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General News

Rabbit Biological Control Takes Small Mammals off the IUCN Red List

A study in South Australia has shown that ecosystem-level impacts of rabbit biological control have allowed populations of three small mammals to recover, and as a result they can be recommended for removal from the IUCN (World Conservation Union) Red List.[1] The authors believe this is the first reported instance of a biocontrol agent reversing declines in multiple threatened species to this extent. They argue that these sustained indirect benefits of biological control highlight its value as a conservation tool, and that it is more effective and cost-effective than single-species approaches in this instance. Biological control and conservation are sometimes seen to be at odds, but this is an instance where they have common interests and those interests are shared by agriculture.

While a fifth of the world's mammals are under threat of extinction in the wild, Australia is worst affected with 43% of terrestrial species rated as 'near threatened' or worse. Its small mammal species have the world's worst extinction rate. Species in the arid interior have been hardest hit over the last 150 years or so, mostly because of the impact of the introduced European rabbit (*Oryctolagus cuniculus*) and its main predators, feral cats (*Felis catus*) and red foxes (*Vulpes vulpes*), whose populations are enhanced by high rabbit numbers.

Rabbit biological control began in Australia in 1950 with the introduction of myxoma virus, but the virus did not perform well in arid areas and the programme as a whole was increasingly affected by rabbit immunity to the virus. The situation altered dramatically in 1995 with the introduction of rabbit haemorrhagic disease virus (RHDV), which led to an initial drop of 95% in rabbit numbers in arid areas. While many studies have reported the impact of RHDV on Australia's native flora and on native and introduced predators, the new study is the first to document its effects on ecological driver relationships and how this has affected native mammals.

The authors investigated changes in rabbit, fox and cat populations and related this to changes in the distribution of four small mammal species (specifically their extent of occurrence and area of occupancy – the broad area the species is distributed over and the specific sites it occupies within it, see [2]), whose distributions had been historically reduced following the introduction of European farming practices and burgeoning rabbit populations. The study area covered 615,000 km^2 of arid South Australia characterized by nutrient-poor soils and comprising nine major bioregions, from sandy desert dunefields and vast stony plains to ephemeral wetland systems.

Rabbit populations fell around 85% across the study area after RHDV arrived, although they rose again in parts of it to reach 20–30% of pre-RHDV levels from 2006 onwards. Fox and cat populations fell with rabbit numbers, and were undetectable for the most of the study period in some parts of the study area.

The study area receives some of the lowest rainfall in the Australian continent, but sporadically it experiences flooding rains linked with continental-scale climatic (La Niña) events. These periods of very heavy rainfall are correlated with population irruptions in small mammal populations, which made rainfall a potentially confounding factor in the study. In 2010–2012, the area experienced record-breaking flooding rains associated with an exceptional La Niña event. By comparing small mammal records collated from various sources for 1970–1995 (pre-RHDV) with 1996–2009 and 2010–2014 (post-RHDV introduction, and before and during/after the exceptional rainfall period, respectively), the authors separated the effects of RHDV and flooding rain. Average rainfall both pre-RHDV and in the second period post-RHDV introduction was higher than in the first period after RHDV was introduced.

The authors found that all four small mammal species increased their distributions after RHDV was introduced, and most of the increases occurred in first 14, relatively drier years after it arrived. Smaller increases were recorded in the second, wetter post-RHDV period. Two rodent species, spinifex hopping-mouse (*Notomys alexis*) and plains mouse (*Pseudomys australis*), which had not been recorded at one long-term monitoring site since intensive monitoring began there a decade earlier, began to appear within three years of RHDV's spread, despite the drier conditions. They are now regionally abundant, and at some sites are, aided by rainfall-associated irruptions, the most common mammals. The dusky hopping-mouse (*Notomys fuscus*) underwent huge changes in its abundance and distribution following the introduction of RHDV. Prior to RHDV, government threatened species programmes could reliably detect it at just one monitoring site in South Australia, yet in the years following it has become one of the most common vertebrates across vast tracts of the Strzelecki Desert. In some places it is so numerous that those driving at night can see dozens crossing the road in their headlights and at times campers have them running around their feet beside the campfire!

On the basis of the results of this study, three species that were listed as Vulnerable on the IUCN Red List qualify to be downgraded. The dusky hopping mouse and plains mouse increased their extent of occurrence by 364% and 241%, respectively, but the greatest impact was seen for the marsupial micropredator crest-tailed mulgara (*Dasycercus*

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cristicauda), whose extent of occurrence increased 70-fold and area of occupancy 20-fold.

Understanding the ecosystem processes that underlie the mammal recoveries is important for planning future conservation management. The authors suggest that RHDV had both bottom-up and top-down effects on these small mammals: decreasing competition for food resources and increasing ground cover because there are far fewer rabbits, and decreasing predation because of declining rabbit-dependent predator populations. This meant that not only seed and vegetation-eating small mammals such as rodents benefited, but also small carnivorous marsupials such as the crest-tailed mulgara, which feed on arthropods, small reptiles and other small mammals – all of which have benefitted from increased vegetation cover and lower numbers of feral predators. This study, which has 'demonstrated species recoveries on a scale rarely documented in any mammal', shows that RHDV can be an important conservation tool for restoration of trophic processes in natural ecosystems over large areas. In some quarters, biocontrol agents that have ecosystem impacts are viewed with concern. So it is worth pointing out that these were positive impacts on biodiversity and were achievable with RHDV only because the introduced rabbit had had such extensive, disastrous and long-lasting effects on the ecosystem.

Funding for conservation falls well short of what is needed to protect the world's biodiversity. The authors suggest that conservation programmes that tackle threatening processes by harnessing trophic cascades provide a better use of scarce economic resources and are more cost-effective than (multiple) programmes focused on conserving single species. In this case, the conservation effects have been effectively 'free' – piggybacking on the enormous economic benefits that rabbit biological control has had for agriculture. Although the introduction of RHDV into Australia was expected to generate benefits for both agriculture and the environment, particularly native vegetation, the true extent and complexity of the flow-on ecosystem effects was not foreseen. These significant and widespread environmental benefits are equally difficult to quantify in economic terms. A recent economic analysis found that the introduction of the myxoma and RHD viruses produced a benefit of at least Au$70 billion for the country's cattle and sheep industries in the first 60 years.[3] The tandem positive impacts of rabbit biological control on agriculture and biodiversity lend weight to the argument for long-term monitoring programmes. Sustained suppression of rabbits needs new strains of virus to be found and developed to maintain control as rabbits acquire immunity to existing strains. In this way, agriculture will continue to be protected and native mammal recovery and survival assured.

[1] Pedler, R.D., Brandle, R., Read, J.L., Southgate, R., Bird, P. and Moseby, K.E. (2016) Rabbit biocontrol and landscape-scale recovery of threatened desert mammals. *Conservation Biology*. DOI:10.1111/cobi.12684.

[2] *IUCN Red List Categories and Criteria*, version 3.1, 2nd edn.
Web: http://jr.iucnredlist.org/documents/redlist_cats_crit_en.pdf

[3] Cooke, B., Chudleigh, P., Simpson, S. and Saunders, G. (2013) The economic benefits of the biological control of rabbits in Australia, 1950–2011. *Australian Economic History Review* 53, 91–107.

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Valuing Biological Control in Urban Trees

The value of urban trees is often underappreciated, although the public is quick to notice if their appearance deteriorates. Where damage is the result of an introduced pest, classical biological control can often be a sustainable solution. Recent economic analyses of biological control projects in California demonstrate that successful biological control in urban trees can give very substantial rates of return on investment. These kinds of study could be critical for developing both grass-roots and governmental support for future urban biological control efforts, because they provide compelling arguments for the cost-effectiveness of the approach.

A city with no trees would be a stark place, but how do you put a value on urban trees? The tree appraisal technique used in these studies, the trunk formula method as defined by the US Council of Tree and Landscape Appraisers, estimates the value of a tree on the basis of replacing it with the largest normally available tree of the same (or comparable) species, and the difference in value if the tree being appraised is larger than the largest available replacement tree – and this figure was multiplied for the estimated number of street trees in urban areas in California.

Two recent papers in the *Journal of Economic Entomology* assess biological control of Cuban laurel thrips (*Gynaikothrips ficorum*) on *Ficus microcarpa*[1] and pests of eucalypts (*Eucalyptus* spp.)[2], respectively, and these are brought together with an earlier analysis in a third study.[3]

Ficus microcarpa is a popular ornamental tree in urban landscapes in California. During the 1960s, trees started to suffer from the build-up of large populations of the introduced Old World thrips *G. ficorum*. The thrips forms colonies of several hundred individuals in leaf-roll galls on expanding leaves. Although introduction of the anthocorid bug *Montandoniola confusa* (= *morguesi*) had been successful in Hawaii and Bermuda, this was apparently not replicated when the biocontrol agent was introduced to California in 1995: no sign of establishment was found during surveys in 1997–1998. However, surveys in the release areas in 2013–2014 found that *M. confusa* was present and thrips galls were significantly reduced. The authors assessed the value of biological control by comparing the difference in value between street trees in good and poor or very poor foliage condition, and estimated a benefit of \$58.77 million and \$73.40 million, respectively. The total cost of the biological control project was approximately \$61,800, so the benefit accrued for every dollar spent on biological control of *G. ficorum* on municipal street trees was in the range \$950–\$1187.

Eucalypts are multi-purpose trees. One of their uses in California is for street planting but their ornamental quality has been reduced by exotic insect herbivores that attack different parts of the trees: eucalyptus longhorned borers (*Phoracantha semipunctata* and *P. recurva*, first recorded in the 1980s and 1995, respectively), the sap-sucking blue gum psyllid (*Ctenarytaina eucalypti*, first recorded in 1991), the defoliating eucalyptus snout beetle (*Gonipterus scutellatus*, first recorded in 1994) and red gum lerp psyllid (*Glycaspis brimblecombei*, first recorded in 1998). Following biological control projects, three species are now under complete control: *P. semipunctata* by the encyrtid *Avetianella longoi*, *C. eucalypti* by the encyrtid *Psyllaephagus pilosus*, and *G. scutellatus* by the mymarid *Anaphes nitens*. *Glycaspis brimblecombei* is under substantial control following introduction of the encyrtid *Psyllaephagus bliteus* in 2000. Biological control of *Phoracantha recurva* is being assessed. Because it is difficult – and not altogether relevant – to disentangle the benefits of the individual biological control projects for pest species that cause similar damage, the study evaluated the combined costs and benefits of all biological control in urban eucalypts. Independent estimates of the number of *Eucalyptus* municipal street trees in urban areas in the state gave a range of approximately 190,700–476,500. The authors surveyed some 3500 trees and estimated an average value of just under \$6000 per tree. Taking the lower and upper estimates of tree numbers as boundaries, California's eucalypts therefore have a total value of \$1.1 billion to over \$2.8 billion. The biological control projects have cost in total \$2.66 million. There has been a return on investment in the range \$428–1070 for every dollar invested.

A poster presented at the 2015 Entomological Society of America Annual Meeting[3] combined the information from these two studies with earlier work on the benefits of biological control of ash whitefly (*Siphoninus phillyreae*, first recorded in 1988) on ornamental pear (*Pyrus* spp.) and ash (*Fraxinus* spp.) trees.[4] The aphelinid parasitoid *Encarsia inaron* was released in urban areas in 1990, and by 1992 had achieved complete control of the psyllid. The biological control project to protect the 1.4 million host trees in California had cost \$1.22 million. The authors of that study calculated a net benefit of \$322 million to \$411 million from biological control, and a return of \$265–337 for every dollar invested in the project.

The studies above demonstrate the perhaps unexpectedly enormous value of urban street trees, and the size of the benefits that accrue from successful biological control projects that preserve them in the face of exotic pest attack: for the systems assessed here, the return across all three biocontrol programmes in urban street trees is estimated to be in the range \$364–729 for every dollar invested.[3] While the size of the benefits may not surprise biocontrol practitioners, they provide useful ammunition for arguing the case for future implementation of classical biological control projects for trees in urban situations.

[1] Shogren, S. and Paine, T.D. (2016) Economic benefit for Cuban laurel thrips biological control. *Journal of Economic Entomology* 109, 93–99.

[2] Paine, T.D., Millar, J.G., Hanks, L.M., Wang, Q., Daane, K., Dahlsten, D.L. and McPherson, E.G. (2015) Cost-benefit analysis for biological control programs that targeted insect pests of eucalypts in urban landscapes of California. *Journal of Economic Entomology* 108, 2497–2504.

[3] Paine, T.D., Millar, J.G., Hanks, L.M., Gould, J., Daane, K.M., Dahlsten, D.L., Jones, M.E. and Shogren, C. (2016) Public benefit of biological control of insect herbivores in California. Entomological Society of America Annual Meeting, 9–14 August 2015, Baltimore, Maryland. (Poster)

[4] Jetter, K., Klonsky, K. and Pickett, C.H. (1997) A cost/benefit analysis of the ash whitefly biological control program in California. *Journal of Arboriculture* 23, 65–72.

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Biological Control and Arthropod Invasions

A review in *Biological Invasions* assesses how concern about nontarget effects has influenced regulation and practice of arthropod biological control, and how far revised procedures and regulations can increase success and minimize risk.[1] The paper is in a special section of 14 papers on 'Drivers, impacts, mechanisms and adaptation in insect invasions' in issue 18(4) of the journal.

The authors focus on biological control of arthropods using arthropod biocontrol agents. They review the use of exotic biocontrol agents in classical and augmentative biological control, and then consider evidence for nontarget environmental effects. They set the context for the discussion by describing how increasing knowledge about the value of biodiversity over recent decades has altered perceptions of what is desirable and acceptable in an exotic biocontrol agent – and a biological control programme. Then they review how regulations and methods used in biological control have changed over time and make recommendations to improve both actual and public perception of the safety of arthropod biological control, so as to enhance its uptake.

Evidence for environmental impact – both direct effects on native species, and indirect effects on these species or ecosystems – is evaluated. Direct effects have attracted most attention and research effort. Looking at the timeline of biocontrol agent introductions, the authors find that direct effects are mostly ascribed to predators or parasitoids introduced before c. 1950, i.e. before environmental concerns came to the fore and when regulatory oversight was patchy. Moreover, they argue that quantified negative effects have been documented for very few (at most 11) species although more than 2000 species of arthropod biocontrol agent have been introduced somewhere in the world. Apart from attacking nontarget species, identified potential impacts include displacement of native species and hybridization, although evidence of these in specific cases remains equivocal. Commenting on the argument that more nontarget effects would be found if they were looked for more extensively, the authors agree but argue that similar investigation would uncover more impacts for all exotic arthropods, including pests that are the target of biological control. For indirect effects, opinions vary about their importance, and because they have received less attention the evidence is harder to evaluate. Part of the problem is that indirect effects may be specific to individual systems, including for example apparent competition, changing pathogen presence/load, and altering host plant choice.

With host-specificity testing at the centre of assessment of risk, the authors identify how the centrifugal approach has been and continues to be adapted to test not only native insects taxonomically related to the prospective biocontrol agent, but also ecologically similar species, species of economic or conservation importance, and also already-introduced biocontrol agents. They describe how criticism that laboratory testing is too simplistic to give an understanding of actual ecological risk has led to development of ways for testing in more complex systems and in the field. They also identify a push for post-release studies to look for positive and negative effects, although they note that this is challenging and will need considerable input in research and funding to make it effective.

The enhanced significance of biodiversity in recent decades has meant consideration of the impact of proposed releases on neighbouring countries should a biocontrol agent disperse across an international border. In view of inconsistency between how countries regulate biological control, the authors call for global rather than national strategies. They note that most advance on this has been made in the Americas. The North and South American regional plant protection organizations (North American Plant Protection Organization – NAPPO, and Mercado Común del Sur – Mercosur, respectively) have developed mechanisms for consulting with neighbouring countries. Europe, where countries currently follow national legislation, is seeking to harmonize regulation.

The authors describe how recognition of the value of biodiversity has had a second, separate impact on biological control. Access and benefit sharing (ABS) issues (as encompassed in the Nagoya Protocol to the Convention on Biological Diversity; www.cbd.int/abs/about/) have hampered export of potential biocontrol agents from areas of origin and in some cases halted biological control initiatives. Achieving a 'fair and equitable' balance and ensuring a country's biodiversity is not exploited are problematic for classical biological control initiatives, which tend to be national or regional and conducted for the public good rather than commercial gain, and many countries have stalled. A way forward is still being sought, perhaps in the form of an exemption as part of scientific research.

Overall, the authors discern a shift away from use of generalist biocontrol agents, and, since the 1980s, a trend of falling introductions in arthropods as classical biocontrol agents as concerns about nontarget impacts have grown. They contrast this with the increasing numbers of new invasive alien species in recent decades, against which classical biological control could be deployed. They describe the decline in implementation of arthropod biological control as a result of a cascade of interlinked processes and events. Fear of nontarget impacts led to the development of enhanced protocols by biological control scientists and at the same time stricter regulation was imposed. As a result, fewer biocontrol agents than before met the criteria for suitability. As testing procedures were more onerous and took longer, fewer agents still reached the point where applications to release could be made. On top of this, ABS issues restricted research and surveying for new potential biocontrol agents. For augmentative biological control, ABS issues alongside safety concerns have meant the sector focuses far more now on indigenous natural enemies for development as biocontrol agents, particularly in Europe.

The authors conclude that the stigma affecting arthropod biological control is a legacy of releases made 65+ years ago. Purported negative effects of classical biocontrol agents have cast the approach in a negative light, although these impacts are actually rare, and especially for biological control carried out under modern protocols and regulation. For augmentative biological control, concerns centre on generalist biocontrol agents whose climatic requirements might allow them to establish in the wild. There are moves in at least some countries against approving agents with these characteristics. The authors argue that the future of biological control using exotic arthropod agents rests on two elements: (i) active and transparent engagement with the public to regain trust, both to communicate how, and how carefully, safety to the environment is assessed, and to ensure the benefits of biological control achieve prominence; and (ii) more and sustained funding focused on improving and demonstrating the safety of the approach, which will lead to 'rigorous evidence-based policy formulation.'

[1] Hajek, A.E., Hurley, B.P., Kenis, M., Garnas, J.R., Bush, S.J., Wingfield, M.J., van Lenteren, J.C. and Cock, M.J.W. (2016) Exotic biological control agents: a solution or contribution to arthropod invasions? *Biological Invasions* 18, 953–969.

BIOCAT: Demonstrating Recent Trends in Insect Biological Control

The BIOCAT database of introductions of insect biocontrol agents against insect targets since the 1890s was developed and maintained by David Greathead, helped by his wife Annette, and together they published a review in this journal in 1992 describing the database and giving an overview analysis of the data.[1] An open-access paper in *BioControl* describes how BIOCAT has been updated to 2010.[2] It explains how the updated database was analysed to extract summary data that allow a comparison with both the 1992 version and other reviews of insect biocontrol agent introductions – and this allows recent trends and the future of the sector to be discussed.

The updating was carried out by a team from CABI and the Center for Biological Control, Florida A&M University, who sourced and collated published information up to 2010. Funding was provided by the CABI Development Fund, the International Organisation for Biological Control, and the US Department of Agriculture/Animal and Plant Health Inspection Service. CABI team members updated and revised the database – which included moving it to a new platform with expanded fields – while the onerous task of reviewing all the records was headed by Matthew Cock. The plan is to make the 2010 version of BIOCAT available as a relational, interrogatable online database via CABI's Plantwise knowledge bank. This new version of BIOCAT will allow the biological control record to be used alongside ecological approaches to help refine the practice of insect biological control.

The decline in implementation of classical biological control in recent decades has been widely reported, but the *BioControl* paper adds data and detail. While a decline since the 1970s was confirmed and seems set to continue, the 18 years 1992–2010 added 20% to the total number of introductions in the previous 112 years. This reflects a general trend of increasing numbers of introductions that peaked in the 1950s–1970s and then fell. The traditionally important countries in insect biological control continue to be strong performers although some of them have cut back, but the number of countries implementing biological control has risen, with many 'new' countries making just one or two introductions so far.

Despite the falling number of total introductions per decade, rates of both permanent establishment and successful control increased substantially in the period after 1992 (by 27% and 20%, respectively). Most of the successfully controlled pests are major invasive species of countries or regions. The authors discuss the influences of a risk-averse culture and access and benefit sharing issues on biological control. They argue that the increasing rate of success of introductions is a reflection of greater research effort with focus on achieving successful outcomes, and also increased confidence in implementing biological control because it is increasingly seen to be effective and predictable for pest management. These factors, they conclude, may help to counterbalance the issues of risk aversion and access and benefit.

[1] Greathead, D.J. and Greathead, A.H. (1992) Biological control of insect pests by insect parasitoids and predators: the BIOCAT database. *Biocontrol News and Information* 13, 61N–68N.

[2] Cock, M.J.W., Murphy, S.T., Kairo, M.T.K., Thompson, E., Murphy, R.J. and Francis, A.W. (2016) Trends in the classical biological control of insect pests by insects: an update of the BIOCAT database. *BioControl*. DOI:10.1007/s10526-016-9726-3.

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Australian Weed Biological Control Back in Business

The announcement in April 2016 of an Au$6.2 million grant with combined equal co-investment from industry and research providers into the Rural Industries Research and Development Corporation for biological control of ten target weeds in Australia signals a new $13 million commitment to weed biological control in Australia. This is clear recognition that biological control is an effective and economically effective way to tackle widespread weeds.

The grant has been made under round two of the Rural Research and Development for Profit (RR&DfP) programme, which implements a government Agricultural Competitiveness white paper commitment to boost funding to rural research and development corporations and fund nationally coordinated, strategic research across the agricultural industries to deliver effective outcomes for Australian producers. The new project covers ten target weeds (either new targets or new biocontrol agents) that collectively cost Australia $400 million. The list comprises giant rat's tail grass (*Sporobolus* spp.); three Asteraceae: fleabane (*Conyza* spp.), ox-eye daisy (*Leucanthemum vulgare*) and sowthistle (*Sonchus* spp.); two further herbaceous weeds: silverleaf nightshade (*Solanum elaeagnifolium*) and the succulent mother-of-millions (*Bryophyllum delagoense*); two invasive shrubs: prickly acacia (*Acacia nilotica* subsp. *indica*) and African boxthorn (*Lycium ferocissimum*); and two water weeds: cabomba (*Cabomba caroliniana*) and sagittaria (*Sagittaria platiphylla*). Some of the listed species are or have been target weeds in other regions. Australian scientists will be seeking to link with international partners, and to draw on existing knowledge and develop new overseas research initiatives.

This is the second weed biological control project funded under the RR&DfP programme – the first, in round 1 in 2015, made $5 million available for a project on six target weeds where existing agents are already currently being considered: cactus species (*Cylindropuntia* spp.), parkinsonia (*Parkinsonia aculeata*), parthenium (*Parthenium hysterophorus*), blackberry (*Rubus fruticosus* spp. aggregate), gorse (*Ulex europaeus*) and silverleaf nightshade. Australia now has nearly $20 million of projects working together across agencies on weed biological control that provide a whole pipeline of weed biological control programmes from new to mature. This new focus is mainly on weeds of agricultural significance, but environmental weeds are expected to be targeted through other funding sources built on the back of this investment. The new tranches of funding represent a renaissance of the field in Australia, and an opportunity for next-generation scientists interested in weed biological control in Australia and beyond.

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Ideal Agent Model to Identify Best Survey Areas

Exploration for prospective biocontrol agents is often guided nowadays by climate modelling, but for targets with a large native range this can still leave a lot of ground to cover. A paper in *Biological Control* describes a novel way of using CLIMEX to decide where to target surveys for natural enemies that are likely to have optimum attributes to tackle the target weed in the proposed area of introduction.[1]

Conyza bonariensis, a herbaceous annual in the Asteraceae that is native to South America, is an introduced weed in many regions of the world. In Australia, it is a widespread and difficult-to-control weed in crops, particularly grain crops, and an emerging weed in natural areas. As it has no close relatives in Australia and has developed resistance to a broad range of herbicides, it seems a promising candidate for classical biological control.

The parameters of the CLIMEX model were decided from (i) plant attributes including values derived experimentally from germination and growth measurements in greenhouse and laboratory studies over the growing season at different temperatures; and (ii) information from databases on the worldwide distribution of *C. bonariensis*. The 'Compare Locations' option was used to develop an Ecoclimatic Index for the weed to identify areas in South America suitable for its growth. The model fitted well with its distribution across most of South America, which was an unhelpfully large area to survey.

The authors thought about what attributes the ideal biocontrol agent would have. Experience with other weeds that also thrive in Mediterranean-type climates in Australia suggests that they do so because they continue to grow during the winter. *Conyza bonariensis* seeds germinate at any time of year, with plants forming rosettes that survive winter and are poised to bolt as the temperatures warm in spring. Such weeds tend to outgrow damage from a biocontrol agent that has the same optimum growth temperature. The ideal agent, the authors postulated, would thrive at lower temperatures than the weed, growing faster than it does in winter, and so be able to inflict damage and contain the plant before spring weed growth takes off.

On the reasonable assumption that such natural enemies would have coevolved with *C. bonariensis* in the colder part of its natural range, they entered the parameters for a hypothetical biocontrol agent for this situation, with the optimum temperature for growth set at 5°C below that of the weed. Running this model delineated areas in central Chile, eastern Argentina and the eastern foothills of the Andes as most suitable for surveying. (A bonus of the CLIMEX model is that because growth is measured across the year, it can also be used to identify best times for surveys in locations with different climates.) Running the model for Australia showed that areas of Australia where this hypothetical agent should perform best include most of the major grain cropping areas.

The authors suggest such a model could be further refined, for example to include other or more ideal attributes. While there are a number of caveats to the approach, they argue that it has prospects for wider adoption for weed or arthropod biological control because refining promising areas for targeted surveys is useful in this era of limited time and funding.

[1] Scott, J.K, Yeoh, P.B. and Michael, P.J. (2016) Methods to select areas to survey for biological control agents: an example based on growth in relation to temperature and distribution of the weed *Conyza bonariensis*. *Biological Control* 97, 21–30.

Awards to Provide Fresh Impetus to Biocontrol Research in India

The Society for Biocontrol Advancement (SBA), operating from the Indian Council of Agricultural Research's National Bureau of Agricultural Insect Resources (ICAR–NBAIR) in Bengaluru, is the only Indian society dedicated solely to biological control research. The 700-member-strong SBA organizes national-level meetings and symposia on a regular basis, and also supports international conferences. Its quarterly publication, *Journal of Biological Control*, first published in 1987, is among the small number of journals worldwide devoted to biocontrol research. It publishes original research articles on all aspects related to biological control of pests, including insects, mites, nematodes, plant pathogens, vertebrates and weeds. It has recently been felt by long-time members and senior biocontrol specialists that rekindling interest in young researchers in biological control through instituting awards would go a long way toward sustaining the research momentum. Further, recognizing senior scientists for their contributions and achievements would send the right message across the biocontrol fraternity. SBA has now instituted five new awards, each carrying the name of the donor: SBA–Dr T.M. Manjunath Young Scientist Award for Excellent Contribution to Biological Control Research; SBA–Dr T.M. Manjunath Award for Outstanding Contribution to Biological Control and Allied Sciences; SBA–Dr S. Sithanantham Award for Outstanding Impact of Biocontrol R&D; SBA–Dr M. Swamiappan Award for Outstanding Contribution to Biosystematics of Biocontrol Agents; and SBA–Dr S.P. Singh Memorial Award for Lifetime Achievement in Biological Control. These awards are like a breath of fresh air, and it is earnestly hoped that biocontrol research will get extra impetus with their arrival.

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Marie Skłodowska Curie Innovative Training Network on Breeding Invertebrates for the Next Generation Biocontrol: BINGO

Increased demand for agricultural goods to feed a fast-growing world population is challenging not only production systems but crop protection practices as well. Invertebrate pests cause yearly worldwide losses of around €73 billion in annual crops and stored products, representing a huge threat to food security. Moreover, movement of exotic pests to new areas due to trade activities and climate change is placing further demands on crop protection. At the same time, crop protection practices are increasingly constrained. This holds for chemical control because of reduced maximum residue limits and the banning of certain pesticides, as well as for biological control using imported invertebrates because of stricter regulation and more difficulty accessing exotic species (see 'Biological control and arthropod invasions, this issue). Thus while the use of invertebrates for biological control has been advocated as a more sustainable approach to control agricultural pests, reliance on exotic natural enemies to control introduced exotic pests may not be a viable approach. This means governments need to find and develop solutions to reduce the dependence on non-native natural enemies for biological control in order to promote more secure and sustainable food production systems.

One promising alternative to reduce or even eliminate the need to import new exotic natural enemies is to optimize established exotic and native biocontrol agents. This is a realistic technical goal, achievable through the exploration of natural genetic variation and selective breeding. It requires professionals with the interdisciplinary skills to bridge the gap between fundamental sciences, such as genomics and genetics, and applied sciences, such as the practice of biological control. Currently, however, there is a lack of such scientists. It was in this context that the expertise of academia, industry and agricultural organizations was drawn on in a collaboration that gave rise to the BINGO project.

The consortium BINGO was created as an International Training Network for early stage researchers and is funded by the Marie Skłodowska Curie scheme of the EU Horizon 2020 programme. BINGO brings together participants from prominent universities, institutes and industry in nine European countries and advisory board members from outside the EU. The network consists of 24 researchers and 13 PhD students, who will carry out their projects at the BINGO partners' facilities. This initiative aims to (i) improve current biocontrol practices through the exploration and exploitation of natural genetic variation present in native natural enemies, (ii) extend the application of quantitative and population genetics to the invertebrate biocontrol field, and (iii) train 13 young researchers in an interdisciplinary environment. BINGO will provide the PhD students with education at established universities as well as access to the state-of-the-art techniques and equipment available at the different participating institutions. Moreover, the young researchers will benefit in terms of career enrichment and networking opportunities from an extensive internship programme of exchanges between BINGO partners. BINGO is not only multidisciplinary by nature, encompassing disciplines from molecular genetics and genomics, to behaviour and physiology, and ecology and evolution, but will also implement new technologies that are likely to improve the efficiency of biological control.

As there are several areas of interest when it comes to selective breeding, BINGO is divided into different Work Packages (WP) in order to target all the steps of biocontrol practice from production, to field performance and risk assessment.

Production of natural enemies is a crucial step for the quality and subsequent performance of these invertebrates in the field. Improvements in production are likely to decrease costs related to handling procedures thus making biocontrol agents more accessible for growers. A WP leading research on rearing and storage focuses on aspects of mass rearing, allergy (to moth scales), sex ratio, clutch size and exploitation of symbiotic bacteria for increased production. The objectives of this WP will be addressed through three research projects: (1) Mutation genetics in the flour moth *Ephestia kuehniella*; (2) Clutch size, sex ratio and differential mortality in the *Bracon hebetor*/*B. brevicornis* species complex; and (3) Optimization of mass rearing of *Bactrocera oleae* and its parasitoids.

A major concern after the release of natural enemies is their impact on local ecosystems, and this is a specific issue underlying the creation of BINGO. Concerns will be addressed by a WP on risk assessment, which will coordinate monitoring and risk assessment aspects through two research projects: (1) Benefits and risks of using the native polyphagous biological control agent, *Anastatus bifasciatus*, against invasive stink bug *Halyomorpha halys*; and (2) Monitoring pre- and post-release diversity in local parasitoid populations.

In terms of performance of biocontrol agents, the different trophic levels at which pest species and biocontrol agents interact will determine the success of pest suppression. A WP focusing on performance will try to identify and predict the key traits related to field performance through mathematical modelling and will attempt to improve these traits using quantitative genetic approaches in three biocontrol agents. The projects in this WP are: (1) Improving pest control efficiency: a modelling approach; (2) Promoting adaptability of *Amblyseius swirskii* predatory mites to tomato crop; (3) Minimizing plant damage through selected *Nesidiocoris tenuis*; and (4) Expanding the range of uses of *Phytoseiulus persimilis*. Success of artificial selection on performance traits of these species will be tested in laboratory, semi-field and field conditions.

The major genomic aspects of BINGO are coordinated in a WP on genomic variations, whose objectives are to (i) develop genome-wide genetic markers for field monitoring, estimating and tracking variation of mass-reared biocontrol agent strains, (ii) unravel the genes underlying phenotypic variation in relevant biocontrol agent traits, and (iii) develop genomic selection methods for improvement of biocontrol agents. These objectives will be targeted through four research projects: (1) Population genomics of natural enemies; (2) Genomic basis of life history traits and reproductive potential; (3) Identification and characterization of naturally occurring variation affecting reproductive diapause; and (4) Genome-based selection for the improvement of natural enemies in biocontrol.

BINGO was officially launched in January 2015 and the first PhD students started their projects six months later. As part of their training the young researchers will attend annual summer schools and they will also participate in local and international scientific conferences to present the main results as their research progresses. Network meetings will be held annually to discuss experimental approaches and present progress and discoveries. The first workshop took place on January 2016 in Valencia, Spain, with approximately 100 participants. Outreach is also an important aspect of the project and those activities will be coordinated locally by each partner in their communities in order to transfer knowledge to professional groups, high school students and the public in general. Moreover, results of the research projects will be disseminated through publication in scientific journals.

For further information about BINGO, the projects, researchers and PhD students, or to subscribe to the BINGO newsletter, visit the website: www.bingo-itn.eu/.

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Protecting Elm Trees

Dutch elm disease, *Ophiostoma ulmi*, killed elm trees (*Ulmus* spp.) across Europe and the USA in the 1920s–30s, with a worse epidemic caused by *O. novo-ulmi* decimating trees from the 1970s. The disease is vectored by bark beetles and also transmitted via interconnecting root systems. Landscapes were left denuded of elms and recovery has been slow. Tree varieties with a high level of resistance to the disease are now available which gives hope for the future. However, mature trees may be very valued, notably in urban settings. The preventative fungus-based product Dutch Trig® (BTL Bomendienst, Apeldoorn), developed by the University of Amsterdam, has been used commercially to protect valuable trees from infection in the Netherlands since 1992, and more recently in other countries. This programme is reviewed in an open-access paper in *BioControl*.[1] The active ingredient, *Verticillium albo-atrum* strain WCS850, is injected as an aqueous conidiospore suspension into the tree's vascular system. It induces disease resistance in healthy elms and protects them from infection via bark beetles although it does not control the disease in infected trees, nor prevent transmission from infected trees via root systems. Since 2010, only 0.1% of treated trees in the Netherlands have become infected via beetles, and 0.4% via root transmission. Infection through beetle transmission in treated trees has decreased significantly since Dutch Trig® was introduced. Up to 30,000 trees are treated at a cost of around €16–25 per tree in the Netherlands each year. Annual treatment is necessary, so it is used mainly for mature trees in settings where their amenity value is high, and replacement would be less desirable and more expensive than treatment. The product is now also registered in the USA, Germany, Canada and Sweden and registration is in progress in the UK. In 2015, it was used to treat over 28,000 valuable, at-risk trees in the five countries where it is registered. One limitation is that survival of the live conidiospores (and therefore product life) is short and there is interest in developing a product with greater shelf-life. Even without that, Dutch Trig® is seen as a valuable component of integrated disease management alongside sanitation and replanting with resistant varieties.

[1] Postma, J. and Gossen-van de Geijn, H. (2016) Twenty-four years of Dutch Trig® application to control Dutch elm disease. *BioControl*. DOI:10.1007/s10526-016-9731-6.

A Gel for Entomopathogenic Nematodes

One problem in developing effective formulations for above-ground application of entomopathogenic nematodes (EPNs) is that, because they are adapted to subterranean environments, they are prone to damage by UV light and desiccation. A study reported in *Biocontrol Science and Technology* assessed whether the efficacy and persistence of above-ground applications of *Steinernema carpocapsae* were enhanced by combining the EPNs with protective gel and anti-UV ingredients (titanium dioxide and octyl methoxycinnamate).[1] The authors found that the gel led to significantly greater target pest mortality outdoors, while greater EPN longevity was recorded in a glasshouse environment, with titanium dioxide increasing the gel's protective properties. They conclude that titanium dioxide in a low concentration formulation of the protective gel makes the product more viable for growers to use.

[1] Dito, D.F., Shapiro-Ilan, D.I., Dunlap, C.A., Behle, R.W. and Lewis, E.E. (2016) Enhanced biological control potential of the entomopathogenic nematode, *Steinernema carpocapsae*, applied with a protective gel formulation. *Biocontrol Science and Technology* 26, 835–848.