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General News

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Tamarisk Biocontrol Success, Controversy and the Legal Resolution

Controversy and legal resolution

Our recent article updating the biological control programme, in which four sibling species in the genus *Diorhabda* (Coleoptera: Chrysomelidae) have been used in North America against introduced shrubs in the genus *Tamarix*, was subtitled "tracking success in the midst of controversy"[1] to reflect two very different and conflicting views of the programme. On one hand *Tamarix* biological control in North America will likely be considered one of the most successful large-scale programmes in the history of weed biological control due to the widespread impact on the target genus *Tamarix*, including substantial mortality and diminished biomass of the invasive shrub. The opposing view is that *Diorhabda* spp. are causing irreparable harm to riparian ecosystems in western North America by defoliating target plants that at the time may contain nests of an endangered passerine bird subspecies, the southwestern willow flycatcher (SWFL), *Empidonax traillii extimus*. Opponents of the biological control programme, led by the Center for Biological Diversity, have filed two successive lawsuits, one in 2010 and one in 2013, and the US District Court has issued Summary Judgement[2] finding that the defendants, including the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS) failed to meet their obligations under Section 7(a)(1) of the Endangered Species Act (ESA) requiring that action be taken by government agencies to conserve endangered species (see [1]). Recently a much anticipated Remedial Order was issued by the Court outlining steps to be taken by APHIS to mitigate the impact of *Diorhabda* on the SWFL.[3] The Order focused on tasks to be completed by APHIS in order to meet its ESA legal obligations. It is not surprising that the court-ordered remedies include many of the same solutions recommended by biocontrol practitioners.[4,5] The primary points of agreement are that riparian restoration, aimed at establishing native plants in previously *Tamarix*-infested ecosystems, should be a priority in order to increase SWFL populations. Other points of agreement include the need for surveys and predictive models to track beetle movements and the need for mapping and for a general repository for information on *Diorhabda* and flycatcher habitat.

The court recommendations above are reasonable and useful, and most practitioners of biological control would agree that they should be part of any integrated management plan. Beyond those recommendations though are recommendations that make it clear that *Diorhabda* is to be considered the problem in need of remediation, and *Tamarix* is considered a plant to be conserved! In case there is any doubt about this, one needs only to read the beginning of Part 3 of instructions imposed by the Court on APHIS:

"Preparing a programmatic Plan—in compliance with NEPA and in consultation with FWS—outlining the specific measures, tools, and collaborative approaches that USDA and APHIS will take to comply with section 7(a)(1) of the ESA, consistent with the comprehensive multi-State eradication plans that Defendants have prepared for other non-native, invasive beetle species such as the Asian longhorned beetle, *see* 81 Fed. Reg.15,677 (Mar. 24, 2016)."[3]

Clearly this instruction and others in the Remedial Order do not leave room for the use of *Diorhabda* in riparian management but rather instruct APHIS to treat *Diorhabda* in the same manner as a destructive agricultural pest. This is counterproductive from the perspective of riparian ecosystem restoration and ultimately for the recovery of SWFL. It is the unfortunate consequence of a misguided focus on the biocontrol agent as the problem, and failing to see the larger picture in which *Tamarix*, as a driver of ecosystem change, has been a causal factor in the shift away from native plant assemblages required by wildlife species, including the SWFL which is named the willow flycatcher for a reason.

Tamarix is a driver of ecosystem change

There is ongoing debate regarding whether *Tamarix* is a driver or passenger of ecological change and while it seems to be both, depending upon the setting, there is increasing evidence that *Tamarix* changes riparian ecology in substantial ways, facilitating its competitive advantage over native species and promoting its dominance of riparian corridors.[6] Recent work has shown that *Tamarix* has a negative impact on root-associated fungi (mycorrhizae) that are essential for the health of native plant species, including a foundational tree species, the Fremont cottonwood (*Populus fremontii*).[7] Given the critical role of cottonwoods in western riparian ecosystems a negative interaction with *Tamarix* could affect an entire assemblage of native species.[8] *Tamarix* foliage is highly flammable and can carry fire into riparian areas which were previously barriers to wildfire.[9] The foliar structure of *Tamarix* enables even healthy green plants to burn vigorously and since *Tamarix* is fire adapted, its plants quickly recover through basal sprouting while native species are killed by fire; the more the tamarisk, the greater the mortality of native plants, leading to a positive feedback loop and eventual monocultures of the weed. It is likely that even in some watersheds with a more natural hydrology (lacking major dams) such as the Virgin River, the invasion of tamarisk has been assisted by increased fire frequency rather than altered hydrologic regimes.[5] There are well-documented instances where fires carried by *Tamarix* have killed native woody plants, destroying SWFL habitat and even active nests.[1,4] It is rare to find nesting SWFL in areas dominated by *Tamarix* and most of the larger stands of *Tamarix* are now devoid of nesting SWFL. The clearest and most sensible solution for reversing *Tamarix* dominance on a regional scale is the introduction of a host-specific herbivore capable of suppressing vegetative growth and reproduction of plants in the genus *Tamarix*. Fortunately we have such a biocontrol agent.

Diorhabda suppresses Tamarix

Tamarix stands across much of western North America are now subject to periodic defoliation events covering tens of thousands of hectares (see map in [1]). Stands defoliated multiple times over several years typically show dieback of major branches and a substantial decrease in green biomass, while some plants may die, with mortality ranging from 10–50%, and one original release site in Nevada experiencing 80% mortality.[1,10] Multiple studies have attempted to tease apart the factors contributing to the impact of herbivory on *Tamarix* health and survival, including ecological and genetic factors, but no single factor is predictive of *Tamarix* susceptibility to herbivory impacts. Interestingly *Tamarix* mortality was not well correlated with total number of defoliation events[10,11], although variation in the seasonal timing of defoliation has not been evaluated as a determinant of plant mortality. The northern tamarisk beetle, *D. carinulata*, was originally constrained by the seasonal timing of photoperiodically induced diapause to northern latitudes, generally north of the 38th parallel. Since release the beetles have steadily moved southward and as of the summer of 2018 they are now well south of the 34th parallel on the Colorado River. Rapid evolution of the developmental response to day length has enabled them to adapt to more southern conditions and the cue for photoperiodic diapause has shortened from nearly 15 hours when they were first released in 2001, down to less than 13 hours.[1] The practical implications include better synchrony with host plant phenology, probably better efficacy as a biocontrol agent and the ability to move southward into some of the densest stands of tamarisk and also deeper into SWFL territory including large areas of historical territory with dense tamarisk thickets that no longer support flycatcher reproductive activity. One of the goals of *Tamarix* biological control is riparian recovery, which includes recovery of SWFL breeding habitat which was lost as *Tamarix* became the dominant woody vegetation.[12]

Projecting the future of Tamarix and Diorhabda

The direct impacts of *Diorhabda* on *Tamarix* include a decrease in foliage, an incremental dieback of branches, including larger main branches, and eventual death of some plants. The authors have also noted that plants subject to defoliation experience decreased flowering, particularly in the year following defoliation.[1] With a decrease in canopy cover, understory vegetation will have more access to sunlight and could begin to thrive. Understory vegetation and the seed bank should be monitored and if undesirable vegetation is present it will need to be managed. Diminished biomass results in a decreased fuel load so *Tamarix* will be less likely to carry fires into riparian areas once biocontrol impacts are realized.[9] Plants will also translocate lesser amounts of salts to the surface and smaller plants will support smaller root systems, which may diminish other undesirable effects on the belowground environment. In short, most of the *Tamarix* impacts to riparian ecosystems will be reduced following biological control using *Diorhabda*. In settings in which restoration is desirable or necessary *Diorhabda* will suppress *Tamarix* and reduce the possibility that restoration and revegetation efforts will be reversed by burgeoning *Tamarix* populations.[13] The authors are currently working to incorporate biological control into *Tamarix* management programmes designed to reverse or slow riparian degradation. This work includes long-term monitoring of *Diorhabda* and impacts of *Diorhabda* on *Tamarix* as well as monitoring indirect effects of *Tamarix* biological control. It also includes research on *Diorhabda, Tamarix* and the integration of biological control into riparian restoration[4] as well as regular presentation of all findings to resource managers and the larger scientific community. As we stated in our review[1] if it becomes fixed in the minds of regulators, resource managers and other stakeholders that *Tamarix* biological control was the problem as opposed to *Tamarix* itself, long-term riparian restoration will be hampered and *Diorhabda* will be seen as a failure instead of as a solution for *Tamarix* suppression in integrated riparian management programmes.

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Rabbit Biocontrol: Greater than the Sum of the Parts

A study based on 18 years of field data has shown that the two viruses (myxoma virus and rabbit haemorrhagic disease virus, RHDV) deployed for European rabbit (*Oryctolagus cuniculus*) control in Australia can work synergistically.[1] While the effect the scientists have uncovered occurs naturally in the field, their results suggest new opportunities for improving rabbit control by manipulating the timing of virus outbreaks.

The study was made possible by the Turretfield Rabbit Research project, run by the South Australian Department of Primary Industries and Regions. At approximately two-month intervals over two decades, a capture–mark–recapture project including carcass recovery and antibody testing of rabbits of all ages from an isolated population has been carried out at the Turretfield Research Centre north of Adelaide. Antibody testing enabled the researchers to assess each rabbit's immunity status to both viruses.

The researchers used data collected from 1998–2015 to model survival histories of 4236 individual rabbits captured during 107 trapping sessions. During this period, they recorded outbreaks of both myxomatosis (28 sessions) and RHDV (13 sessions), with some outbreaks spanning more than one session.

The authors investigated whether survival of one disease affected a rabbit's risk of succumbing to the other disease later on. They used multi-state models to compare mortality during disease outbreaks and non-outbreak periods for rabbits with different histories of virus exposure. They were interested in whether the impact of the two diseases was merely additive (i.e. surviving one disease had no impact on whether a rabbit would die from the other later on) or whether surviving one disease changed the risk of dying from the other disease (i.e. there was a synergy). If there was a synergy, they wanted to know whether prior exposure/immunity to both diseases had this effect, or only one of them.

The strongest effect was from prior exposure to myxomatosis. Myxomatosis outbreaks themselves had relatively low impact on rabbit mortality compared with mortality during non-outbreak periods (although it increased appreciably during longer outbreaks). This was consistent with perceptions that myxomatosis is a weaker biocontrol agent nowadays because of genetic resistance and attenuation of virus virulence, yet investigation of RHDV outbreaks shed a slightly different light on this.

RHDV outbreaks increased mortality in naïve rabbits by 37.7% (cf. non-outbreak periods), consistent with the virus's performance as a useful biocontrol agent. Looking at all rabbits that died, however, naïve and myxomatosis-immune rabbits were 39.9% and 50% more likely to die, respectively, than RHDV-immune rabbits. So while some myxomatosis outbreaks might have limited immediate impact, survivors of the disease are on average 10% more likely to succumb to RHDV than naïve rabbits.

The reverse was not true: immunity to RHDV had no impact on subsequent survival of myxomatosis. Thus, the impact on mortality was synergistic if myxomatosis survival preceded RHDV infection, but only additive if a rabbit survived RHDV first.

This is not the first record of synergy between two animal diseases, but it is the first evidence of synergy for these rabbit diseases, and has implications for rabbit management and use of biocontrol agents in general. Such is the norm in nature, little stays the same, and the recent arrival of the new version of

RHDV (often called RHDV2) in Australia has been a new game changer. This new RHDV2 can kill rabbits immune to the original RHDV and kills young rabbits.[2] It has been associated with 80% declines in two, long-term monitored South Australian rabbit populations.[3] This new RHDV2 has been causing outbreaks at Turretfield 2–3 months earlier than RHDV, and has changed the timing of myxomatosis outbreaks, so the future scenario hopefully will be one where the biocontrol agents continue to suppress pest rabbits and provide some welcome relief from their grazing pressure on pastoralism, agriculture and the environment.

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Looking for Rabbit Disease in the Media

In 2012, Australian scientists began to use international digital media and digital search tools as a novel but simple method of monitoring for pathogens and disease outbreaks in lagomorph rabbits (see *BNI* 34(2), June 2013). A new paper in the *Journal of Wildlife Diseases* describes the outcome of the project.[1]

Biological control of European rabbits (*Oryctolagus cuniculus*) by introduced diseases has proved to be critical in the control of rabbits in Australia, especially in the vast, remote 'outback', but the exotic viruses have not been as successful in some environments, and more generally and importantly, their efficacy attenuates over time. The national strategy includes being continually on the lookout for new potential agents. The approach taken by the 'digital' project grew out of an observation in a 2008 paper outlining Australia's strategy for classical biological control of rabbits: "The most cost-effective method for finding potentially useful but as-yet undiscovered [biocontrol agents] would be to maintain a global watch on new diseases and pathologies in domestic rabbits."[2] The logic behind this is illustrated by the provenance of the three biocontrol agents released in Australia so far: the first, the myxoma virus, was first identified in Uruguay in 1896 as a cross-species infection from a *Sylvilagus* cottontail species, while the second/third agent, rabbit haemorrhagic disease virus (RHDV), was identified for the first time in China in 1984 in pet rabbits and also suspected as a cross-species infection; strains of RHDV have been introduced from the Czech Republic and most recently the Republic of Korea. Thus potential agents could arise almost anywhere in the world and though they may be detected by mortality events in the European rabbit, it appears most likely the new pathogen will arise from a related species of rabbit or hare (lagomorphs; order Lagomorpha).

During the four years of the project (2012–2016) Wildlife Health Australia captured emerging information on pathogens and disease outbreaks in the order Lagomorpha, focusing especially on the European rabbit. Disease outbreaks are now most often reported in published papers and via digital media. To actively monitor these sources, the team used RSS feeds, specific keyword searches in Google News and Google Scholar, and some specific website searches/scanning. RSS feeds can be very efficient, allowing many websites to be aggregated in one place: over the course of the project some 12,000–18,200 articles from 195–252 sources from RSS feeds were scanned per month. Some key sources are not picked up this way, however – hence the other parts of the strategy.

Results were collated monthly by country and topic, and reports of novel pathogens were reviewed in terms of potential (e.g. for virulence, host specificity; were they self-disseminating, humane, socially acceptable). In total, 356 items on rabbit diseases were detected from 50 countries. Most items related to RHDV and then myxoma virus (which, as an add-on, benefitted current biological control research), while 52 of 299 from scientific publications were described as 'unusual or interesting', and 31 were of specific interest for European rabbit biological control. The remaining items were news reports and official disease outbreak reports, and a small number of university theses.

With the small timescale of the project, it was always unlikely that a new potential biocontrol agent would be detected. In fact, five possibilities from five different countries were considered worth further review, although in the end none proved suitable. However, the project was successful as proof of concept. Given the high economic, environmental and social benefits of rabbit control in Australia (Au$70 billion in agricultural benefits from RHDV and mxomatosis up to 2011[3]), the low costs of routine surveillance of the kind undertaken in this project (less than $20,000 a year), and the capacity to add search words for other pest species/pathogens, make it very worthwhile.

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A Look Back at a Whitefly Biological Control Programme

A retrospective study published in the *Journal of Applied Ecology* provides a rigorous assessment of the impact of a classical biological control programme. It demonstrates how native predators in cotton crops in the US state of Arizona are having more impact than two introduced parasitoids on populations of the invasive species *Bemisia tabaci* MEAM1. It also shows that the introduced parasitoids have replaced but not enhanced parasitism by native species.[1] The author draws attention to the paucity of rigorous studies on the outcome of biological control programmes generally, and suggests that methods such as those employed here could be provide benefits in terms of explaining success and failure of introduced biocontrol agents, and insights on how control might be enhanced.

Bemisia tabaci MEAM1 (Middle East–Asia Minor sp. 1) was first identified (as a new strain, *B. tabaci* biotype B) in the mid-1980s after it invaded the southern states of the USA. It had colonized all southern states by 1990, and subsequently spread worldwide. Although still not clear why biotype B became such an important pest, its pest status was increased by a wide host range, ability to vector many plant viruses, high fecundity and propensity to develop pesticide resistance. Since 2005, advances in taxonomic techniques have allowed phylogenetic relationships of *B. tabaci* genotypes from around the world to be elucidated. Current understanding, supported by the International Whitefly Symposium Network, is that *B. tabaci* comprises 11 genetic groups represented by up to 40 or more morphologically indistinguishable species. Among these, the invasive biotype B has been designated MEAM1.[2,3]

The inter-agency classical biological programme for *B. tabaci* MEAM1 in the USA is fully described in a 2008 book.[4] Given the success of classical biological control against other whitefly pests and the limited parasitism of *B. tabaci* by the existing parasitoid guilds in affected crops in the USA, an approach based on introducing parasitoids seemed sound. During the programme (1992–2002), the Mission Biological Control Laboratory in Texas received 135 shipments of over 235 populations of natural enemies from global surveys. Further encouragement for the classical approach came from parasitism rates of 44% recorded in Spain and 67% in Thailand, mostly by *Encarsia* and *Eretmocerus* species. This programme was one of the first to benefit from development of PCR, with the emerging technology allowing morphologically indistinguishable parasitoid species and populations to be characterized. Thirteen natural enemy species were prioritized and evaluated in research on climate matching and quarantine and field testing, led by ‘Mission Control’ in Texas. Based on the results, different combinations of species/populations of different origins were released in Texas, Arizona and California.

In Arizona, two of the five released species established: *Eretmocerus* sp. from Ethiopia and *Encarsia sophia* from Pakistan. They had established by 2001 and largely replaced native parasitoids by 2004.[5] The new study[1] includes prospective and retrospective analytical approaches on data from 1997 to 2010 based on life-table analyses and matrix modelling including life-table response experiments (LTREs). Matrix models can prospectively identify life-stage vulnerabilities (and thus inform biocontrol agent choices) and retrospectively identify the contribution of different abiotic and biotic factors in (and thus what affected) success or failure. The LTRE approach helps to separate causes of population growth changes into individual contributions of the different factors.

Pest populations (and insecticide use) have declined dramatically since the initial *B. tabaci* MEAM1 invasion. Yet analyses from the cotton system indicate that the introduced parasitoids did not increase any factors contributing to pest suppression, specifically, they did not increase marginal rates of parasitism, or introduce novel sources of mortality and as a consequence did not lower rates of pest population growth. Host feeding by aphelinid parasitoids, common in laboratory studies, was not observed in this study. The author notes that even if this mortality source was mis-identified in the field the results are unaffected. Overall mortality did not change before and after exotic parasitoid establishment. The greatest impact on *B. tabaci* populations was shown to be via mortality of fourth instar nymphs, and this was mostly through predation by native species and to a lesser extent dislodgement, which includes chewing predation and weather-related events. The author says that “multiple tactics associated with improved integrated pest management strategies for all pests in major host crops such as cotton and various vegetables have affected this outcome.” He describes how, in cotton, a key tactic has been the use of economic thresholds and selective insecticides to conserve generalist arthropod predators. The net result has been a generally increased level of predation of pests, reflecting an agroecosystem that is now more favourable to biological control, including that provided by parasitoids. Parasitoids contribute to biological control but the introduction of exotic species did not change their overall role in the cotton system.

The paper is not critical of the classical biological control programme. The author notes that the analyses are for one crop in one location, and discusses possible reasons for the lack of impact of the parasitoids in Arizona cotton and the challenges to implementing biological control in annual crops. He points out that the prospective analyses he conducted in this retrospective study, using life-table data collected before the parasitoid introductions, would have supported the classical approach. And in Australia, introducing a parasitoid is reported to have met with success. Using data generated from research during the US programme, *Eretmocerus hyati* (from Pakistan) was identified as the most promising biocontrol agent for Queensland.[6] Three years after its release in 2004, 30–80% parasitism was being recorded in a wide range of host crops, and 45% even in regularly sprayed crops.[7] In the absence of the kind of detailed life-table based analysis conducted in Arizona cotton it is difficult to accurately quantify the role of parasitism for this multi-generational pest, but *E. hayati* was credited with a significant role in *B. tabaci* population suppression.

As the author of the new study points out[1], analyses based on the BIOCAT database of insect introductions for insect biological control (see [8] and references therein) indicate rates for establishment and successful control by entomophagous insect biocontrol agents as some 33% and 10%, respectively. Over the decades, authors have consistently pointed to the lack of knowledge about the results of many introductions. Unfortunately, most classical biological control programmes run short on resources and personnel once the agents are established and the final steps of documenting impact are often lacking. This is exacerbated by the general pattern that even after establishment, positive results often take many years to be seen. The author suggests that detailed pre- and post-introduction analyses such as carried out in his study for the *B. tabaci* biological control programme should be more widely applied to our science. Another useful research avenue, where introduced biocontrol agents have not performed as expected, would be to determine what went wrong, e.g. why the introduced parasitoids did not perform better in Arizona cotton, given the promising prerelease studies. Analyses of these kinds would not only help explain the results and improve the programmes and projects for which they are carried out, but also provide a body of literature to help advance the science of insect biocontrol agent introductions for insect pest control.

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Progress in Tradescantia Biological Control

Seven years on from the release of the world’s first biocontrol agent against tradescantia (*Tradescantia fluminensis*), evidence indicates that infestations of the weed in New Zealand are starting to be reduced. There is significant impact from two of the three insect agents released to date, while a fourth agent – and the first pathogen – has been released in 2018. This is also good news for Australia and South Africa, where biological control programmes against the weed are being developed.

New Zealand

Tradescantia, one of the world’s most popular ‘pot’ plants, is a hardy, shade-tolerant South American plant that has become widespread in frost-free parts of New Zealand’s North Island and to a lesser extent South Island. Thriving in shaded, cultivated and wild areas, its dense ground-smothering growth prevents regeneration of other plants, including trees. It threatens indigenous forest in northern New Zealand and is arguably the most widespread and troublesome weed in gardens throughout the country. Infestations are difficult to control; plants easily break into small pieces capable of re-sprouting. The plant also causes allergic dermatitis in dogs.

The first three biocontrol agents to be released are all beetles from Brazil. The leaf beetle *Neolema ogloblini* was released in 2011. Adults and larvae feed on leaf tissue, but the larvae inflict most damage, skeletonizing the leaves sequentially along a stem. The stem borer *Lema basicostata* and the tip feeder *Neolema abbreviata*, released in 2012 and 2013, respectively, damage different parts of the plant. Adults of both species feed on leaves, but most damage is done by the larvae. Stem-borer larvae bore into mature stems, causing collapse and necrosis. Tip-feeder larvae bore into young growing tips and destroy them, readily moving between tips to inflict maximum damage.

The biocontrol agents were released widely in North Island and some sites in South Island, and a monitoring project was set up to assess their impact. Initially the species were released at different sites to enhance establishment and to allow impact of each to be assessed.

In the first few years after the insects were released, monitoring indicated that they had established and encouraging levels of damage were recorded sooner than anticipated. However, there was variation between sites. While some of this has yet to be explained, in some cases flooding that washed away the beetles was clearly implicated – this was in spite of release sites being selected to avoid all but extreme flooding. Tradescantia is, in any case, a problem in riparian areas that are subject to regular flooding. A pathogen might be better able to survive at these flood-prone sites – and an appropriate biocontrol agent was ready and waiting.

While scientists at Landcare Research were researching the insect agents in New Zealand, Robert Barreto at the University of Viçosa in Brazil was conducting research on a fourth potential agent: the highly damaging and host-specific fungus *Kordyana brasiliense*. In infected tradescantia plants, expanding yellow spots develop on the upper leaf surface as the fungus colonizes host tissue. The fungus produces aerial, readily-dispersed basiodiospores on the under surface of these spots, giving them a white-woolly appearance. These spores cause new infections on plants. The leaves subsequently become necrotic, shrivel and die. Approval for releasing this agent in New Zealand was obtained in 2013, but importation and release was delayed to allow the three insect agents to establish and to determine where the pathogen might best complement their impact.

In the past year, detailed surveys of some of the insect monitoring plots have provided up-to-date quantitative information. Scientists have been focusing on the leaf beetle and the stem borer because more monitoring plots were established for them by the regional councils. Results indicate that the leaf beetle, the first to be released, is established and showing success across northern sites in North Island, but establishment has been more sporadic at southern release sites. In some northern sites, tradescantia has been all but eliminated by the leaf beetle and replaced by native plant species. In other sites, while percentage cover by tradescantia is still high, the plants are shorter and biomass has been reduced sufficiently to allow native plants to begin to regenerate. The stem beetle is also showing encouraging potential in drier northern sites. Plant cover remains higher in wetter sites where this agent has established, however, possibly because stems severed by beetle damage are able to regenerate in the damp soil. With the beetle species now being released at some of the same sites, future monitoring will be able to assess how they perform in combination, and monitoring will also be extended to other areas.

The fungus was imported into New Zealand from Australia, where it was being tested in quarantine (this was easier logistically than having it shipped from Brazil). It was released in North Island from March 2018 at sites with no beetle biocontrol agents, again to maximize the chance of establishment and assess its initial impact. With monitoring results beginning to indicate where insect agents are proving least successful, a strategy for deploying the fungus to these areas can be drawn up. Release sites will be monitored to assess how the insect species and fungus interact, but as they co-exist in their area of origin, adverse interactions are considered unlikely. There are promising signs that the fungus may be already establishing at three sites.

Given the impact of the insects so far and the damaging potential of the fungus, there is optimism that control of tradescantia in New Zealand will be ultimately successful.

Since its inception this project has been variously funded by the Department of Conservation, the Ministry of Business, Innovation, and Employment under the Beating Weeds programme, and the National Biocontrol Collective, with assistance also from Auckland Council and Northland, Horizons and Greater Wellington regional councils with assessment studies.

Australia

Tradescantia is recorded widely in south-eastern Australia, and has been identified as a serious environmental weed, particularly in coastal and riverine forest ecosystems, and an ecosystem engineer. *Tradescantia fluminensis* was nominated as a biocontrol target by the Invasive Plants and Animals Committee (IPAC) in December 2015 – a necessary step before an application to release a biocontrol agent can be submitted. Under a project funded by the Department of the Environment and Energy, the fungus and leaf beetle were prioritized for host-specificity testing. *Kordyana brasiliense* was imported from Brazil into the CSIRO containment facility at Black Mountain, Canberra, in July 2014, while *Neolema ogloblini* was imported into Agriculture Victoria's containment facility, Melbourne, in February 2015 from cultures provided by Landcare Research.

Host-specificity tests for the imported pathogen and leaf beetle were conducted, extending those already completed in Brazil by testing a range of Australian accessions of tradescantia and previously untested native and cultivated plant species closely related to tradescantia that are of relevance to Australia. The pathogen was confirmed to be highly host specific and was also able to damage all of the tradescantia accessions tested. An application to release has been submitted and the outcome is awaited. For *N. ogloblini*, oviposition and adult feeding damage to non-target plants was low compared to tradescantia and the few eggs laid on non-target plants failed to develop. Off-target damage would therefore only occur to some Australian native plants in the same family (Commelinaceae) in spill-over situations where ranges overlap with *T. fluminensis*, and where *T. fluminensis* is temporarily unavailable. An application for release is in preparation.

South Africa

Although not yet a major weed in South Africa, incipient infestations of tradescantia have been found in KwaZulu-Natal, Mpumalanga, Limpopo, Gauteng, Eastern Cape and Western Cape provinces, where the plant threatens natural ecosystems. A biological control project was therefore initiated in 2013 by the Agricultural Research Council – Plant Health Protection (ARC-PHP).

Phylogenetic studies in New Zealand showed that the populations in South Africa are similar to the ones in New Zealand. The tip feeder *Neolema abbreviata* was imported from New Zealand, and tested against South African indigenous Commelinaceae species and found safe to release in the country. A release permit was issued by the Department of Agriculture, Forestry and Fisheries in March 2018. A second species, the stem borer *Lema basicostata*, was imported in late 2016, also from New Zealand, but unfortunately the culture was lost.

In preparation for releases of *N. abbreviata*, field studies have been conducted to assess the functional plant and animal composition of invaded landscapes, which provide baseline information for post-release monitoring. Investigations on how water and nutrient availability might influence oviposition and subsequent herbivore performance have also been conducted to help inform release site selection.

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Protecting Nurseries from *Phytophthora ramorum*

The horticultural trade is a potential pathway for the movement and spread of invasive pests and diseases of plants. A paper in *Biological Control* reports the use of the hyperparasitic fungus *Trichoderma asperellum* (isolate 04-22; US Patent No. 9,320,283) as a biocontrol agent in *Phytophthora ramorum* infested soil.[1] To demonstrate the effectiveness of *T. asperellum*, field research was conducted at the United States Department of Agriculture (USDA) funded National Ornamentals Research Site at Dominican University of California (NORS-DUC). This is the first, and only, research nursery of its kind in the USA, operating under common commercial practices to investigate management options for quarantine pathogens affecting nurseries, including one of the most significant threats on the US Pacific coast: *P. ramorum*.

Sudden oak death, the common name for the disease caused by *P. ramorum*, gained its name after tan oaks and oaks (various *Quercus* spp.) began to die in northern California in the mid-1990s. *Phytophthora ramorum* was ultimately identified as the causal agent in 2000. The death of millions of trees in coastal California and Oregon has been attributed to the disease – and the movement of infested ornamental plants by the nursery industry has been implicated in its spread. Its natural origin remains unknown.

Controlling and stopping the spread of *P. ramorum* in wild land and nursery management is complicated by its wide range of shrub and tree hosts, including popular ornamentals, as well as a complex life cycle requiring multiple management approaches. Symptoms and their severity vary between species: from lethal stem canker to mild leaf blight (ramorum blight). Given the invasive threat the disease poses to native woodlands, US federal and state regulations on the nursery trade were implemented to reduce the risk of the pathogen spreading further. Trade in the host plants was both a risk and at risk.

Infested soil is an important inoculum source for *P. ramorum*, surviving as chlamydospores for extended periods. If the pathogen is detected in nursery soil through routine inspection, achieving and maintaining disease-free status using methods required by the USDA APHIS (Animal and Plant Health Inspection Service) quarantine programme is difficult and costly. Yet without it, the nursery trade is compromised.

A control measure for *P. ramorum* in infested soil is necessary to address the risk it imposes for further disease spread. Previous lab and greenhouse studies have shown *T. asperellum* isolate 04-22 could reduce *P. ramorum* in soil to undetectable levels. However, a common criticism of promising experimental biological control results is that they cannot be replicated in the field.

This paper reports promising results obtained from a two-year study into the biological control of *P. ramorum* by *T. asperellum* isolate 04-22 at NORS-DUC. Although the authors say that further work is needed, the results of field experiments in microplots infested with *P. ramorum* chlamydospores showed experimental results could be replicated under commercial nursery conditions using wheat-bran and wettable-powder formulated *T. asperellum* 04-22 products. Moreover, a separate trial using the wheat-bran formulation in a commercial nursery quarantined with a natural infestation of *P. ramorum* found that after five weeks, *P. ramorum* had been reduced to undetectable levels in the soil, and the quarantine status of the nursery was subsequently lifted.

[1] Widmer, T.L., Johnson-Brousseau, S., Kosta, K., Ghosh, S., Schweigkofler, W., Sharma, S. and Suslow, K. (2018) Remediation of *Phytophthora ramorum*-infested soil with *Trichoderma asperellum* isolate 04-22 under ornamental nursery conditions. *Biological Control* 118, 67–73.

Also see web: https://sciencetrends.com/biological-control-can-help-to-stop-an-aggressive-invasive-forest-pathogen/

Spraying Cattle with Nematodes for Tick Control

A study in the USA indicates the potential for controlling tick disease in wild and domestic animals by infecting the host animals with nematodes.[1] Heifers experimentally infested with *Rhipicephalus* (=*Boophilus*) *microplus* and subsequently infected (by spraying) with infective juvenile *Steinernema riobrave* or *Heterorhabditis floridensis* had 14.5% and 25.4%, respectively, fewer adult engorged female ticks for 21 days post-treatment than (water-sprayed) control animals. The nematodes also significantly affected reproductive parameters, although not egg hatchability. The authors say this is the first report, to their knowledge, showing a negative impact on ticks of entomopathogenic nematodes applied to a mammalian tick host, although additional research is needed, including on formulations to enhance nematode penetration and survival in the host animal.

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Saprophytic Fungi for Soil Helminth Control

Potential for using saprophytic fungi to control soil-transmitted helminths (*Toxascaris leonina* and *Trichuris* sp.) that infect domestic and wild mammals has been demonstrated by a study on lynxes (*Lynx lynx*) and dromedaries (*Camelus dromedarius*) in a zoological park in Spain.[1]

The study assessed effects of (i) *Mucor circinelloides* and *Verticillium* sp. on eggs of *Toxascaris leonina* in faeces of captive lynxes and (ii) *M. circinelloides* and *Trichoderma atrobrunneum* on eggs of *Trichuris* sp. shed by captive dromedaries. Fungi were applied directly to retrieved eggs placed in Petri dishes or sprayed on faecal samples. Results indicated that all the fungal species delayed egg development and increased egg mortality, indicating a potential novel approach to controlling soil-transmitted helminths affecting captive animals kept in zoo conditions.

[1] Hernández, J.A., Cazapal-Monteiro, C.F., Arroyo, F.L., Silva, M.I., Palomero, A.M., Paz-Silva, A., Sánchez-Andrade, R. and Arias, M.S. (2018) Biological control of soil transmitted helminths (STHs) in a zoological park by using saprophytic fungi. *Biological Control* 122, 24–30.

BioControl Special Issue on Weeds

The June 2018 issue of *BioControl* (63(3)) is subtitled "Perspectives on progress in classical biological control of weeds". The issue, edited by M. Schwarzländer, V.C. Moran and S. Raghu, contains a compilation of 12 papers derived from the symposium 'Rise or Demise? A Global Outlook on the future of Classical Biological Weed Control', held at the 25th International Congress of Entomology (ICE) in 2016. The introductory editorial says that the contributions, while describing the ups and downs of the sector in recent years, suggest an optimistic prognosis for weed biological control following the regulatory and funding hiatuses in many of the leading practitioner countries.