GUEST EDITORIAL

Biological Control, a Century of Pest Management

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In 1989, California celebrated the centennial of the introduction of the vedalia beetle (*Rodolia cardinalis* (Mulsant)) from Australia for the biological control of the cottony cushion scale, *Icerya purchasi* (Maskell), that was devastating the young citrus industry in the southern part of the state. This spectacularly successful example of classical biological control, the importation and release of a natural enemy collected from the native home of an 'exotic' pest, was well publicized and initiated a whole series of similar natural enemy importations throughout the world. It is generally accepted that the vedalia success also led to the recognition of biological control as a very valuable strategy in the fight against insect pests. It was soon realised, however, that not all natural enemy importations would lead to spectacular successes and the need to explain the action of natural enemies gave rise to the discipline of insect population dynamics (Howard & Fiske, 1911), firmly rooting biological control as an experimental exercise in applied ecology.

Biological control enjoyed continued success in pest control until the dawning of the pesticide era that followed World War II. The development of synthetic organic insecticides was seen as a 'silver bullet' solution to all insect pest problems and biological control took on a secondary role as a rather unpredictable and demanding method of pest control. However, with the development of pest resistance, the accumulation of toxic residues and the development of secondary pests, the disadvantages of synthetic insecticides became clear. The greater susceptibility of natural enemies than their hosts to insecticides led both to the phenomenon of secondary pests, and to the development of the concept of integrated pest management (Stern *et al.*, 1959). The calendar spraying of insecticides in fact highlighted the pivotal role played by natural enemies in preventing a large number of insects inhabiting the crop environment from attaining pest status.

With the widespread use of the term integrated pest management, the concept of biological control has become confused and broadened to include almost anything other than the application of synthetic toxic chemical pesticides. Unfortunately, this loses sight of the ecological basis and the historical precedence of biological control which concern 'top down' control of a pest by organisms from a higher trophic level and the impact of which is determined by the dynamics of the interaction between these natural enemies and their hosts. Biological control, from this ecological perspective, is limited to the use of natural enemies in the suppression of pest abundance and is quite distinct from other non-chemical approaches to pest control. As a natural phenomenon, biological control forms the central component of integrated pest management which, through careful manipulation, provides sustainable control of pests with little or no disturbance to the environment.

It is generally recognised that biological control comprises three areas of activity; importation of exotic natural enemies into a target area (classical biological control),

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increasing the numbers of natural enemies present in a target area (augmentation) and prevention of any reduction in numbers of natural enemies within the target area (conservation). Now that biological control has been practised for over a century it is interesting to consider what insights have been gained, what improvements could be made and what opportunities exist for the future.

Importation

Classical biological control is the best known and most extensively implemented form of biological control. More than 1000 natural enemy species have been imported and established against a range of about 300 insect pests around the world and of these about 40% have provided significant success (Waage & Greathead, 1988). The procedure for importations has changed little from the early years of the vedalia importation, although host specificity of the imported natural enemy to increase impact on the target host and quarantine to verify the identity of the organisms for release and thus avoid importation of antagonists, have emerged as essential components of the system. Traditionally, importations have been considered suitable only for exotic pests but success has been reported for a number of opportunistic importations against indigenous pests indicating a neglected potential for classical biological control against this group of pests.

One of the most exciting and challenging aspects of biological control importation is the need to decide on which natural enemies to release against the target pest. Should all the component species of the natural enemy complex of an exotic pest be imported or can pest abundance be reduced more effectively by the importation and release of selected natural enemies from the original complex? In practice the number of natural enemies released in importation programmes has varied from 1 to 53, being limited either by time or lack of financial support rather than by positive selection of only the 'best' candidates. However, this trial and error approach serves only to highlight our ignorance about natural enemy impact and does nothing to improve the scientific basis and predictive ability of classical biological control.

During the past century of classical biological control, the most successful projects have been those targetted against exotic pests that have not been of pest status in their region of origin. These projects have, by necessity, made use of a limited number of low-density natural enemies, those that are particularly effective in both locating and synchronizing with low-density host populations. In contrast, many of the projects that failed were against targets that were also pests in their region of origin, despite the importation of a wide variety of natural enemies with high fecundity and hence potential for host attack. Natural enemy complexes change composition with host abundance (Mills, 1990) and the high-density species do not need to be as well adapted to their hosts as their low-density counterparts, although their absolute host attack potential may be higher. This being the case, then the process of natural enemy selection for classical biological control projects can be simplified to examination of the following three field testable requirements:

1. A high level of host specificity
2. An absence of any antagonistic interactions (e.g., hyperparasitism, cleptoparasitism) with other members of the natural enemy complex
3. Occurrence as a dominant species in the natural enemy complex of low-density host populations.

It is unfortunate that both financial and time constraints in classical biological control have resulted in inadequate evaluation of the outcome of many projects, which tend then either to be optimistically labelled successes or ambiguously cited as partial successes. As a result, the past record of importations can only be rather subjectively analysed and has not provided a firm basis from which to improve biological control success in the future. The re-examination of key successes and failures from the past would be a very rewarding exercise in this regard but emphasis must be placed on more critical evaluation of all future importations.

Augmentation

Not all pests can be successfully controlled through natural enemy importations. Modern agricultural techniques have tended towards increasing acreages of even aged and genetically similar crops using high input agrochemicals to maximize yield, all of which improve conditions for pests but reduce colonization potential and survival for natural enemies. In these situations, natural enemies are often unable to prevent the pest from causing economic losses. One of the biological control options in this instance is augmentation of the impact of natural enemies by increasing their numbers in the target area at critical times. While classical biological control tends to be self-sustaining and to be effective over broad geographic ranges, augmentation has only local impact and is an application that must be repeated.

Augmentative biological control has also developed as a widely recognised form of biological control. The principle has been to colonize natural enemies in the crop at the start of the growing season (inoculation) or to mass release natural enemies in a crop for immediate impact as a biological pesticide (inundation). While arthropod natural enemies have been used for inoculative augmentation, pathogens and nematodes (and egg parasitoids) are more appropriate for inundation due to the logistics of mass production. *Bacillus thuringiensis* (Bt) has been widely used as a microbial insecticide against Lepidoptera larvae, but it is questionable whether this constitutes biological control since its action is dependent on a toxin rather than on infection of the host by the bacteria.

In any field augmentation programme it is necessary to be able to distinguish the action of the released natural enemies from that of the naturally occurring population and to prove that an observed reduction in pest abundance is due to the augmentation. Many biological control workers fail to address this problem adequately and as a result are unable to assess critically the success of an augmentation release. A range of techniques, such as genetic or elemental markers, can be used to characterize material before release and should be used in the development of augmentative biological control programmes together with monitoring programmes that assess pest mortality due to the augmentation as well as pest abundance.

One of the largest question marks in augmentative biological control is the effectiveness of mass-reared laboratory material when released in the field. The extent to which artificial propagation reduces field viability and responsiveness to host related cues remains largely untested. In the case of predators and parasitoids, host preference and host location have both a genetic and learned component. The latter can probably be adequately restored in mass rearings by appropriate conditioning prior to release but the former effect requires detailed attention to rearing conditions. Field observations of viability, movement patterns and behaviour of released arthropods are urgently needed, to indicate more clearly, possible limitations of the augmentation process and the features of the system that could most readily be improved.

Conservation

The conservation of natural enemies in cropping systems is the least well understood and the most infrequently practised form of biological control. The reasons for this are clear, however, in that conservation solutions require a very detailed knowledge of individual crop-pest-natural enemy conditions. The effect of each step in the cultivation of a crop from planting through to harvesting must be scrutinized to determine its effect on the natural enemies and to determine how modifications could enhance the impact of natural enemies.

The most spectacular and successful application of conservation biological control has evolved along with the development of integrated pest management. The simple expedient of changing from prophylactic calendar spraying of pesticides to remedial threshold spraying can reduce the incidence of pest damage in many crops through conservation of natural enemies in the crops. Use of selective insecticides and the breeding of insecticide resistant strains of natural enemies for field release can also help to maintain natural enemy pressure in modern cropping systems. Insecticide resistance has been achieved more readily with predatory spider mites than with insect parasitoids and careful field evaluation is needed to assess the possible loss of resistance through time or through dilution effects from natural populations.

Another development that is thought to be of value for natural enemy conservation is intercropping. This more traditional approach to crop management involves the diversification of cropping systems by combination of two or more crop species together, which may in turn improve the general environmental conditions for natural enemies. Unfortunately, there has been insufficient detailed experimental study of the effects of intercropping on natural enemies and most of the evidence so far is largely anecdotal. There is an urgent need for more quantitative studies on the complex interactions between intercrops, pests and their natural enemies to more clearly resolve the direct effects of intercropping on the pests themselves from the indirect effects of intercrops on natural enemy impact. The extent to which any generalizations will emerge, however, is unclear at this point since such complex interactions are likely to be dependent on specific intercropping systems and locations.

Future challenges

While the absence of good alternatives was the primary motivation for the vedalia importation in 1888, the deterioration of our environment and toxic residues one century later, through the intensification of agriculture and the widespread use of agrochemicals, is turning both public opinion and political pressure back towards biological control as a more sustainable and safe form of pest management. This also means that whereas exotic pests and natural enemy importation led to the recognition of biological control, it is likely that native pests and natural enemy augmentation or conservation will be the prime focus for biological control in the future. That is not to say that new pest invasions will cease, as evidenced from the past decade in Africa, where mango mealybug (*Rastrococcus invadens* (Williams)) greater grain borer (*Prostephanus truncatus* (Horn)), cypress aphid (*Cinara cupressi* (Buckton)) and screwworm (*Cochliomyia hominivorax* (Coquerel)) have all been recorded as recent invasions. In many regions, however, the most important pests are now either native or exotic species that have not been successfully controlled by natural enemy importations.

The challenge to biological control in the future will be to develop programmes against a variety of pests for which pesticides currently provide tenuous control. This challenge will require the restructuring of biological control from its traditional background of entomology to combine a broader range of talents from related agronomic and biological disciplines, providing further insights into cropping systems, pests and their natural enemies and leading to the development of new techniques in biological control. These initiatives offer exciting prospects for research and development in the application of biological control that are likely to be hampered only by insufficient financial support.

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