Rate of dispersal a key success factor for weed biological control agents within forest plantations

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Summary *Buddleja davidii* (buddleia) is an invasive weed of both natural and plantation forests in New Zealand. The weed has been estimated to cost the New Zealand plantation forest industry up to $2.9 million annually in chemical control costs and lost production. The buddleia leaf weevil, *Cleopus japonicus*, was released in New Zealand in 2006 as a biological control agent for this weed. If *C. japonicus* can reduce the growth rate of *B. davidii* in the first three years after clearing of land for planting it has the potential to reduce the need for chemical control of this weed. To determine the effectiveness of this control agent, *B. davidii* seedlings were planted in an insecticide exclusion trial and the dispersal of *C. japonicus* and feeding damage on plants was monitored according to distance from a single source population. *Cleopus japonicus* dispersed at a rate of approximately 100 m per annum. There was a strong correlation between larval numbers per plant and percentage defoliation. A significant reduction in *B. davidii* height in untreated compared to insecticide-treated plants only became apparent 436 days after trial initiation.

Keywords *Buddleja davidii*, *Cleopus japonicus*, buddleia, buddleia leaf weevil, dispersal, biological control.

INTRODUCTION

Buddleja davidii Franchet (buddleia) is a prime example of a garden ornamental that has become an invasive weed of both exotic and native areas of New Zealand. *Buddleja davidii* quickly colonises disturbed areas, such as slips, roadsides and riverbeds; its rapid growth allows it to outcompete both native and plantation species (Tallent-Halsell and Watt 2009).

Management of *B. davidii* has been estimated to cost the New Zealand plantation forest industry up to $2.9 million annually in control costs and loss of production (Kriticos 2007). Control is currently achieved with herbicides, but eco-certification criteria require the forest industry to move away from herbicide use and chemical control may therefore not always be an option (FSC 2007).

The only biological control agent for this weed, the buddleia leaf weevil (*Cleopus japonicus* Wingelmüller), was released in New Zealand in 2006. The agent has two damaging life stages, the larva and adult, both of which feed externally on the leaves of *B. davidii*. Initial trials within plantation forests have demonstrated that the weevil has the ability to heavily defoliate large *B. davidii* plants repeatedly over several years, with damage greatest in autumn (M. Watson unpublished data).

For *C. japonicus* to be an effective management tool for the control of *B. davidii* in commercial forests, the biological control agent must reduce the growth of *B. davidii* in the first three years after planting such that competition with crop trees is reduced. Specifically, a reduction in *B. davidii* height is required so that it does not exceed 60% of tree height (Richardson *et al*. 1999). Due to the short period of opportunity, rapid agent dispersal into newly planted areas, and rapid population build up are two key attributes likely to determine successful weed biocontrol in plantation forestry. *Cleopus japonicus* adults can fly readily, and population growth is rapid. However, there is no quantitative estimate of the rate at which weevils disperse from a founder population onto establishing host plants

This trial examines the rate at which *C. japonicus* can disperse from a source into an open area with *B. davidii* seedlings, as would occur in a newly planted forest, and subsequent feeding damage to the seedlings. The first 14 months of data are presented here.

MATERIALS AND METHODS

Experimental design This trial was established in the Scion Long Mile Road research area in Rotorua, New Zealand, in November 2008 in an area with several large *B. davidii* plants and an established population of *C. japonicus*. Additional *B. davidii* were planted to form a row of plants (founder plants) at one end of the 100 m long area. An additional 800 field-collected weevils were released on the founder plants in the summer of 2008–2009.

One hundred and sixty *B. davidii* seedlings (7.9 ± 0.44 cm tall) were planted into bare soil on 1 November 2008. The trial consisted of 20 rows of four pairs of plants spaced 2 m apart within the row. The rows were placed parallel to the founder plants and extended to 100 m away, spaced at regular 5 m intervals. The experiment was divided into four longitudinal blocks, each running the length of the 100 m trial.

Within each row each pair of plants was allocated a treatment that included either spraying with insecticide (acephate) to prevent *C. japonicus* from feeding (termed hereafter 'treated plants') or not spraying (termed hereafter 'untreated plants'). Insecticide treatments were initially applied every 2 weeks, with the frequency reduced to monthly as the trial progressed. The area immediately around the *B. davidii* seedlings was kept free of competing vegetation by hand-weeding and spraying with glyphosate.

Measurements For each seedling, the height, *C. japonicus* feeding damage and number of weevils and larvae on each plant were recorded at regular intervals from spring to autumn. Values reported here are for the following seven measurement dates with days after exposure to *C. japonicus* given in brackets: 4 November 2008 (4), 7 January 2009 (67), 11 February 2009 (102), 5 March 2009 (124), 20 May 2009 (200), 19 November 2009 (383) and 11 January 2010 (436).

Data analysis All analyses were undertaken using SAS (SAS-Institute-Inc. 2000). A mixed effects model that accounted for the spatial correlation within the experimental design was used to determine the main and interactive effects of treatment and distance from the point of release on plant height and weevil numbers. Each measurement date was analysed separately using this model and appropriate transformations were applied to variables with non-normal distributions.

RESULTS

Feeding damage from *C. japonicus* was first recorded on *B. davidii* on 19 February 2009 (110 days after exposure to *C. japonicus*). On all measurement dates after this, untreated plants had significantly higher numbers of *C. japonicus* than plants treated with insecticide (Figure 1). There was a significant treatment by distance interaction for the first two dates, reflecting the decline in insect numbers with distance from the point of release.

Variation in the percentage feeding damage broadly corresponded to the changes in insect numbers. Percentage defoliation in untreated plants was significantly higher than that of treated plants from 124 days following trial initiation (Figure 2). There was a significant treatment by distance interaction for the first two measurement dates, reflecting the decline in defoliation with distance from the founder plants.

There was a strong relationship between the percentage defoliation and the total number of larvae

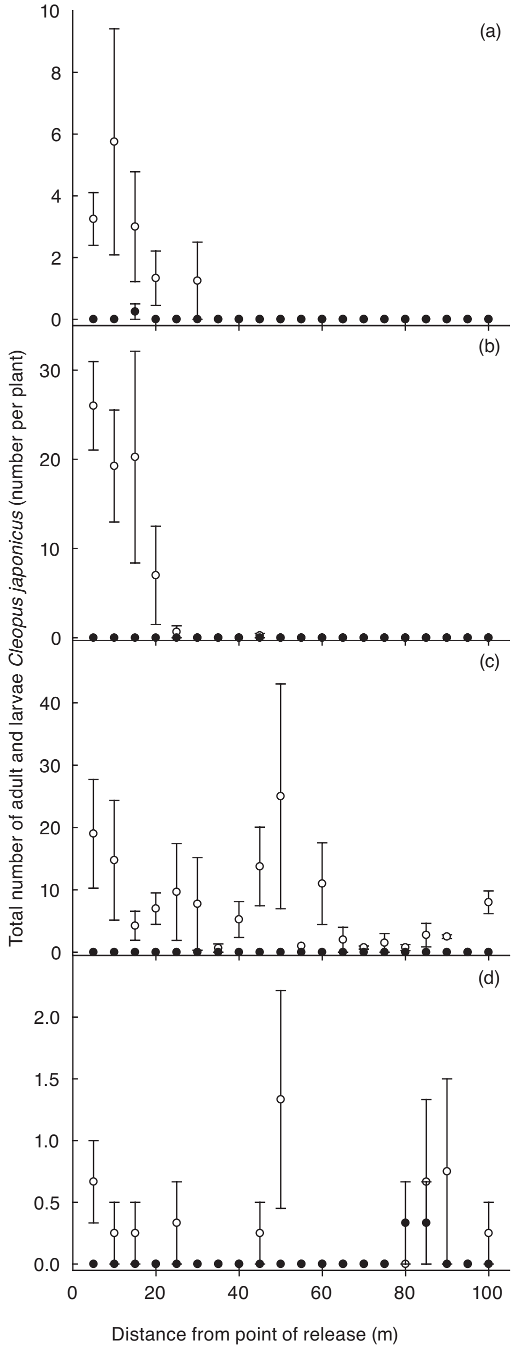

Figure 1. Total number of *Cleopus japonicus* at different distances from point of release for (a) 124, (b) 200, (c) 383 and (d) 436 days after exposure to treated (filled circles) and untreated plants (open circles). Each value shown is the mean ± standard error from four blocks.

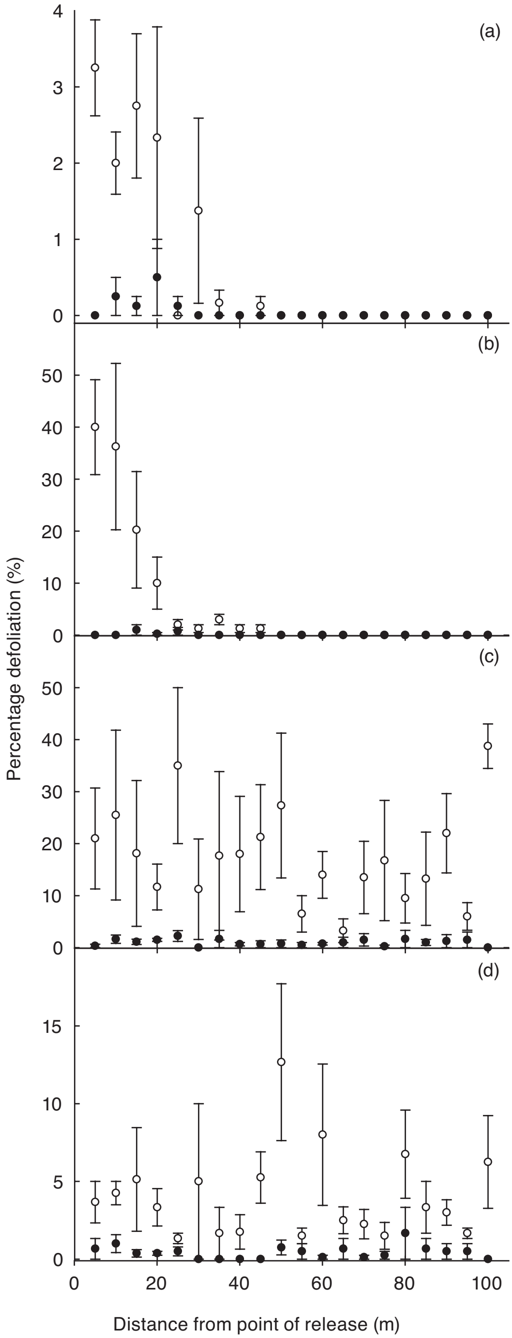

Figure 2. Percentage foliage damage for *Buddleja davidii* at different distances from point of release for (a) 124, (b) 200, (c) 383 and (d) 436 days after exposure to treated (filled circles) and untreated plants (open circles). Each value shown is the mean ± standard error from four blocks.

(Figure 3), but not the total number of adults (data not shown). The percentage defoliation increased markedly up to approximately three larvae per plant, after which defoliation increased at a lower rate with increasing number of larvae (Figure 3).

Height of the *B. davidii* seedlings was relatively unaffected by the presence of the *C. japonicus* until the last measurement 436 days after the trial began (Figure 4). In comparison to the insecticide-treated plants, height of untreated plants at this time was

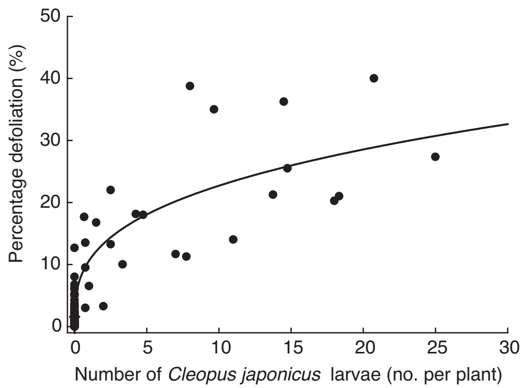

Figure 3. Relationship between the number of *Cleopus japonicus* larvae plant^{-1} and percentage defoliation of *Buddleja davidii*. Data shown are treatment level averages, by distance, for all days after release. The fitted line is a power function ($y = 10.62x^{0.33}$) and has an R^2 of 0.81.

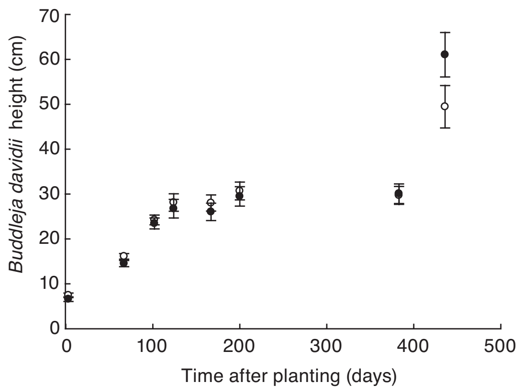

Figure 4. Relationship between the time after planting of *Buddleja davidii* seedlings and height for treated (filled circles) and untreated plants (open circles). Values shown are least square means and standard errors.

significantly reduced (P = 0.01) by an average of 19%. As the interaction between distance from the founder plants and treatment was not significant at this time these reductions were relatively uniform across the 100 m transect (data not shown).

DISCUSSION

The lag between when the *B. davidii* seedlings were planted in November and the first *C. japonicus* adults found on the seedlings in February may reflect the ability of adults to locate small host plants, or the motivation to disperse to new hosts. The dispersal of adult *C. japonicus* from the founder plants in February is likely to have been associated with a rapid decline in the availability of suitable foliage as these founder plants had become heavily defoliated (up to 90% of the total leaf area removed). Female adults are also likely to seek undamaged host foliage for oviposition sites. *Cleopus japonicus* adults are able to lay up to 30 eggs per day (Gresham *et al.* 2009). Thus, even a single dispersing female can induce a rapid new population build-up.

In this trial, dispersal of *C. japonicus* was initially faster than that recorded at an adjacent commercial forest (Whakarewarewa) release site consisting of 3- to 7-year old *Pinus radiata* trees and other weeds. In the present trial *C. japonicus* dispersed 45 m in 6 months in comparison to only 30 m at Whakarewarewa forest. In contrast, initial releases within commercial forests in other regions of New Zealand recorded higher rates of dispersal, 100 m and 70 m over 6 months, at Kinleith (Waikato) and Esk (Hawke's Bay) forests, respectively. It is possible that climate is driving dispersal rate across different regions, although differences in weed density, size and population structure between sites could also account for this variation.

The relatively uniform reduction in untreated plant height of 19% across the trial after 436 days suggests that *C. japonicus* has the ability to suppress growth of *B. davidii* seedlings in close proximity to source populations. Whether this level of control will be sustained and sufficient to reduce the competitive advantage of *B. davidii* in commercial forests still needs to be determined. Economic success will only result if *C. japonicus* can disperse rapidly into newly planted areas, and exert significant height reductions of *B. davidii* across entire compartments within the first 3 years. Given the large size of most new plantings, distributing *C. japonicus* across newly planted areas may be needed. However, whether or not this will be economically viable will be examined in the future. The next stage in this programme will be to develop an integrated weed management protocol for control of *B. davidii* in New Zealand commercial forests.

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