Biological Control in the Light of Contemporary Evolution

Dr Peter McEvoy

Scientia

BIOLOGICAL CONTROL IN THE LIGHT OF CONTEMPORARY EVOLUTION

'Biological control' refers to the practice of controlling invasive pest populations by introducing their natural enemies into an ecosystem. Although biological control can reduce reliance on toxic chemicals and protect natural ecosystems, this approach is not without its challenges. **Dr Peter McEvoy** and his colleagues at Oregon State University discovered that certain biological control organisms show unexpectedly fast rates of evolution, which can lead to unforeseen impacts on ecosystems and agriculture. These scientists believe that it is time to develop an all-embracing theory to help assess the evolutionary potential of biological control organisms that may influence the efficacy and safety of future introduction programs.

What is Biological Control?

In the United Nations' recent landmark [IPBES Global Assessment], which details the most extensive evaluation of life on Earth ever performed, invasive alien species were identified as one of the five major drivers of global biodiversity loss. In addition to causing widespread ecological destruction, such introduced invasive species can wreak havoc on agricultural production, causing billions of dollars in crop damage every year.

As a way to avoid the excessive use of chemical pesticides and herbicides, farmers can control populations of invasive insects, mites and weeds by introducing other species to a cropping system, typically herbivores, predators, parasites or pathogens. Similarly, many land managers also take this approach to reduce the environmental damage caused by invasive species. The process relies on natural mechanisms that the new species can bring to a system, such as eating the pest, out-competing it, or causing disease, without damaging crops or the environment.

Such biological approaches to pest control first emerged in the late 1800s, but it wasn't until 1919 that entomologist Harry Smith introduced the term 'biological control'. It is now a well-established form of pest management, which reduces the use of chemicals and their adverse effects on the environment, while also not requiring repeated and costly applications. This approach is generally seen as a sustainable method that requires a low level of resources and can be maintained indefinitely.

However, there are historical examples showing that this method can sometimes be unsafe, as biological control organisms can begin to show harmful effects towards non-target species. Unlike chemicals, biological control organisms can reproduce and spread autonomously, and even evolve. As a result, many scientists advocate for more research into the long-term impacts of introducing biological control species. The reality is that biological control organisms can become invasive pests themselves, creating even more problems for farmers and ecosystems. This is certainly the worst-case scenario, but is not beyond the realm of possibility.

Purple loosestrife, a highly invasive plant in North America

In the past, there have been several reported cases of weed-controlling

‘Without theory, biological control will continue to rely on ad hoc procedures based mainly on inadequately documented past experiences’

Cinnabar moth larvae feeding on invasive ragwort

organisms that started to directly damage the plants they were meant to protect. To avoid further cases like this, the introduction of biological control species is now tightly regulated. Scientists must now conduct extensive lab and field trials, to demonstrate that the species they wish to introduce will attack only the target species. Such pre-release trials must also show that the candidate control organism is likely to be effective in controlling the target organism.

However, these assessments are imperfect when it comes to identifying potential risks. For example, this approach does not assess whether an introduced species can evolve rapidly in response to its new environment. For the past two decades, this has been the focus of Dr Peter McEvoy’s research in the Department of Botany and Plant Pathology at Oregon State University. Dr McEvoy strongly recommends that the foundations of biological control technology must be reviewed, in order to establish ways to improve it, both in terms of safety and efficacy.

Rapid Evolution

The introduction of a new biological control species is currently performed under the assumption that its rate of evolution is extremely slow and can be safely ignored. However, Dr McEvoy and his colleagues discovered that in certain species, evolution occurs much faster than anticipated. From a practical point of view, this not only makes the outcome of a species introduction program rather unpredictable, but also raises concerns about the safety of biological control practices.

In one study, Dr McEvoy and his team followed the human-assisted migration of the cinnabar moth from Willamette Valley in Oregon to nearby habitats at much higher elevations, namely the Coast Range and the Cascade Mountains. This moth was originally introduced to North America as a biological control species that targets invasive ragwort, on which the moth’s larvae feed.

Within just 10 years, the team observed that the cooler temperatures in the mountains shortened the moth’s growth phase, and individual insects completed their life cycle faster as they emerged earlier as adults in spring, developed faster through egg and five larval stages, and arrived earlier at the over-wintering pupa stage in fall. This effect was stronger in the Cascade Mountains, which are higher than the Coast Range.

The team’s results mean that the cinnabar moth has the ability to adapt rapidly to a new environment. In this particular case, the reduced number of days that were warm enough for egg and larval development meant that only individuals with a shorter growth phase would survive, passing this rapid-growth trait on to subsequent generations.

This is the essence of evolution by natural selection, whereby the underlying genetic variation within a population allows advantageous traits to be passed on to the next generation, while detrimental traits die out. Without this underlying genetic variation, the moths would not have been able to adapt so quickly. Therefore, Dr McEvoy suggests that a compulsory review for evolutionary potential should be conducted prior to any introduction program.

Cinnabar moth

There is a positive aspect to evolutionary potential. Rapid evolution could improve biological control organism's success by adaptation to new environments. For example, rapid evolution of the cinnabar moth allows it to better control the target weed in mountain environments; however, the downside is that the moth can now feed and develop on non-target plant species growing in mountain environments.

Dr McEvoy and his team's research has had an enormous impact on the field. 'Rapid evolution is one of the most talked-about topics in ecology that has recently spread to biological control,' he says. 'The growth and interest in biological control are due, in no small measure, to recent advances in rapid evolution for which we helped lay the foundation.' Despite these recent advances, Dr McEvoy knows that more studies are needed. Research must combine real cases of evolution and theoretical approaches to develop a more reliable basis to understand potential impacts.

To continue this work, Dr McEvoy and his team plan to identify the genes associated with the changes detected, as well as conduct international surveys to find out whether other populations of the cinnabar moth are undergoing similar changes. Locations to survey include Canada and New Zealand, where the moth was introduced as a biological control species, and in Central Europe, where it occurs naturally. In all of these places, the cinnabar moth is found at both low and high altitude, providing a perfect model for comparing with the situation in Oregon.

Rejuvenating the Field

Along with their investigations into evolutionary changes in the cinnabar moth, Dr McEvoy collaborated with statisticians to develop new methods for comparing the timing of important life-cycle events. 'Ecology is a young science, and scientific investigations in our field often need both new discoveries and development of better methods to progress,' he says.

Typical methods used in this field of research are useful for describing the timing of life-cycle events and for comparing patterns of development between different populations, locations and times. However, most models that are used today were created more than 50 years ago, and are in need of improvement.

As a way of rejuvenating the field, Dr McEvoy's team introduced two new models into the mix. Essentially, their methods provide a simple way to compare different stages of the life cycle between two populations and are easily implemented and interpreted. Dr McEvoy is keen to replace older and more complex models with these simpler versions, which are not only easier to use, but produce much better results in simulations than any method previously used.

In Search of a Unifying Theory

When biological control methods first emerged, few anticipated the evolutionary changes that would arise. Now, scientists are aware of the potential for rapid evolution, which can have unexpected effects on ecological interactions among control organisms, target organisms, and non-target organisms.

According to Dr McEvoy, these issues are starting to emerge due to the absence of an adequate theoretical foundation of biological control to help scientists, farmers and land managers decide on the best species to introduce. He explains that such a theoretical framework would help in recognising problems and identifying possible ways to solve them. When faced with new locations and new target species, an overarching theory would also help scientists to compare and extrapolate to these new situations.

For example, a theory could help in identifying how observable traits of control organisms, such as their tolerance of environmental conditions, searching and feeding behavior, growth rates and reproduction, contribute to effective control of the target organism without harming non-target organisms. This would then allow investigators to screen for genetic variation in those traits, which natural or artificial selection might influence to improve performance.

Ideally, a theory would combine knowledge from natural history, mathematical models and both experimental and observational field studies, so that the strength of one approach can compensate for the weakness of another. Theory converts examples and case studies into more powerful explanations that can be applied to different situations, and even suggests ways to investigate further. 'Without theory, biological control will continue to rely on ad hoc procedures based mainly on inadequately documented past experiences,' says Dr McEvoy.

As a stepping stone, his team is currently developing a database of all biological weed control projects conducted in the United States. This is not just a catalogue of what species were introduced but, for the first time in North America, it collates data linking the tests conducted before the release with actual outcomes after release. Once this database is complete, it will be a valuable tool to predict the risk of non-target host use associated with each candidate species before its introduction.

Meet the researcher

Dr Peter McEvoy
Department of Botany and Plant Pathology
Oregon State University
Corvallis, Oregon
USA

After achieving his bachelor's degree in biology from Amherst College and a PhD in ecology and evolutionary biology at Cornell University, Dr Peter McEvoy joined the Department of Entomology at Oregon State University in 1977. Currently, he holds the position of Emeritus Professor at the Department of Botany and Plant Pathology. In addition to his extensive research into biological control systems, Dr McEvoy conducts broad-based research on behaviour, ecology, and evolution. He also teaches undergraduates and mentors multiple MSc and PhD students and post-doctoral fellows. Throughout his career, he has been involved in several introduction projects of biological control species, including four insect species to control purple loosestrife in 1992 and one moth species to control rush skeletonweed in 2005, and in redistributing three species for control of ragwort.

CONTACT

E: mcevoyp@science.oregonstate.edu
W: https://mcevoyp.weebly.com/

KEY COLLABORATORS

Linda Buergi, Oregon State University
Monte Mattsson, Oregon State University
Katarina Lunde, Oregon State University
Madison Rodman, University of Minnesota
Keith Hopper, Agricultural Research Service, USDA
Kimberley Higgs, US Forest Service
Paul Murtaugh, Oregon State University
Sarah Emerson, Oregon State University
Fritzi Grevstad, Oregon State University
Tyson Wepprich, Oregon State University
Evrim Karaçetin, Erciyes University, Turkey
Eric Coombs, Oregon Department of Agriculture

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