natural dispersal is largely irrelevant when measuring invasiveness. For example, Aikio et al. (2010) noted that 'the frequency with which relatively long-distance dispersal events were observed across over 100 plant species in NZ is suggestive that, in most cases, it is human-mediated at the spatial scales reported here'. Prioritising weeds on correlates of natural dispersal ability may therefore underestimate the invasiveness of weeds that are primarily dispersed by human activities, prioritising the wrong species.

Growth rate and other invasive traits should also be removed as they are likely to discriminate against slow-growing species that inhabit low resource and/or undisturbed environments (Funk 2013). This is because weed invasiveness is often attributed to traits promoting rapid reproduction and growth that take advantage of resource-rich and disturbed habitats (Dainese and Bragazza, 2012; McGrannachan et al. 2019).

Invasive in climatically similar countries elsewhere is also an imperfect measure of potential future risk. For example, many WRA schemes recognise that invasiveness of a plant elsewhere is a good predictor of the risk it will be invasive in a novel environment (e.g. Virtue et al. 2006). However, some species which are problematic overseas are not invasive in New Zealand despite having been naturalised for many years. For example, ten *Centaurea* species have become fully naturalised (8 species) or casually (2 species) naturalised in New Zealand (Howell & Sawyer 2006), some dating back to the mid-1800s (Webb et al. 1988). Although several of these species (e.g. *Centaurea jacea, Centaurea maculosa (=C. stoebe subsp. micranthos) Centaurea solstitialis*) are highly problematic weeds that have been targeted for biocontrol in other countries (Winston et al. 2020), they were either not mentioned as weeds or only described as 'occasional' in New Zealand by Popay et al. (2010). We do not think there is much to gain by raising their status as potential targets for weed biocontrol.

A reason for this unreliability is that although WRA models correctly identify most potential invasive species, the rate of false positives (i.e. non-invasive species are incorrectly identified as invasive) is very high, outnumbering the correct decisions (Smith et al. 1999). In pre-border WRA, the high rate of false positives is considered acceptable because the damage caused by introducing a pest is generally greater than that caused by not introducing a harmless organism that is potentially useful. However, the high rate of false positives means that if a WRA approach is applied injudiciously to post border prioritisation to identify weed biocontrol targets, a high proportion of potential weed targets are likely to be relatively harmless. The number of false positives could potentially be reduced by adopting a higher threshold score (Caley et al. 2006). Nevertheless, we think prioritisation based on plant traits that predict invasiveness is likely to be far less reliable than assessing weed impacts directly, and as noted previously, weed biocontrol is normally reserved for the most pressing priorities where impacts are already evident. We, therefore, think these questions should be removed from the NBC prioritisation tool.

Persistence of weeds is covered by a range of questions in the tool where: Primary control method asks if a weed is controlled by selective or non-selective herbicide or is controlled manually and a second question asks if multiple follow ups are required.

Scoring Primary control method is problematic: For example, manual control methods are often more expensive (time consuming) than herbicide treatments, but the non-target impacts are likely to be less severe. Multiple follow ups required? is a factor associated with efficacy and cost of existing control options as well as the potential severity of non-target impacts. We therefore recommend replacing these questions in the tool with three questions to specifically address **Efficacy of existing control measures, Cost of existing control measures,** and **Non-target impacts of existing control measures** as follows:

G. Efficacy of existing control measures asks whether current options are effective:

- Yes, current options are highly effective.
- Current options are moderately effective.

- No, current options are largely ineffective.

The cost factor could be captured under a new question **H. Cost of existing control measures** as follows:

- Cheap
- Expensive
- Prohibitive (e.g. multiple follow ups required or area to be controlled is vast)

I. Non-target impacts of existing control measures are addressed as follows. Do existing control methods have significant non-target impacts on valued flora?

- Minimal or temporary non-target impacts
- Some long-term, non-target impacts (e.g. selective herbicides kill native dicots)
- Major long-term, non-target impacts to desirable vegetation.

We also recommend combining the following questions in the tool (*Restricted site access – physical*, *restricted site access – eco/socio-cultural*, and *legislative limits*) into one question: **J. Restrictions to implementing control** with the following responses:

- None or few restrictions to implementing control.
- Access is restricted at a minority of infestations due to a lack of physical access, eco/socio-cultural reasons, or legislative limits to current control methods (e.g. application over water) (5)
- Access to most infestations is restricted due to a lack of physical access, eco/socio-cultural reasons, or legislative limits to current control methods (e.g. application over water) (10)

4.1.2 Cost of implementing biocontrol

The plant research prioritisation worksheet has several questions that are relevant to estimating the cost of implementing biocontrol. There are no major gaps/missing questions although we recommend some modifications to questions and their weightings. We do not recommend retaining all questions, and a full list of questions and comments on why they should or should not be retained is given in Appendix 2 with some further explanation below:

We recommend retaining a question pertaining to: *native range – political risk (safety and regulatory regimes)?* In in most cases, alternative countries can be surveyed if parts of the native range of a target weed are unsuitable. For example, we would not currently recommend surveying for agents on a novel weed target in Argentina due to the problem of exporting agents from there but exporting candidate agents from neighbouring Uruguay is currently feasible. However, if the entire native range of a weed is within a country or countries that are unsafe to visit, or where obtaining export permits is currently problematic, then native range survey work on a target weed should not proceed. We therefore regard this as a stop/go question:

Are their safety or regulatory issues preventing agents from being sourced from the native range?, where Y = the programme should not proceed until agents can be sourced; N = the programme (or further consideration within the prioritisation scheme) can proceed.

We recommend replacing the question concerning money already invested in biocontrol with a stop/go question: *Are there any additional candidate agents that have the potential to be host-specific and to control the target weed?* If the answer is No (i.e. all known promising candidate agents have been investigated), then work should cease. This is because past investments (i.e. sunk costs) should not justify further expenditure – it can be better to cut one's losses and cease work on a target weed if the prospects for finding a suitable agent appear unlikely, rather than proceed in the hope of justifying past investment (the Concorde fallacy).

Selecting the most damaging agent is by no means easy. Denoth et al. (2002) demonstrated that there is a correlation between the numbers of agent species released and success of weed biocontrol projects but noted that a single agent species was responsible for successful control in many instances. They argued that the correlation between the number of agent species released and biocontrol success is because the chance of finding the right agent increases with number of agents released (akin to a lottery).

McFadyen (1998) noted that two-thirds of weed biocontrol agents that establish fail to suppress their target weed (i.e. only one in three agents (33%) that establish is effective). The establishment rate of weed biocontrol agents in New Zealand to date has been c. 82% (67 agent species released; 51 established/recovered in the field after one winter; 11 assumed to have failed to establish; and 5 where it is too early to tell). Combining these probabilities indicates that on average only c. 27% (i.e. 82% of 33%) of released agents are likely to suppress their target weed. If we assume that the lottery model proposed by Denoth et al. (2002) is accurate, then we might expect that the release of multiple agent species will often be required before an effective agent is finally found. For example, based on these probabilities, approximately one in five programmes is likely to fail to select an effective agent in the first five species released (Table 4). Recent scientific advances in agent release strategies and agent selection should increase the success rate of biocontrol. Nevertheless, the failure of previously released agents does not necessarily mean a target weed is not amenable to biocontrol and should not be a reason to cease a programme if there are additional candidate agents that have the potential to be host-specific and to control the target weed.

Table 4. Cumulative probabilities of selecting an effective or ineffective agent against number of agents released and the estimated cost of a programme based on a correlation between number of agents released and programme cost (Paynter et al. 2015)

No. agents released	Cumulative probability of selecting an effective agent	Cumulative probability of failing to select an effective agent	Estimated cost of programme ($M) (novel programmes)
1	0.272	0.728	0.692
2	0.469	0.531	1.254
3	0.614	0.387	1.816
4	0.719	0.282	2.378
5	0.795	0.205	2.940
6	0.851	0.149	3.502
7	0.891	0.109	4.064
8	0.921	0.079	4.626
9	0.942	0.058	5.188
10	0.958	0.042	5.750

The question *Targeted for biocontrol overseas?* is important because this is the biggest predictor of programme cost. The NBC Prioritisation tool poses this as a Yes/No question, but we recommend a more nuanced approach, reflecting the status of a programme overseas and how far it has progressed (Table 5). The scores suggested in Table 5 reflect the fact that novel programmes cost c. 4 times more than repeat programmes.

As discussed in Section 3.1.3, above, we think there is justification for including taxonomic isolation of the target weed as a factor when estimating the cost of implementing biocontrol, although, in the absence of quantitative data, the adjusted score that we have suggested for weeds that have a valued congeneric plant in NZ (Table 5) will likely need to be revised in the future when the impact of this factor has been assessed. Note that we have simplified the question to *Presence of a valued congeneric plant in New Zealand*. We do not think there is any merit in having separate questions regarding Closely related – native species and Closely related primary-production species, as it only takes one key test plant to derail a biocontrol programme. Moreover, the potential for non-target attack on ornamentals is unlikely to influence an EPA decision because of the benefit to cost considerations and the fact that alternatives to ornamental species are always available.

Agents approved by the EPA in the past that might attack ornamentals include the moth plant beetle *Freudeita cupripennis* (which can develop to adult on tweedia *Oxypetalum caeruleum*), the Japanese honeysuckle stem beetle *Oberea shirahatai* (which is a potential risk to ornamental *Lonicera* spp.), and the green thistle beetle *Cassida rubiginosa* (which may attack ornamental *Centaurea* spp.). Furthermore, if an agent has already been released, it might be hard to justify releasing a subsequent agent that could attack an ornamental if the impact of the first agent has not been assessed. However, this is an agent prioritisation issue not a weed prioritisation issue and should therefore not influence weed prioritisation. We therefore recommend excluding consideration of potential risk to ornamental plants in the 'plant research prioritisation' section of the NBC Prioritisation tool or giving the response a very low weighting.

Table 5. Suggested scoring the cost of a weed biocontrol programme

Programme type	Score
a. Novel programme	38
b. Novel shared programme: overseas exploration stage	28
c. Novel shared programme: overseas exploration has already been conducted; agents testing stage	18
d. Repeat programme (agents have already been released overseas and could be imported into NZ)	10
e. Presence of a valued congeneric plant in New Zealand	Add 12 points to the above scores if a valued congeneric plant is present in New Zealand

4.1.3 Efficacy (impact) of implementing biocontrol

As discussed in section 3.1.4, the impact of a biocontrol programme is best estimated by assuming that a repeat programme will have a similar impact to that reported in regions where biocontrol was pioneered and, for novel targets, that the likely impact (i.e. scoring) will depend on the combination of three predictor variables, according to Paynter et al. (2012). These predictor variables were omitted from the NBC Prioritisation tool and should be added. The average impact (converted to percentage reduction) for each combination of these factors is given in Table 6.

Table 6. Predictions of the percentage reduction achieved by biocontrol for each of the eight combinations of the predictor variables (From Paynter et al. 2012)

Major weed in native range	Reproduction	Ecosystem	Percentage reduction from biocontrol
No	Asexual	Aquatic/wetland	93
No	Sexual	Aquatic/wetland	77
No	Asexual	Terrestrial	80
No	Sexual	Terrestrial	50
Yes	Asexual	Aquatic/wetland	69
Yes	Sexual	Aquatic/wetland	36
Yes	Asexual	Terrestrial	41
Yes	Sexual	Terrestrial	15

Questions in the NBC Prioritisation tool that pertain to the impact of biocontrol are identified in Appendix 1. We do not recommend retaining all questions, and a full list of questions and comments on why they should or should not be retained is given in Appendix 1 with some further explanation below:

As discussed in section 3.2.2, we think the question *Taxonomic certainty of what we have in NZ* should be moved from the Weed Prioritisation to the Agent Prioritisation section. This is because it is generally unknown whether genetic matching is likely to be necessary until a programme is underway and plant samples have been collected in the native and exotic range for comparison. Even then, this work is often only performed if testing results indicate that there might be a problem or if there is some uncertainty regarding the native range of a weed. If it is discovered that agent/weed biotype matching is required, then this might influence agent prioritisation once a programme has begun.

The potential benefits of targeting *closely related pest species* are also likely to be limited. For pioneering programmes, the potential to target multiple species would normally be unknown until specificity testing has been done. We suggest that this factor could either be omitted or included with a relatively low weighting and a proviso added to the question to account for the increased risk of non-target attack when using oligophagous agents, e.g. *Provided there are no closely related (generally congeneric) valued species at risk of non-target attack, are there closely related pest species that could be targeted*.

As discussed in Section 3.1.3, we think there is theoretical justification for including taxonomic isolation of the target weed as a factor when estimating the impact of biocontrol. The potential importance of this factor stems from the observation that several successful agents released in the past worldwide would not be approved for release under the current more risk-averse regulatory systems due to the potential for them to damage congeneric non-target plants. This implies that if more complex specificity testing could not be performed to demonstrate safety, these programmes would have been forced to search for other less risky candidate agents, potentially increasing the risk of failure (as well as increasing the cost of the programme). However, in the absence of quantitative data, it is unclear how to score this. We recommend a small adjustment to the scores in Table 6 – perhaps a 5% reduction to the mean percentage reduction from biocontrol score for plants that possess a valued congener. Note that we recommend simplifying this question to *Presence of a valued congeneric plant in New Zealand*. We do not think there is any merit in having separate questions regarding Closely related – native species and Closely related primary-production species as it only takes one key test plant to derail a biocontrol programme. Moreover, potential for non-target attack on ornamentals is unlikely to influence an EPA decision because of benefit to cost considerations and the fact that alternatives to ornamental species are always available (Pemberton 2002).

As noted by Paynter et al. (2009), there is a risk that if a predictive framework is used as the only tool for prioritisation, then it may become a self-fulfilling prophesy. If conventional wisdom states that biological control is unlikely to succeed against weed species that possess a certain combination of features, then it may result in that weed type never being targeted for biological control, reinforcing the belief that biocontrol could never succeed against such weeds. It should therefore be emphasised that biocontrol has succeeded against weeds with the worst combination of predictor variables (i.e. a terrestrial weed that reproduces sexually that is regarded as a major weed in the native range), such as ragwort *Jacobaea vulgaris* (e.g. McEvoy et al. 1991; McLaren et al. 2000).

This may indicate that biocontrol can potentially succeed against any target weed, provided programmes are adequately resourced (Paynter et al. 2012).

Moreover, the predictive framework does not account for the potential benefits of partial biocontrol when integrated with other control options. For example, even if the impact of biocontrol is insufficient to reduce populations of a target weed on its own (resulting in a low impact index) it may nevertheless assist in integrated control by reducing the amount or reinvasion after control by conventional means (e.g. Rees & Paynter 1997; Rees & Hill 2001). For example, seed-feeding biocontrol agents rarely reduce the existing infestations of a weed on its own, but may significantly reduce seed dispersal and seedling regeneration, enabling conventional control regimes to keep it contained more cheaply and effectively. We therefore do not recommend slavishly ranking weeds according to a scoring system, but to use the scores as a guide to assist ranking.

It is also worth bearing in mind that relatively small beneficial impacts against a major widespread weed can result in greater overall benefits than complete control of a relatively minor weed (Page & Lacey 2006). This is why weed importance and the cost of implementing a biocontrol programme needs to be considered alongside predicting the potential impacts of biocontrol. Paynter et al. (2009) recommend an integrated pragmatic decision-making process to stand alongside the framework, which will serve to deliver a portfolio of weed targets that includes a range of good, medium, and hard weed management targets. An advantage of this approach over, for example, commencing multiple projects against novel or difficult targets at the same time is that this is more likely to result in a steady supply of novel agents over time, rather than boom and bust cycles.

4.1.4 Combining scores

We recommend multiplying the weed impacts score together with the total biocontrol score and ranking by total score, but also presenting the weed impact score and the total biocontrol score separately so that stakeholders can see how the two components contribute to the overall score.

Total Score	=	*Weed impacts score*	×	*Total biocontrol score*

The total biocontrol score is limited between a minimum score of 0.2 and a maximum score of 9.8, which is 49 times greater than the minimum score. We will not know the range between the minimum and maximum weed impacts scores until we have populated data into the tool. This is because the weed impacts score depends on the number of regions and habitats invaded by each nominated weed species, which will not be known until we obtain information from each region. However, we suspect that it is potentially several orders of magnitude greater than 49×. Care will need to be taken to weight the scores to ensure that the scoring system does not result in total scores that are completely dominated by the weed impacts score vs the total biocontrol score.

4.2 Agent prioritisation

As noted in section 3.2.2, there has been a long history of research aimed at identifying the ideal biocontrol agent and probably only two reliable tools to enhance the success rate of biocontrol:

1. Although rarely essential (not all weeds have invasive biotypes that only highly specific agents are adapted to attack), the use of molecular techniques enables invasive weed populations to be compared with the populations in the native range. This helps narrow down where to search for natural enemies that are adapted to attack the invasive biotype. This subject was included in the NBC Prioritisation Tool Plant Research Prioritisation Tab. We think it is better placed here.
2. Using the ecological analogue approach to predict whether a candidate agent is likely to escape attack by specialist parasitoids or predators in the introduced range. This appears to have been captured in the NBC Prioritisation Tool question: *Closely related – native species or ecologically co-occurring native species* but the question should really be *Is there an ecological analogue present?*

Candidate agents that have obviously damaging outbreaks in the native range (e.g. heather beetle) are likely to perform well in the introduced range (particularly if they escape parasitism or predation). The question Appears to be damaging in the native range should assist agent selection, although as noted in Section 3.2.2, the cause of damage can be easily overlooked if damage is cryptic (e.g., root-feeders) or highly transient.

Reviews have indicated that some taxonomic groups appear to make better biocontrol agents than others and that some feeding niches tend to be more damaging than others, but it is likely that 'universal criteria for agent selection appear unlikely' because the traits of successful agents are likely to vary according to the traits of the target weed. It is likely that there are insufficient completed weed biocontrol programmes worldwide for an analysis that includes both plant and agent traits to identify tailored selection criteria that matches the ideal agent with the type of target weed.

We believe that, with the current state of knowledge, it is unlikely that a points-based scoring system can be developed to assist agent selection that will capture the intricacies of these relationships and reliably prioritise the best agent. However, a relatively simple approach that prioritises candidate agents according to their potential host specificity and capacity to damage the target weed (including the presence or absence of ecological analogues, and information of weed biotypes) should formalise how an initial triage is usually done to eliminate the least suitable candidates and develop a pool of species that are worth further investigation. A proposed scoring system is given in Table 7 and Table 8 lists ranks candidate arthropod agents found during native range surveys on Japanese honeysuckle *Lonicera japonica* according to their ranking score. This prototype system appears to be a promising means for formalising how agents for further study are initially selected but we recommend that a dataset should be compiled in the future to enable the weightings suggested in Table 7 to be fine-tuned.

As is apparent in the notes section of Table 8, priorities can change (e.g. due to additional literature records being obtained for *A. aequalis*) and some candidate agents were not successfully reared: stakeholders must be prepared to support the importation of more than one candidate agent species to increase the chance of success.

Table 7. Suggested scoring system for prioritising candidate agents for further study. Where Total Score = Score A x (Score B + Score C) x Score D

Is the candidate agent likely to be host-specific?	Score A	Is the candidate agent potentially damaging	Score B	Is there an ecological analogue present?	Score C	Is agent adapted to attack weed biotype(s) present in NZ	Score D
Yes, testing already conducted overseas; agent already known to be sufficiently host-specific	1	Yes, efficacy already proven overseas (repeat programmes)	10	No	10	Yes	1
Yes, published host records indicate a good chance that it is sufficiently host-specific	0.8	Yes, published information indicates it can be damaging	10	Yes, but agent may have a refuge from natural enemies (e.g. leaf-buckling eriophyid mites) or is damaging in the native range, despite enemies	7	No	0.1
Likely to be adequately host-specific, based on taxonomic considerations	0.7	Yes, appears damaging in native range surveys	10	Yes, and the agent is likely to be severely impacted by natural enemies	1	Unknown but no reason to suppose compatibility may be an issue	0.9
Unknown, but native range surveys indicate it may be host-specific	0.6	Yes, damaging in containment	7	No, but agent belongs to a group that is susceptible to high levels of parasitism (Agromyzidae, Cecidomyiidae)	3	Unknown, but reasons to suppose compatibility may be an issue	0.2
Unknown/insufficient information	0.3	Unknown/insufficient information	5				
Unlikely to be adequately host-specific	0.1	Does not appear to be particularly damaging	1				
Not adequately specific	0						

Table 8. Prioritisation of insects found on Japanese honeysuckle during native range surveys, according to the scoring system in Table 7

Species	Score	Insect Order	Guild	Status	Notes
Nematus sp. nr wahlbergi	14.40	Hymenoptera	Defoliator	Imported but rearing was unsuccessful	We have learnt a lot about overwintering and rephasing sawfly larvae during the field horsetail project. Could try again.
Oberea shirahatai	14.40	Coleoptera	Stem miner	Imported, tested, and approved for release	
Zaraea lewisii	14.40	Hymenoptera	Defoliator	Imported but rearing was unsuccessful	We have learnt a lot about overwintering and rephasing sawfly larvae during the field horsetail project. Could try again.
Allotalanta sp.	10.80	Lepidoptera	Stem-miner/defoliator	Imported and tested. An EPA application could potentially be made in the future	Testing indicated this species can rear through on some ornamental *Lonicera* species. It will be difficult to justify to the EPA that it should be released until impact of other agents has been monitored to assess the benefits/need for another agent vs the risk.
Limenitis glorifica	10.80	Lepidoptera	Defoliator	Imported, tested, and approved for release. Now established in NZ	Impact in the native range was unknown before introduction to NZ as surveys were done at a time of year when only adults and eggs were present, so larval feeding damage could not be assessed.
Bhadorcosma lonicerae	7.92	Lepidoptera	Defoliator	Not imported	Only active in early spring, did not appear to be particularly damaging.
Perittia lonicerae	7.92	Lepidoptera	Leaf-miner	Not imported	Generally, did not appear to be particularly damaging although an outbreak observed in Japan in September 2014 indicated it may be damaging if it escapes parasitism.
Phytomyza lonicerae	2.88	Diptera	Leaf-miner	Not imported	Similar impacts to the old man's beard leaf-miner. Despite a lack of an analogue in NZ, considered likely to be vulnerable to the same parasitoids.

Species	Score	Insect Order	Guild	Status	Notes
Apha aequalis	1.80	Lepidoptera	Defoliator	Imported into containment but soon discarded when host records were discovered in the Japanese literature indicating a lack of specificity	This species ranked much higher when initially imported (Total Score = 14.40), showing the limitations of scoring and the need to revisit/reprioritise.
Lobesia coccophaga	1.44	Lepidoptera	Defoliator	Not imported	Likely host-specific but native analogue present in NZ.
Limenitis camilla	1.35	Lepidoptera	Defoliator	Not imported	Literature records indicate this species has a much broader host-range than *L. glorifica* (including some NZ ornamentals, such as *Weigela*) and is restricted to shaded habitats.
Trichosiphonaphis lonicerae	0.99	Hemiptera	Sapsucker	Not imported	Literature mentions host-range unclear but thought to have *Polygonum* as an alternate host; tended by ants and may interfere with other agents by attracting more predatory ants onto honeysuckle plants.
Zipangia obscura	0.99	Coleoptera	Root-feeder	Not imported	Host-range considered too broad.
Abraxas grossulariata	0.00	Lepidoptera	Defoliator	Not imported	
Alcis angulifera	0.00	Lepidoptera	Defoliator	Not imported	
Archips viola	0.00	Lepidoptera	Defoliator	Not imported	
Bothrogonia ferruginea	0.00	Hemiptera	Sapsucker	Not imported	
Ectropis crepuscularia	0.00	Lepidoptera	Defoliator	Not imported	
Euproctis subflava	0.00	Lepidoptera	Defoliator	Not imported	
Hemaris sp.	0.00	Lepidoptera	Defoliator	Not imported	
Lemyra imparilis	0.00	Lepidoptera	Defoliator	Not imported	
Orgyia thyellina	0.00	Lepidoptera	Defoliator	Not imported	
Pagaronia sp.	0.00	Hemiptera	Sapsucker	Not imported	

5 Recommendations

In addition to this review, we have edited the excel spreadsheet developed by the NBC to reflect our recommended scoring systems for prioritising weed targets and candidate agents.

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Appendix 1 – Evidence regarding the predictive values of attributes that were hypothesised by Harris (1973) to be predictors of agent impact

Attribute	Reason	Evidence and potential for assisting agent prioritisation
1. Host specificity	Within the constraints that an agent must not attack valued non-target species Harris (1973) suggested that oligophagous agents were more likely to be damaging than agents that are restricted to host biotypes.	Not supported: Wapshere (1985) argued that restricted monophagous species are often more effective agents than oligophagous agents. There are now numerous examples where highly specific agents are effective, provided they have been correctly matched to the target weed biotype.
2. Direct damage inflicted	Harris (1973) suggested that certain guilds are more damaging than others.	Limited potential: Some of Harris's predictions are now known to be wrong. For example, Harris (1973) assumed that gall-formers have "evolved a homeostasis with their host that renders them incapable of inflicting serious damage to it". However, gall-formers are often constrained by parasitism in the native range and can become very damaging in the introduced range in the absence of parasitism. There is evidence that root-feeders have a higher success rate than agents that attack above-ground parts (Blossey & Hunt-Joshi 2003). However, leaf-miners, sapsuckers, stem-borers, defoliators, gall-formers, plant pathogens, etc., can all be highly successful agents. For any weed, the most damaging agent is unlikely to be predictable in advance.
3. Indirect damage	Harris suggested that agents that transmit disease or render plant susceptible to invasion by other organisms should be more effective	Limited potential: Secondary parasites such as fungi and bacteria can augment the impacts of weed biocontrol agents (Caesar 2003). However, Wapshere (1985) argued that the potential for secondary impacts cannot be estimated in advance as it is unknown whether secondary parasites present in the introduced range will colonise the target weed or what their impacts will be. Moreover, the potential for disease transmission is an additional risk that would have to be investigated. Agents that can transmit disease (e.g. aphids) tend to be avoided in biocontrol programmes due to the difficulties assessing that risk.
4. Phenology of attack	Harris suggested that agents that cause prolonged attack throughout the season should be more effective than agents that damage plants for a limited period.	Not supported: Wapshere (1985) noted that it is rare to find an agent which is individually very damaging, and which produces a prolonged attack on a weed and there are clear examples of agents that damage during a limited period can be effective. For example, on *Echium* spp., the larvae of the two *Ceutorhynchus* spp. damage the tap root of the weed during a short period in late spring have more effect than the continuous attack of the leaf miner *Dialectica scalariella.*

Attribute	Reason	Evidence and potential for assisting agent prioritisation
5. No. generations	Harris suggested that multivoltine agents are more likely to be effective than univoltine species.	Limited evidence: Crawley (1986) noted that agent establishment and impact was correlated the intrinsic rate of increase of an agent (which is correlated to voltinism). Nevertheless, there are contradictory arguments above.
6. Progeny per generation	Harris suggested that more fecund agents are likely to be more effective.	Limited evidence: Crawley (1986) noted that agent establishment and impact was correlated to agent fecundity. However, Wapshere (1985) argued that fecundity was correlated to agent life history risk where high fecundity tends to reflect a high risk of predation or parasitism and should therefore be a neutral trait if risk of predation or parasitism is the same in the introduced range. Moreover, the fecundity of a candidate agent is often unknown in advance of rearing and agents must be prioritised before attempts are made to rear them.
7. Extrinsic mortality factors	Harris argued that agents that suffer extensive mortality due to specific natural enemies and are relatively immune to generalist enemies are more likely to be effective	Very strong evidence: Wapshere (1985) considered this to be a strong criterion because if predators or parasites occurring in the native habitat are absent from the new habitat, there will be a corresponding increase in reproductive capacity of the agent available to be employed in controlling the weed. Wapshere (1985) considered that the likelihood of an agent avoiding parasitism and predation could not be estimated. However, Paynter et al. (2010) subsequently developed the 'ecological analogue' approach to predicting parasitism and predation by specialist predators (Paynter et al. 2018) so that it should be possible to identify agents that are likely to escape parasitism and predation by specialists in the introduced range.
8. Feeding behaviour	Harris argued that an agent whose effect on the weed is restricted by intrinsic territorial behaviour or by cannibalism will be less damaging than those able to build up dense and damaging infestations on the plant with little deleterious effects to themselves.	Limited evidence/low potential: Frick and Garcia Jr (1975) considered that larval cannibalism was one of several factors contributing to the failure of *Bactra verutana* as a biological control agent for purple nutsedge. However, this is the only example we could find where cannibalism has been listed as a potential cause of failure in a weed biocontrol programme. In contrast, *Larinus minutus* causes heavy damage to the target weed *Centaurea diffusa* in Canada and the USA (Winston et al. 2020), even though its larvae are reported to be cannibalistic (Kashefi & Sobhian 1998). Moreover, whether a candidate agent is cannibalistic is often unknown in advance of rearing and agents are usually prioritised before attempts are made to rear them.
9. Compatibility with other agents		Some evidence: Competition between agents can reduce effectiveness, For example, of two agents released against *Carduus nutans* that infest the seed heads, *Urophora solstitialis* is a superior agent (as it is active throughout the flowering season) but an inferior competitor, compared to *Rhinocyllus conicus* (Woodburn 1996). In hindsight only *U. solstitialis* should have been released. Wapshere (1985) noted that this is a criterion has little value at the beginning of a programme against a given weed, but it could be used to select later introductions in a continuing programme. However, it is not uncommon to begin specificity testing on more than one agent simultaneously. Under these circumstances it makes sense to select agents that attack different parts of the target plant to reduce the risk of direct competition.

Attribute	Reason	Evidence and potential for assisting agent prioritisation
10. Distribution	Harris argued that agents that are widespread in the native range should be more likely to be effective than localised ones.	Little evidence: Wapshere (1985) argued that if a localised agent is abundant and damaging to the weed in an ecoclimatic situation closely like that of the weed-infested region, then the localised agent could be more effective than one with a broader habitat distribution. Most native range survey work focuses on ecoclimatic situations that are the closest match to the weed-infested region, so this hypothesis is rarely tested.
11. Evidence of effectiveness	Agents that are proven to be effective in one locality should be effective when introduced against the same weed elsewhere.	There is clear evidence that agents redistributed to other locations/countries will have a similar impact to the original releases. However, a criterion based on previous use of the agent elsewhere is only useful for repeat programmes
12. Size of agent	Harris assumed that impact should be correlated to agent size.	There is limited evidence that size matters – opposite to Harris's prediction: Crawley (1986) noted that biocontrol success is correlated with intrinsic rate of increase, which is negatively correlated with body size. Size does not appear to be a strong predictor of agent impact.

Appendix 2 – Questions on the 'Plant research prioritisation' worksheet

Theme	Question in the Tool V6	Relates to	Why	Comments
Plant name	Common name			
	Scientific name			
Taxonomic relatedness	Taxonomic certainty of what we have in NZ	Biocontrol impact	Potential for agent/weed mismatch	Exclude: Plant incompatibility can be a cause of failure. We suspect that this factor is unlikely to have a major influence on biocontrol impact nowadays because molecular techniques have been developed so that invasive weed populations can be compared with the populations in the native range to narrow down where to search for natural enemies that are adapted to attack the invasive biotype(s).
		Biocontrol cost	Using molecular tools for genetic matching is an extra cost	Exclude: True but for novel programmes, it is generally impossible to predict whether genetic matching is likely to be necessary in advance. For repeat programmes, where the importance of genetic matching is known, it will generally be very cheap to check that the biotype present in NZ is a good match to the available agent(s) as genetic markers will have already been developed.
	Closely related – pest species	Biocontrol impact	Potential to target > 1 weed with the same agent	Include: There are examples where agents have successfully controlled > 1 closely related weed species. An agent that had a broad enough host-range to attack multiple weed spp. may also be a risk to related valued plants. Multi-targeting is therefore only likely to be possible for weed targets that have no native or valued exotic closely related spp. in NZ.
	Closely related – native species	Biocontrol impact	Need for greater specificity means there should be a smaller pool of candidate agents that are sufficiently host-specific.	Include: but with a relatively low weighting (logical argument but little empirical evidence to support it; Paynter et al. 2012).
		Biocontrol cost	More complex specificity testing required to demonstrate an agent is safe/find a safe agent.	Include: but with a relatively low weighting (logical argument but little empirical evidence to support it; Paynter et al. 2012).

Theme	Question in the Tool V6	Relates to	Why	Comments
Taxonomic relatedness (cont.)	Closely related primary - production species	Biocontrol impact	Ditto	Duplication – combine with previous question to ask if there are closely related native or primary production species.
		Biocontrol cost	Ditto	Ditto
	Closely related – Ornamental/socially valued species	Biocontrol impact	Ditto	Exclude: Potential for non-target attack on ornamentals is unlikely to influence an EPA decision.
		Biocontrol cost	Ditto	Ditto
Impacts	Reproductive ability (mark with x in second column if relevant)	Weed impacts & future threat score	Question taken from Weed Risk Assessment (WRA) protocols?	Exclude: We do not think predicting risk relevant for ranking weeds that are already invasive (and would likely have failed a WRA) – if something is a serious weed it must be reproducing successfully however it does it.
	Plant fecundity (Average # of seeds per fruit/raceme*# of fruit per plant over lifetime)	Weed impacts & future threat score	Taken from WRA?	Ditto
	Seed bank persistence	Weed impacts & future threat score	Taken from WRA?	Exclude: We do not think predicting risk relevant for ranking weeds that are already invasive (and would likely have failed a WRA) - tradescantia does not have a seed bank, should it be ranked lower because of that…?
	Growth rate	Weed impacts & future threat score	Unclear; this is not a question in pre-entry weed risk assessments	Exclude: It is difficult to identify a suite of general traits explaining invasiveness, because traits of invaders depend on characteristics of the invaded habitats (Funk 2013) and this question is likely to discriminate against slow growing invaders in cold and/or nutrient poor habitats (e.g. heather).
	Primary dispersal type (mark with x in second column if applicable)	Weed impacts & future threat score	Taken from WRA?	Exclude: We do not think predicting risk relevant for ranking weeds that are already invasive (and would likely have failed a WRA) – if something is a serious weed it must be dispersing successfully however it does it.

Theme	Question in the Tool V6	Relates to	Why	Comments
Impacts (cont.)	Other invasive traits (mark with x in second column if applicable)	Weed impacts & future threat score	Taken from WRA?	Exclude: We do not think predicting risk relevant for ranking weeds that are already invasive (and would likely have failed a WRA).
	Primary impact	Weed impacts & future threat score	Ensures focus on environmental weed	Replace with two new attributes: economic impact and environmental impact. Economic impact can include costs of control. Environmental impact can report the primary impact(s) with the largest magnitude.
	Ecosystems impacted (at the full extent of plant range)	Weed impacts & future threat score	More ecosystems impacted, the worse the weed; greater weighting to weeds of native habitats vs. disturbed habitats and exotic plantations etc.	Include. Needs to consider the importance (i.e. conservation value) of specific ecosystems in combination with the number of ecosystems impacted.
	Human health impacts	Weed impacts & future threat score		Include but update to 'social-cultural impacts' to include other potential impacts such as loss of cultural value and recreational use.
	Invasive in climatically similar countries elsewhere?	Weed impacts & future threat score	Taken from WRA?	Exclude: is predicting risk relevant for ranking weeds that are already invasive (and would likely have failed a WRA)?
National distribution	List of regions (actual/current)			
	Regional distribution (actual/current)	Weed impacts & future threat score	Current distribution and impacts by region.	Include
	No. of regions: potential under current without management			
	Regional distribution (potential under current without management)	Weed impacts & future threat score	Potential distribution and impacts by region.	Exclude in favour of regional distribution (potential under climate change).
	No. of regions: potential under climate change			

Theme	Question in the Tool V6	Relates to	Why	Comments
National distribution	Regional distribution (potential under climate change)	Weed impacts & future threat score	Potential distribution and impacts by region.	Include if possible (by replacing the previous question given climate change is going to happen so a potential distribution under the best guess climate scenario for NZ is most relevant). But how is the potential distribution determined (it would be quite an effort to predict the potential distribution of multiple weed species under climate change)?
	No of RPMPs listed (mark with x in second column if applicable)	Weed impacts & future threat score	Current distribution and impacts by region.	Exclude/combine? Duplicate of previous question (Regional distribution (actual/current)).
	Socio-political pressure to control per region	Weed impacts & future threat score	Current distribution and impacts by region.	Include? Somewhat duplicates previous question (Regional distribution (actual/current)) but could still be a separate question more defined to ask how many regions have high socio-political pressure to control – although defining high pressure may be fraught in and of itself.
Control methodology and limitations	Primary control method	Weed impacts & future threat score	Cost of control is an economic impact. Control method also relates to non-target impacts.	Include but modify: Could split the question into two (one asking about the current cost of control and another asking about non-target impacts of control). Cost could come under Economic impact if it were to be adopted and Primary control method could be renamed as Non-target impacts of control?
	Multiple follow ups required?	Weed impacts & future threat score	Cost of control is an economic impact. Control method also relates to non-target impacts.	Include, but need guidance on scoring, e.g. manual is more expensive, but has fewer non-target effects than herbicide, so which is best? Note even selective herbicides are not all that selective and manual control is only likely to be practicable for a tiny fraction of infestations of a widespread weed.
	Restricted site access - physical	Weed impacts & future threat score	Links to weed impacts because current control options are ineffective in restricted sites that cannot be treated.	Combine with following two attributes and rename as 'restrictions toward implementing control'.

Theme	Question in the Tool V6	Relates to	Why	Comments
Control methodology and limitations (cont.)	Restricted site access – eco/socio-cultural (e.g. KD)		Links to weed impacts because current control options are ineffective in restricted sites that cannot be treated.	Duplicate of previous question – combine?
	Legislative limits (e.g. application over water)	Weed impacts & future threat score	Links to weed impacts because current control options are ineffective in restricted sites that cannot be treated.	Duplicate of previous question – combine?
	# of current biocontrol agents	Biocontrol impact		Exclude? There is the law of diminishing returns: if many agents have been released and a weed has not been brought under control it may mean that it is an intractable weed. However, it could also mean the best candidate agent has still not been identified. Especially true for programmes like gorse where there were restrictions on what agents could be used until recently – initially only seed-feeders were released to reduce dispersal but not damage the plant (as it was valued as a hedging plant and by beekeepers) and more recently agents that were a risk to a related experimental fodder crop tree lucerne could not be released. There are candidate agents that could now be released. Really a decision should be based on continued prospects and not just on past success (or otherwise). There should perhaps be a question that asks if the pool of candidate agents appears to have been exhausted, Y/N.
	Current biocontrol effectiveness	Biocontrol impact	If you already have an effective agent do you need more?	Include, but in the 'agent prioritisation' worksheet. Also need to decide on scoring (current scoring seems to say yes to the question 'if you already have an effective agent do you need more?'!).
	Project development stage			
	$ already invested in biocontrol	Biocontrol cost		Exclude: Law of diminishing returns but likely to discriminate against novel/pioneering programmes which cost a lot more than repeat programmes. Moreover, a decision to continue should be based on continued prospects and not on past expenditure.

Theme	Question in the Tool V6	Relates to	Why	Comments
Control methodology and limitations (cont.)	Targeted for biocontrol overseas?	Biocontrol cost	Repeat programmes cheaper; can share development costs in joint pioneering programmes.	Include.
	Can plant be found in native range?	Biocontrol cost		Probably irrelevant. We cannot think of any weed biocontrol programmes worldwide that could not proceed because the target weed is extinct or could not be found in the native range. For some weed species. There is uncertainty regarding the native range (but usually pan-tropical weeds).
	Native range – political risk (safety and regulatory regimes)?	Cost of implementing biocontrol		This is worth considering, perhaps as a stop/go question.
	Difficulties with growing host or non-target hosts in containment	Cost of implementing biocontrol	Not relevant prior to the start of a programme (how would you know?)	Exclude: Some weeds (e.g. old man's beard) do seem to be prone to outbreaks of pests in containment, but that's life. It would be an odd decision to abandon work on an important weed because it was hard to rear.

Appendix 3 – Questions on the 'Agent prioritisation' worksheet

Theme	Question in the Tool V6	Relates to	Why	Comments
Plant name	Common			
	Scientific			
Agent Research name	Agent #			
	Common			
	Scientific			
	Taxonomic certainty of agent	Cost of implementing biocontrol	Additional costs required to ID and resolve taxonomic uncertainty.	Exclude: This question may potentially discriminate against weeds that are native to regions where the fauna is poorly known (e.g. South America). The additional cost will be minor in relation to the overall cost of a programme. All agents must be identified to obtain approval for release, but undescribed species can be released provided a taxonomist can advise the EPA/MPI that the agent culture is pure, and an undescribed entity closely relate to…).
Taxonomic relatedness	Closely related – pest species	Efficacy (impact) of biocontrol	Impact might be reduced if a closely related pest species has had biocontrol agents released against it, they might attack the candidate agent.	Worth considering on a case-by-case basis (not a scoring system). There are a few examples where deliberately released parasitoids have attacked weed biocontrol agents in NZ. For example, boneseed leafroller *Tortrix s.l.* sp*. chyrsanthemoides* larvae were parasitized by *Trigonospila brevifacies* which was deliberately introduced from Australia to control tortricid orchard pests (Paynter et al. 2010). However, some parasitoids are feeding niche specialists (e.g. attack leaf-miners regardless of taxonomy), habitat specialists, etc. so presence of closely related pest species is not necessarily a problem.
			Impact might be predictable high if an agent has a similar biology to a well-known pest.	Potentially true – although care needed as threshold for economic impacts of some pests may be very low, e.g. a single moth larva in an apple will render it unsaleable and not translate to the kind of damage that will control an invasive plant.
			Safety? Should not be relevant provided the agent is host specific.	Exclude: Agents closely related to notorious pests have been used as biocontrol agents safely (e.g. Leptinotarsa spp.; Hoffmann et al. 1998)

Theme	Question in the Tool V6	Relates to	Why	Comments
Taxonomic relatedness (cont.)	Closely related – native species or ecologically co-occurring native species	Efficacy (impact) of biocontrol	Closely related native species are a potential source of parasitoids than are likely to be adapted to attack the candidate agent.	Include: There is good evidence to include this as a predictor of biocontrol impact (Paynter et al. 2010).
	Closely related exotic species beneficial to primary production	Efficacy (impact) of biocontrol?	I assume this question refers to other biocontrol agents? It may well be that similarity to other proven agents predicts impact.	Research question: To our knowledge the hypothesis that closely related biocontrol agents have similar levels of success has not been tested (but could be tested). There are certainly examples where this is not the case. For example, although the weevil *Cyrtobagous salviniae* has been a spectacularly successful biocontrol agent, a virtually identical species *C. singularis* has been unsuccessful (Crawley 1988).
	Closely related – Ornamental/socially valued species	?	?	Exclude: We cannot think of any examples of Ornamental/socially valued species that are closely related to any weed biocontrol agents.
Effectiveness	Damage type	Efficacy (impact) of biocontrol	Some guilds have a higher success rate than others (e.g. Crawley 1988; Syrett et al. 1996; Blossey & Hunt-Joshi 2003).	May be worth considering on a case-by-case basis (not a scoring system). Not many examples to parameterise a scoring system reliably and guild may not be a terribly reliable predictor of success and may be context dependent (i.e. certain guilds are effective against certain types of weed)
	Impact level	Efficacy (impact) of biocontrol	Species that have an impact in the native range are likely to have an impact in the introduced range.	Could include for repeat programmes, but very limited predictive power for novel programmes, as often unknown before an agent is released but there are some examples such as the heather beetle (Syrett et al. 2000), where agents that are damaging in the native range have proven to be highly successful.
	Released overseas	Efficacy (impact) of biocontrol	Assume impact/success of an agent in NZ will be similar those reported elsewhere.	Novel/repeat already included in target weed selection criteria.
		Cost of implementing biocontrol	Repeat agents cheaper (less testing, no need for native range surveys, etc.).	Novel/repeat already included in target weed selection criteria.

Theme	Question in the Tool V6	Relates to	Why	Comments
Effectiveness (cont.)	Fecundity	Efficacy (impact) of biocontrol	It is possible that more fecund species can build up in numbers and becoming more damaging more rapidly than less fecund species.	Limited evidence that fecundity correlates with damage; other factors affect population increase (e.g. parasitism, predation, voltinism).
	Longevity (average lifespan of organism)	Efficacy (impact) of biocontrol	It is possible that longer-lived species damage the target weed for longer.	Exclude: No evidence that lifespan correlates with damage and short-lived species with multiple generations may be even more damaging.
	Dispersal ability	Efficacy (impact) of biocontrol Cost of implementing biocontrol	Agents that disperse better may control the weed better. Less money spent redistributing agents that disperse well.	Exclude: Dispersal ability can be predicted but it is irrelevant to efficacy: Both successful and unsuccessful agents were equally likely to be fast or slow dispersers (Paynter & Bellgard 2011). Exclude: Dispersal ability should not influence agent selection as it is likely to be a minor factor in the overall benefit: cost ratio of a programme: Paynter & Bellgard's (2011) aim was to identify poor or good dispersers so that appropriate release strategies could be developed, not prioritise agents (as noted above, slow dispersers can be highly effective agents).
Risks	Host specificity	Efficacy (impact) of biocontrol	We cannot release something that is not sufficiently host-specific.	Exclude. The reason we do host-specificity testing is because we typically do not know if an agent is sufficiently specific in advance (unless it is a repeat programme).
	Vulnerability (e.g. predation, parasitoids, gut parasites, microbial diseases)	Efficacy (impact) of biocontrol	Agents that are likely to be attacked by parasitoids or predators are more likely to fail.	Good evidence to include risk of parasitism and predation as a predictor of biocontrol impact (but this largely duplicates question: *Closely related – native species or ecologically co-occurring native species as native analogues are a predictable source of predators and parasitoids*). There is some evidence that larvae that feed externally on the plant are more prone to predation, but this is not a reliable predictor of efficacy (several highly damaging agents have externally feeding larvae, such as heather beetle, tradescantia leaf beetle and green thistle beetle). There are no examples of agents that are adversely affected by gut parasites/disease. Agent cultures must be disease-free before permission to release is given.

Theme	Question in the Tool V6	Relates to	Why	Comments
Risks (cont.)	Climatically suitable	Efficacy (impact) of biocontrol	Agents that are not adapted to the NZ climate will not thrive.	Could include if there is some prior knowledge but unlikely to be a major problem: generally, if a climate suits a weed, then it should also suit a natural enemy that coevolved with that plant.
	Agent-Host compatibility (e.g., shade, microhabitats, flow regime, flooding, etc.)	Efficacy (impact) of biocontrol	Some agents are only effective in certain habitats.	Could include if there are some prior knowledge as past programmes have shown that some agents (e.g. alligator weed beetle) are only effective in certain microhabitats but we think it would be generally unwise to reject an agent that only works in certain habitats. Clearly if a weed is only a concern in certain microhabitats then releasing an agent that shuns those situations is not wise. If the aim is to control a weed everywhere then it may be necessary to find complementary agents rather than search for an elusive agent that will thrive in all habitats.
	Ease of rearing (e.g. sex ratios, continued presence of gut parasites, low reproductive output, etc.)	Efficacy (impact) of biocontrol	Ease of rearing is correlated to probability of success (establishment) but can often be overcome.	Exclude: For repeat programmes, rearing methods will almost certainly have been developed. For novel programmes, rearing should not influence agent selection as agents can be established despite rearing problems (Paynter et al. 2016).
	Food web impacts	Safety	Safety concerns might lead to a candidate agent being rejected by the EPA.	Native analogue approach (question *Closely related - native species or ecologically co-occurring native species*) should link to potential food web effects and reduce risk.
	Next step in project development phase - (Efficacy)			Do not really follow the reasoning/scoring here.