

PREDICTING THE SEASONAL PHENOLOGY OF FALL WEBWORM (*HYPHANTRIA CUNEA*) IN NEW ZEALAND

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ABSTRACT

A cohort-based model for the seasonal phenology of the black-headed strain of the fall webworm, *Hyphantria cunea* (Lepidoptera: Arctiidae), was constructed from published development rates for each life stage. Model predictions were successfully verified against field observations from Japan, China, Italy, Serbia and the USA. The model was then used to predict phenology in New Zealand, and the potential for establishment near major ports. Populations are predicted to be bivoltine in the north and univoltine in central areas, but are unlikely to form self-sustaining populations south of Timaru. Fall webworm demonstrated the ability to adapt to specific local conditions after its invasion of Japan, so the risk may be greater than these results suggest. Successful validation of the model means that it could be used to inform surveillance and control operations targeting fall webworm outbreaks overseas and potential invasions into new ranges such as New Zealand.

Keywords: biosecurity, development rates, invasive insects, risk assessment.

INTRODUCTION

The fall webworm, *Hyphantria cunea* (Lepidoptera: Arctiidae), is a native of North America, where distinct red-headed and black-headed strains are recognised. The more invasive black-headed strain has now spread through central Europe, eastern Asia and Japan. Several incursions of the black-headed strain have been detected recently in Auckland, New Zealand. A small colony of larvae was found in Mt Wellington in March 2003, and five adult males were trapped in surrounding areas in early 2005. Further trapping suggests that the subsequent eradication has been successful, but the pathway of entry of these incursions was never determined, suggesting a high risk of future invasions. During the incursion response, a phenology model was constructed to help inform management decisions, such as the optimal timing for ground searches and biopesticide applications. This paper describes the phenology model for fall webworm, validates it against a range of overseas data, and uses it to suggest the potential for establishment and likely seasonal phenology at New Zealand's major ports.

METHODS

A cohort-based model was formulated for the black-headed strain of the fall webworm, following the approach of Logan (1988), with separate life stages for eggs *E*, larvae *L*, developing pupae *P*, diapausing pupae *D* and adults *A*. Within each life stage, individuals were divided into integer-based cohort groupings of equal physiological age, and binomial rounding was used at all model transitions to maintain integer quantities and introduce realistic demographic stochasticity. Development rates were assumed to follow a linear degree day accumulation above a base temperature *b*, with the degree day requirement *q* of individuals in each life stage being normally distributed (Dennis et al. 1986) with a 10% standard deviation. Adult moths were subjected to a constant daily mortality rate of 0.33/day, and were replaced with new eggs to simulate reproduction.

The degree day requirements of each life stage were assumed to follow those measured by Nordin & O'Conna (1985, black-headed strain) for North American simulations: $b_E = 13.6^\circ\text{C}$; $q_E = 93^\circ\text{d}$; $b_L = 10.7^\circ\text{C}$; $q_L = 488^\circ\text{d}$; $b_P = 10.7^\circ\text{C}$; $q_P = 198^\circ\text{d}$, where b is the base temperature and q the total degree day requirement of the stage indicated by the subscript. In all other cases the parameter values measured by Gomi et al. (2003, Kobe parameter set) were used: $b_E = 12.6^\circ\text{C}$; $q_E = 106^\circ\text{d}$; $b_L = 10.5^\circ\text{C}$; $q_L = 363^\circ\text{d}$; $b_P = 11.3^\circ\text{C}$; $q_P = 152^\circ\text{d}$. Daily thermal accumulation D was estimated from a weighted average of daily maximum T_{max} , minimum T_{min} and mean T_{mean} temperatures: $D = [T_{min}-b]/4 + [T_{max}-b]/4 + [T_{mean}-b]/2$ where the quantities in square brackets were set to 0 if negative (Barlow & Dixon 1980). This method is more accurate than the widely used triangle or sine functions when T_{mean} is known (J.M. Kean, unpubl. data).

Pupal diapause was initiated at mid-larval development by day length being less than 13 hours and 35 minutes, derived from the 14:35 hours critical value observed in laboratory studies (Morris 1967; Gomi & Takeda 1991) less one hour for twilight (Takeda & Masaki 1979). Diapausing pupae were assumed not to develop further until diapause termination, at which time individuals started their normal pupal development. Diapause termination date was assumed to be normally distributed with a standard deviation of 10 days. The median diapause termination date was assumed to be 1 March for Northern Hemisphere scenarios (Li et al. 2001), and this was tested by comparison with the median dates for egg hatch reported by Herms (2004) from Ohio in 1997-98. Southern Hemisphere simulations assumed 1 September for median diapause termination.

The model was validated against field data for the adult flight period of the black-headed strain in Japan, China, USA, Italy and Serbia, as summarised in Table 1. In each case, temperature data to drive the model were obtained from the Weather Underground

TABLE 1: Summary of model validation case studies.

Field observations			Model simulations		
Location	Year	Reference	Meteorological station	Year	Diapause induction
(a) Tokyo, Japan	2002	Kusama, unpubl. data	Tokyo, Japan	2002	12 Aug
(b) Himeji, Japan	1997	Satoda (2002)	Osaka, Japan	2005	11 Aug
(c) Dandong, China	1993	Zhang et al. (1998)	Dandong, China	2005	20 Aug
(d) Shenyang, China	2000	Kusama, unpubl. data	Shenyang, China	2005	22 Aug
(e) Columbia, Missouri, USA	1975-78	Takeda (2005), black-headed strain only	Columbia, Missouri, USA	1975-78 ¹	18 Aug
(f) Morgantown, West Virginia, USA	2005	Sandy Liebhold, unpubl. data	Morgantown, West Virginia, USA	2005	18 Aug
(g) Crevalcore, Italy	2005, 2006	Stefano Maini, unpubl. data	Bologna, Italy	2005, 2006	25 Aug
(h) Beska, Serbia	2005	Slobodan Krnjajic, unpubl. data	Sremska Mitrovica, Serbia	2005	25 Aug

¹Daily temperatures sampled randomly from the available record for each day of the year.

database (<http://www.wunderground.com>) for the nearest available weather station, for the closest possible year(s). The model was then used to predict the seasonal phenology of fall webworm at major New Zealand ports, based on long-term mean temperatures obtained from NIWA. The potential for a self-sustaining population to establish was assessed by comparing the date of diapause induction with the thermal requirements of late instar larvae. If there were insufficient degree days available for larvae to complete their development between the diapause induction date and midwinter then it was considered likely that the population would be susceptible to cold-related winter mortality.

RESULTS

The model accurately predicted the median date of egg hatch in Ohio reported by Hems (2004): field = 24 June 1997 and 12 June 1998; model = 25 June 1997 and 12 June 1998. Results were relatively insensitive to the assumed date of diapause termination because of the relatively low temperatures at that time of year. The model also gave a good fit to adult flight times across a range of Northern Hemisphere locations and years (Fig. 1). Voltinism was predicted correctly in all cases for which a full season's

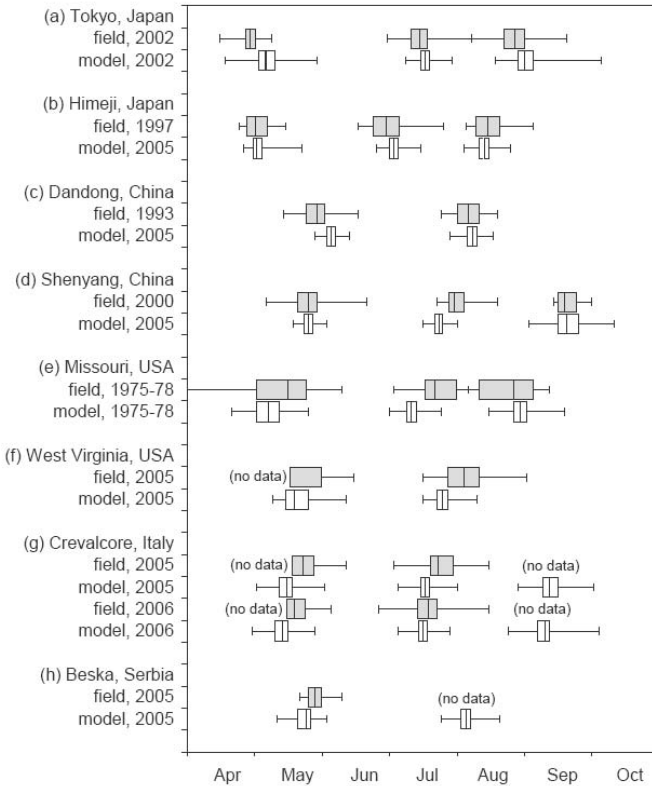


FIGURE 1: Box plot comparing the male flight period observed in the field (solid boxes) with that predicted from the model (open boxes). Boxes show 25th, 50th and 75th percentiles, while error bars indicate the first and last for each generation.

data were available, and the average error in the predicted median timing of the adult stage was only 4.4 days. However, in most cases there was greater variability in the field data than in the model predictions.

The model predicted that fall webworm would be bivoltine in the far north of New Zealand and univoltine through central latitudes (Fig. 2). The model suggests that fall webworm would probably not persist south of Timaru because there is insufficient thermal potential for a full generation to develop in one year (Fig. 2b) and inadequate time to allow diapausing pupae to develop before winter, unless the diapause trigger occurs late in the larval stage (Fig. 3). If diapause is initiated in early larval development then there may be insufficient thermal time available in the south for pupation to occur before winter arrives.

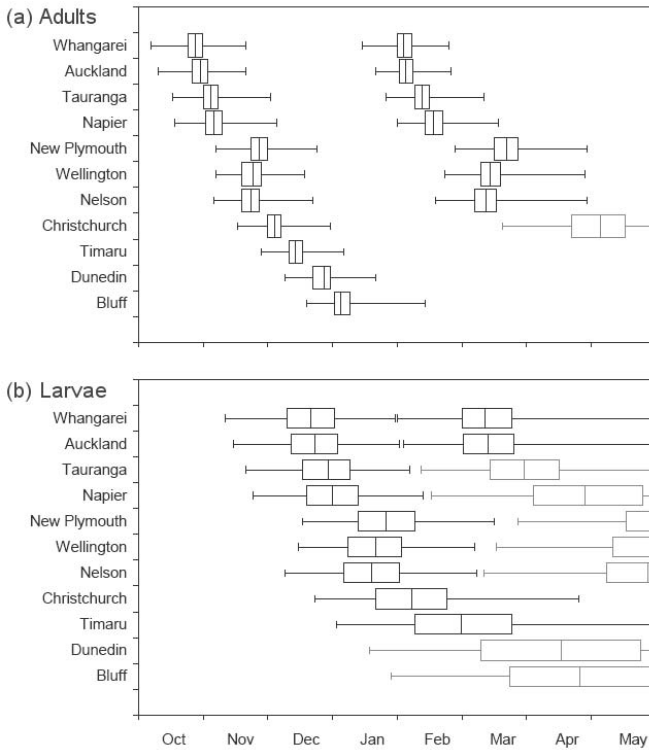


FIGURE 2: Box plot showing predicted timing of adult and larval fall webworm stage at New Zealand ports. Grey boxes refer to partial generations that are unlikely to complete development before midwinter.

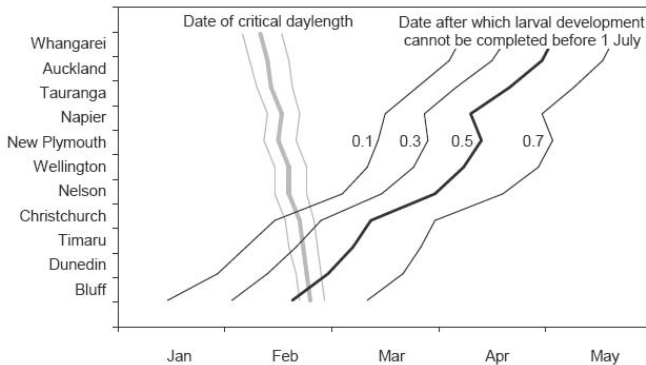


FIGURE 3: Comparison of the timing of diapause induction (including the range observed from Japanese populations) with the median date after which larval development cannot be completed before midwinter. Contours refer to the proportional stage of larval development that is assumed to be sensitive to diapause induction. Diapausing pupae are unlikely to appear before midwinter at locations below where the lines intersect.

DISCUSSION

The reliability in the field of insect development models based on measurements under constant laboratory conditions is by no means assured. Insects may develop differently under fluctuating temperatures than they do under the equivalent constant temperatures (Worner 1992). In addition, the ambient air temperatures used to drive models may not reflect the conditions experienced by some life stages, such as pupae in the soil. In the case of fall webworm, there may also be potential for early instar larvae to thermoregulate within their communal webs (Rehnberg 2002). Despite these circumstances, the close fit of the fall webworm model to the validation data sets across at least three Northern Hemisphere continents suggests that it is a suitably reliable tool for predicting fall webworm phenology in a range of temperate climates.

New Zealand’s maritime climate is generally less extreme than those of the continental locations used for model validation, and this is reflected in the model results. New Zealand’s relatively cooler summers extend the time required to complete a generation, with the result that only one annual generation is likely over much of the country, except in the far north where two may occur, and the southern South Island where a complete generation may not be possible within a season (Fig. 2). The inability to persist in the far south is backed up by there being insufficient degree days in autumn for diapausing pupae to be formed (Fig. 3). However, even non-diapausing life stages can survive temperatures as low as -5°C for up to 2 weeks (Li et al. 2001), so New Zealand’s relatively warm winters might not present a barrier for fall webworm establishment. In this case, the potential risk of fall webworm in the south may be greater than the model suggests. Similarly, New Zealand’s relatively mild winters might affect diapause termination in ways that cannot be easily predicted from the current distribution of fall webworm.

At New Plymouth, Wellington and Nelson, the model suggests that the first generation larval stage might be completed before declining day lengths are present to induce diapause, so that the incipient second generation might be exposed to winter conditions as non-diapausing life stages. However, Japanese fall webworm populations have shown a degree of plasticity in their day length diapause trigger, which has allowed them to

adapt successfully to local seasonal conditions (Gomi & Takeda 1991; Gomi et al. 2004), so it seems unlikely that there would be a significant impediment to establishment in central New Zealand.

Apart from helping to assess the risk of establishment, as discussed above, the model can inform surveillance and control operations for the black-headed strain of the fall webworm, suggesting the appropriate timing for sampling or the right period for applying an insecticidal treatment against a particular life stage. The successful validation of the model suggests it might be widely applicable across the current and potential distributions of this high-profile invasive pest.

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