Biological Control 92 (2016) 120–127

Contents lists available at ScienceDirect

Biological Control

journal homepage: www.elsevier.com/locate/ybcon

Laboratory and field-based temperature-dependent development of a monophagous weevil: Implications for integrated weed management

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HIGHLIGHTS

- Degree-day developmental requirements were determined for *Rhinoncomimus latipes*.
- Results were applied to a population model using field temperatures for three years.
- Warmer temperatures one year allowed much higher populations to develop.
- Field monitoring of *R. latipes* and its host were consistent with the model.
- Temperature along with precipitation data can help predict biocontrol effectiveness.

ARTICLE INFO

Article history:
Received 30 July 2015
Revised 21 September 2015
Accepted 16 October 2015
Available online 23 October 2015

Keywords:
Degree days
Development rate
Persicaria perfoliata
Polygonum perfoliatum
Rhinoncomimus latipes
Seasonal population growth

ABSTRACT

The stem-boring weevil, *Rhinoncomimus latipes* Korotyaev (Coleoptera: Curculionidae) was imported from Asia to North America and approved for release as a classical biological control agent for the invasive annual vine *Persicaria perfoliata* (L.) H. Gross (Polygonaceae) in 2004. Its impact on the weed has been somewhat variable, depending in part on environmental conditions. We reared *R. latipes* in environmental chambers at different temperatures to determine the lower developmental threshold and number of degree days required for development. Results, along with known *R. latipes* reproductive parameters, were used to develop a simple population model, and compared to field data from sites that had been intensively monitored from 2008 to 2010. The lower developmental threshold was estimated at 10.2 °C. On average, 358 degree days (°C) were required for development from egg to adult, with an additional 139 degree days needed for the preoviposition period. Field sites had relatively high *P. perfoliata* cover and low *R. latipes* densities in 2009 compared to either 2008 or 2010. Based on degree-day accumulations for these three years, the population model estimated that fewer than half the number of weevils would have been produced by the end of the season in 2009 as in 2008, and only about a quarter as many as in 2010. Substantially higher rainfall during April–June 2009 compared to 2008 and 2010 probably also helped promote more abundant *P. perfoliata* cover in 2009.

1. Introduction

Successful control of invasive weeds by exotic herbivorous insects depends on their establishment and reproduction, with large numbers of insects often required to impact and substantially reduce the target weed population. Temperature is among the most important factors affecting population growth rates in insects, and the temperature-based development rate curve is a fundamental feature of an insect's life history (Campbell et al., 1974; Taylor, 1981; Wagner et al., 1984; Jarosik et al., 2004; Trudgill et al., 2005). Development in insects occurs only within a definite temperature range. At the lower limit, the development curve asymptotically approaches the point of no development, and considerable mortality may occur, making it difficult to measure the true threshold where no development occurs (Campbell et al., 1974; Wagner et al., 1984). At the mid-range of the curve, development rates typically increase linearly with temperature, and the lower developmental threshold can be approximated by extending the linear regression line to the point where it intersects

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http://dx.doi.org/10.1016/j.biocontrol.2015.10.009
1049-9644/

with the *x*-axis (Wagner et al., 1984). As the temperature increases above the optimum, both development and survival rates generally decline (Taylor, 1981; Wagner et al., 1984).

Laboratory assessments of development curves and associated estimates of development time in degree days have been conducted for a variety of species, primarily pest insects, but also for insects used for biological control of weeds (Godfrey and Anderson, 1994; McClay and Hughes, 1995; Mazzei et al., 1999; Herrera et al., 2005; May and Coetzee, 2013). Such assessments can contribute to an understanding of how field populations may vary with temperature regimes and in different geographic regions.

Persicaria perfoliata (L.) H. Gross (Polygonaceae), also known as mile-a-minute weed or devil's tearthumb, is an aggressive annual vine native to Asia that was accidentally introduced into the mid-Atlantic region of the USA in the 1930s (Moul, 1948; Mountain, 1989). The host-specific Asian weevil *Rhinoncomimus latipes* Korotyaev (Coleoptera: Curculionidae) was first released in North America as a biological control agent in 2004 (Colpetzer et al., 2004a; Hough-Goldstein et al., 2009; Lake et al., 2011). The weevil has had a substantial impact on the weed in some habitats and in some years (Hough-Goldstein et al., 2008, 2009; Hough-Goldstein and LaCoss, 2012; Cutting and Hough-Goldstein, 2013; Smith and Hough-Goldstein, 2014). In other years, however, *P. perfoliata* populations appear to escape suppression. For example, monitored release quadrats had low percent cover of *P. perfoliata* and high weevil densities in 2008 and 2010, but relatively high percent cover and low weevil densities in 2009 (Lake, 2011). The spring and summer of 2009 were cooler than in 2008 and 2010. We hypothesize that these abiotic conditions reduced weevil population growth, which resulted in decreased control of the weed. In addition to low temperatures, high moisture availability in 2009 compared to other years may also have contributed to extensive weed growth. In greenhouse trials, both water limitation and herbivory reduced *P. perfoliata* biomass and seed production (Berg et al., 2015).

R. latipes overwinter as adults, emerging in the spring when seedlings and small plants of their host plant are present, with substantial numbers of weevils and eggs generally observed in the field in mid-May in southeastern Pennsylvania (Lake et al., 2011). Eggs are laid on *P. perfoliata* leaves, petioles and capitula (Colpetzer et al., 2004b). Soon after hatching, larvae bore into stems at nodes and feed internally until fully grown, when they drop or crawl to the ground and pupate in the soil. Three to four overlapping generations are produced during the summer, with no distinct generational peaks (Lake et al., 2011). Under laboratory conditions, weevils live for 2–5 months with little mortality, and females can lay 2–3 eggs per day continuously for at least 2 months (Price et al., 2003; Colpetzer et al., 2004b).

More than 80% of quadrats in monitored plots had weevil eggs or larvae present in mid-May in 2008 and 2009 (E.C.L., unpublished data). In 2005–2007, the proportion of quadrats with weevil eggs stayed relatively high from May until late August, when egg production began a steep, synchronous decline each year until mid to late September, by which time no eggs were found in the field (Lake et al., 2011). This reproductive diapause is probably cued primarily by declining host plant quality, although photoperiod and temperature may also play a role (Lake et al., 2011; Hough-Goldstein et al., 2014). Weevils present in the fall continue to feed on *P. perfoliata* until the first substantial frost (generally in late October in the mid-Atlantic region), when the vines die and weevil adults enter the soil or leaf litter for overwintering.

In this study, we reared *R. latipes* at several constant temperatures, to determine the lower developmental threshold and the number of degree days required for *R. latipes* to develop from egg to adult. In addition, we measured the preoviposition period and numbers of eggs laid at different temperatures. Results, along with known *R. latipes* reproductive parameters, were used to develop a simple population model, which was applied to three years of field data (Lake, 2011; Lake et al., 2011) with known weather conditions.

2. Materials and methods

2.1. Development at different temperatures

P. perfoliata seedlings were dug from the field in White Clay Creek State Park, Newark, DE, in early June, 2014, and held in 13-cm pots in the University of Delaware greenhouse until needed. Additional plants were produced from field-collected cuttings dipped in powdered rooting hormone (Hormodin® 1, OHP Inc., Mainland, PA, USA), placed in vermiculite cells for two weeks, and then transplanted into 13-cm pots. New plants from cuttings were potted on 19 June and 3 July. All potted plants were trimmed as needed to prevent them from growing into each other and to encourage new terminal growth. Plants were fertilized with all-purpose 21–5–20 (N–P–K) fertilizer (Peters Excel Base Formulation, Everris NA, Inc., Dublin, OH, USA) every other week.

Adult *R. latipes* were collected as needed from an established field population at White Clay Creek State Park (Hough-Goldstein et al., 2009). On 17 June 2014, groups of three male and three female *R. latipes* were put in each of 30 cylindrical plastic cages (20 cm diameter, 15 cm deep) with fine mesh tops, containing 8 cm of moist vermiculite. Each cage was supplied with a 30-cm length of *P. perfoliata* stem, still attached to a potted plant, through a small slit in the center of the cage top, plugged with cotton. Only one stem was used from each plant. Cages were held at room temperature to allow weevils to lay eggs. After 24 h, weevils were removed, eggs were counted, and cages containing stems with eggs along with their associated potted plants were distributed to four environmental chambers (Percival Scientific, Perry, IA, USA) so that each chamber had four or five plants, with about the same total number of eggs. All chambers were set at 16:8 (light:dark), and supplied with new light bulbs (Sylvania 22083 F20T12/D T12) that provided light output of 300–310 μmol m^{-2}.

Three growth chambers dedicated to this experiment were set at 20, 25, and 30 °C, and a fourth shared chamber was set at 11 °C. Temperature loggers (Onset HOBO UX100, MicroDAQ.com, Contoocook, NH, USA) set to record temperatures every 30 min were placed in the 20, 25 and 30 °C chambers. The 11 °C chamber was checked daily with a thermometer suspended in the chamber. Cages were monitored daily for adult weevil emergence. As weevils emerged, they were placed together in a 9-cm Petri dish in the same chamber in which they had developed, and allowed to mate for approximately 2 h. They were then placed individually in plastic containers (18 × 12 × 7 cm) and given terminals cut from potted *P. perfoliata* plants, in water in aqua picks, again in the same environmental chambers in which they had developed. Terminals were changed and eggs counted every 3 days for 3 weeks. Each time plant material was changed, all available weevils in each chamber were placed in a 9-cm Petri dish and allowed to mate for approximately 2 h. The experiment was repeated beginning on 31 July, 2014, at 20 and 25 °C but using the environmental chambers originally set at 25 and 30 °C, respectively, for greater replication and to control for any chamber effects.

2.2. Data analysis for environmental chamber trials

For each chamber and trial, the time of emergence of insects held on different plants was compared using a one-way ANOVA followed by Tukey's test. The number of days from egg to adult emergence for the two trials at 20 °C and the two trials at 25 °C