

How best to release a biological control agent

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Abstract. In New Zealand 69% of insects released against alien pests and weeds have failed to establish in the field. At present, release strategies are based on experience, knowledge of agent biology and demands of the clients rather than on experimentally proven protocols. In this paper we describe and demonstrate a scientific protocol developed to optimize the establishment rate of biocontrol agents in the field. A field experiment is used to determine the relationship between the number of insects released and the probability of establishment for two biocontrol agents in New Zealand: the broom psyllid *Arytainilla spartiophila* (Förster) and the gorse thrips *Sericothrips staphylinus* Haliday. In both species a positive relationship between the size of the release and the probability of establishment is demonstrated. These are the first occasions that this relationship has been unequivocally tested in the field for biological control agents. A model is used to demonstrate how the relationship between the number of insects released and the probability of establishment can be used to determine the optimal release strategy for an insect. An optimal release strategy is designed for both gorse thrips and broom psyllids in New Zealand and we show that the optimum release size for both thrips and psyllids is just under 100 agents per release site. These predictions are in contrast to the current strategy of 1000 thrips and 1000 psyllids per release and the suggestion in the biocontrol literature that large releases optimize establishment.

Introduction

Worldwide, fewer than 65% of agents released against alien weeds successfully establish in the field (Julien *et al.* 1984), and in New Zealand, 69% of the insect agents released have failed to establish (Cameron *et al.* 1993). Better release strategies might improve these statistics and a field experiment was used to investigate the relationship between the probability of establishment and the number of individuals released for two weed biocontrol agents, the broom psyllid *Arytainilla spartiophila* and the gorse thrips, *Sericothrips staphylinus*. We use the results to predict the optimum release size for the two species.

Broom, *Cytisus scoparius* (L.) Link and gorse, *Ulex europaeus* L. are leguminous shrubs which have been deliberately introduced into many countries. Like many alien plants, they have become serious weeds of pasture, forest and native habitats. One of the most badly affected countries, New Zealand, has conducted its current classical biological control programmes against broom and gorse since 1981 and 1979 respectively. The programmes aim to introduce a range

of specialist herbivorous insects from Europe to reduce the vigour and invasiveness of the plants in New Zealand. Ideally, biological control agents would be released in huge numbers, but difficulties in the collection, rearing, shipment or quarantine of potential agents invariably result in limited numbers being available for release. Therefore biological control workers face a dilemma: should they make a limited number of large releases or a large number of small releases?

Advice on the number of insects to release varies: (i) release not less than 1000 at a site (Bierne 1975; Hopper and Roush 1993); (ii) start with small releases of a few hundred and if these fail try larger releases of thousands (Cock 1986); or (iii) make repeated releases at the same site as population establishment and persistence are stochastic phenomena (Lawton 1990). Biocontrol agents may be released in the field or confined to a cage in the initial phases of release (Debach and Bartlett 1964).

Despite the multifarious advice, or maybe because of it, the particular release method chosen depends heavily on the individual biocontrol practitioner and

may be based on untested assumptions. While the chosen approach may have worked admirably in many circumstances in the past, a view exists that a more scientific approach is desirable for future biological control programmes.

In New Zealand, the effective distribution of biocontrol agents is achieved by means of co-operative programmes which involve central government, regional councils, forestry companies, Landcorp Farming Ltd. and the Department of Conservation. Biocontrol agents are released at nursery sites and as their numbers build up the agents disperse naturally or can be moved to areas where the target weed is a problem. Noxious-plant officers and other field staff assist with site selection, release, monitoring and distribution of insects. One thousand insects is the standard release propagule, although smaller numbers are used if experience shows that they will establish (Cameron *et al.* 1993). While our protocol was developed specifically for New Zealand, and we realize that there may be difficult practical or logistic constraints in other countries, we believe that it has implications for the release of biological control agents in general. For example, if the release method involves making re-releases from a nursery site then it would be valuable to know the minimum number needed for establishment and thus maximize the number of re-releases.

Many factors are responsible for the failure of biocontrol agents to establish in the field (Lawton 1990). These include inclement weather immediately following an introduction (Crawley 1986), failure to adapt to the new climate (Wapshere 1985), competition with other insects (Ehler and Hall 1982), predation (Holt 1977) and parasitism (Samways 1979). In this paper we consider how the size of release influences the rate of establishment. Both theory (Lande 1988; Pimm *et al.* 1988; Schoener and Spiller 1992; Richter-Dyn and Goel 1982) and retrospective analyses (Hall and Ehler 1979; Pimm 1991; Cameron *et al.* 1993) predict that the probability of establishment increases as the number of individuals released increases. For example, Cameron *et al.* (1993) point out that the establishment rate of releases of more than 30000 insects is 80% compared to 56% for releases of less than 30000. However, the effect is not consistent as at least one release of only two individuals has led to establishment, while other releases of tens of thousands have failed (Cock 1986). While the effect of the number of agents released is not clear cut, small

releases have largely been avoided as they are believed to establish less frequently in the field (Schaffer 1981; Lande 1988; Hopper and Roush 1993).

In this context, while there are many retrospective analyses of the biocontrol literature and large bodies of work on extinction theory, there is a paucity of field tests. Limitations in current knowledge indicate the need for a more experimental approach to introductions (Simberloff 1989; Hopper and Roush 1993). This is the approach that we use in this paper.

Methods

The first stage in determining an optimal release size consists of a manipulative field experiment which determines the relationship between the size of release and the probability of establishment. The broom psyllid and the gorse thrips were released in replicated propagules, the propagules increasing in size on a logarithmic scale. The thrips were released in replicated propagules of 10, 30, 90, 270 and 810. The largest release size approximates to the standard release size of 1000 which is currently used for thrips in New Zealand. The releases were made onto separate bushes within the same field, an adjacent bush being used as a control to check for dispersal. The thrips is polymorphic but predominantly wingless and its dispersal abilities are known to be poor. For the psyllid, the first release at a nursery site in New Zealand had been successful with an introduction of 88 insects (Harman *et al.* in press), so a range of smaller release sizes was used, namely replicates of 2, 4, 10, 30, 90 and 270. In the case of the three smallest release sizes, the psyllids were sexed to ensure a 50:50 sex ratio and releases were made along a transect 150 km in length, with at least 2 km between adjacent release sites. Broom bushes were sampled between adjacent sites and no dispersal between sites was recorded during the first year of the experiment.

In both field experiments the insects were left for one year and then sampled to test for establishment. A sampling problem exists with this type of experiment because it is easier to recover insects from larger releases regardless of any differences in establishment success, simply because there are more insects present. It is possible to test for the presence of this confounding effect using a method devised by McArdle (1990). McArdle (1990) looked at the problem of deciding whether a rare species was absent from a site or was missed in the sample, by chance,

because of its rarity. Our small releases are analogous to rare species and our large releases to common species (assuming that there are no differences in the probability of establishment between the small and the large releases). Thus McArdle's method can be used to predict a null model based on the expected number of insects which would be found if insects are more likely to be found in the larger releases, thereby generating a spurious correlation between the number released and their apparent persistence one year later.

Results

Both gorse thrips and broom psyllids showed a positive relationship between the size of release and the probability of establishment. These data will be reported in full elsewhere. Once the relationship between the number of insects released and the probability of establishment is understood, a decision can be made on the best numbers of insects to release. Figure 1 shows three potential relationships between the number of insects released and the probability of establishment. While these are model data sets, the shape of the relationships are typical of real data as for thrips (in preparation), psyllids (in preparation), parasitoids (Campbell 1975) and game birds (Pimm 1991). The data sets describe three types of probability of establishment: Fig. 1a describes a situation where the insect will establish from all releases, albeit at very low probabilities for the smallest ones. Figure 1b describes an insect in which none of the very small releases establish, but the remaining release sizes establish with increasing levels of success. Figure 1c describes an insect with a distinct threshold of establishment, thus none of the small releases establish.

Using the three data sets in Fig. 1, and a supposed 10000 insects available for release, we propose that for each of the three examples a release strategy is devised by calculating the expected number of successful establishments for each release size. We define the optimal release size as that which has the highest number of successful establishments. More complex calculations of the optimum strategy can be made, for example by including labour and travel costs of visiting a small or large number of release sites. We will develop these arguments in a later paper. Here we calculate the optimal release strategy, in two stages.

Firstly, given 10000 insects, the number of releases for each of the six release sizes is calculated (Table 1).

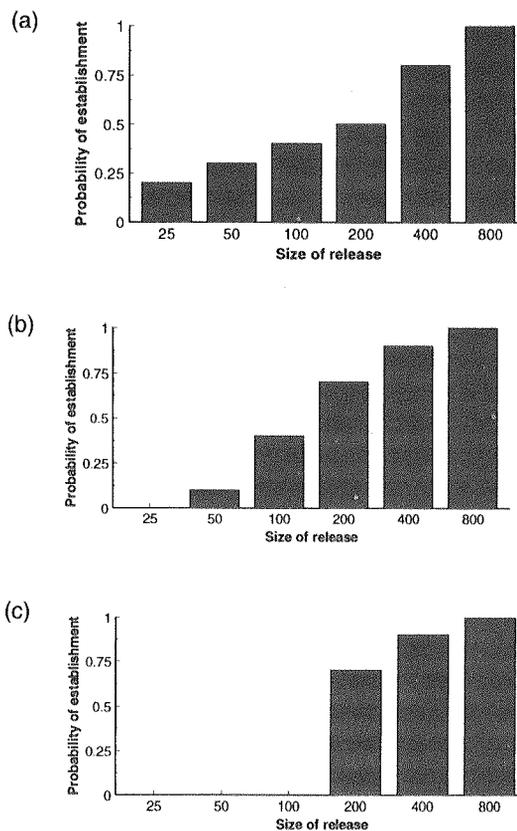


Fig. 1. Hypothetical (but realistic) examples of the establishment by three insects as a function of the size of initial releases. See text for details.

Secondly, the number of expected successful establishments for each release size is calculated by multiplying the number of releases (Table 1) by its probability of establishment (Fig. 1). The predicted optimal release size for each of the three probability-of-establishment relationships is shown in Fig. 2.

For a probability of establishment of the type shown in Fig. 1a, the release strategy which maximizes the average or expected number of successful establishments, is 400 releases of 25 insects, of which an average of 80 will establish. This, and the predicted average number of successful establishments for the probability-of-establishment relationships shown in Fig. 1b and 1c are shown in Fig. 2.

Applying this methodology to gorse thrips, the release strategy to optimize establishment is relatively small, initial inocula of just under 100 insects, in contrast to the original releases in New Zealand which used inoculates of 1000 thrips. The new strategy would

Table 1. The relationship between the size of release and the number of releases, given that 10000 insects are available for release.

Size of Release	Number of Releases
25	400
50	200
100	100
200	50
400	25
800	12.5

lead to a more than ten-fold increase in the total number of release sites, leading to an improvement in geographical coverage and probably in the efficiency of the gorse thrips control programme, both in New Zealand and in other countries where release of the gorse thrips is imminent.

With the broom psyllid experiments, releases as small as two or four were apparently successful in the field experiment, at least after one year, which leads us to predict (see Fig. 2a) that a large number of small releases will be optimal. However, more work is required to determine the relationship between size of release for establishment and long-term persistence. A risk-averse strategy may suggest the choice of a rather larger release of, for example, 100 insects per site. As with the gorse thrips, the newly suggested release size remains lower than the present choice of 1000 insects.

Conclusions

There is an urgent need to develop simply measured, unambiguous parameters which can be used to improve the success rate of biological control. The probability-of-establishment is such a parameter and if appropriate experiments were done, with regard to the number of insects released per site in the early stages of a release programme, biocontrol agents may be released in a more efficient and effective manner. We propose that the type of experiments described here, could be built into the very early stages of a release programme and the results used to optimize subsequent releases.

Here we defined our optimal release strategy as the maximum expected number of successful establishments. However, other optimal release strategies exist, for example the aim of the release programme may be to have a high probability-of-establishment at one site. The exact release strategy

chosen by the biocontrol practitioner will depend on the nature of the weeds' distribution and the needs of the clients.

Establishment is the first stage in a successful invasion by an organism; further experiments are required to investigate the relationship between the minimum viable population size for establishment and the minimum population size for persistence. The thrips and psyllid experiments will be monitored for a further three years and the relationship between release size and both population persistence and population growth will be determined. Establishment remains an essential precursor to persistence and while the strategy chosen to optimize establishment is likely to vary, both with the species and with the environment,

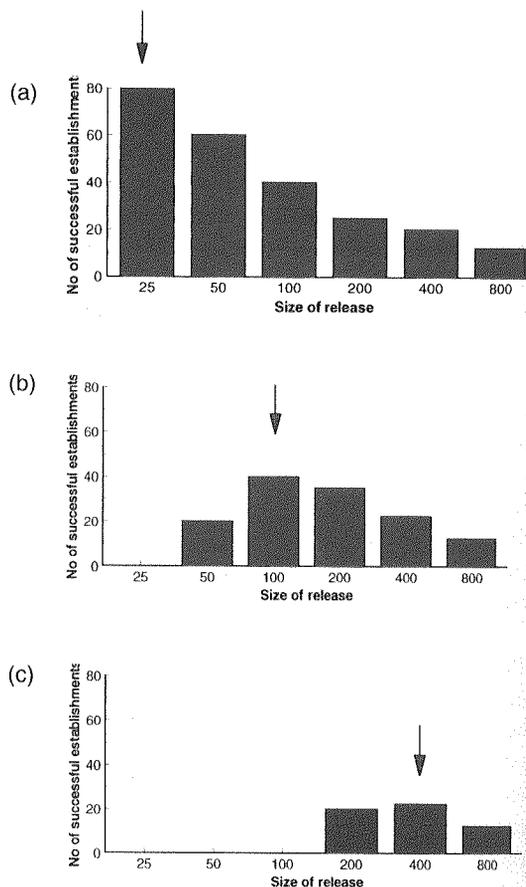


Fig. 2. The predicted number of successful establishments, for three species of insects, (a) - (c), assuming that 10000 individuals were released in batches of different sizes, using the probability of establishment from Fig. 1 and the number of possible releases shown in Table 1. Arrows show the optimal release size.

the general principles experimentally demonstrated here should apply to all releases of organisms into the environment.

Most biocontrol agents in New Zealand have a slow rate of natural dispersal from their original release site. For example, ragwort flea-beetles moved less than 200 m in three years at a site near Hanmer Springs, Canterbury (Harman and Syrett 1989). For these agents, it is vital to make a large number of releases throughout the range of the weed so that the beneficial effects of the agents are achieved early. The method demonstrated here could be used to maximize the number of successful releases.

Future programmes in New Zealand are likely to differ in several ways from those in the past. The legislation affecting the control of noxious plants in New Zealand has been replaced by the Biosecurity Act 1993, which comes into force in July 1996. In future extension programmes a larger proportion of time may be spent on monitoring and assessment as greater accountability is demanded. Co-operative extension programmes funded by end users have a number of advantages (Syrett *et al.* 1993), one of which is that large-scale manipulative experiments can be set up within release programmes, thus providing opportunities for determining a scientific basis for release strategies. Obviously the type of experimental approach described here is most suited to biological control programmes where the infrastructure for making multiple releases exists. There will be occasions where just a very small number of agents are available for release and experiments, such as those described here, may not be possible.

The size of release and the number of releases are only two of the factors that theory predicts will affect the establishment rate. Others include predation (Holt 1977), community characteristics (Lawton and Brown 1984; Pimm 1991), environmental variation (Leigh 1981), genetics (Lande 1988; Roush 1990) and demographic stochasticity (Pimm *et al.* 1988). All of the above are experimentally tractable and it is possible to determine their effect on an insect's probability of establishment in the field. In New Zealand, experiments are currently underway to partition the effects of environmental and genetic stochasticity in the extinction of small populations of insects. Such experiments are not just of use to the science of biocontrol, they also offer unparalleled opportunities to unravel the invasion process on a scale not available to any other branch of biology.

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