Classical Biological Control of Weeds in Areas of Conservation: Opportunities for Brazil Based on a Global Perspective

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Abstract

Non-native invasive weeds pose a serious threat to the biodiversity of nature conservation areas; but are inherently difficult to manage successfully due often to the scale of the invasion. Chemical control in many situations is prohibited; often with good reason, since it can be challenging to target only the non-desirable plants, without affecting valuable native species. Mechanical control is expensive and often impractical when large areas are invaded. Both of these approaches are not sustainable in the long term. One useful tool is integrated weed management including the introduction of co-evolved natural enemies (arthropods and plant pathogens) from the centre of origin of the target weed. Where scientifically implemented, using a comprehensive evaluation and screening programme, this 'classical' biological control approach (CBC) has an impeccable safety track record. It has proven to be an efficacious, cost-effective and sustainable option for the management of exotic invasive weeds and should be more widely used in Brazil. A current prioritisation exercise is highlighted which should provide a tool for decision makers on which are the best weeds to target with this tried and tested approach.

Introduction

Trade liberalisation and rapid globalisation are the main causes of increased spread of non-native invasive plant species across the globe over recent decades (Perrings *et al.*, 2002). Non-native or alien invasive species are recognised as the second greatest threat to biodiversity next to habitat loss, and can inflict irreversible damage to ecosystems with incurred costs measured in $-billions (Pimentel *et al.*, 2001; Pimentel *et al.*, 2005). It is widely accepted that only a small proportion of introduced plant species actually become invasive (Williamson, 1996). However, it is this small minority, which incur high economic (Williams *et al.*, 2010) and ecological impacts (Gaertner *et al.*, 2009; Vilà *et al.*, 2011).

The plasticity to adapt life history characteristics has been shown to differ in native and non-native populations of the same species, suggesting that invasive populations gain from being released from regulation in the native range. Invasive non-native plant species are often regarded as being more successful; showing increased biomass (Kleunen *et al.*, 2011; Prati & Bossdorf, 2004), fecundity (Caňo *et al.*, 2008; Erfmeier & Bruelheide, 2004; Ebeling *et al.*, 2008), density (Jakobs *et al.*, 2004) and a wider geographical distribution than their native congeners (Crawley, 1987; Jakobs *et al.*, 2004). A number of hypotheses have been proposed to explain why introduced populations show increased performance where the common denominator for most is the escape from regulation coupled with the ability to adapt and exploit decreased regulation in the introduced range.

The Enemy Release Hypothesis (ERH) posits that when a plant species is introduced into a new region it is released from the influence of natural enemies (both arthropods and plant pathogens) which regulate the population in the native range. Thus, introduced populations are able to show increased growth and range expansion over native plant species (Keane & Crawley, 2002). The release from specialist natural enemy pressure affords non-native plant species an advantage over native plant species, which are suppressed by their array of natural enemies (both specialist and generalist species). In addition to the release from specialist natural enemies, the ERH predicts that specialist natural enemies on closely related species, if present in the introduced range, will not adapt to feed on the introduced plant species, and generalists within the introduced range will have a greater impact on native species over introduced species (Keane & Crawley, 2002).

Classical biological control, defined as the utilisation of co-evolved, host specific natural enemies from the plant's native range to control host populations in the invasive range, aims to redress this imbalance by re-associating the weed with its natural enemies. Classical biological control has been utilised as a pest management tool for over 100 years, where to-date there have been approximately 7,100 introductions (this figure includes repeated introductions in one country) of classical biological control agents, using 2,677 species (Cock *et al.*, 2010). For weeds more than 400 different biocontrol agents have been used against around 150 target plants, totalling over 1,300 introductions around the globe.

High costs of implementing more traditional control methods on a landscape-level, such as chemical application and manual removal, coupled with the declining number of chemical products available to control non-native plant species, mean that classical biological control may be the only sustainable method of control for some of Brazil's most prevalent invasive plant species. When faced with the fact that there has not been a scientific breakthrough in the discovery of a new herbicide, with a new mode of action in the last 30 years; and the application of those on the market is largely undesirable in areas of high conservation status, biological control is one of the main tried and tested environmental safe management tools for invasive plant species and perhaps the only remaining option.

As a continent, South America has a lot to lose from the invasion of non-native plant species into natural areas high in conservation potential. Being one of the mega-bio-diverse regions of the world, containing over 20% of all known species on the planet, the threat posed to South America from invasive plant species is high (GISP, 2005). To-date, cross continental utilisation of classical biological control agents against weed species has been largely a one-way process where South America has been the source of a large number of biological control agents though only the recipient of 5% of the world-wide releases of biological control agents (Ellison & Barreto, 2004). However, in order to tackle some of the invasive plant species issues in the region, classical biological control remains a tangible tool. In Brazil there are 117 plant species regarded as invasive, with a further unknown number which may become invasive and problematic in the future (Zenni & Ziller, 2011).

A brief history of classical biological control in Latin America

Although South America is the source of some of the most invasive plant species in the world, and the source of some of the most successful biological control agents to control these species, there are surprisingly few classical releases against weeds in the region (Barreto, 2008). To-date there have been no releases of classical biological agents against weed species in Brazil, though neighbouring countries (Argentina and Chile) have utilised the management tool for the control of a handful of non-native invasive plant species (Julien & Griffiths, 1998). Chile has had the most releases of biological control agents against weed species where five species have been targeted using six biological control agents. The first target for classical biological control was against *Hypericum perforatum* L. in Chile in 1953 using two Chrysolina leaf beetles *Chrysolina hyperici* Forster and *Chrysolina quadrigemina* Suffrian. Both species proved effective at controlling *H. perforatum* (Marcoy 1959) though *C. quadrigemina* is regarded as the most effective agent (Julien & Griffiths, 1998).

In Argentina, eight biological control agents, both arthropod and fungal agents, have been utilised against three weed targets, namely *Chondrilla juncea* L. *Carduus acanthoides* L. and *Carduus nutans* L. Similar to the weed species targeted for biological control in Chile, in Argentina the weed targets for biological control were implemented due to the impact the species were having on agricultural habitats and rangelands. To-date no biological control agents have been released against weeds in South America where their impacts are exclusively environmental.

The majority of classical weed biological control releases worldwide have involved arthropod biological control agents. This appears somewhat surprising, with the benefit of hindsight, as fungal control agents, and in particular rusts, have proven to be highly host specific and when applied to control invasive weed populations successes have been spectacular (Evans & Tomley, 1994; Tomley & Evans, 2004), with few non-target impacts recorded (Barton, 2004; Waipara *et al.*, 2009). Chile was one of the first countries to utilise fungal biological control agents against weed species with the release of a rust species against *Rubus constrictus* Lef. & M. *Rubus ulmifolius* Schott. The sheer scale of the invasion by these two *Rubus* species was vast (over 5 million ha in southern Chile) deeming traditional control methods simply unattainable. In 1973, in the infancy the utilisation of fungal classical biological control agents, *Phragmidium violaceum* (Schults) Winter was introduced into Chile from Germany where it quickly established and acted to reduce the spread and density of the two species (Ellison & Barreto, 2004).

The threat of invasive non-native plant species to Latin America

Impact assessments provide baseline data which can underpin policy and research grant applications for the management and control of invasive plant species. However, more research is needed into the perceived effects non-native species have on the ecosystems they invade. Although difficult to put a price on the extinction or displacement of a species, or the invasion of a weed into a natural habitat, relating the impact of a weed in monetary terms to that of ecosystem services is a potential way forward (Vilá *et al.*, 2009). Binimelis *et al.* (2007) classified four main categories of ecosystem services, and Vilá *et al.* (2009) suggest the impacts invasive species can have on them including:

- supporting services where invasive plant species can potentially change the composition of the habitat, species assemblages or soil properties
- provisioning services where invasive plant species can threaten the genetic resources of an environment displacing threatening endangered species
- regulating services where invasive weeds can disrupt the pollinator network or potentially alter erosion regimes
- cultural services tourism is important for the South American countries and invasive species can change recreational uses of the habitats and degrade pristine habitats which effect ecotourism

Where economic data is available, it addresses agricultural habitats or rangeland and considers yield loss or land degradation resulting in the reduced carry-capacity of livestock. *Eragrostis plana* Nees was accidently introduced into Rio Grande do Sul state in Southern Brazil in 1969 as a contaminant of *Chloris gayana* Kunth seed from South Africa (Rosa *et al.*, 2007). The species currently covers some 2-million ha and it is estimated that the economic costs associated with this species between 1995-2005 total US$ 29 million (Rosa *et al.*, 2007).

Classical biological control in natural ecosystems

The implementation of classical biological control programmes, as a tool to combat non-native invasive plants, has been shown to provide significant results, which provide benefits to agriculture and native biodiversity (Van Driesche *et al.*, 2010). In a landmark review paper which dealt with biological control programmes in protected natural ecosystems, Van Driesche *et al.* (2010) showed that of 49 programmes, over 60%, achieved complete or partial control.

Although a biological control programme requires significant funds during the research and monitoring phase of the programme, the benefits have been shown to far outweigh the costs (van Wilgen *et al.*, 2004). In Australia, the cost benefit ratio of a biological control programme against Patterson's curse (*Echium* species) has been predicted to increase over time, where at the beginning of the release phase the cost: benefit ratio is estimated to be 14:1, rising to 47:1 35 years after release (Nordblum *et al.*, 2001). Classical biological control does not aim to eradicate the host, but instead aims to reduce the invasive population to a threshold where it has a lower ecological impact compared to that before the biological control agent has been applied (McFadyen, 1998). Any impacts on the target weed may take time as the classical biological control agent establishes, adapts to its new environment, and builds up the population and disperses. However, biological control may act to facilitate the natural regeneration of native plant species as they may be able to better compete with the weakened host, due to the damage inflicted by their re-associated co-evolved and host specific natural enemies.

In isolation, biological control alone may not be enough to facilitate habitat restoration, though its cumulative effects are more sensitive on the environment compared to traditional methods such as chemical and manual control. Long-term monitoring of the biocontrol agent, the host population and the successional changes in native/invasive plant species is required to avoid the void left by the suppression of the target species filled by yet another invasive non-native species. The real issue here is to understand the impact of the target species at an ecosystem level.

Target selection- an important aspect in gaining acceptance

An important aspect of the adoption of weed classical biological control is appropriate target selection, especially in South America, where the history of weed biological control is not widely known and public, governmental and scientific opinion would strongly influence the adoption of the weed management tool. Barreto (2008) highlights that there are a large number of non-native plant species in Brazil where there is a potential conflict of interest over proposals for their control. Many of the grass species introduced into Brazil, although they have become problematic and invasive in some natural ecosystems, still hold economic value as fodder to the large cattle industry (Ellison & Barreto, 2004). Potentially, in the future, although it may already be the case, there may come a tipping point where the cost (impact) of the species outweighs the benefits as these species invade and impact on natural ecosystems. However, these 'conflict of interest species' may still not be the best first targets for Brazil (Barreto, 2008; Ellison & Barreto, 2004). Target selection is further discussed below when considering specific case studies.

Prioritising weeds for classical biological control

When faced with such a large number of non-native invasive plant species to potentially manage, governments, land-managers and scientists alike must prioritise their efforts based on the limited resources available. Understandably, at a government and policy level, resource allocation for the control and management of non-native invasive species has been led by economics - the costs of a particular species to the economy. Prioritising weeds for classical biological control was originally developed by the Australians for their invasive plant species issues (Paynter *et al.*, 2009). Effectively, the prioritisation tool provides a ranking system for invasive plant species based on their suitability for biocontrol. Since the adoption of the tool for Australia, the methodology has been utilised in the Pacific islands (Paynter, 2010), the UK South Atlantic Islands (CABI, 2012) and is currently being adapted for weed targets in China and Brazil from funding from the CABI Development Fund. The prioritisation tool evaluates target species under four categories:

The importance of the weed and the desirability of biological control. The questions require yes or no answers and aims to eliminate species which are known to be native, or potentially native, and species where the benefit may outweigh the impacts of the weed. As in the case of the latter, species with monetary value to sectors of society, for example *Coffea Arabica* L. are excluded from further evaluation as a potential conflict of interest may arise.

The impact of the weed. In total, ten questions are asked for each weed based on the occurrence of the weed in Brazil, the ecological and economic impact of the weed in Brazil and other geographical regions, the human and/or animal health impacts and the type of habitats invaded by the weed. Any one species can have a maximum score of 100 and only those species with an impact score greater than 40 are evaluated further. As previously mentioned, a classical biological control programme requires reasonable funding, from initiation to release, if it is to be considered successful. Therefore, a weed species should only be considered if it has a suitably high impact to justify the resources required for a biocontrol programme.

The effort required for biological control research. Where plant species have been successfully control using classical biological control in other geographical regions, the potential cost of implementing a control programme against the target in Brazil is likely to be significantly reduced. In these cases, a lot of information would have already been gathered on the host range and climatic limitations of the agent utilised. Thus, it may only be considered necessary to host range test a small selection of key plants from the region. If not a successful target in other geographical regions, information may still be available on the natural enemy complex in the plants native range and thus may significantly reduce the effort required to realise biological control against the target.

Predicting the potential impact of biocontrol against the target. This section includes questions on the target weed and the habitat it invades in an effort to predict the potential impact of a biocontrol agent on the target. Questions include information on the reproduction mechanisms of the plant, if the species spreads by seed alone, or by seed and vegetatively. Additionally, questions are asked on the habitat the weed predominantly occurs in, is the target a weed of agricultural systems or environmental systems, where the former may prove harder to implement classical biological control.

Based on the scoring of the three categories an overall biocontrol feasibility score is calculated where the equation is:

Impact Score x Feasibility Score x (1/Effort)

The result of prioritising weed targets for classical biological control in Brazil will be to form a ranked list highlighting the top ten or twenty species where the feasibility of completing a successful biological control programme against these targets is high.

Case studies

The following section highlights case studies of invasive non-native plant species in Brazil and details their impact, where known, and the feasibility for their classical biological control to show the aspects being considered under this on-going research.

Cryptostegia grandiflora **R. Br.** – commonly known as rubber-vine weed is an asclepiadaceous climbing vine from Madagascar which has been the subject of a successful biological control programme in Australia using the co-evolved rust *Maravalia cryptostegiae* (Cummins) (Tomley & Evans, 2004). In Brazil *C. grandiflora* invades extensive areas of the steppic-savanna in the north –east of Brazil (Barreto, 2008). In Australia, the invasion by *C. grandiflora* had significant impact on the native biological diversity and the economic productivity of the invaded region (Tomley & Evans, 2004). As a target for classical biological control in Brazil, this species is arguably the most attractive target as there is no conflict of interest associated with this species.

Acacia mearnsii **De Wild.**- remains an important commodity species in Brazil due to the plant being grown for the extraction of vegetable extracts for the leather industry which makes the prospects for classical biological control against this species slim. However, *A. mearnsii* invades natural habitats from subtropical ombrophilous forest to Brazilian savannas where the species can outcompetes native plants so biological control may potentially be an appropriate management tool should the negative impacts begin to outweigh the benefits. Biological control has been utilised againt *A. mearnsii* in South Africa with both a seed feeding weevil *Melenterius maculatus* Lea. a mycoherbicide containing *Cylindrobasidium*. More recently a Cecidomyiid midge, *Dasineura rubiformis*, which forms galls in the flowers and prevents pod development was released (CABI, 2012).

***Prosopis juliflora* (Sw.) DC.** - is highly invasive in the north-east of Brazil where it invades watercourses in the semi-arid Caatinga region. Several biological control programmes have been implemented against this species across the globe in particular using seed-feeding bruchid beetles. In Brazil, there remains a conflict of interest with this species as *P. juliflora* is considered a valuable plant in many arid regions in South America. However, biological control may still be an option for this species and may act to halt the spread of the tree into other areas of nature conservation. The seed-feeding insects *Mimosetes protractus* (Horn.) and *Neltumius arizonensis* (Schaeffer) was introduced to eastern South Africa in conjunction with the bruchid beetles *Algarobius Prosopis* (LeConte) and *A. bottimeri* Kingsolver for the control of invasive *Prosopis* species. *N. arizonensis* and *A. prosopis* were successful in establishing themselves in large numbers and having a significant effect on *Prosopis* spp., whereas the other species were only found in low numbers (CABI, 2012). The same two bruchid species were introduced into the Ascension Islands where *P. juliflora* occupies some 80% of the island. A Gelechiid moth, *Evippe* sp. from Argentina has been released for the additional control of *P. juliflora* in Australia where it is inflicting high levels of damage on the population (CABI, 2012).

***Pinus elliottii* Engelm.** - has a significant occurrence in Brazil where the 13N Brazil database records over 165 records. Although invasive in 11 physiognomic regions from deciduous or semi deciduous forests to alpine meadows in Brazil this species is not regarded as a suitable target for classical biological control due to the conflicts of interest that arise with this species and others from the same genus (Barreto, 2008). In southern Brazil, the grasslands, sand dunes and savannahs are threatened by the encroachment of *Pinus* species, in particular *P. elliottii* and some conservationist and land managers may welcome the control of the species within these regions. However, striking a balance between habitat protection and forest production highlights potential problems for classical biological control.

***Tecoma stans* (L.)** - is invasive in nine physiognomies in Brazil, and a problematic weed in natural and agricultural environments. Host specificity tests on two rust fungus species, namely, the microcyclic *Prospodium transformans* (Ellis & Everh.) and the macrocyclic *P. appendiculatum* Winter from Mexico are underway in South Africa. A raceme-feeding membracid and the pyralid pod-feeding moth Clydenopteron sp. are to be introduced into quarantine in South Africa for possible biological control (CABI, 2012).

***Melinis minutiflora* P. Beauv.** - and other grass species constitute a large proportion of the non-native plant species in Brazil. *Urochloa decumbens* (Spapf.) has the highest number of occurrences of any invasive species in Brazil (13N brazil database) though as highlighted by Ellison and Barreto (2004) there is a difficulty in adopting classical biological control against grass species and this is further emphasised where to-date there have been no releases of arthropod agents against grass targets (Julien & Griffiths, 1998). Potentially, fungal agents may provide a more suitable approach due to their species specific host specificity though as previously discussed before any biological control programme could be initiated against this group of weeds a cost-benefit analysis would be essential to gain support.

***Eragrostis plana* Nees**, - as previously highlighted, could be a potentially interesting target for classical biological control due to the high environmental and economic impact this weed has in the Southern Brazil. However, before the implementation of a biological control programme against this species a full literature review should be conducted on the natural enemies, in particular fungal pathogens, in the native range.

***Hedychium* spp.** - two Hedychium species are considered invasive in Brazil, *Hedychium coronarium* J. König and *Hedychium gardnerianum* Sheppard. Both species are native to the Eastern Himalayas, Nepal and China, and were introduced into South America some 300 years ago. *H.coronarium* is now present in all 12 phytophysiognomies in Brazil from salt meadows to subtropical ombrophilous forests (Zenni & Ziller, 2011). Since 2008, the Hedychium complex has been the subject of a classical biological control programme from New Zealand and Hawaii. Surveys in the plants native range have identified a number of potential agents including a Chloropid shoot mining fly and a *Puccinia* rust fungus, both of which cause substantial damage to the species in the native range.

Conclusions for Brazil

Gardener *et al.* (2011) highlight that Latin American countries should adopt biological control programmes where the target has been controlled successful in other geographical regions. For Brazil, this is potentially the best way forward for the control of many invasive weeds. The end result of the current prioritisation project will be a ranked list of target weeds highlighting those species for which the biocontrol option is most favoured. The best targets are always likely to be those which have serious impacts and for which off the shelf agents are available that have proven successful against the same target weed in a similar eco-climatic range. Our current research will aid the decision-making process through the production of an official report and an associated peer-reviewed paper.

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