Honeydew Moth

***Cryptoblabes gnidiella* (Lepidoptera: Pyralidae)**

Phenology/Degree-Day and Climate Suitability Model Analysis for USPEST.ORG
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Summary

A phenology model and temperature-based climate suitability model for the Honeydew moth (also known as the Christmas berry webworm), *Cryptoblabes gnidiella* (CGN), was developed using data from available literature and through modeling in CLIMEX v. 4 (Hearne Scientific Software, Melbourne, Australia) and DDRP (Degree-Days, Risk, and Pest event mapping; under development for uspest.org).

Introduction

Cryptoblabes gnidiella (Lepidoptera: Pyralidae) is a polyphagous pest of several dozen economically important crop plant species, including avocado, citrus, corn, cotton, grape, loquat, and pomegranate (Yehuda et al. 1991, Molet 2013). The species is native to and ubiquitous in the Mediterranean Basin, and has been introduced to many regions with a similar (Mediterranean) climate, particularly in cultivated areas (Silva and Mexia 1999, Dawidowicz and Rozwałka 2016). *Cryptoblabes gnidiella* usually attacks fruit that has been injured by other insects including aphids and pseudococcids (e.g., *Planococcus citri*), which produce honeydew that adults females and larvae feed on (Avidov and Gothilf 1960, Silva and Mexia 1999, Ioriatti et al. 2012). However, they will also infest healthy plants (Ioriatti et al. 2012). If introduced into the US, this species would likely occur wherever major host plants and pseudococcids are found (Molet 2013). The species may overwinter as either larvae (instars 1–5) or pupae or a combination of both, and it lacks a true winter diapause (Avidov and Gothilf 1960, Yehuda et al. 1991, Vidart et al. 2013, Lucchi et al. 2019).

Phenology modeling

Objective.—We aimed to estimate rates and degree days of development in *C. gnidiella* by solving for a best overall common threshold and corresponding developmental degree days (DDs) using data from available literature. While the DDRP platform allows for different thresholds for each stage, the site-based phenology modeling tools at uspest.org require common thresholds. Building the model for both platforms keeps models simpler and able to be cross-compared. For example, a prediction mapped via DDRP can be confirmed using any of the degree-day calculators at uspest.org, such as https://uspest.org/dd/model_app, which is mobile-device capable and can be readily run in the field.

Temperature developmental thresholds.—This is a summary of the spreadsheet analysis that is available online (https://uspest.org/wea/cryptoblabes_gnidiella_model.pdf). A summary of temperature developmental thresholds and durations is reported in Table 1. We re-interpreted temperature vs.

development rate data from a lab development study of immature stages of *C. gnidiella* that were raised on garlic at eight temperatures (Salama 2008). We used the x-intercept method with forcing through the x-intercept to estimate a common lower developmental threshold, which resulted in a lower temperature threshold (LDT) of 12.22°C. Egg data were not included in this analysis because durations (in days) did not have a realistic relationship with temperature.

Our common lower threshold is in line with two previous studies that estimated lower thresholds for some or all life stages of *C. gnidiella*. Ringenberg et al. (2005) estimated a lower threshold of 12.26°C for the entire life cycle based on laboratory collected data, and they reported a lower threshold of 11.97°C for eggs, 13.4°C for larvae, 10.36°C for pupae, and 12.26°C for adults. Unfortunately, this study did not report the temperature-development data (only the thresholds), which prevented re-analysis. Avidov and Gothilf (1960) estimated a low threshold of 12.7°C for the combined pupa-larva stage.

We used an upper developmental threshold (UDT) of 35°C. Salama (2008) reported an increase in deformed and failed adult emergences at temperatures ≥35°C, as well as a large reduction in the number of eggs hatching.

Development in degree days.—At a lower threshold of 12.22°C, the pupa and larva stages (pre-pupa was grouped with larva) were 290 and 145 DDs, respectively. We relied on other sources of data to estimate DD requirements for the egg stage (Avidov and Gothilf 1960, Ringenberg et al. 2005, Kareim et al. 2018) and the adult stage (Ringenberg et al. 2005, Öztürk 2018). From these sources, we derived a compromise value of 50 and 45 DDCs for the egg and adult stage, respectively.

Emergence parameters.—We assumed seven cohorts emerged in the spring according to a normal distribution, with an average (peak) emergence of 191 DDCs (range = 123–259 DDCs; Table 1). These values were chosen based on monitoring studies of *C. gnidiella* in Tuscany, Italy (Lucchi et al. 2019) and in Tarsus, Turkey (Öztürk 2018). Both studies detected emergence of the OW generation adults at *ca.* 220 DDCs, which was followed by a peak in adult density between *ca.*149 and 233 DDCs. We averaged the values of the two studies to derive first emergence and peak emergence. We assumed that post-peak emergence occurred over the same amount of time (*ca.* 68 DDCs) as pre-peak emergence, based on the shape of the distribution in OW adult density depicted in Fig. 1 of Öztürk (2018).

Climate suitability modeling

Objective.—The aim of these analyses was to determine which climate stress parameters in DDRP (chill stress temperature threshold, heat stress threshold, and chill and heat stress unit limits) resulted in map outputs most similar to the CLIMEX model generated for this study. Unfortunately, it does not appear that any climatic suitability studies for *C. gnidiella* have been published, which limits our ability to corroborate either of our two climate suitability models (i.e., the CLIMEX and DDRP models). DDRP models used a PRISM data set of daily temperature data from 1960 to 1990, which matches the gridded weather data interval used for the CLIMEX analysis. A summary of DDRP and CLIMEX parameters used for climate suitability modeling is reported in Table 1.

CLIMEX climate suitability model

Methods.—We generated a CLIMEX model for *C. gnidiella* in its native and established range (Fig. 1). We obtained 129 locality records from GBIF.org (accessed 12 August 2019), and 60 records from the literature. Localities that were on islands where CLIMEX data were missing were removed, resulting in a total of 116 records. We then adjusted CLIMEX parameters to ensure that the majority of these locality records fell within areas with relatively high climatic suitability (as measured by the ecoclimatic index).

We applied a lower developmental temperature threshold (DV0) of 12.2°C based on our estimations for the phenology model, as described above. Using a slightly lower values of 12°C over-predicted suitability in England, where the species is frequently imported but has not permanently established (at least outdoors)(https://species.nbnatlas.org/species/NHMSYS0000502033). The lower (DV1) and upper (DV3) optimal temperature was set 20C and 31°C, respectively, because Salama (2008) reported that fewer eggs hatched and a greater proportion of deformed adults emerged when temperatures dropped below 20°C or increased above 30°C. As with our phenology model, the upper developmental threshold (DV4) was set to 35°C.

The cold stress threshold and heat stress threshold were set to 12°C and 35°C, respectively. Salama (2008) reported a large increase in deformed and failed adult emergences at 15°C (31% deformed and 38% failed) and at 35°C (27% deformed and 35% failed), and the number of eggs hatching declined below 20°C and above 30°C (Salama 2008). No eggs hatched and all adult emergences failed at 10°C and 40°C, which suggests that the lower lethal temperature falls between 15°C and 10°C, and the upper lethal temperature falls between 35°C and 40°C. In CLIMEX, we tested cold stress thresholds values as low as 10°C; however, this resulted in EI > 10 (i.e., low suitability) through many parts of France, where the species is not known to be established. The literature (Lucchi et al. 2019) and our locality records (Fig. 1) both indicate that the species is established only along the Mediterranean coast of France.

We ran an irrigation scenario using the top-up irrigation option with a reasonable rate of 2.5 mm day^{1} (Kriticos et al. 2015) because the model was under-predicting suitability for *C. gnidiella* in hot, arid regions. For example, CLIMEX predicted low suitability along coastal areas of North Africa including in Egypt; however, the species is common and abundant there due to irrigation (e.g., Egypt gets 97% of their agriculture water supply from the Nile River). A rate of 2.5 mm day^{-1} is likely conservative, as research from the University of Arizona has found that mature citrus trees use about 60 inches of water per year (Wright 2000), which translates to 4 mm day^{-1}. Nonetheless, the application of the irrigation scenario resulted in more realistic estimates of suitability for *C. gnidiella*.

Results.—In the native and established range, 21% of locality records had EI values between *ca.* 20 to 30 (Fig. 1), which suggests that areas with EI > 20 are climatically suitability for *C. gnidiella*. Suitable conditions (EI > 20) were predicted for 94% of the locality records (97/103), indicating that the CLIMEX model adequately predicted the species' known distribution. Additionally, the model correctly predicted suitable conditions in countries where the species has been documented but precise locality records do not exist, including in Africa (e.g., South Africa, Nigeria, Sierra Leone, Liberia, Democratic Republic of Congo, and Morocco) and Asia (e.g., Pakistan, Lebanon, and Malysia) (Molet 2013, CABI 2019).

The absence of suitable conditions for *C. gnidiella* in northern Europe is consistent with a lack of evidence for established populations in this region. The species is unable to survive in cooler temperature in areas where it is sometimes imported with produce, including the Netherlands, Scandinavian countries (Denmark, Finland, Norway and Sweden) and the United Kingdom (Carter

1984, Dawidowicz and Rozwałka 2016). In England, the species is frequently imported but has not permanently established (https://species.nbnatlas.org/species/NHMSYS0000502033). We could not find any supplemental information regarding the status of the species in Belgium and northern France, which suggests that some GBIF records from these areas were not collected from established populations. Dawidowicz and Rozwalka (2016) documented *C. gnidiella* in Poland but concluded that it would not establish there or in Eastern European country due to the cold climate.

DDRP climate suitability model

Methods.—Based on the CLIMEX model for *C. gnidiella*, we assumed that areas in CONUS with EI > 20 are highly suitable, areas with 20 > EI > 0 have low suitability, and areas with EI = 0 are unsuitable (Fig. 2). We used these definitions as a basis for defining chill and heat stress limits (Figs. 3 and 4): areas under moderate stress exclusion in areas have low suitability according to CLIMEX, and areas under severe stress exclusion have EI = 0. We applied a lower chill stress threshold in DDRP (8°C vs. 12°C in CLIMEX) to match the CLIMEX model; however, we used the same heat stress threshold (35°C).

Results.—DDRP's climate suitability model predictions were very consistent with CLIMEX in the eastern half of CONUS (Fig. 5). However, DDRP predicted higher suitability in California (particularly in the Central Valley) compared to CLIMEX, and it predicted only moderate stress exclusion in certain coastal areas of Oregon and Washington, whereas CLIMEX predicted unsuitable conditions there.

Suggested applications

The DDRP model may be run to test where *C. gnidiella* may become established and reproduce in CONUS under past, current and future climate conditions, and to estimate the dates when specific pest events will occur. For example, one can estimate the date of adult flight for one or more generations to guide APHIS supported Collaborative Agricultural Pest Survey (CAPS) programs. We provide two example maps using 2012 PRISM data (the hottest year on record for CONUS) showing (a) the date of first egg laying by females with severe climate stress exclusions (Fig. 6), and (b) potential voltinism (number of generations; Fig 7).

Improvements needed

The development of *C. gnidiella* is influenced by diet, which suggests that incorporating diet factors in the model would improve estimation of the length of stage durations, although this is currently beyond the scope of DDRP. For example, Avidov and Gothilf (1960) found that the development of larvae was 6-8 days shorter on grapes than grapefruit, and Ringenberg et al. (2005) found variation in the duration of the entire life cycle when insects were fed different artificial diets. Additional sensitivity analyses should be conducted to identify optimal parameter values for the CLIMEX model for *C. gnidiella*. Additionally, data on the impacts of moisture on development and survival are needed to inform moisture stress parameters in CLIMEX.

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Table 1. DDRP parameter values for *Cryptoblabes gnidiella*.

Parameter	Code	Value
Lower developmental thresholds (°C)		
Egg	eggLDT	12.22
Larvae	larvaeLDT	12.22
Pupae	pupaeLDT	12.22
Adult	adultLDT	12.22
Upper developmental thresholds (°C)		
Egg	eggUDT	35.0
Larvae	larvaeUDT	35.0
Pupae	pupaeUDT	35.0
Adult	adultUDT	35.0
Stage durations (°C degree-days)		
Egg	eggDD	50
Larvae	larvaeDD	290
Pupae	pupDD	145
Adult	adultDD	45
Pest events (°C degree-days)		
Egg event	eggEventDD	45
Larva event	larvaeEventDD	145
Pupa event	pupaeEventDD	145
Adult event	adultEventDD	38
Chill stress		
Chill stress temperature threshold (°C)	chillstress_threshold	8
Chill degree-day (°C) limit when most individuals die	chillstress_units_max1	1100
Chill degree-day (°C) limit when all individuals die	chillstress_units_max2	1950
Heat stress		
Heat stress temperature threshold (°C)	heatstress_threshold	35
Heat stress degree-day (°C) limit when most individuals die	heatstress_units_max1	200
Heat stress degree-day (°C) limit when all individuals die	heatstress_units_max2	600
Cohorts		
Degree-days (°C) to emergence (average)	distro_mean	191
Degree-days (°C) to emergence (variation)	distro_var	600
Minimum degree-days (°C) to emergence	xdist1	123
Maximum degree-days (°C) to emergence	xdist2	259
Shape of the distribution	distro_shape	normal

Table 2. Parameter values used to produce a CLIMEX model for *Cryptoblabes gnidiella*.

CLIMEX parameter	Code	Value
Temperature		
Lower temperature threshold (°C)	DV0	12.2
Lower optimal temperature (°C)	DV1	20
Upper optimal temperature (°C)	DV2	31
Upper temperature threshold (°C)	DV3	35
Degree-days per generation (°C days)	PDD	531
Moisture		
Lower soil moisture threshold	SM0	0.10
Lower optimal soil moisture	SM1	0.3
Upper optimal soil moisture	SM2	1
Upper soil moisture threshold	SM3	1.7
Cold stress		
Cold stress temperature threshold (°C)	TTCS	11
Cold stress temperature rate (week^{-1})	THCS	−0.00015
Heat stress		
Heat stress temperature threshold (°C)	TTHS	35
Heat stress temperature rate (week^{-1})	THHS	0.0005
Dry stress		
Dry stress threshold	SMDS	0.1
Dry stress rate (week^{-1})	HDS	−0.0001
Wet stress		
Wet stress threshold	SMWS	1.7
Wet stress rate (week^{-1})	HWS	0.002

Fig. 1. Predictions of climatic suitability for *Cryptoblabes gnidiella* (CGN) as estimated by the Ecoclimatic Index (EI) in CLIMEX. Cyan circles depict locality records for the species that were derived from the literature and GBIF. Cyan "X's" in Europe represent records for which the species was transient (i.e., it is not known to be established; Great Britain and Poland), or where there is no evidence that is has established.

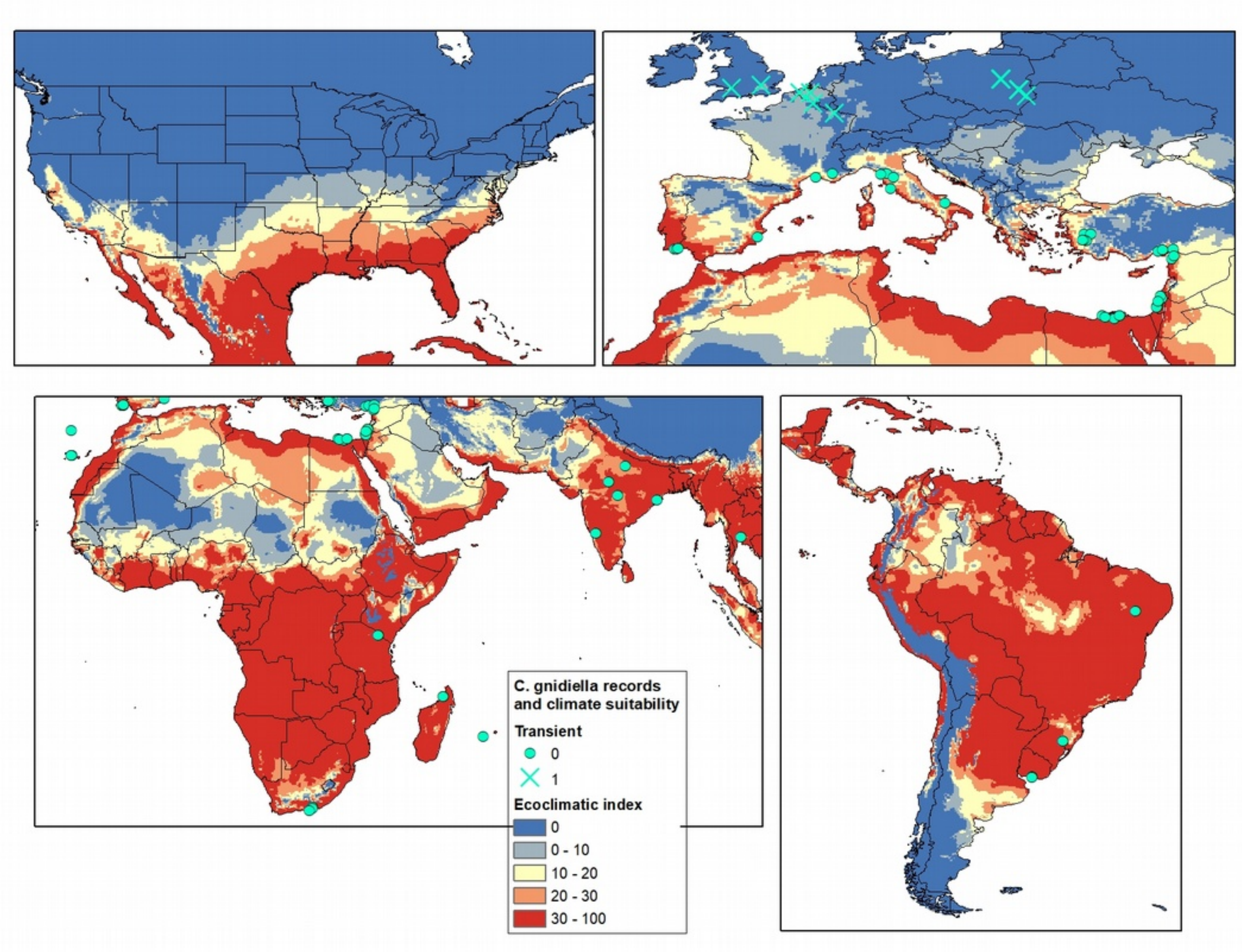

Fig. 2. Predictions of climatic suitability for *Cryptoblabes gnidiella* (CGN) in CONUS as estimated by the Ecoclimatic Index (EI) in CLIMEX. We defined areas with EI > 20 as highly suitable, areas with 10 < EI < 20 as having low suitability, and areas with EI < 10 as unsuitable. [this figure may not be necessary]

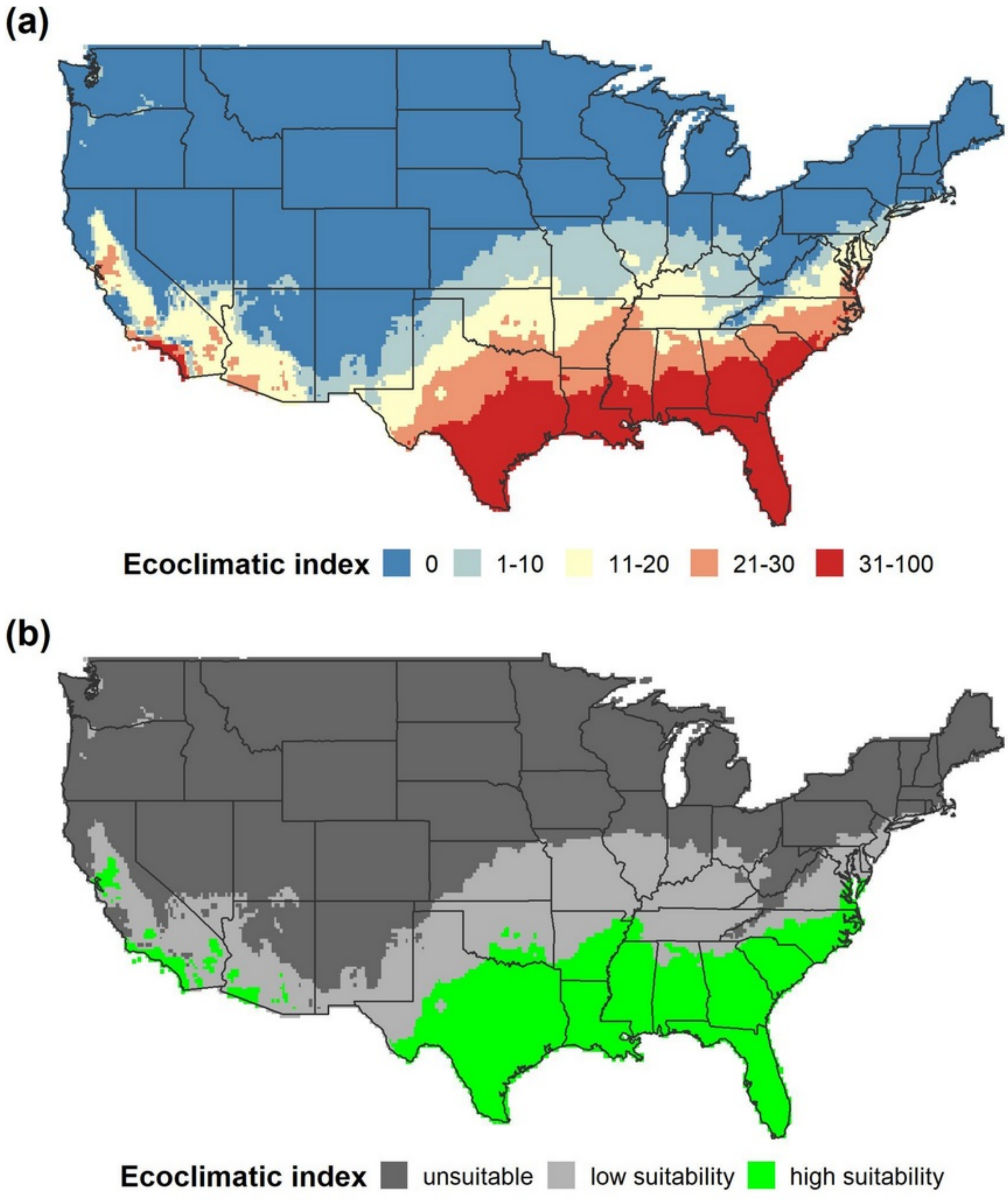

Fig. 3. Maps of cold/chill stress units for *Cryptoblabes gnidiella* (CGN) produced by (a) CLIMEX (cold stress temperature threshold, TTCS = −1ºC) and (b) DDRP (chill stress temperature threshold = −1ºC). DDRP chill stress units have been scaled from 0 to 100 to match the scale used by CLIMEX. Reference climate data for DDRP were from 1960−1990 Normals (matched to available CLIMEX data). The pink and black lines in (b) depict the chill stress unit limits 1 and 2 (1100 and 1950 CSUs, respectively; Table 1).

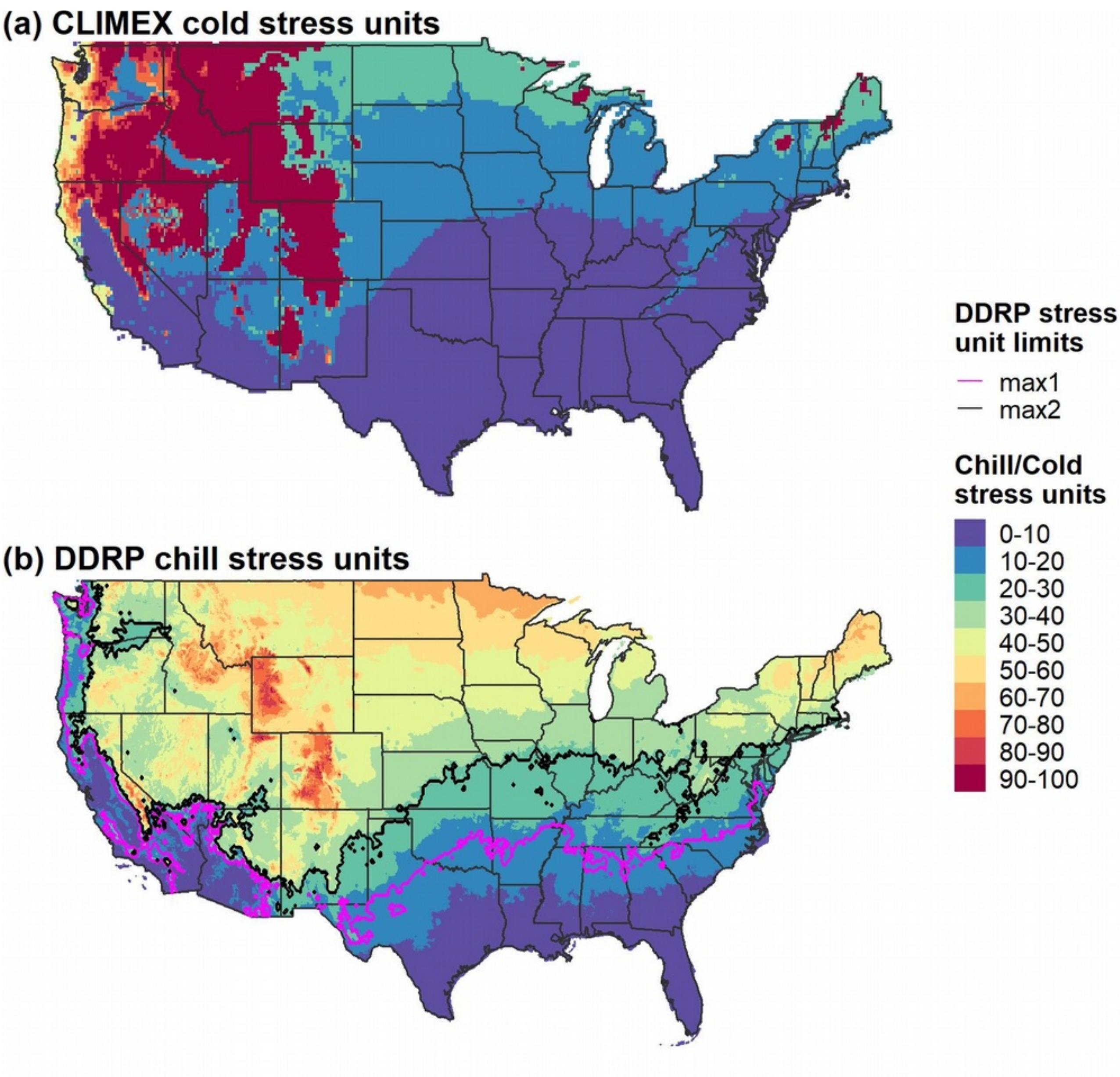

Fig. 4. Maps of heat stress units for *Cryptoblabes gnidiella* (CGN) produced by (a) CLIMEX (heat stress temperature threshold, TTHS = 40ºC) and (b) DDRP (heat stress temperature threshold = 40ºC). DDRP heat stress units have been scaled from 0 to 100 to match the scale used by CLIMEX. Reference climate data for DDRP were from 1960–1990 Normals (matched to available CLIMEX data). The pink and black lines in (b) depict the heat stress unit limits 1 and 2 (75 and 150 CSUs, respectively; Table 1).

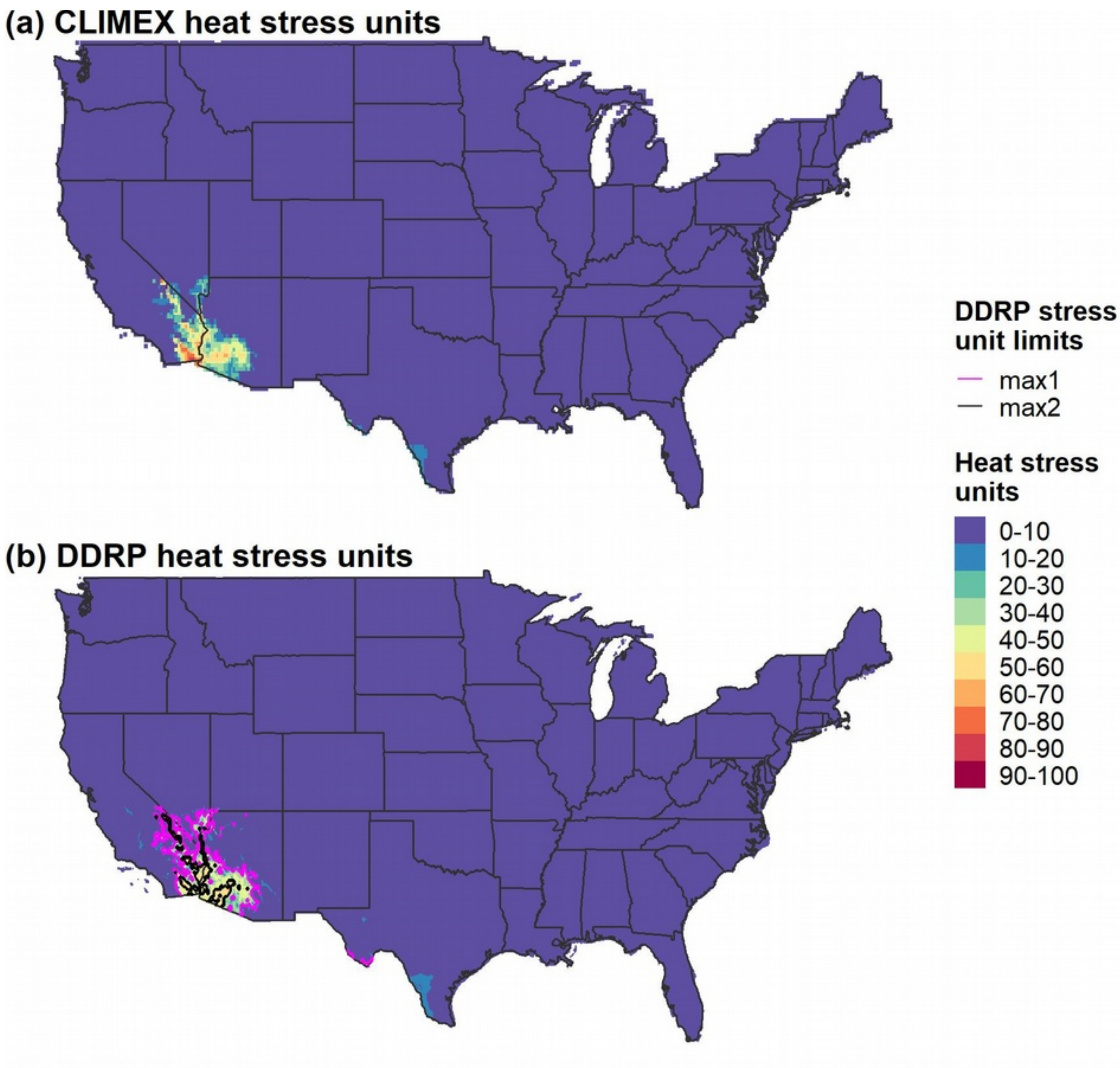

Fig. 5. Climate suitability models for *Cryptoblabes gnidiella* (CGN) in CONUS produced by (a) CLIMEX and (b) DDRP. DDRP measures exclusion status of the species based on chill and heat stress units (all stress exclusion). CLIMEX applied a cold stress threshold of 11ºC while DDRP applied a chill stress threshold of 9ºC. Both models applied a heat stress threshold of 35ºC. Reference climate data for DDRP were from 1960–1990 Normals (matched to available CLIMEX data).

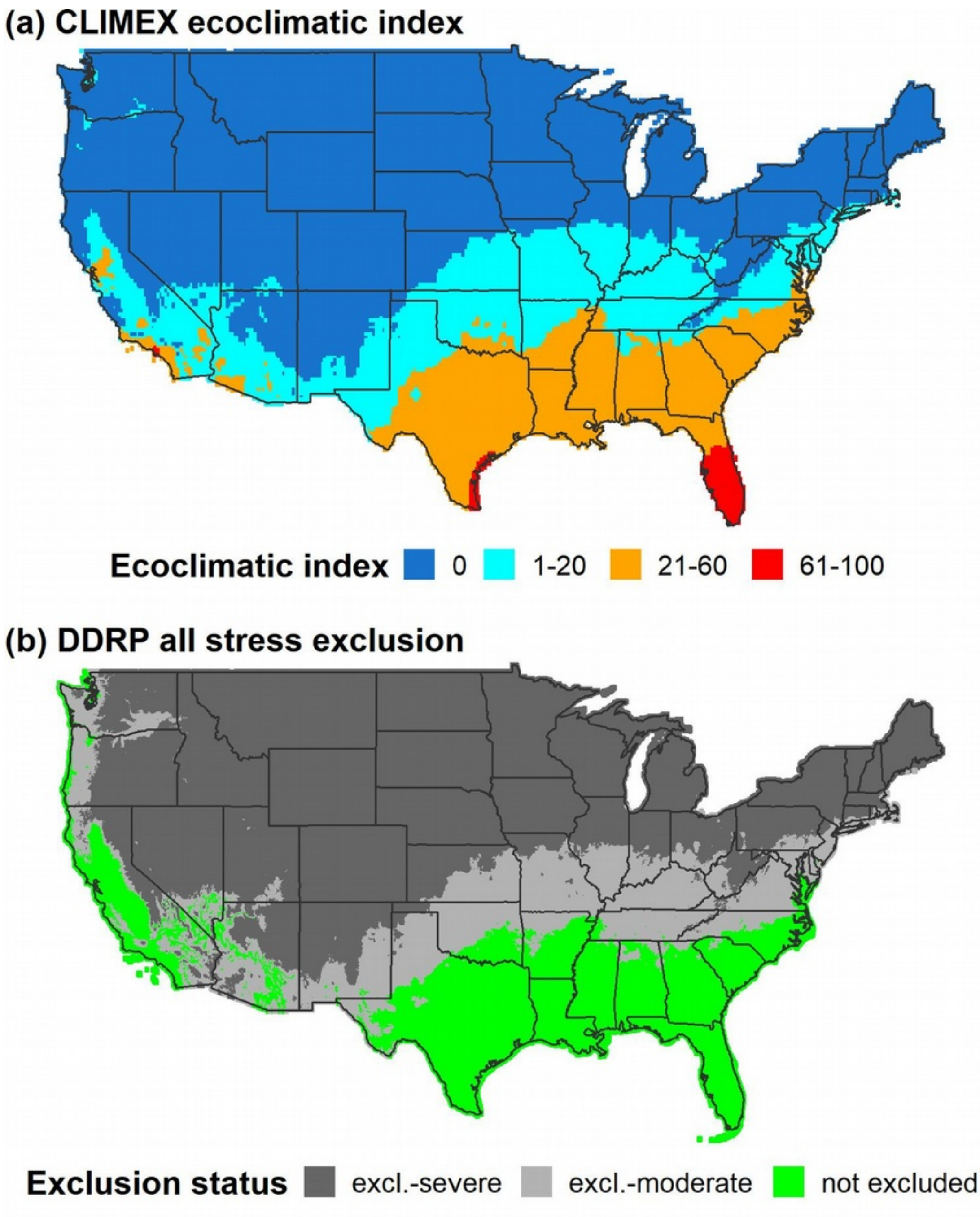

Fig. 6. Map depicting the date of first egg laying by females of the overwintering generation with severe climate stress exclusion for *Cryptoblabes gnidiella* (CGN) for 2012 (based on chill and heat stress units) produced by DDRP.

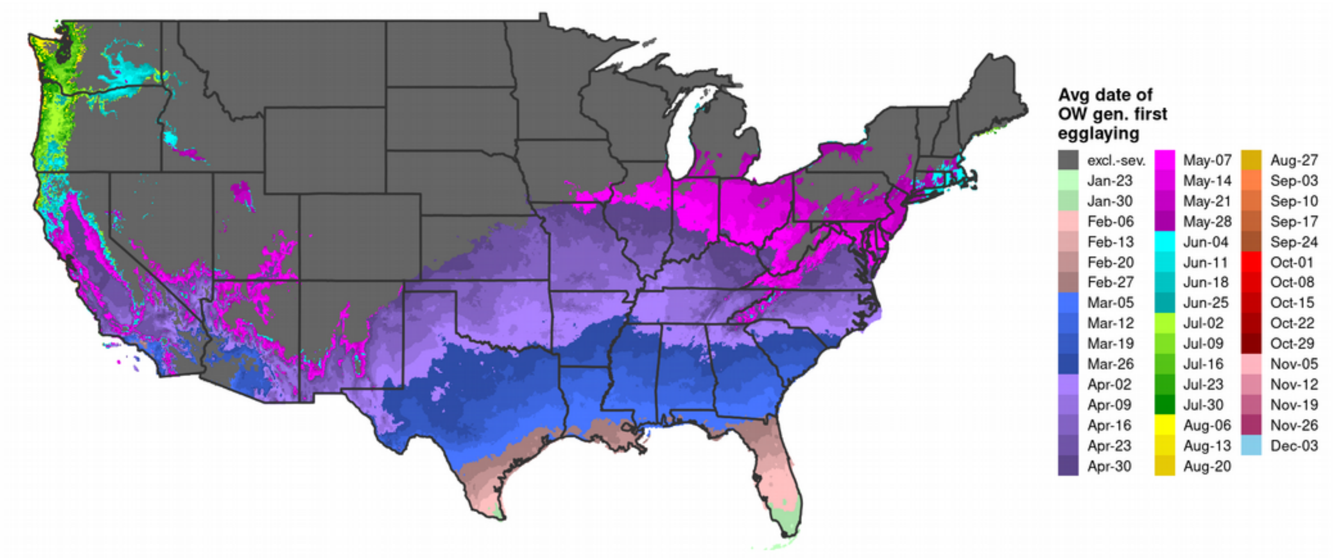

Fig. 7. Map showing the voltinism (number of generations) of *Cryptoblabes gnidiella* (CGN) with severe climate stress exclusion (based on chill and heat stress units) for 2012 produced by DDRP.