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Predictions of invasion success of *Gonatocerus triguttatus* (Hymenoptera: Mymaridae), an egg parasitoid of *Homalodisca vitripennis* (Hemiptera: Cicadellidae), in California using life table statistics and degree–day values

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Abstract

The number of expected generations of *Gonatocerus triguttatus* Girault, a parasitoid of the glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar), in California (USA) was estimated using life table statistics and degree–day requirements. Between 0–18.9 and 0–25.3 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_0, were estimated in California using a laboratory-derived equation and ranged from 0 to approximately 29.4 and analyses indicate that a minimum of 7–7.8 generations (calculated using life table and degree–day models) are required each year to sustain a population of *G. triguttatus* in a given area. Long-term weather data from 381 weather stations across California were used with an Inverse-Distance Weighting algorithm to map various temperature-based demographic estimates for *G. triguttatus* across the entire state of California. This Geographic Information Systems model was used to determine number of *G. triguttatus* generations based on degree–day accumulation, generation time, T_c, and R_o. GIS mapping indicated that the only areas in California that may have climatic conditions favorable for supporting the permanent establishment of invading populations of *G. triguttatus*, should *H. vitripennis* successfully establish year-round populations, are Imperial, San Diego, Riverside, Orange and the southern areas of Santa Barbara, Ventura, Los Angeles and San Bernardino counties. Northern counties in California that experience cooler average year-round temperatures do not appear to be conducive to the establishment of permanent populations of *G. triguttatus*. The mechanisms facilitating *G. triguttatus* invasion and the implications of these temperature-based estimates for biological control of *H. vitripennis* are discussed.
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Keywords: Biological control; Degree–days; Demographics; Generation time; GIS mapping; *Gonatocerus triguttatus*; *Homalodisca vitripennis*; *Homalodisca coagulata*; Invasion; Life table statistics; Net reproductive rate

1. Introduction

Following the successful invasion of the glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae), into California USA (*circa* 1990), French Polynesia (*circa* 1999), Hawaii USA (*circa* 2004), and Easter Island Chile (*circa* 2005), this serious insect pest has demonstrated extremely high rates of population growth and rapid spread (Pilkington et al., 2005). A lack of effective natural enemies in the receiving range, no significant competitors, and climatic conditions favorable for establishment, proliferation, and spread (Hoddle, 2004) in California and other infiltrated areas has contributed, in part, to the high invasion success of *H. vitripennis*. In California, there are many uninfested areas with varying

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biogeographical attributes that appear to be vulnerable to invasion by *H. vitripennis* as 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 (Hoddle, 2004).

Gonatocerus triguttatus Girault, (Hymenoptera: Mymaridae) is a solitary endoparasitoid that attacks the eggs of sharpshooters in the cicadellid tribe Proconiini (Triapitsyn et al., 2002). In 2000, *G. triguttatus* was deliberately introduced into California, USA as part of a classical biological control program against *H. vitripennis* (Pilkington et al., 2005). Limited recoveries from some release areas have been made tentatively suggesting *G. triguttatus* may have established localized perennial populations in California (Pilkington et al., 2005). Climate, especially 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. triguttatus* 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 for this parasitoid (Pilkington and Hoddle, 2007).

The acquisition of thermal units over time above a critical minimum for which development is required (referred to as degree–day accumulation), have been used to predict many aspects of insect life history. 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 (Sutherst, 2000; Baker, 2002), and whether incursion will be transient due to unfavorable conditions for prolonged periods (Jarvis and Baker, 2001; Hatherly et al., 2005) or potentially permanent due to year-round conditions favorable for growth and reproduction (Sutherst, 2000; Baker, 2002).

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 which temperature ranges are suitable for sustained population growth of a parasitoid (Pilkington and Hoddle, 2007). An understanding of how a temperature range affects 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).

Using laboratory-derived demographic data and long-term climate records it should be possible to assess the establishment and invasion potential of *G. triguttatus* throughout California. This technique has already been used to assess the establishment potential of *G. ashmeadi* Girault (Hymenoptera: Mymaridae) in California in response to continued spread by *H. vitripennis* (Pilkington and Hoddle, 2006b). A better understanding of abiotic factors affecting incursion success by *G. triguttatus* will greatly aid comprehension of potential *H. vitripennis* control, parasitoid spread within invaded ranges, establishment success in new areas where inoculative releases of *G. triguttatus* against *H. vitripennis* are being considered, and intensity of competition and distribution overlap with resident biological control agents. The objectives of the present study were to use developmental and life table statistics to predict the invasion potential of *G. triguttatus* throughout California in response to expected continued range expansion by *H. vitripennis*. To assess invasion potential, laboratory-derived demographic data (Pilkington and Hoddle, 2007) were used to develop models to predict and map using GIS the number of *G. triguttatus* generations and subsequent net reproductive rates for this parasitoid across a range of temperatures (Pilkington and Hoddle, 2006b).

2. Materials and methods

2.1. Collection of California weather data for use in GIS analyses

Daily maximum and minimum temperatures were collected from 121 weather stations maintained by the California Irrigation Management Information System (CIMIS, http://wwwcimis.water.ca.gov) and 260 weather stations maintained by the Western Regional Climate Center (WRCC, http://www.wrcc.dri.edu/). Weather stations for which data were downloaded are all located in California. Daily maximum and minimum temperatures were averaged over 5–10 years of complete weather data between January 1, 1995 and December 31, 2004.

2.2. Calculation of accumulated degree–days for GIS mapping

Degree–day accumulation for *G. triguttatus* was calculated using a Microsoft Excel spreadsheet application (http://biomet.ucdavis.edu, last accessed February 23, 2005) from temperature data downloaded for each of the 381 accessed weather stations. Daily maximum and minimum temperatures, averaged for each weather station, were used to calculate accumulated degree–days for *G. triguttatus* using the single sine method (UC IPM, 2005). The lower developmental threshold value, calculated from the linear portion of the developmental data (Pilkington and Hoddle, 2007), was 10.4 °C and upper lethal threshold used was 38.8 °C.

2.3. Calculation of the number of G. triguttatus generations by location for GIS mapping

Two measures of the number of *G. triguttatus* generations in a given year were calculated for each weather