Chapter 4

Augmentation: inundative and inoculative biological control

The second and third major ways to use biological control, inoculative and inundative biological control, both involve releasing biological control agents without the goal of permanent establishment. Although these two strategies have different goals and ways in which they work, there are strong commonalities and thus they are usually jointly referred to as augmentation. These strategies are used to control pests when natural enemies are absent, when the control due to natural enemies would naturally occur too late to prevent damage, or when natural enemies occur naturally in numbers too low to provide effective control. The term augmentation is used because natural enemies are being augmented, even when they already occur in the release area but are not abundant enough to provide control.

4.1 Inundative biological control

> The use of living organisms to control pests when control is achieved exclusively by the organisms themselves that have been released
>
> (Eilenberg *et al.*, 2001)

This strategy is directed toward rapid control of pests over the short term. In all cases, no reproduction by the natural enemy is expected. Because control is only due to the released individuals, inundative releases would have to be repeated if pest populations increase again after natural enemies are released. In practice, releases are often repeated if pest populations were not all present in a susceptible stage during the previous application, if new pests disperse into the crop, or if the crop is long lived, increasing the length of time it could become infested. The released agents must contact and kill a sufficiently high proportion of the pest population, or by other means reduce the damage level, to provide control. Of course, to achieve sufficient control rapidly, it is important to release a large number of organisms to inundate the pest population. It has been suggested that microbes being released inundatively must be applied at the density that would be present during a disease epizootic or epidemic because control would be due to the natural enemies that are released and not their progeny.

Inundative control is often used for short-term crops because viable, breeding populations of the natural enemies do not occur in the habitats provided by temporary monocultures. Alternatively, inundative releases are appropriate where damage thresholds are very low and rapid control is required at early stages of pest infestation.

In many ways, the goals and expectations of this strategy are similar to those for use of synthetic chemical pesticides. Perhaps the similarity of inundative biological control with the pesticide paradigm helps account for the popularity of this approach compared with inoculative release. Natural enemies applied inundatively can be referred to as biopesticides (Hall & Menn, 1999). A few of the many examples of macro-beneficials sometimes referred to as biopesticides when applied inundatively are lady beetles to control aphids, the predatory mite *Neoseiulus cucumeris* to control thrips, and beneficial nematodes to control fungus gnats. Microorganisms that are inundatively applied, for control of arthropods, weeds, or plant pathogens, are often referred to as microbial pesticides for microbial control. An example of these would be the bacterial pathogen used to control numerous species of insects, *Bacillus thuringiensis* (see Chapter 10). Inundative release is also the strategy used to apply a fungal pathogen against locusts in Africa (Box 12.2), a viral pathogen against velvetbean caterpillars (*Anticarsia gemmatalis*) in soybeans (Box 11.2) and a fungal pathogen for control of the weedy stranglervine, *Morrenia odorata*, in citrus orchards (Box 15.1). This latter natural enemy can also be called a bioherbicide or, because this is a fungus, a mycoherbicide.

Strengthening the view that microbes for biological control are similar to chemical pesticides, microbes for inundative release are often sold in forms similar to synthetic chemical pesticides, for example formulated as flowable concentrates or wettable powders, and can be applied repeatedly, often with the same spray equipment that could be used to apply chemical pesticides. However, it has been argued that we cannot think of using these so-called biopesticides in the same way as chemical pesticides. These are living organisms and care must be taken to store and transport them so that they remain alive and are released in an appropriate way (Cook, 1993). Due to the large numbers of natural enemies that must be released when using an inundative approach, methods for cost-efficient and successful mass-production, storage, transport, and release are critical for development and use of this strategy.

4.2 Inoculative biological control

> The intentional release of a living organism as a biological control agent with the expectation that it will multiply and control the pest for an extended period, but not that it will do so permanently
>
> (Eilenberg *et al.*, 2001)

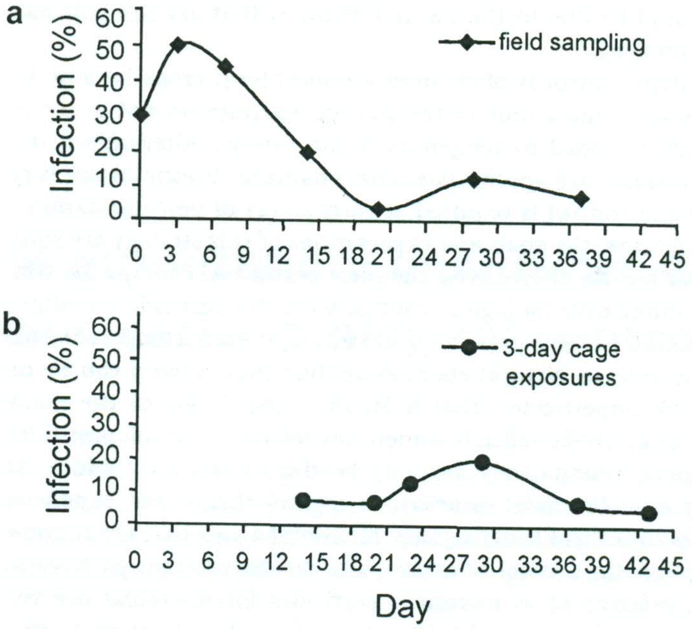

Fig. 4.1 Primary infections initiated after release of *Metarhizium anisopliae* var. *acridum* against African grasshoppers, followed by secondary infections. a. Infection of *Hieroglyphus daganensis* collected at varying times after fungal application on day 0. At each sampling date, 50 grasshoppers were collected and subsequently reared in the laboratory. b. To detect secondary infections, 14 days after the application, healthy grasshoppers were caged in the field for 3-day periods to detect whether infective fungal inoculum was still present in the environment. (Adapted from Lomer *et al.*, 1997.)

For this strategy, control is due not only to the released organisms themselves but also to their progeny. This strategy provides more long-term and self-sustained control than inundative releases. It is used in systems where a natural enemy can respond to and control a pest population, often in a density-dependent manner, but does not persist, or where a natural enemy provides density-dependent control but is difficult to mass-produce in large enough quantities for inundative releases. If an inoculative release is intended for predators, parasitoids, or pathogens, sufficient pest numbers (or other means for growth of the biocontrol agent) must be present following the initial release to support a second or third generation of the released agent, and conditions that allow multiplication of the natural enemy must occur. Studies with the fungal pathogen *Metarhizium anisopliae* var. *acridum* in central Africa have demonstrated this secondary cycling of infection where spores produced from the first cohort of grasshoppers that were killed in the field infect a second cohort (Fig. 4.1). Although fewer natural enemies need to be released than with the inundative approach, these programs still usually require some aspect of mass-production to supply enough agents at appropriate times for release.

For biological control of plant pathogens, in general microorganisms that are released are intended to increase in the microhabitat

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4.3 | Inundative

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