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Use of life table statistics and degree-day values to predict the invasion success of *Gonatocerus ashmeadi* (Hymenoptera: Mymaridae), an egg parasitoid of *Homalodisca coagulata* (Hemiptera: Cicadellidae), in California

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Abstract

Life table statistics and degree-day requirements for *Gonatocerus ashmeadi* Girault, a parasitoid of the glassy-winged sharpshooter *Homalodisca coagulata* (Say), were used to estimate the number of expected parasitoid generations in California (USA). Between two to 51 and one to 37 generations per year were estimated across different climatic regions in California, using life table and degree-day models, respectively. Temperature-based values for net reproductive rate, R_o, were estimated in California using a laboratory-derived equation and ranged from zero to approximately 48 and analyses indicate that a minimum of eight generations are required each year to sustain a population increase of *G. ashmeadi*. Long-term weather data from 381 weather stations across California were used with an Inverse-Distance Weighting algorithm to map temperature-based estimations for the entire state of California. This Geographic Information Systems model was used to determine number of *G. ashmeadi* generations based on day-degree accumulation, T_c, and R_o. GIS mapping indicated that Californian counties in the north, central west coast, central west and Sierra Nevada regions may be climatic conditions unfavorable for supporting the permanent establishment of invading populations of *G. ashmeadi* should *H. coagulata* successfully establish year-round populations in these areas. Southern counties in California that experience warmer year round temperatures and support year round populations of *H. coagulata*, appear to be conducive to the establishment of permanent populations of *G. ashmeadi*. The mechanisms facilitating *G. ashmeadi* invasion and the implications of these temperature-based estimates for biological control of *H. coagulata* are discussed.

Keywords: Degree-days; Demographics; Biological control; GIS mapping; *Gonatocerus ashmeadi*; *Homalodisca coagulata*; Invasion; Net reproductive rate; Life table statistics

1. Introduction

Homalodisca coagulata (Say), the glassy-winged sharpshooter, a xylophagous insect, is a serious pest that has experienced a high rate of population growth following successful invasion into California USA (ca. 1990), French Polynesia (ca. 1999), Hawaii USA (ca. 2004), and Easter Island Chile (ca. 2005) (Pilkington et al., 2005). In California, invasion success has been facilitated, in part, by a lack of effective natural enemies in the receiving range, no competitors, and climatic conditions favorable for establishment, proliferation, and spread (Hoddle, 2004). Many areas with varying biogeographical attributes in California appear to be vulnerable to invasion by *H. coagulata* (Hoddle, 2004) and this pest has been observed feeding and reproducing in agricultural, urban, and natural areas that range from the relatively cool California coast to much hotter and arid desert interior regions that are irrigated.

There is a large economic cost associated with the invasion of *H. coagulata* and the subsequent vectoring of the

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bacterial pathogen *Xylella fastidiosa* (Pilkington et al., 2005). Invasion by *H. coagulata* has been facilitated, in part, via infested ornamental plants that are translocated to new regions. These plants will most likely enter an urban environment where stochastic events that could cause extinction of incipient populations (e.g., drought or lack of suitable host plants) are either eliminated or severely reduced because of anthropogenic influences such as irrigation and high abundance of other host plants in gardens, and warmer temperatures due to heat retention by buildings, concrete sidewalks, and asphalt road surfaces (Imhoff et al., 2004). One potentially effective mechanism for area-wide suppression of *H. coagulata* involves effective and host-specific natural enemies that have the potential to track *H. coagulata* spread into new agricultural, urban, and natural areas and attacking this pest on a wide variety of host plants thereby preventing development of high population densities.

Gonatocerus ashmeadi Girault, a solitary endoparasitoid of proconiine sharpshooter eggs, is a self-introduced resident of California and Hawaii and is currently the major biological control agent of *H. coagulata* (Bautista et al., 2005; Vickerman et al., 2004). Release of *G. ashmeadi* in French Polynesia for biological control of *H. coagulata* is imminent, and little is known of environmental factors that facilitate successful invasion by this parasitoid either when introduced accidentally or deliberately into new areas. Temperature can have a major influence on the establishment, proliferation, spread, and impact of an organism in a new area (Baker, 2002). To this end, we have studied the reproductive and developmental biology of *G. ashmeadi* in the laboratory at constant temperatures to better determine the effects of temperature on basic biological parameters such as development times, degree-day requirements, longevity, fecundity, and sex ratio (Pilkington and Hoddle, 2006).

Degree-days, the acquisition of thermal units over time above a critical minimum for which development is required, have been used to predict many aspects of insect life history. For example, degree-day calculations allow the estimation of life stage duration for an insect given accumulation of degree-days above the critical minimum temperature threshold. This physiological approach can assist in the calculation of the theoretical number of generations that an insect could be expected to have over a specific time period (Purcell and Welter, 1990). The ability to accumulate sufficient degree-days to complete development and begin reproduction in a new area may indicate how vulnerable that region is to invasion by an exotic organism (Baker, 2002; Sutherst, 2000), and whether incursion will be transient due to unfavorable conditions for prolonged periods (Hatherly et al., 2005; Jarvis and Baker, 2001) or potentially permanent due to year-round conditions favorable for growth and reproduction (Baker, 2002; Sutherst, 2000).

Many factors within a receiving ecosystem will influence invasion success, perhaps making accurate forecasts pertaining to successful incursion impossible (Williamson, 1996). In many instances, a priori determination of ecosystem and regional vulnerability to invasion will be assessed in terms of top down effects mediated primarily by climatic conditions (Sutherst, 2000). Using laboratory estimations of degree-day requirements and net reproductive rate, a calculation that is dependent on fecundity and the number of daughters produced per female across a range of experimental temperatures, can be used to determine what temperatures are suitable for sustained population growth (Pilkington and Hoddle, 2006). An understanding of how temperature ranges affect estimates of population growth of an invading or deliberately introduced biological control agent can assist with the prediction of invasion success by indicating geographical areas where unfavorable temperature regimens may prevent permanent populations establishing (Hoelmer and Kirk, 2005). Similar studies have looked at cold tolerances of biological control agents in the laboratory as an indication of field survivability (Hatherly et al., 2005) and evaluation of climatic conditions in the home range of proposed biological control agents for comparison to climates at introduced areas has provided ecologically based criteria for rationalizing the selection of the most appropriate agents for expensive evaluations in quarantine and potential release (Goolsby et al., 2005).

Using laboratory-derived demographic data and long-term climate records it should be possible to assess the establishment and invasion potential of *G. ashmeadi* as it either follows the continued spread of *H. coagulata* in California, after accidental (e.g., as in Hawaii) or deliberate introduction into other countries (i.e., as planned for French Polynesia) as part of a classical biological control program against this pest. A better understanding of abiotic factors affecting incursion success by *G. ashmeadi* will greatly aid comprehension of potential *H. coagulata* control, parasitoid spread within invaded ranges, and establishment success in new areas where inoculative releases of *G. ashmeadi* against *H. coagulata* are being considered. The objectives of the present study were to use developmental and life table statistics to predict the invasion potential of *G. ashmeadi* throughout California in response to expected range expansion by *H. coagulata*. To assess invasion potential, laboratory-derived demographic data (Pilkington and Hoddle, 2006) were used to develop models predicting the number of *G. ashmeadi* generations and subsequent net reproductive rates for this parasitoid across a range of temperatures. These models were used in a Geographic Information Systems (GIS) analysis to ascertain where *G. ashmeadi* could possibly establish permanent populations in California. An interpolation approach using GIS to estimate invasion likelihood is considered more robust than using data from sparsely distributed weather stations that may be unrepresentative of general prevailing conditions due to topography, proximity to urban areas, or water bodies (Baker, 2002).