Japanese Pine Sawyer Beetle

***Monochamis alternatus* (Coleoptera: Cerambycidae)**

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

A phenology model and temperature-based climate suitability model for the Japanese pine sawyer beetle (JPSB), *Monochamus alternatus* (Hope), was developed using data from available literature and through modeling in CLIMEX v. 4 (Hearne Scientific Software, Melbourne, Australia; Kriticos et al. 2015) and DDRP (Degree-Days, Risk, and Pest event mapping; under development for uspest.org).

Introduction

Monochamus alternatus is a major insect vector of pine wilt disease in its native range in Asia (principally China, Japan and Korea). While it is not known to be present in the United States, it may pose a serious threat to its urban and forest ecosystems if introduced. Like other beetles in the genus *Monochamus*, Japanese pine sawyers breed in dying or weakened trees. Adults feed on the bark of twigs of healthy hosts and oviposit on dying or recently trees, and larvae feed on the inner bark. The major hosts of *M. alternatus* are pine trees (*Pinus* spp.), but it will also feed and breed on numerous trees in the Pinaceae family including cedar, fir, Douglas fir, hemlock, larch, and spruce, in addition to juniper (cypress family) and beech (Fagaceae family) (CABI 2019).

Phenology model

Objective.—We estimated rates and degree days of development in *M. alternatus* by solving for a best overall common threshold and corresponding developmental degree days (DD) 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.

Developmental parameters.—This is a summary of the spreadsheet analysis for *M. alternatus* that is available online at http://uspest.org/wea/Monochamus_alternatus_model.pdf (Coop and Barker 2020). The species completes one or two generations per year in temperate and sub-tropical climates, and up to three generations in warmer climates. We solved for a common lower threshold of 12.2°C for all four life stages (eggs, larvae, pupae, adults) by analyzing data presented by Okuda 1973 and Yamane 1974, Kobayashi et al. 1984, Togashi and Magira (1981), and Togashi (1989). Using the x-intercept method, we measured egg, larval, pupal, egg-to-adult and pre-oviposition DD requirements as 83, 647, 166, 895, and 103 DDs, respectively. No studies have firmly established an upper threshold of development, so we surmised that it may be approximately 35°C based on a linear response in developmental rates for temperatures to 30°C found by Okuda (1973), and from climate suitability studies (see below). The generation time was approximated as immature plus pre-oviposition times (above) plus 35% of the full oviposition period of 368 DDC (103 DD; Tlow of 12.5°C) (Kobayashi et al. 1984 and Takizawa 1980).

Emergence parameters.—Overwintering in *M. alternatus* occurs in the larval stage. We assumed seven cohorts pupate in the spring according to a normal distribution. According to our analysis of data presented in Song et al. (1991), near Guangdong, China, where this insect is trivoltine, first emergence occurs at about 200 DDC (Tlow=12.2°C). Results from Park et al. (2014), indicate that emergence of adults of the overwintered generation occurs between 196 to 576 DDCs, and 50% emerged by 370 DD. We subtracted the duration of the pupal period (166 DDCs) from these numbers to estimate when larvae would pupate. This resulted in an average (peak) pupation of 204 DDCs (range = 10–410 DDCs; Table 1).

Climate suitability model

Objective.—We estimated which climate stress parameters in DDRP (chill stress temperature threshold, heat stress threshold, and chill and heat stress units; Table 1) resulted in map outputs most similar to the CLIMEX model of *M. alternatus* produced by Kim et al. (2016). DDRP models used a PRISM data set of daily temperature data averaged over 1961-1990, 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

We used a modified CLIMEX model that was presented by Kim et al. (2016) to calibrate a climate suitability model for *M. alternatus* in DDRP. Kim et al. (2016) synthesized development data from several studies and used 10-year average climate data (2006 to 2015) from 68 domestic weather stations to predict climatic suitability in Korea. They conducted a sensitivity analysis of the parameter values used in the CLIMEX model of Song and Xu (2006), which they evaluated by setting eight parameter groups based on developmental and distribution data. The final result was simulated by comprehensively considering different developmental data and by determining the final parameter values (Table 2) that had the most similar distribution to the actual observations.

We modified the cold stress temperature threshold and cold stress temperature rate values in the CLIMEX model of Kim et al. (2016). Their TTCS value (TTCS = 8°C) is probably too high. A lab study of overwintering larvae found that mortality decreased at a linear rate when temperatures dropped below 0°C, while there was no significant differences in survival at 0, 5, and 25°C (Ma et al. 2006). Additionally, using a TTCS of 8°C resulted in high levels of cold stress being predicted in areas where the species is known to occur (Estay et al. 2014).

A TTCS of 0°C and cold stress temperature rate (THCS) of −0.0003/week resulted in lower levels of cold stress than Kim et al.'s (2016) threshold, such that all but a single locality record occurred in areas where cold stress was less than *ca.* 70 (Fig. 1). The boundary where cold stress increased to >70 corresponds roughly to the predicted range limit for the species presented by Ma et al. (2006).

Despite adjusting the TTCS value from 8 to 0°C, unsuitable conditions (EI = 0) were still predicted for the northern-most locality records of *M. alternatus*. Thus, the CLIMEX model is under-predicting the potential distribution. The species may require two years to complete its life cycle in Japan (CABI 2019), which suggest that CLIMEX's method of calculating population growth based on data for a single year may be inappropriate, at least in northern (colder) areas.

DDRP climate suitability model

We adjusted thresholds and limits for chill and heat stress in DDRP in accordance with outputs from our adjusted CLIMEX model. For DDRP, we derived a chill stress temperature threshold of −4ºC (Table 1). We set the chill stress limits such that moderate and severe chill stress excluded the species from areas where CLIMEX predicted cold stress values of 70−200 and >200, respectively. This resulted in the exclusion of *M. alternatus* from much of the Intermountain West, Midwest, and Northeast.

We applied a heat stress threshold of 36°C in DDRP. This value is slightly higher than the threshold used in the Kim et al. CLIMEX study (TTHS = 33°C); however, the justification for this value is unclear. Using a threshold that may be too high is preferable over using one that is too low, because temperatures recorded at weather shelters would likely be a few degrees warmer than those experienced by insects under tree bark. In CLIMEX, heat stress occurred only in small parts of the Southwest, and it was not high enough to exclude the species there (i.e., EI values were still greater than 20). We therefore set high heat stress limits in DDRP.

Suggested applications

The DDRP model may be run to test where *M. alternatus* may become established and reproduce in the continental US under past, 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 flight for one or more generations to guide APHIS supported Cooperative Agricultural Pest Survey (CAPS) programs. We provide two example maps using 2012 PRISM data (the hottest year on record for the conterminous US (CONUS) showing (a) the date of first egg laying by females with severe climate stress exclusions (Fig. 5), and (b) potential voltinism (number of generations; Fig. 6).

Improvements needed

Several studies have reported that moisture affects the life cycle and distribution of *M. alternatus*. Total precipitation was the most important factor in a fitted Maxent model for the species, potentially due to the link between precipitation and the distribution of host trees (Estay et al. 2014). Additionally, longevity and egg hatchability may be influenced by relative humidity

(Kong 2006). These data suggest that a DDRP model that includes moisture factors may improve model predictions.

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Table 1. DDRP parameter values for *Monochamus alternatus*.

Parameter	Code	Value
Lower developmental thresholds (°C)		
Egg	eggLDT	12.2
Larvae	larvaeLDT	12.2
Pupae	pupaeLDT	12.2
Adult	adultLDT	12.2
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	83
Larvae	larvaeDD	647
Pupae	pupDD	166
Adult	adultDD	207
Pest events (°C degree-days)		
Egg event (egg-hatch)	eggEventDD	80
Larva event (mid-larval development)	larvaeEventDD	320
Pupa event (mid-pupae development)	pupaeEventDD	83
Adult event (first egg-laying by females)	adultEventDD	107
Chill stress		
Chill stress temperature threshold (°C)	chillstress_threshold	-4
Chill degree-day (°C) limit when most individuals die	chillstress_units_max1	525
Chill degree-day (°C) limit when all individuals die	chillstress_units_max2	800
Heat stress		
Heat stress temperature threshold (°C)	heatstress_threshold	36
Heat stress degree-day (°C) limit when most individuals die	heatstress_units_max1	800
Heat stress degree-day (°C) limit when all individuals die	heatstress_units_max2	1100
Cohorts		
Avg. degree-days (°C) to OW pupation	distro_mean	204
Var. in degree-days (°C) to OW pupation	distro_var	3000
Minimum degree-days (°C) to OW pupation	xdist1	10
Maximum degree-days (°C) to OW pupation	xdist2	410
Shape of the distribution of degree-days (°C) to OW pupation	distro_shape	normal

Table 2. Parameter values used in the CLIMEX model for *Monochamus alternatus*.

CLIMEX parameter	Code	Value
Temperature		
Lower temperature threshold (°C)	DV0	10.8
Lower optimal temperature (°C)	DV1	15
Upper optimal temperature (°C)	DV2	30
Upper temperature threshold (°C)	DV3	33
Degree-days per generation (°C days)	PDD	1690
Moisture		
Lower soil moisture threshold	SM0	0.1
Lower optimal soil moisture	SM1	0.55
Upper optimal soil moisture	SM2	1.35
Upper soil moisture threshold	SM3	4
Cold stress		
Cold stress temperature threshold (°C)	TTCS	0
Cold stress temperature rate ($week^{-1}$)	THCS	−0.0003
Heat stress		
Heat stress temperature threshold (°C)	TTHS	33
Heat stress temperature rate ($week^{-1}$)	THHS	0.0001
Dry stress		
Dry stress threshold	SMDS	0.25
Dry stress rate ($week^{-1}$)	HDS	−0.001
Wet stress		
Wet stress threshold	SMWS	4.0
Wet stress rate ($week^{-1}$)	HWS	0.0001

Fig. 1. Predictions of climatic suitability [ecoclimatic index (EI)] and cold stress for *Monochamus alternatus* (JPSB) in Asia (left) and CONUS (right) using a cold stress threshold and rate of 0°C and −0.0003/week, respectively. Yellow dots depict locality records used in the Maxent model of Estay et al. (2014).

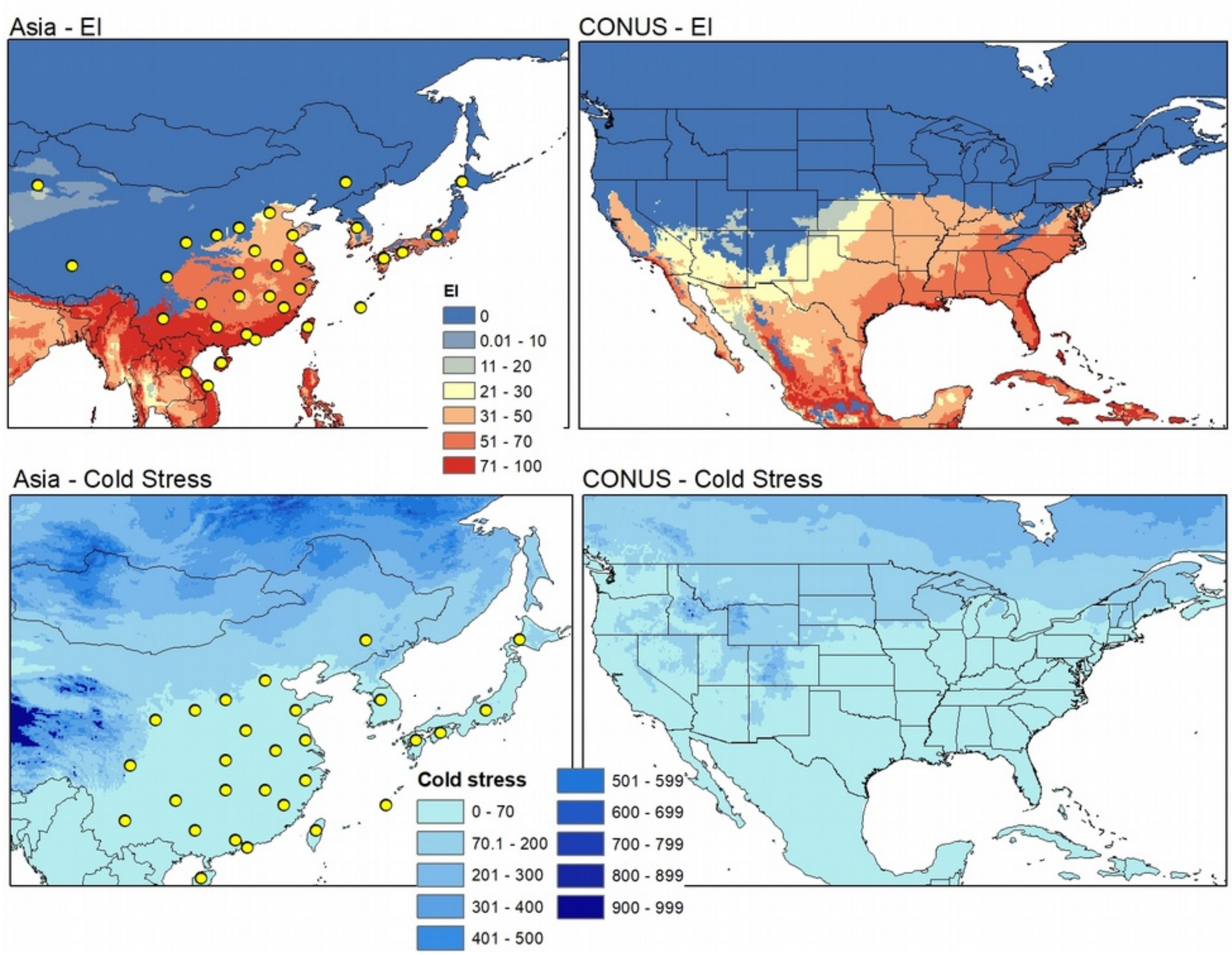
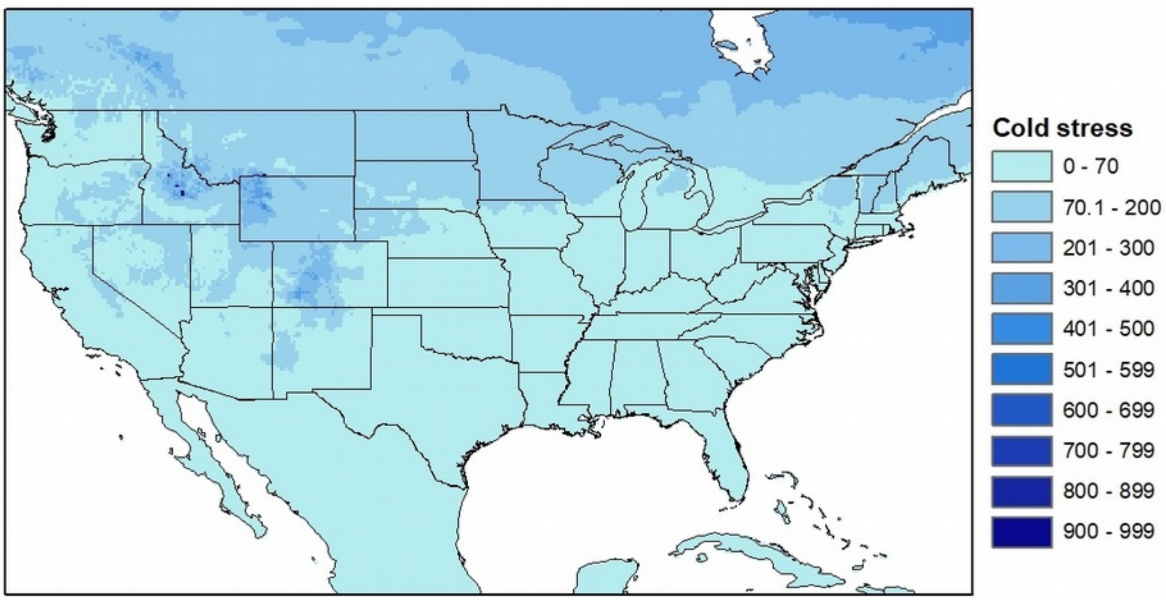


Fig. 2. Maps of cold/chill stress units for *Monochamus alternatus* (JPSB) produced by (a) CLIMEX (cold stress temperature threshold, TTCS = 0ºC) and (b) DDRP (chill stress temperature threshold = −4ºC). Reference climate data for DDRP were from 1960−1990 Normals (matched to available CLIMEX data). The pink and black lines in (b) depict the chill stress unit limits 1 and 2 (525 and 800 CSUs, respectively; Table 1). All but a single locality record in the native range occur in areas where cold stress is less than 70 in CLIMEX, so the max2 limit in DDRP was adjusted to generally match the boundary where CLIMEX cold stress rose above 70.

(a) CLIMEX cold stress units



(b) DDRP chill stress units

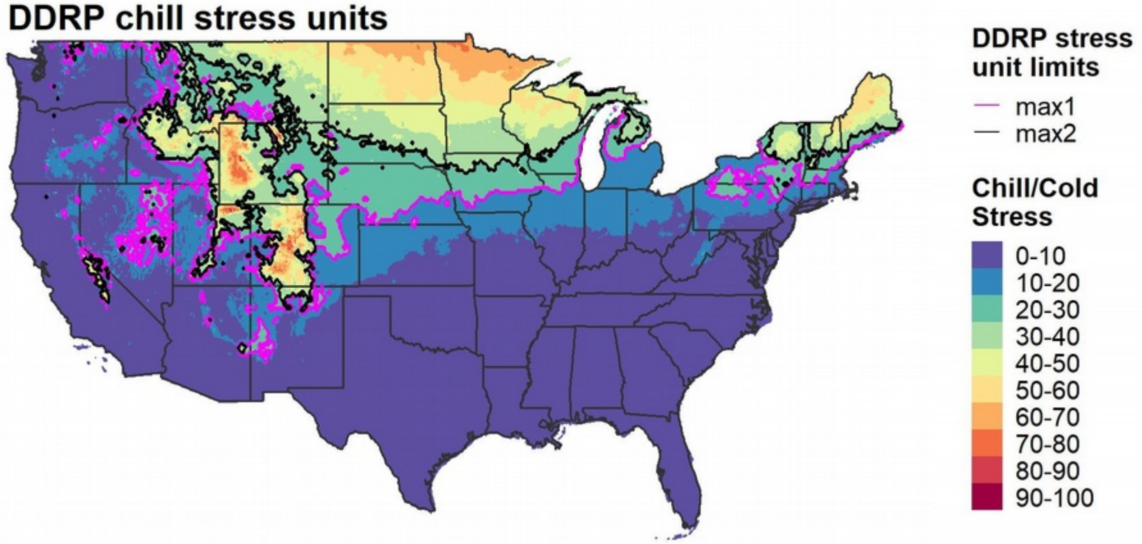


Fig. 3. Maps of heat stress units for *Monochamus alternatus* (JPSB) produced by (a) CLIMEX (heat stress temperature threshold, TTHS = 33ºC) and (b) DDRP (heat stress temperature threshold = 36ºC). DDRP heat stress units have been scaled from 0 to 100 to match the scale used by CLIMEX. Reference climate 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 (800 and 1100 CSUs, respectively; Table 1).

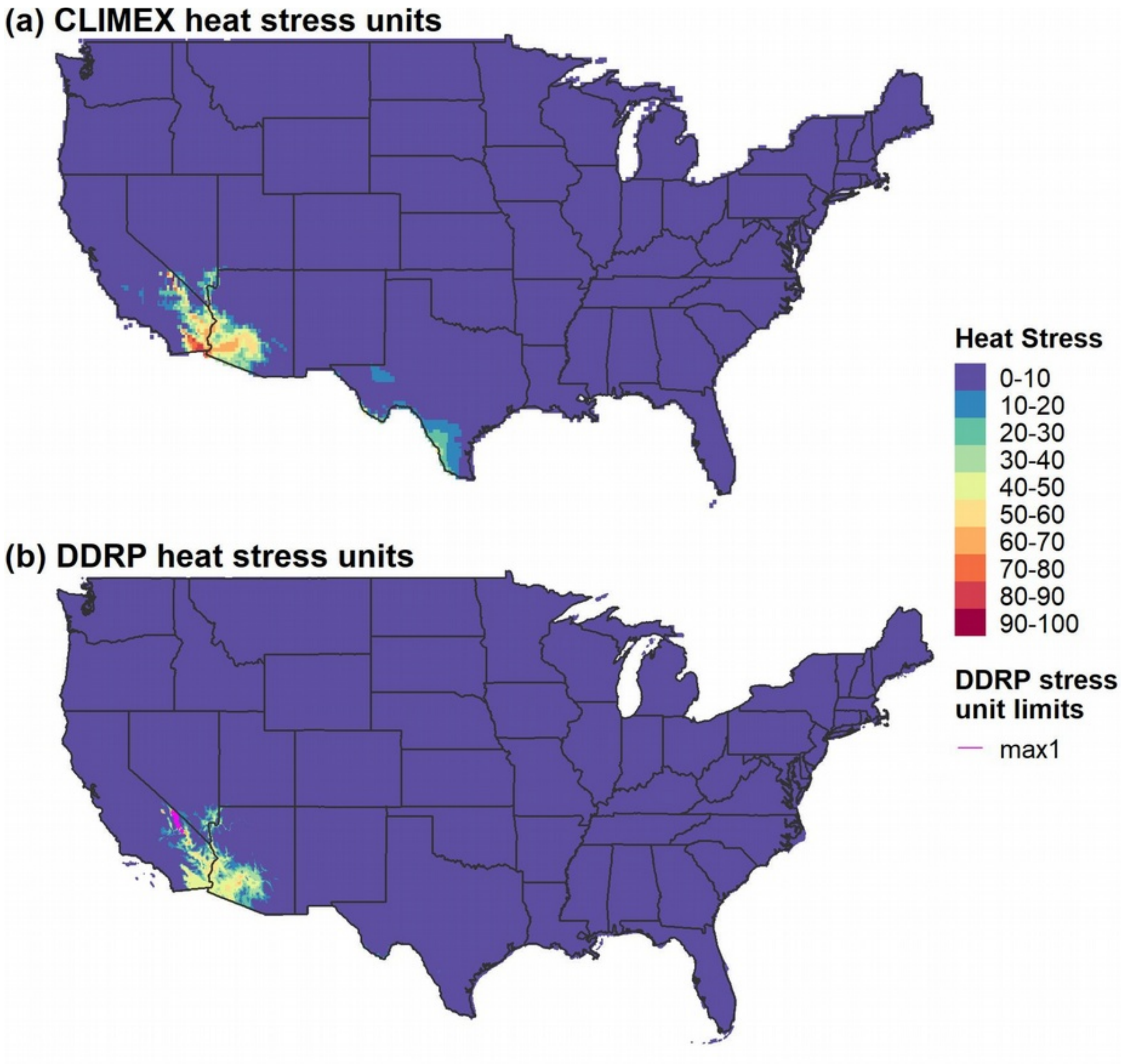
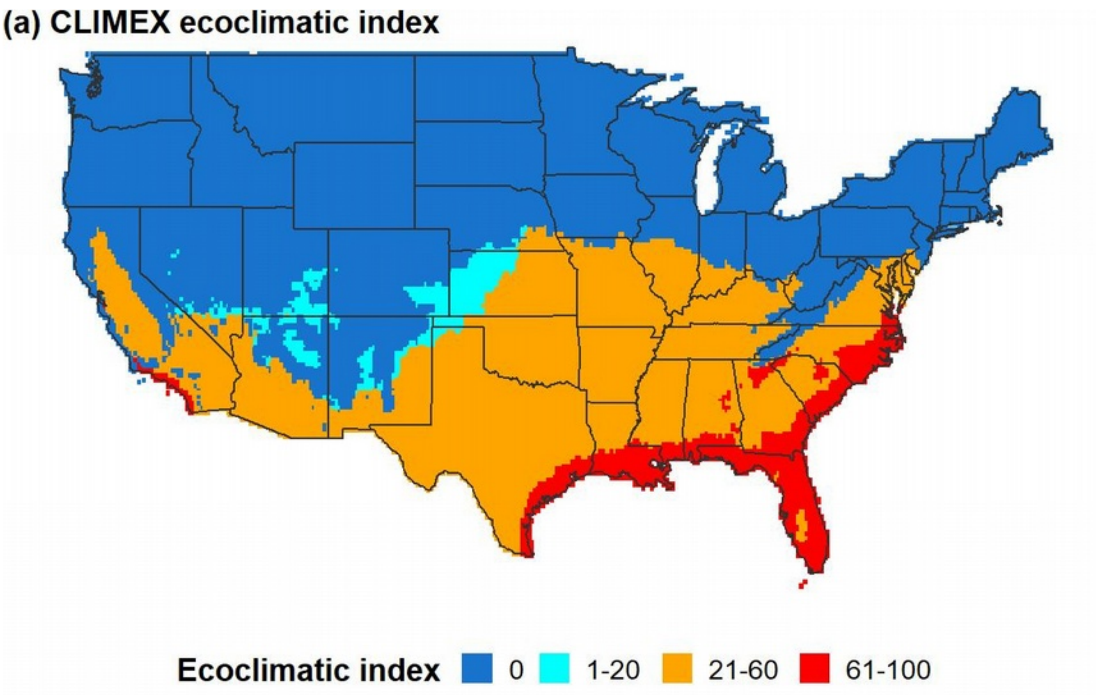


Fig. 4. Climate suitability models for *Monochamus alternatus* (JPSB) in CONUS produced by (a) CLIMEX and (b) DDRP. DDRP measures exclusion status of the species based on chill and heat stress units (all stress exclusion). The map for DDRP also shows predicted voltinism to demonstrate that areas where *M. alternatus* completes fewer than two generations per year also tend to have low Ecoclimatic index (EI) values according to CLIMEX, which incorporates estimates of population growth in EI calculations. Reference climate data for DDRP were from 1960−1990 Normals (matched to available CLIMEX data).



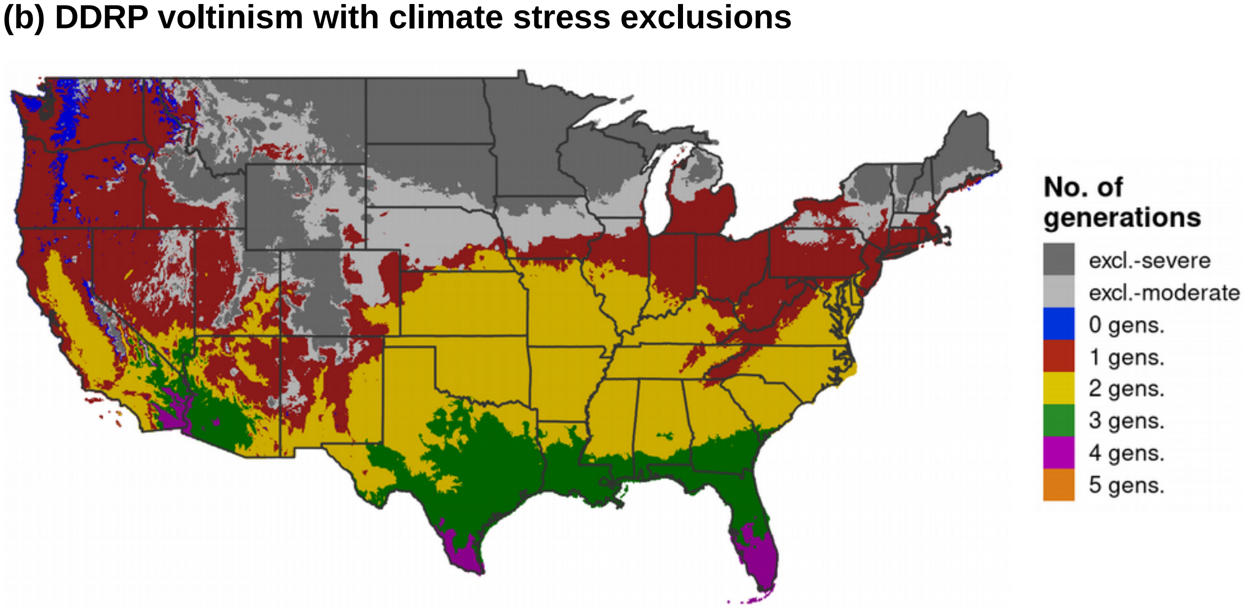


Fig. 5. Map depicting the date of first egg laying by females of the overwintering generation with severe climate stress exclusion (based on chill and heat stress units) for *Monochamus alternatus* (JPSB) for 2012 produced by DDRP.

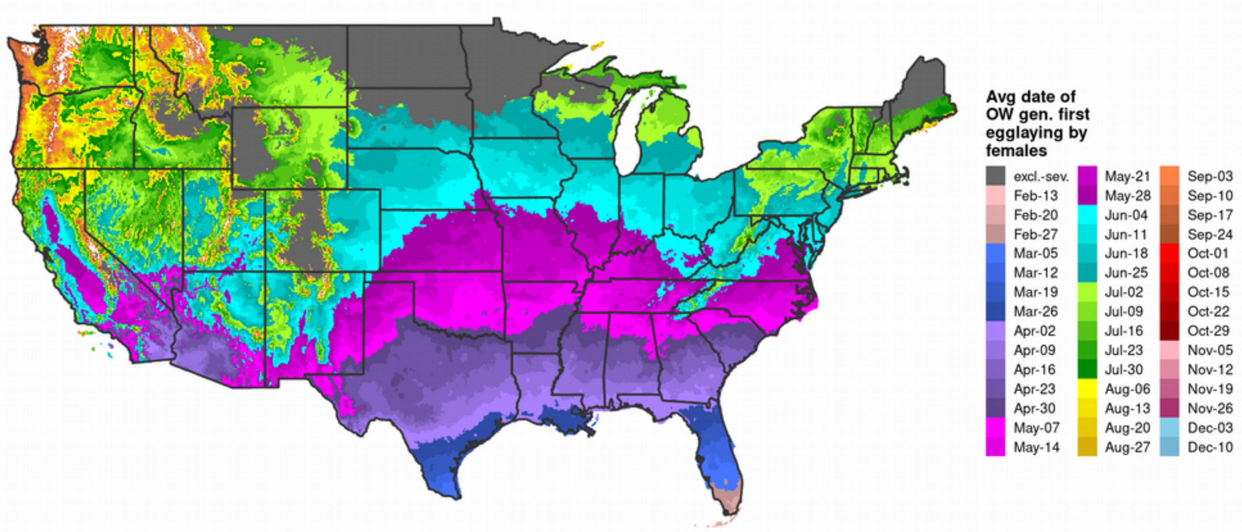


Fig. 6. Map showing the voltinism (number of generations) of *Monochamus alternatus* (JPSB) with severe climate stress exclusion (based on chill and heat stress units) for 2012 produced by DDRP.