Sunn Pest

Eurygaster integriceps (Hemiptera: Scutelleridae)

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 Sunn pest (SUNP), *Eurygaster integriceps* (Puton), was developed using data from available literature and through modeling in CLIMEX v. 4 (Hearne Scientific Software, Melbourne, Australia; Kriticos et al. 2016) and DDRP (Degree-Days, Risk, and Pest event mapping; under development for uspest.org; Barker et al. 2020).

Introduction

Eurygaster integriceps is a major pest of wheat, barley, and oats in the cereal-growing regions of West and Central Asia, Eastern Europe, and North Africa (Critchley 1998, Davari and Parker 2018, Mackesy and Moylett 2018). It is the most serious pest of wheat in West Asia, causing up to 100% crop loss in the absence of control measures and costing over $42 million to manage (Davari and Parker 2018). Nymph and adult stages both cause high damage to all vegetative hosts by feeding sap on stems, spikes, and leaves. The insect is active for only *ca.* 2.5–3 months of the year, spending the rest of the year in an almost completely inactive state as an adult in aestivation during the hot, dry months of late summer or in hibernation during the winter (Brown 1962, Davari and Parker 2018). In spring, when temperatures reach *ca.* 10 to 14°C depending on the year and location, adults emerge and migrate to cereal fields to feed and reproduce. Five nymphal instars develop in the fields, and new-generation adults disperse to overwintering sites. In most of its range, adults migrate *ca.* 10–20 km to mountains around cereal fields to diapause under bushes and litter after grain harvesting in June-July, but insects will overwinter in the vicinity of cereal fields in northern latitudes (Brown 1962, Davari and Parker 2018).

Phenology model

Objective.—We estimated rates and developmental degree-days (DDs) for *E. integriceps* by solving for a best overall common threshold and corresponding developmental 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 DD 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.

Developmental parameters—This is a summary of the spreadsheet analysis that is available online at https://uspest.org/wea/Eurygaster_integriceps_model.pdf (Barker and Coop 2020). A summary of phenology model parameters is reported in Table 1. Only a handful of readily accessible studies (i.e., written in English) have quantified development of *E. integriceps* at multiple temperatures (Kivan 2008, Iranipour et al. 2010), although one Russian study reported a graph depicting a temperature-dependent development curve of the egg stage (Shumakov and Vingradova 1958). The remaining studies raised insects at one or two temperatures and recorded development durations (Şimşek and Yılmaz 1992, Kafil et al. 2013, Gözüaçik et al. 2016).

We solved for a lower threshold of 12.22°C (54°F) for all life stages. This value is in line with a lab-derived egg lower thresholds of 11.7°C, 11.5–12.5°C, and 12.4°C estimated by Kivan (2008), Gözüaçik et al. (2016), and Shumakov and Vingradova (1958), respectively. Additionally, several field studies found that adults emerged in the spring to feed and mate when average daily temperatures reached *ca.* 11.5–12.5°C (Shumakov and Vingradova 1958, Tafaghodinia 2006, Mackesy and Moylett 2018), although emergence at higher temperatures (up to 14–15°C) have been documented as well (Critchley 1998). Egg, larval, pupal, egg-to-adult and pre-oviposition DD requirements calculated using a 12.22°C threshold were 91, 410, 94, and 111 DDs, respectively. We set up DDRP to halt development after the completion of the first generation pupal stage because *E. integriceps* is univoltine and must complete an obligatory diapause as a pre-reproductive adult. We set the upper developmental threshold to 36°C because field observations made by Pekedel'skii (1947) and Makhotin (1947) indicate that insects seek shade or shelter when temperatures approach the high 30°C's, which suggests that these temperatures are unsuitable for development.

Emergence parameters.— Sunn pest overwinters outside grain fields and has been reported to arrive once daily maximum temperatures regularly reach 20°C and daily average temperatures reach 12°C (Shumakov and Vingradova 1958, Tafaghodinia and Majdabadi 2006, Gözüaçik et al. 2016). We performed a DD analysis of when these temperatures tend to occur across five locations and three years in U.S. regions where *E. integriceps* is likely to survive. Reports of first egg-laying in several regions of Turkey (Gözüaçik et al. 2016) were used in another DD analysis to estimate DD requirements for the arrival of overwintered adults. Both analyses converged on *ca.* 100 DDC (lower threshold = 12.22°C, single sine calculation method) for first arrival and egg-laying in fields (model spreadsheet Appendix 1). The peak and end of arrival and oviposition are less well known, but reports of oviposition lasting 39 or more days (Shumakov and Vingradova 1958, Iranipour et al. 2011) and several reports of adult longevity (Iranipour et al. 2010, Abdul-Bassit et al. 2007) were used to develop the peak and end of spring adult activity as 210 and 350 DDC, respectively.

Climate suitability model

Objective.—We parameterized a climate suitability model for *E. integriceps* in CLIMEX and DDRP. This involved fitting a CLIMEX model for the species in Eurasia and using model predictions for CONUS to help parameterize the DDRP model. DDRP models used a PRISM data set of daily temperature data averaged over 1961−1990, which matches the gridded weather data interval used in CLIMEX.

CLIMEX climate suitability model

We modified a previously published CLIMEX model for *E. integriceps* (Aljaryian et al. 2016) by adjusting certain parameter values in accordance with published research on the species. Parameter values were calibrated by fitting the model to 257 locality records obtained from GBIF.org (11 December 2019, GBIF Occurrence Download https://doi.org/10.15468/dl.m9kupg) and the literature (Fig. 1). A summary of CLIMEX parameters used for climate suitability modeling is reported in Table 2.

We applied a cold stress threshold of −30ºC because well-fed insects may resist frosts of *ca.* −30ºC, and mortality after these frost events did not exceed 20% of the population (Radjabi 1994). We applied a heat stress threshold of 40ºC because Makhotin (1947) reported "pathologic activity" between 37−48°C, and Pekedel'skii (1947) reported that soil surface temperatures >40ºC were destructive to the insect.

In CLIMEX, a minimum amount of thermal accumulation during the growing season (PDD) influences population growth and therefore the ability for a species to persist at a location. Typically PDD denotes the number of DDs above the lower threshold that are needed to complete a generation. However, using a PDD of 990 (the estimated generation time) underpredicted the northern boundary of the distribution of *E. integriceps*. Instead, we set PDD to 784 DDC, which corresponds to the sum of the estimated minimum time to spring adult emergence (100DD) and the duration of all immature stages (80 + 410 + 194 DDC). Thus, we assume that the species may persist at a location if it can reach the pre-reproductive adult stage when it undergoes an obligate diapause.

Estimates of climate suitability generated by CLIMEX for Eurasia aligned well with recorded presences and absences of *E. integriceps* (Fig. 1). The majority of locality records [93% (232/249)] fell within areas that had an ecoclimatic index (EI) greater than 20, which indicates that climatic suitability is being predicted at most localities where the species has been documented (eight localities along coastlines had missing values due to the coarse resolution of CLIMEX data). The northern boundary of its distribution in Eurasia occurred at *ca.* 55º N, as documented by previous research (Syromyatnikov et al. 2017). A lack of sufficient DD accumulation above this latitude, rather than cold stress (Fig. 2), appears to be responsible for limiting its distribution. Suitable conditions (EI > 20) were predicted at all but a single locality in the hottest parts of the distribution (Figs. 1 and 2).

In CONUS, *E. integriceps* was not excluded from any areas due to cold or heat stress, but unsuitable conditions (EI = 0) were predicted in mountainous and higher latitude areas of the West due to insufficient DD accumulation (Fig. 1). However, climatic suitability was high (EI > 30) throughout all wheat growing regions. Heat stress slightly lowered suitability in the hottest portions of CONUS, which occur in southern California and Arizona (mostly in and around Death Valley).

DDRP climate suitability model

A summary of DDRP parameters used for climate suitability modeling is reported in Table 1. We applied the same cold and heat stress thresholds in DDRP as CLIMEX (−30°C and 40°C, respectively). CLIMEX predicted that temperature stress would not exclude the species from anywhere in CONUS, which hindered calibrating stress limits in DDRP. However, we set heat stress limits so that the species may potentially be excluded by heat stress in the same general areas where CLIMEX predicted that heat stress lowered suitability. Thus, DDRP predicted that heat stress may potentially exclude the species only from a very small area in the vicinity of Death Valley. Similar to CLIMEX, DDRP predicted that the species would likely not persist in parts of the West owing to insufficient DD accumulation (Fig. 4).

Suggested applications

The DDRP model may be run to test where *E. integriceps* may become established and reproduce in CONUS under current and future weather conditions, and to estimate the dates when specific pest events will occur. For example, one can estimate the date of adult emergence in the spring 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) first flight of overwintered adults and (b) emergence of 1st generation adults (Fig. 4).

Improvements needed

Quantitative data on the thermal tolerances of *E. integriceps* are needed to define more accurate heat and cold thresholds and limits in DDRP and CLIMEX. Additionally, data on the impacts of moisture on development and survival are needed to inform dry and wet stress parameters in CLIMEX. Relative humidity may impact survival and emergence times of overwintering adults, and heavy rainfall can affect its post-diapause activity (Brown 1962). Oviposition may continue for entire month, resulting in overlap of various nymphal stages within a season (Iranipour et al. 2011), so a model that accounted for this variability may produce more accurate estimates of pest events for larvae and 1st generation adults.

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Tables and Figures

Table 1. DDRP parameter values for *Eurygaster integriceps* (SUNP).

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	36.0
Larvae	larvaeUDT	36.0
Pupae	pupaeUDT	36.0
Adult	adultUDT	36.0
Stage durations (°C degree-days)		
Egg	eggDD	80
Larvae	larvaeDD	410
Pupae	pupDD	194
Adult	adultDD	306
Pest events (°C degree-days)		
Egg event	eggEventDD	91
Larva event	larvaeEventDD	205
Pupa event	pupaeEventDD	10
Adult event	adultEventDD	112
Cold stress		
Cold stress temperature threshold (°C)	coldstress_threshold	-30
Cold degree-day (°C) limit when most individuals die	coldstress_units_max1	10
Cold degree-day (°C) limit when all individuals die	coldstress_units_max2	25
Heat stress		
Heat stress temperature threshold (°C)	heatstress_threshold	40
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	400
Cohorts		
Avg. degree-days (°C) to OW adult spring 1st flight	distro_mean	210
Var. in degree-days (°C) to OW adult spring 1st flight	distro_var	5000
Minimum degree-days (°C) to OW adult spring 1st flight	xdist1	100
Maximum degree-days (°C) to OW adult spring 1st flight	xdist2	350
Shape of the distribution of degree-days (°C) to OW adult spring 1st flight	distro_shape	normal

Table 2. Parameter values used to produce a CLIMEX model for *Eurygaster integriceps* (SUNP).

CLIMEX parameter	Code	Value
Temperature		
Lower temperature threshold (°C)	DV0	11
Lower optimal temperature (°C)	DV1	18
Upper optimal temperature (°C)	DV2	32
Upper temperature threshold (°C)	DV3	36
Degree-days per generation (°C days)	PDD	784
Moisture		
Lower soil moisture threshold	SM0	0.01
Lower optimal soil moisture	SM1	0.02
Upper optimal soil moisture	SM2	1.3
Upper soil moisture threshold	SM3	2.5
Cold stress		
Cold stress temperature threshold (°C)	TTCS	−30
Cold stress temperature rate (week^{-1})	THCS	−0.00025
Heat stress		
Heat stress temperature threshold (°C)	TTHS	40
Heat stress temperature rate (week^{-1})	THHS	0.003
Dry stress		
Dry stress threshold	SMDS	0.01
Dry stress rate (week^{-1})	HDS	−0.005
Wet stress		
Wet stress threshold	SMWS	2.5
Wet stress rate (week^{-1})	HWS	0.002

Fig. 1. Predictions of climatic suitability for *Eurygaster integriceps* (SUNP) 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. Areas outside of wheat growing regions in CONUS (hollow polygon; available at http://www.earthstat.org) are semi-transparent to indicate that the species would only establish in areas where its main host plant is available.

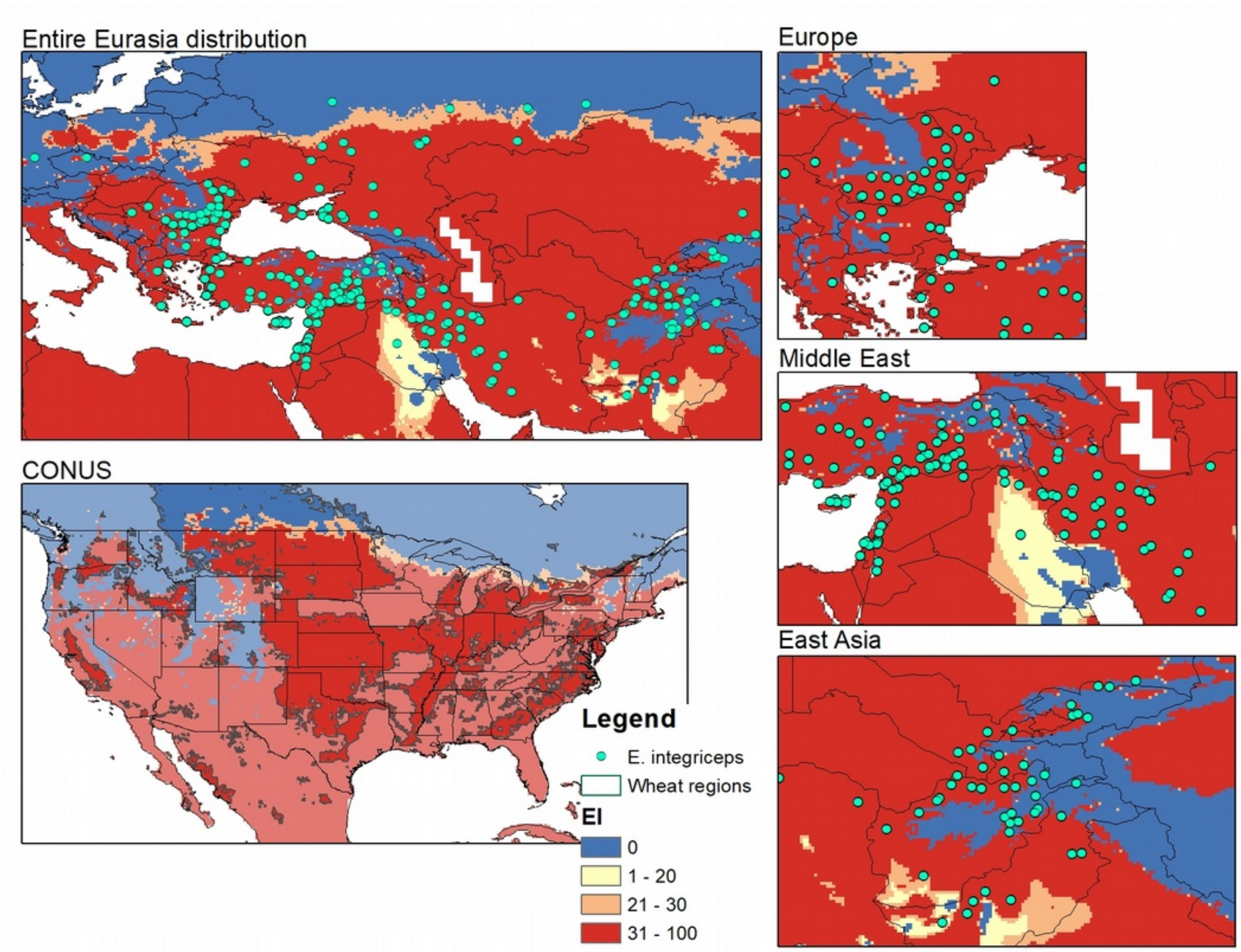


Fig. 2. Maps depicting (a) cold stress and (b) heat stress for *Eurygaster integriceps* (SUNP) produced by CLIMEX. Cold stress is shown for all of Eurasia and North America, whereas heat stress is shown only for the hottest parts of its native distribution (Middle East and South Asia) and the potential distribution in CONUS (California and Arizona).

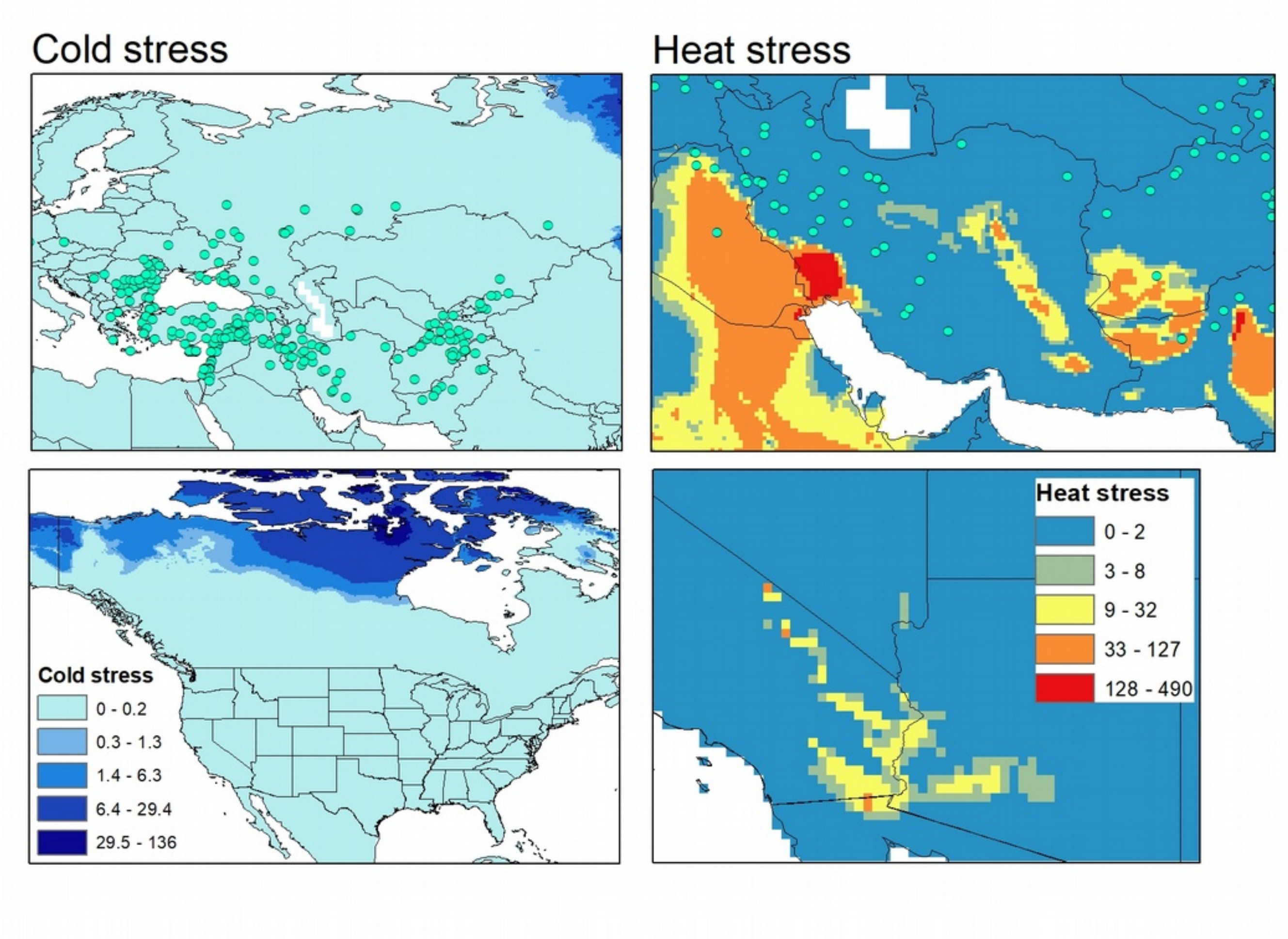


Fig. 3. Maps depicting (a) cold stress, (b) heat stress, and (c) all stress exclusion for *Eurygaster integriceps* (SUNP) produced by DDRP. Reference climate data for DDRP were from 1961–1990 Normals (matched to available CLIMEX data).

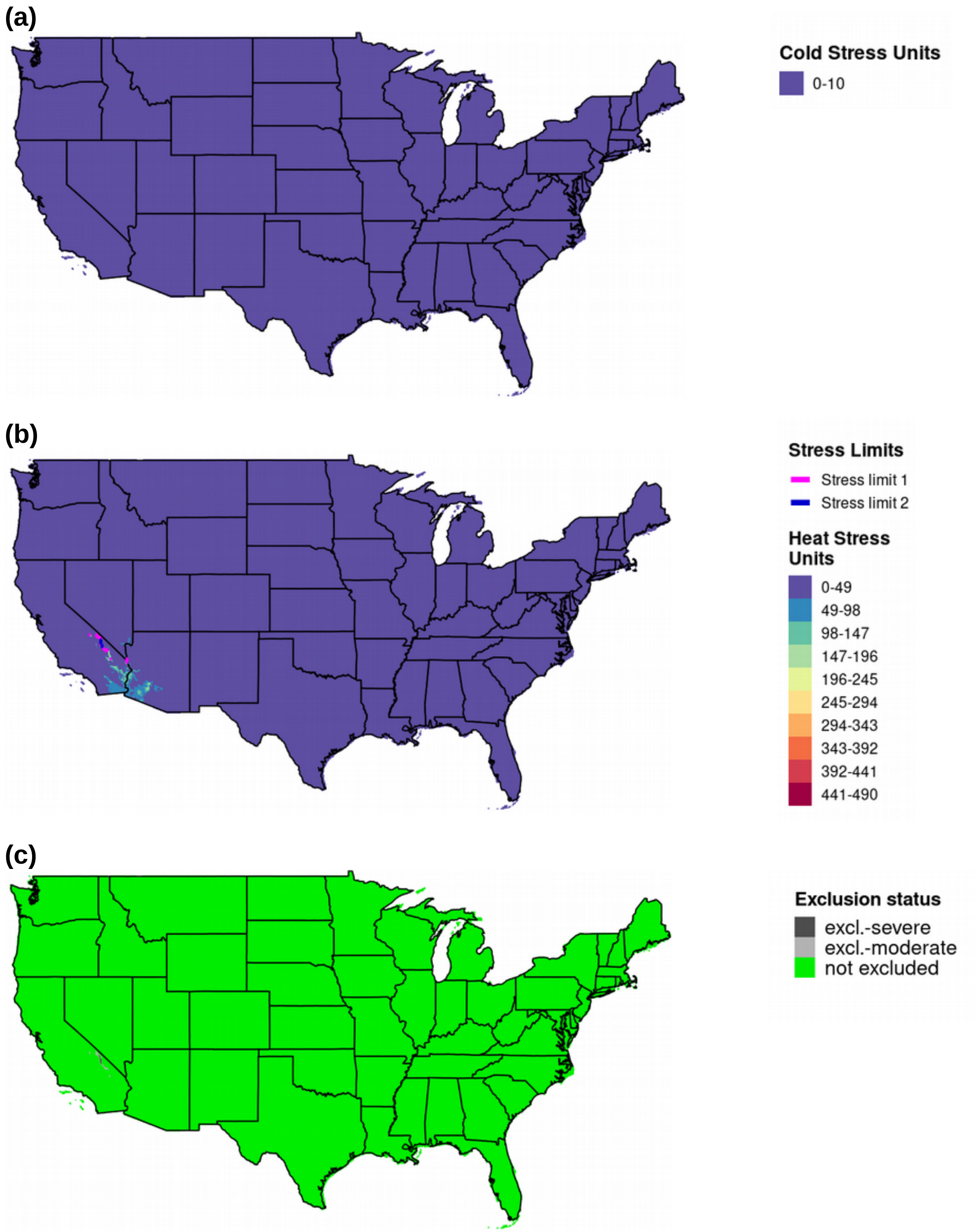
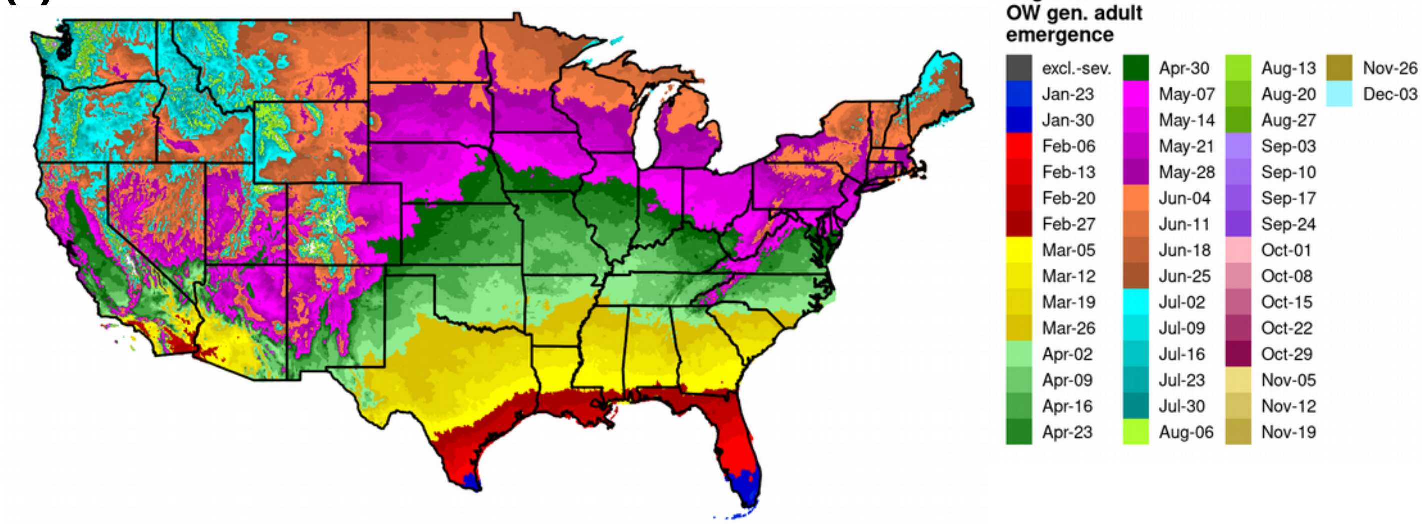


Fig. 4. Maps depicting the average date of (a) first flight of overwintered adults and (b) emergence of 1st generation adults of *Eurygaster integriceps* (SUNP) with severe climate stress exclusion for 2012 produced by DDRP. Severe heat stress may exclude the species only from a very small area in the vicinity of Death Valley in California.

(a)



(b)