DEVELOPING DAY-DEGREE MODELS TO PREDICT SPREAD WITHIN CALIFORNIA OF *GONATOCERUS TRIGUTTATUS* RELEASED FOR GLASSY-WINGED SHARPSHOOTER CONTROL, AND USING DEMOGRAPHIC DATA TO INVESTIGATE PARASITOID SPREAD IN CALIFORNIA

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ABSTRACT

The reproductive and developmental biology of *Gonatocerus triguttatus* Girault, a parasitoid of the glassy-winged sharpshooter (GWSS; *Homalodisca vitripennis*; formerly *H. coagulata*), was determined at five constant temperatures in the laboratory; 15; 20; 25; 30; and 33°C. At 25°C, *G. triguttatus* maintained the highest successful parasitism rates with 25.1% of parasitoid larvae surviving to adulthood and lowest parasitism was observed at 15°C with 7.3% of parasitoid larvae surviving to adulthood. Lifetime fecundity was greatest at 25°C and fell sharply as temperature either increased or decreased around 25°C. Temperature had no effect on sex ratio of parasitoid offspring. Mean adult longevity was inversely related to temperature with a maximum of 20.6 days at 15°C to a minimum of four days at 33°C. Developmental rates increased nonlinearly with increasing temperatures. Developmental rate data was fitted with the modified Logan model for oviposition to adult development times across each of the five experimental temperatures. Optimal, lower, and upper lethal, temperature thresholds for *G. triguttatus* were, 30.7°C, 10.4°C and 38.8°C, respectively. The lower developmental threshold estimated with linear regression was 10.57°C, and is very close to the lower temperature threshold estimated by the modified Logan model. Linear regression of developmental rate across all five experimental temperatures indicated that 204 degree-days were required above the minimum threshold of 10.57°C to complete development. Demographic parameters were calculated and pseudo replicates for intrinsic rate of increase (r_m), net reproductive rates (R_o), generation time (T_c), population doubling time (T_d), and finite rate of increase (□) were generated using the bootstrap method. Mean bootstrap estimates of demographic parameters were compared across temperatures using ANOVA and nonlinear regression.

INTRODUCTION

Gonatocerus triguttatus Girault, (Hymenoptera: Mymaridae) is a solitary endoparasitoid that attacks eggs of sharpshooters in the cicadellid tribe Proconiini. This parasitoid was originally described from specimens reared from an unidentified leafhopper egg mass collected in Trinidad, and has been subsequently reared from glassy-winged sharpshooter (GWSS; *Homalodisca vitripennis*; formerly *H. coagulata*; Hemiptera: Cicadellidae) egg masses collected in Texas and Mexico. This natural enemy has a natural range that includes southeastern U.S.A. and northeastern Mexico where it is associated with GWSS. *Gonatocerus triguttatus* was deliberately imported from Texas U.S.A. and introduced into California U.S.A. in 2002 as part of a classical biological control program against GWSS. Some recoveries from release areas have been made tentatively suggesting *G. triguttatus* may have established perennial populations in California (Pilkington et al., 2005). A thorough understanding and characterization of biological attributes of natural enemies such as degree-day requirements, and intrinsic rates of increase can have multiple practical applications, such as: (1) quantification of the reproductive and developmental biology of candidate natural enemies can assist with predicting potential establishment and population growth of natural enemies introduced into a new area, (2) can aid preliminary evaluation of natural enemies for use potential use in classical biological control, (3) assist with interpretation of natural enemy impact and spread in the field, and (4) provide realistic values for parameters of models investigating incursion risks pertaining to movement of natural enemies into environments beyond those intended for permanent inhabitation. Improved understanding of the basic biology of *G. triguttatus*, a recently released and established natural enemy of GWSS in California, will assist mass-rearing efforts of this parasitoid; optimize timing of inoculative field releases; facilitate better understanding of parasitoid spread and impact on GWSS in various climatic zones in California; and will assist with targeted collecting for biotypes of *G. triguttatus* in the home range of GWSS that may exhibit unique climatic adaptations that current parasitoid populations in California lack.

OBJECTIVES

1. Develop day-degree models for mymarid parasitoids by quantifying the developmental and reproductive biology of *G. triguttatus* at 5 different temperatures (this work has been completed for the principal egg parasitoid of GWSS, *G. ashmeadi*).
2. Use day-degree data from Objective 1 in a Geographic Information Systems approach to predict the geographic range of parasitoids within California and use GIS to map these predictions to known and potential GWSS distributions.

RESULTS

The reproductive and developmental biology of *G. triguttatus* was determined at five constant temperatures in the laboratory; 15; 20; 25; 30; and 33°C. At 25°C, *G. triguttatus* maintained the highest successful parasitism rates with 25.1% of parasitoid larvae surviving to adulthood and lowest parasitism was observed at 15°C with 7.3% of parasitoid larvae surviving to adulthood. Lifetime fecundity was greatest at 25°C and fell sharply as temperature either increased or decreased around 25°C. Temperature had no effect on sex ratio of parasitoid offspring. Mean adult longevity was inversely related to temperature with a maximum of 20.6 days at 15°C to a minimum of four days at 33°C. Developmental rates increased nonlinearly with increasing temperatures. Developmental rate data was fitted with the modified Logan model for oviposition to adult development times across each of the five experimental temperatures. Optimal, lower, and upper lethal, temperature thresholds for *G. triguttatus* were, 30.7°C, 10.4°C and 38.8°C, respectively. The lower developmental threshold estimated with linear regression was 10.57°C, and is very close to the lower temperature threshold estimated by the modified Logan model. Linear regression of developmental rate across all five experimental temperatures indicated that 204 degree-days were required above the minimum threshold of 10.57°C to complete development. Demographic parameters were calculated and pseudo replicates for intrinsic rate of increase (r_m), net reproductive rates (R_o), generation time (T_c), population doubling time (T_d), and finite rate of increase (λ) were generated using the bootstrap method. Mean bootstrap estimates of demographic parameters were compared across temperatures using ANOVA and nonlinear regression (Figure 1).

The number of expected generations of *G. triguttatus* was estimated using life table statistics and degree-day requirements from Objective 1 above. Between zero to 18.9 and zero to 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_o, were estimated in California using a laboratory-derived equation and ranged from zero to approximately 29.4 and analyses indicate that a minimum of seven to 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 day-degree 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* (Figure 2).

CONCLUSIONS

G. triguttatus has been mass released in southern California since 2002, and small localized populations appear to have established, but have failed to become robust, abundant, and widespread (D. Morgan pers. comm. 2006). Two potential reasons may exist for these localized low density populations of *G. triguttatus*: (1) not enough time has elapsed since release and establishment for *G. triguttatus* to have reached its full potential, (2) in the field this parasitoid is an ineffective competitor with self-introduced and omnipresent *G.ashmeadi*. Laboratory studies suggest interspecific competition with *G. ashmeadi* may be severely limiting to *G. triguttatus*, in comparison to *G. ashmeadi*, *G. triguttatus* has reduced longevity, parasitizes fewer GWSS eggs, spends more time resting and grooming, and in some instances devotes little time to defending host patches from competitors. The reduced impact of *G. triguttatus* as a regulating factor of populations of GWSS in southern California may also be influenced by climatic conditions in the invaded areas. Low temperatures over winter appear reduce or prevent oviposition by GWSS for extended periods which results in a shortage of hosts for *G. triguttatus*, and other mymarid parasitoids attacking GWSS. Further, *G. triguttatus* has not been recorded from an alternative host in California, *H. liturat*a, whereas the common *G. ashmeadi* is often associated with this common native sharpshooter. Temperature can have a significant impact on R_o estimates for *G. triguttatus*. The fitted quadratic model for R_o, a measure of a population's growth rate, indicated that at approximately 14.9°C the value of R_o falls below 1.0, indicating that parasitoid population growth will cease and begin to contract. During this 10 year span, the weather station at the University of California, Riverside Agricultural Operations Facility recorded the average daily temperature fall below 14.9°C 127 times or 35% of the year. The ten-year average daily temperature in Riverside falls below 14.9°C in a single, discrete block of 100 days typically over the period November to March. During this three month time span, temperatures fluctuate from a minimum of 3.8°C to a maximum high temperature of 22.89°C. Although temperatures rise above the development threshold required by *G. triguttatus*, calculations indicate that the population would accumulate enough degree-days to complete 2.5 generations in this time. Temperatures may rise enough to prompt sporadic oviposition by parasitoids if host eggs are available but persistent low temperatures over winter will retard parasitoid population growth. Host availability notwithstanding, this suggests populations of *G. triguttatus* in Riverside California would contract markedly over the period November-March each year because of impaired reproductive performance at temperatures below 14.9°C periods for prolonged periods. Consequently, demographic data from studies completed here, coupled with long-term weather data sets for southern California, may explain why populations of *G. triguttatus* are not more common, widespread or have been particularly successful in attacking abundant GWSS egg masses in California.

REFERENCES

Pilkington, L. J. and M. S. Hoddle, 2006. Use of life tables to quantify reproductive and developmental biology of *Gonatocerus triguttatus* (Hymenoptera: Mymaridae), an egg parasitoid of *Homalodisca vitripennis* (Hemiptera: Cicadellidae). Biological Control (submitted).

Pilkington, L.J. and M.S Hoddle. 2006. Reproductive and developmental biology of *Gonatocerus triguttatus* (Hymenoptera: Mymaridae), an egg parasitoid of *Homalodisca vitripennis* (Hemipter
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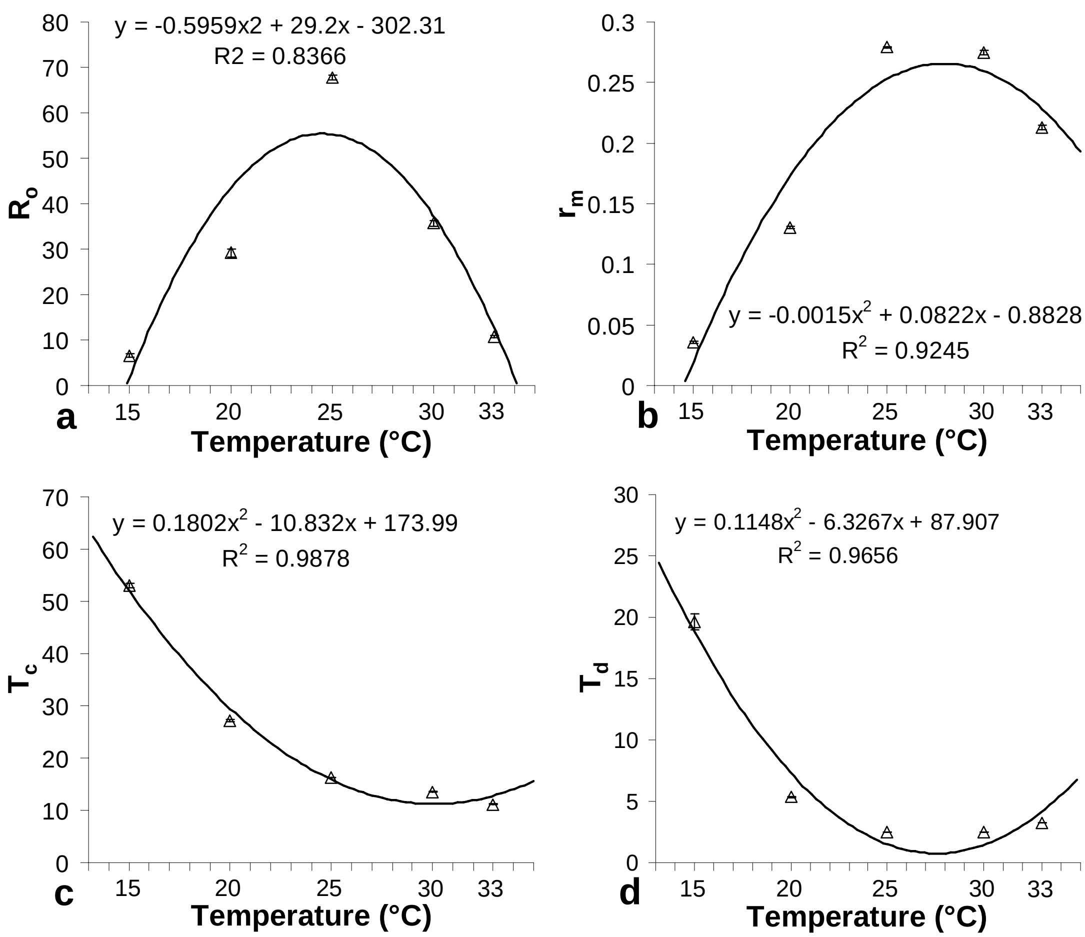

Figure 1. Fitted quadratic lines for life table statistics R_o (a), r_m (b), T_d (c) and T_c (d) for *G. triguttatus* at each of five experimental temperatures.

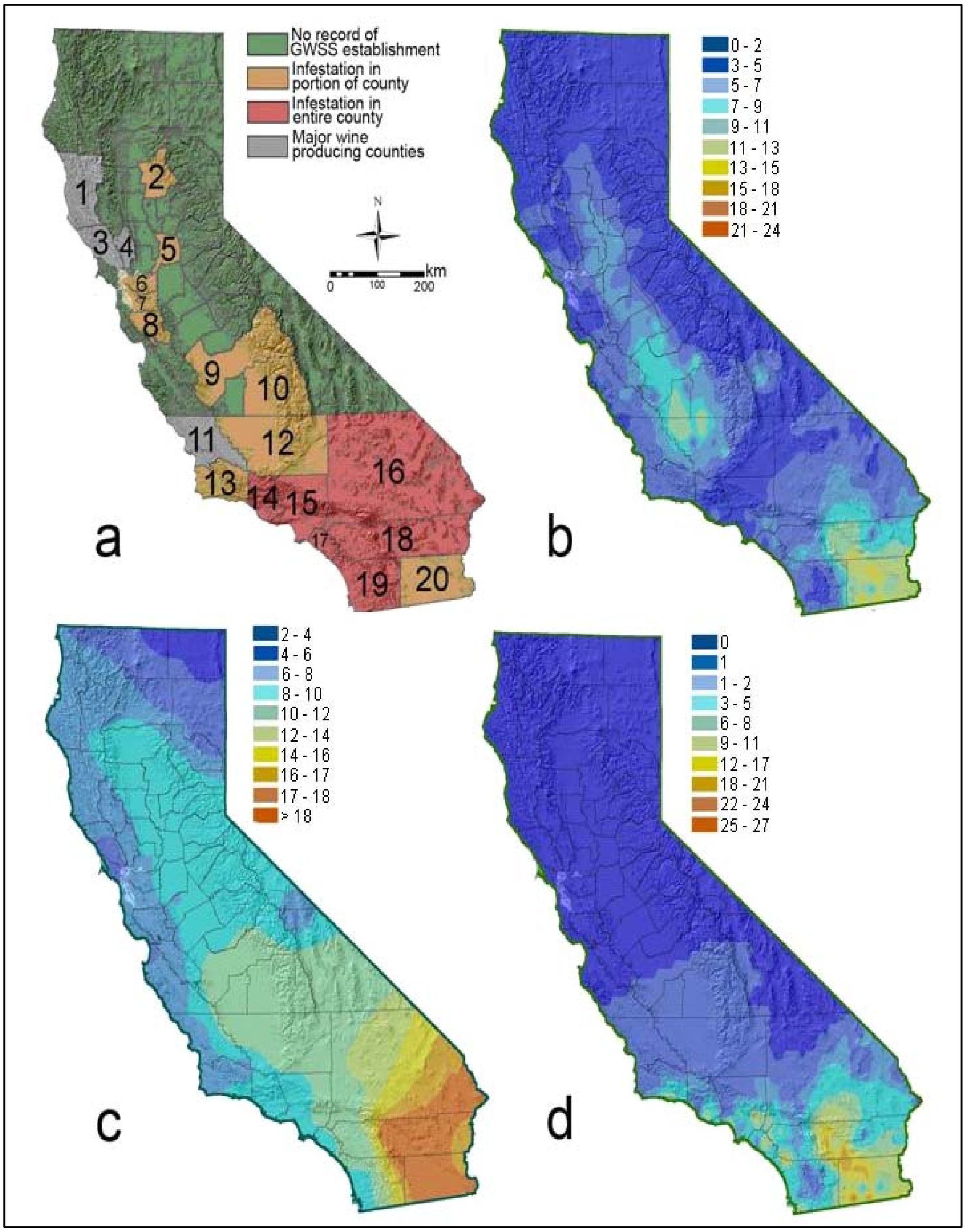

Figure. 2. Geographical information systems mapping of estimated life table statistics for the parasitoid *G. triguttatus* in California, U.S.A.; A) Counties in California and the status of GWSS populations in each area 1. Mendocino 2. Butte 3. Sonoma 4. Napa 5. Sacramento 6. Contra Costa 7. Alameda 8. Santa Clara 9. Fresno 10. Tulare 11. San Luis Obispo 12. Kern 13. Santa Barbara 14. Ventura 15. Los Angeles 16. San Bernardino 17. Orange 18. Riverside 19. San Diego 20. Imperial; B) estimated number of generations populations of *G. triguttatus* may experience in each area calculated by dividing the year's accumulated degree-days by the total degree-days required by *G. triguttatus* for development; C) estimated number of generations that hypothetical populations of *G. triguttatus* may experience in each area calculated by applying historical weather data to the formula for yearly generations, T_{num}, derived from the life table statistic for generation time, T_c. and; D) estimation of the yearly value for net reproductive rate, R_o, derived by applying historical weather data to the ormula for R_o. For Figs. 1b-d the colored legend indicates the value of the particular statistic of interest for an entire year.

NON-TARGET IMPACT OF THE GLASSY-WINGED SHARPSHOOTER PARASITOIDS *GONATOCERUS ASHMEADI* AND *G. FASCIATUS* ON SHARPSHOOTERS NATIVE TO CALIFORNIA, WITH NOTES ON INDIGENOUS PARASITOIDS OF THE BLUE-GREEN SHARPSHOOTER AND THE GREEN SHARPSHOOTER

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ABSTRACT

A rigorous testing strategy involving choice and no-choice test arenas was developed to explore the potential non-target impacts of classical biological control agents. The glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae), biological control program was studied as a model system for analyzing choice and no-choice host preferences for natural enemies and also for performing retrospective non-target impact assessments. *Gonatocerus ashmeadi* Girault and *G. fasciatus* Girault (both Hymenoptera: Mymaridae), egg parasitoids of the exotic GWSS, were tested against three potential non-target sharpshooters indigenous to southern California. Work conducted here showed that the solitary *G. ashmeadi* was able to successfully parasitize eggs (i.e., viable progeny resulted) of smoketree sharpshooter (STSS), *H. liturata* Ball, but not eggs of the blue-green sharpshooter (BGSS), *Graphocephala atropunctata* (Signoret), or the green sharpshooter (GSS), *Draeculacephala minerva* Ball (all Hemiptera: Cicadellidae). *G.ashmeadi* exercises no parasitization preference when presented with a choice of STSS and GWSS eggs simultaneously. The gregarious *G. fasciatus* parasitized eggs of STSS and GSS, but not eggs of the BGSS. BGSS and GSS eggs were collected from the field and reared to catalog their indigenous egg parasitoid fauna. Any parasitoids reared from these eggs were reciprocally exposed to 'clean' lab colony eggs. Two parasitoids, *G. latipennis* Girault and a *Polynema* sp. (Hymenoptera: Mymaridae) were confirmed as parasitoids of BGSS eggs. Three parasitoids, *G. mexicanus* Perkins and two unidentified trichogrammatids were confirmed as parasitoids of GSS eggs.

INTRODUCTION

Examining possible non-target effects of biological control agents is becoming a more common requirement for many biological control programs targeting arthropod pests. Currently, for classical biological control of weeds, the centrifugal method provides a robust theoretical framework for identifying potential natural enemies that could cause harm to non-target plants. However, a rigorous, reliable, and universally applicable testing standard for arthropod biological control with a strong theoretical basis is currently lacking. No-choice and choice testing strategies are a common way to test for possible non-target effects of new biological control organisms. However, these lab studies are often carried out in small testing arenas where the study organism is forced onto the host which may be adequate for determining physiological host range but may seriously overestimate its ecological host range in nature. Under these conditions, efficacious natural enemies may be unnecessarily eliminated from the candidate natural enemy pool as being insufficiently host-specific. To more accurately determine the host range of a natural enemy our research involved the use of rigorous testing strategies utilizing standard Petri dish test arenas, coupled with larger-scale entire plant test arenas in no-choice and choice comparisons. As retrospective studies in ongoing biological control programs can yield valuable information on non-target impacts, we chose the glassy-winged sharpshooter (GWSS) classical biological control program in California as a model for our non-target impact studies. We are examining the possible non-target impacts of the self-introduced and omnipresent *Gonatocerus ashmeadi* and the recently introduced *G. fasciatus*, both egg parasitoids of GWSS, on three sharpshooters native to California, U.S.A.: the smoketree sharpshooter (STSS) *Homalodisca liturata* Ball (Hemiptera: Clypeorrhyncha: Cicadellidae: Cicadellinae: Proconiini) (native congener to GWSS), blue-green sharpshooter (BGSS) *Graphocephala atropunctata* (Signoret), and green sharpshooter (GSS) *Draeculocephala minerva* Ball (the latter two, all Hemiptera: Clypeorrhyncha: Cicadellidae: Cicadellinae: Cicadellini). Our experiments with small-scale Petri dish studies and larger-scale full plant studies were supplemented with deployment of sentinel plants bearing eggs from laboratory colonies of BGSS or GSS and habitat surveys to determine the invasiveness of GWSS parasitoids into habitats occupied by BGSS or GSS.

OBJECTIVES

1. Classify the native egg-parasitoid fauna in California associated with sharpshooters native to California, primarily the STSS, BGSS, and GSS.
2. Assess the possible non-target impacts of *G. ashmeadi* Girault and *G. fasciatus* (both Hymenoptera: Mymaridae), parasitoids being used for the classical biological control of GWSS, on the above mentioned native sharpshooters.