Memoirs of the Museum of Victoria 56(2):611–615 (1997) 28 February 1997
https://doi.org/10.24199/j.mmv.1997.56.58

THE 'SAFETY' OF BIOLOGICAL CONTROL AGENTS: ASSESSING THEIR IMPACT ON BENEFICIAL AND OTHER NON-TARGET HOSTS

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Abstract

Sands, D.P.A., 1997. The 'safety' of biological control agents: assessing their impact on beneficial and other non-target hosts. *Memoirs of the Museum of Victoria* 56(2): 611–615.

Biological control agents considered for introduction into Australia must demonstrate a high degree of specificity before approval is given for their release from quarantine. In assessing 'safety', potential agents for weeds are tested to determine if they can damage crops, ornamentals or native plants and for arthropod pests, if they can adversely affect beneficial insects (including biological control agents) or have a detrimental impact on native arthropods. Effective arthropod biological control agents are rarely monospecific in their native range, most being adapted to a group of closely related species of plant or arthropod hosts. When introduced for control of exotic organisms, the potential host range of agents is usually more restricted due to absence or scarcity of taxa closely related to the target. While such agents utilise a target species as preferred host, some potentially valuable agents will on occasions reproduce on non-target taxa including native species. Host preference in agents is difficult to quantify in the confines of a laboratory, a problem more frequently encountered in arthropod than weed programs. Confinement often favours attack on a wider range of organisms than under field conditions and the results of such tests may influence a decision whether to or not, release an organism. In cases where non-target development is demonstrated by narrowly specific agents in quarantine, the benefits of biological control of pests must be weighed against any real detrimental affects to native species. In Australia some agents occasionally develop on non-target taxa but no exotic arthropod agents are known to seriously damage populations of native species. Most threats or extinctions quoted overseas are poorly justified.

Introduction

When introduced for biological control of pests, several predators with broad host ranges (e.g., cane toad, snails) have also detrimentally influenced beneficial and native organisms. They often failed to control the target pests while their impact on non-target organisms has led to some uninformed distrust in biological control programs. The success and environmental benefits from introductions of narrowly specific exotic agents are often overlooked with more public attention given to the impact by generalist predators on native species.

Proposals to import generalist predators into Australia, especially vertebrates, are not now approved. When biological control agents are considered for introduction, tests must confirm a high degree of host specificity before permission is given by relevant authorities for their release from quarantine. In assessing acceptable levels of specificity, potential agents are tested to determine for weeds, if they can damage or reproduce on crops, ornamentals or native plants and for arthropod pests, if they are likely to influence the abundance of beneficial insects (including other biological control agents), or have an significant impact on native arthropod species. Before release, tests with exotic agents are conducted in quarantine to determine their potential host range and to assess the significance of any development on non-target hosts or prey.

Procedures for testing the specificity of agents for weeds have been widely practiced (Wapshere, 1974) but tests on agents for arthropod pests have not received the same attention (Sands and Papacek, 1993). In most countries other than Australia and New Zealand, host specificity tests are rarely carried out in arthropod programs. For example in the United States agents are only tested if thought likely to attack beneficial organisms (Ertle, 1993). Recently, guidelines (Waterhouse, 1991, Anon, 1995) for conducting biological control projects have included host specificity procedures for testing agents for both weed and arthropod targets. Though there are no known examples for any undesirable impact on beneficial organisms, native flora or fauna by narrowly-specific agents (Waterhouse, 1991), practitioners are focusing on developing and refining the methods for testing exotic agents with non-target and native invertebrates prior to their release in biological control programs.

Selecting non-target and native species for testing with exotic agents

When selecting non-target and native species for host specificity testing with exotic agents, Wapshere's (1974) centrifugal (phylogenetic) approach is equally valid for weeds and arthropod programs. Both exotic beneficial and native species are selected based on their taxonomic relationships with a target organism. For weeds projects, once plants related to the target are selected, potted plants can be used in host specificity tests. However, there are serious constraints with native arthropods since collecting and maintaining living species for testing with agents may be difficult. The biologies of native arthropods related to a target are frequently unknown, preventing culture of appropriate stages required for tests. Where 100 or more non-target potted plant species are often tested with agents in weeds programs the testing of more than 10 species of non-target arthropods may be impractical and is often unnecessary. Moreover, the anomalies experienced when testing agents in the confinement of cages and insectaries tend to occur more frequently in arthropod than in weed programs (Sands, 1993).

Information on the taxa related to a target species in its native range is most useful when selecting a centrifugal range of species related to a target pest. However, if tribes are not designated it may be difficult to associate genera or species in groups according to their taxonomic relationships. Beneficial organisms related (within the same family) to the target pest should be included when compiling a list of non-target species for host specificity tests. When considered for release, development of a biological control agent on another beneficial agent is generally unacceptable. When testing agents on native species, selected taxa closely related (family, subfamily, tribe or genus) to the target, or in certain cases, those morphologically similar, are often sufficient to provide adequate information on the host specificity of an agent, rather than testing extensive lists of species of distantly-related taxa. Additional species can be included if justified by the initial test series. The methods by which taxa related to an agent select their hosts or prey (e.g., certain taxonomic groups, pheromones, host size etc.) can be used to guide the design of tests.

Few agents in arthropod biological control programs are monophagous. Most are oligophagous (e.g., develop on other hosts in the same tribe as the target) in their native range. However, they may utilise only the target species or one or two others very closely related to the target, when introduced to a country where the target is a pest.

Some problems with determining host specificity of exotic agents

The methods for determining the host specificity of potential biological control agents for weeds are relatively well established and practiced (e.g., Harley and Forno, 1992; Waterhouse, 1991; Anon, 1995). However, the methods for testing agents for arthropod targets are more varied and are still being developed. These are needed to reflect the different means by which agents locate, oviposit and develop on/in arthropod hosts when compared with agents interacting with plant hosts.

The methods for rearing agents on their host may not be appropriate for host-specificity tests with non-target taxa. Small containers can often be used for agents to induce oviposition, feeding or development in arthropod hosts. However, restricted space often leads to an inaccurate assessment of specificity by disrupting host recognition and acceptance (Sands and Papacek, 1993). When confined, natural enemies of arthropod pests may oviposit on organisms that do not support their development or they may complete development on hosts or prey not attacked in the field. For example, in Papua New Guinea the egg parasitoid, *Ooencyrtus erionotae* Ferrier, is believed to be narrowly-specific to banana skipper, *Erionota thrax* (Linn.), since it has never been reared from other lepidopteran eggs, even when eggs of the related hesperiid, *Cephrenes mosleyi* (Butler) are deposited less than a metre away on palms. However, its host specificity could not be demonstrated accurately in the restricted space of the laboratory since eggs of *C. mosleyi* and other species readily attracted parasitoid oviposition and supported its development (Sands et al., 1991).

Choice tests with a target host and test species caged together may lead to misleading results. Field and Darby (1991) found that the parasitoid, *Sphecophaga vesparum* (Curtis) (Hymenoptera: Ichneumonidae), for biological control of the European wasps, *Vespula ger-*

manica (Fabricius) and *V. vulgaris* (Linnaeus)(Hymenoptera: Vespidae), oviposited in and developed sparingly on two native wasps, *Ropalidia plebeina* Richards and *Polistes humilis* (F.)(Hymenoptera: Vespidae), when exposed in presence of *V. germanica*. However, the parasitoids failed to oviposit when exposed separately to the native species. This attack on non-target hosts may have been stimulated by the close proximity of *V. germanica* providing the necessary kairomones or other ovipositional cues. This and other studies indicate that choice tests with arthropod target and non-target species exposed to an agent at the same time, should be interpreted with caution and led to a recommendation that choice tests are better avoided when alternative methods are available (Sands and Papacek, 1993).

Plant material which is substrate to a host may be required to stimulate host recognition by an agent. Plant kairomones may also influence the behaviour of natural enemies of arthropods and need to be considered when designing the host specificity procedures (Anon, 1995). Olfactometers can sometimes be used to contrast an agents' response to plant volatiles with their response to the host alone. Some cage materials may affect scatter of light entering cages and those made of black materials may be necessary to stimulate mating or oviposition by certain natural enemies of arthropods. Several parasitoids, e.g., some Tachinidae, require sunlight before mating will occur.

Assessing the impact of agents developing on native hosts

Some information is available on native, non-target hosts utilised by exotic agents but very little information is available on their influence on the density of these host populations. For example, the egg parasitoid, *Trissolcus basalis* (Wollaston), contributed to biological control of *N. viridula* in most crops in southern Australia after various imports, the first from Egypt in 1933 (Wilson, 1960). Without parasitisation of *N. viridula* by *T. basalis*, *N. viridula* would undoubtedly be a much more serious pest in Australia. However, this parasitoid is by no means host-specific in Australia where it has been reared from eggs of a range of native Heteroptera, including more than 10 species of Pentatomidae (Waterhouse and Norris, 1987). While alternative hosts for *T. basalis* provide a reservoir for parasitoid in the absence of eggs of *N. viridula* (Waterhouse and Norris, 1987), there is no evidence in Australia for a decline in the abundance of native species which occasionally act as hosts to this parasitoid (Gross pers. comm.).

Nafus (1993) when studying the natural enemies of the butterflies *Hypolimnas* spp. in Guam, found no detrimental impact by biological control agents even though introduced parasitoids frequently attacked them and one had become the most significant mortality factor for pupae of a native species. For an exotic agent some development on indigenous fauna or flora may be acceptable, provided that the benefit gained by controlling a pest outweighs any slight risks of effects on the abundance of indigenous species. The advantage of an oligophagous natural enemy was described as a 'lying-in-wait' strategy and contrasted with a 'search-and-destroy' strategy of host-specific species (Murdoch et al., 1985). Monophagous agents may sometimes be considered to be at a disadvantage in an exotic range since dispersal between pest infestations can be restricted by a lack of supporting hosts. Every case requires careful assessment based on the results of carefully-planned research.

The following criteria may be useful when assessing acceptable host specificity of an exotic agent for release:

1. Exotic agents are acceptable if narrowly-specific in their native range and shown by tests with related beneficial or native species, to be specific to the target pest in the new environment.
2. If an agent completes development in/on any non-target (beneficial/native) organisms, a decision must be made as to whether this may have any detrimental effects.
3. The ability of a narrowly specific agent to develop in/on non-target organisms should not automatically preclude a recommendation for release.
4. Development in/on some non-target organisms may be acceptable provided the host range has been shown to be narrow (i.e., confined to a small group of organisms related to the target), and provided that the non-target organisms are not preferred to the target.
5. Development in/on some non-target taxa may sometimes be beneficial — when non-target hosts provide a medium for transmission to crop sites (for arthropod pests).

Claims of rarity and extinction induced by exotic agents

Howarth (e.g., 1985, 1991) has suggested that many extinctions have followed introductions of biological control agents into Hawaii. However, according to Funaski et al. (1988), only one of 30 biological control agents introduced into Hawaii in the last 15 years has been found to attack native or beneficial species. Cullen (1989) has suggested that when agents are introduced for biological control of weeds, their impact on plants will be limited to very abundant species if the agent is not entirely host specific for the weed and that an agent will not affect those already held in equilibrium by natural enemies, including sparsely distributed or endangered species. The same is likely for arthropod targets.

Biological control of the moth, *Levuana iridescens* Bethune-Baker (Zygaenidae) in Fiji, is often quoted as an example of extinction of a native insect following introduction of an exotic agent. Control of this coconut pest was achieved in 1925 following introduction of the tachinid, *Bessa remota* (Aldrich) (Diptera: Tachinidae), reared from a related Malaysian moth, *Cathartona (Amuria) catoxantha* (Hampson) (Zygaenidae) (Tothill et al., 1930). Howarth (1991) suggested that the last authentic specimen of *L. iridescens* was collected in 1929 (with possible survival of species to 1940s). However, there is a specimen in the Koronivia Research Ministry of Agriculture, Fisheries and Forests Station in Fiji, collected in August 1941.

Paine (1994) reported an outbreak of *L. iridescens* (accompanied by *B. remota)* on coconuts near Vunindawa, Fiji, in 1956. Paine's identification is likely to be accurate since he was familiar with the moth and its parasitoid. He had been associated with Tothill during the biological control program on *L. iridescens.* In view of the rapid control of *L. iridescens,* its rarity by late 1920s and later survival until 1956 (even causing outbreaks), it is probable that *L. iridescens* has not become extinct. Another likely cause for rarity of this moth is change in its original habitat. Coconut plantations have displaced native palms on most of the lowlands in Fiji, leaving little indigenous habitat for the moth to survive on native hosts.

The closely-related *Amuria catoxantha* (Hampson) from which *B. remota* was collected, is extremely rare or absent from coconuts between outbreaks in Java (Kalshoven, 1981). *A. catoxantha* is said to be confined to native palms in rainforest but occasionally causes outbreaks in coconuts when transported by wind (Kalshoven, 1981). These are phenomena quite possible for *L. iridescens* in Fiji. *L. iridescens* was not considered by Tothill et al. (1930), to be native to Fiji since it behaved in a way similar to an exotic species. *L. iridescens* had almost no native parasitoids prior to the introduction of *B. remota* and after its first appearance in previously unaffected coconut plantations, spread rapidly from Viti Levu towards the eastern, copra-producing islands (Paine, 1994).

As those entomologists reported, most of the zygaenid moths closely-related to *L. iridescens* occur in countries from New Guinea to Malaysia. Though evidence suggests that *L. iridescens* was most likely exotic in Fiji, its presence elsewhere remains unknown — unless Kalshoven's (1981) unlikely claim that *A. catoxantha* and *L. iridescens* are con-specific proves to be correct. Whether or not *L. iridescens* is an exotic species in Fiji, is now extinct, or still survives in rainforest on native palms, this is not an appropriate example of extinction of a native species caused by introduction of an exotic biological control agent. *B. remota* would not now qualify as suitable as a biological control agent since it is not sufficiently specific even to the target family (Zygaenidae) (Waterhouse and Norris, 1987).

Discussion

Improving existing methods and developing techniques for assessing the host specificity of agents in arthropod biological control programs are high priorities for research in Australia. This is especially relevant following recent fears overseas relating to threats of extinction of native invertebrates. A better understanding of the methods by which natural enemies select their hosts is also needed if host specificity tests are to be meaningful. The criteria used to evaluate agents for arthropod pests differ considerably from those used for weeds (Goldson and Phillips, 1990), for example results of host choice tests on agents with arthropods which as shown by Field and Darby (1991), may be misleading. In addition, foraging behaviour of parasitoids is important (Lewis et al., 1990) but is difficult to test in the laboratory.

The range of cues used by each natural enemy to recognise their hosts differ greatly between species. In the past, the influence of plant kairomones has not been considered fully when testing host acceptance by parasitoids. Plants may be important in stimulating host acceptance or rejection by parasitoids. The design and size of cages used for host specificity tests need to be evaluated for each taxonomic group of agents. It may be necessary to ensure that containers are not re-used or ensure that they are free of residual kairomones or pheromones from a host or its plant substrate before non-target organisms are tested.

Fears that an agent might change its host range and attack other target taxa after introduction are sometimes expressed. However, there are no recorded examples of monophagous or narrowly oligophagous agents changing their host range to cause damage to beneficials, native plants or non-target insects (Waterhouse, 1991). Agents should not be automatically excluded from further consideration when confinement is suspected of causing anomalous results during host specificity testing. When all laboratory tests are inconclusive, it may still be possible to determine accurately the host range of a potentially valuable agent by studies in its native range. In addition, information from the native range may be useful in determining the adaptation of an agent to a particular habitat, e.g., agricultural land and grassland vs rainforest. Very few species are adapted to both environmental situations.

In every example where biological control of a weed or arthropod pest is considered the criteria for safety may sometimes differ, based on the results of host specificity tests, either under quarantine conditions alone or by taking into account information from the agent's indigenous range. There is an urgent need to examine the interaction of exotic agents introduced for past biological control arthropod programs, for example, the development of *T. basalis* on native Heteroptera. Protocols for assessing exotic imports of agents should be developed for arthropods taking account of the often different criteria used in weeds programs.

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