Oak Ambrosia Beetle

Platypus quercivorus (Coleoptera: Platypodidae)

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 oak ambrosia beetle (OAB), *Platypus quercivorus* (Murayama), was developed using data from available literature and through modeling in CLIMEX v. 4 (Hearne Scientific Software, Melbourne, Australia; Kriticos et al. 2016), Maxent (Phillips et al. 2006), and DDRP (Degree-Days, Risk, and Pest event mapping; under development for uspest.org).

Introduction

Platypus quercivorus is the vector of a pathogenic fungus (*Raffaelea quercivora*) that causes Japanese oak wilt disease, which has caused massive mortality in oak trees (*Quercus* spp.) in Japan and can infect other species in the Fagaceae family including chestnut (*Castanea* spp.), chinquapin (*Castanopsis* spp.), and stone oaks (*Lithocarpus* spp.). Wood boring by *P. quercivorus* can slow growth and increase mortality of both host and adjacent non-host trees, and it predisposes trees to further damage by secondary pests (Davis et al. 2005). At least 28 species of *Quercus* in the continental U.S. may potentially serve as hosts (Davis et al. 2005). The establishment of *P. quercivorus* in the U.S. would likely have high environmental and economic impacts because oak forests provide numerous ecosystem services including high value timber for industry, wildlife habitat, and valued environments for recreation and other cultural activities.

Phenology model

Objective.—We assessed the literature to derive developmental thresholds and life stage durations for *P. quercivorus.* We assumed the same threshold for each life stage because 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 *P. quercivorus* that is available online at http://uspest.org/wea/Platypus_quercivorus_model.pdf (Coop and Barker 2020). The species typically completes one generation per year, although in cooler climates two years may be required to complete their life cycle. As no temperature-development studies are available for this species, we estimated a lower developmental threshold of 11.1°C for all major life stages (eggs, larvae, pupae, adults) based on temperatures and beetle trapping data presented for seven bark beetle species in Southwestern U.S.A. (Gaylord et al. 2008). The beetles were trapped at lower daily maximum temperatures ranging from *ca*. 11–18°C, which could serve as flight temperature thresholds. Typically, insects require warmer temperatures for adult flight and mating than for immature development. Therefore, we chose the lower end of the minimum flight temperature range (11.1°C) to use as the common threshold for *P. quercivorus* development, which is also close to the temperature threshold (11.0°C) used for three related species of bark beetles (Gaylord et al. 2008).

Using this threshold, we analyzed monitoring data reported in Soné et al. 1998 to derive egg, larval, pupal, and teneral adult DD requirements of 125, 805, 218, and 111 DDs, respectively. The generation time was estimated as 1486 DDC, which is the sum of the duration of egg, larvae, pupae, teneral adult, tunnel building, and initial egglaying periods. We are unaware of any study that has studied the impacts of high temperatures on *P. quercivorus*. We therefore set the upper developmental threshold to 38°C because the same field study of seven pine bark beetles in Arizona reported a cease in flight activity at this temperature (Gaylord et al. 2008).

Emergence parameters.—Overwintering in *P. quercivorus* occurs in the 5th instar of the larval stage. We assumed seven cohorts begin pupating in the spring according to a normal distribution, and used field monitoring data collected in the Kagoshima Prefecture of Japan (Soné et al. 1998) to estimate the range of pupation times. The earliest degree-days until pupation was set to 120 DDC, which corresponds to an average estimate of first adult emergence (453 DDC) minus the pupal and teneral adult periods (330 DDC). The average and maximum degree-days until pupation was set to 353 DDC [50% emergence (683 DDC) – 330 DDC] and 840 DDC [last emergence (1170 DDC) – 330 DDC], respectively.

Climate suitability model

Background and Objective

Two risk assessments for *P. quercivorus* in the contiguous U.S. (CONUS) have been conducted. Davis et al.'s (2005) risk assessment was based on matching biomes that the species occupies in its native range to those in CONUS, whereas USDA-APHIS (2011) generated a risk map based on the density of potential host trees (Fig. 1). However, we are unaware of any climate suitability modeling studies of the species, and little is known about its climatic tolerances (e.g., cold stress, heat stress, dry stress, and moisture stress thresholds). Additionally, only a handful of locality data for the species exist outside of Japan, which hinders fitting a robust climate suitability model.

Given an overall lack of data, we used three different approaches [CLIMEX, CLIMEX regional climate matching (CLIMEX-MCR), and Maxent) to assess climatic suitability for *P. quercivorus* in CONUS (Fig. 2). Identifying common results across the three models could provide a more robust assessment of climate suitability. The ultimate objective of these analyses was to help parameterize a climate suitability model in DDRP.

Methods

CLIMEX model.—The parameters used for the CLIMEX are reported in Table 2. We set the cold stress threshold as −10°C because the lowest average temperature of the coldest month of the year in Sapporo, Japan (close to where the northernmost locality for the species are located) is −7°C, which suggests that even lower temperatures may limit the species' distribution. We assumed that *P. quercivorus* would begin experiencing heat stress at 38°C, which is the same temperature as the upper developmental threshold.

CLIMEX-MCR model.—We generated a CLIMEX-MCR model (Kriticos et al. 2015) to assess which regions of CONUS had a similar climate to localities where the species has been documented in the native range. We obtained 44 locality records from GBIF.org (14 February 2020; GBIF Occurrence Download https://doi.org/10.15468/dl.mxi5iu) and gathered 60 additional records from the literature. Records that lacked coordinate data and did not have information about the prefecture/municipality of origin (i.e., records for an entire country or region) were excluded. To correct for potential bias in sampling effort, we removed localities < 20 km apart, which roughly corresponds roughly to the spatial resolution of CLIMEX gridded climate data. This resulted in a total of 39 localities from Japan (N = 35), Indonesia (N = 1), Taiwan (N = 1), Thailand (N = 1), and Vietnam (N = 1).

The level of similarity of native range ('Home') locations to the climate of CONUS is given by the 'Composite Match Index, CMI', which is the product of six component indices that are represented by maximum and minimum temperature, total rainfall, rainfall pattern, relative humidity and soil moisture. Each component index can range from 0 to 1, where a value of 1 indicates an exact match with the 'Home' locations. Our climate match analysis applied the default CMI weight values, which are used to rank the importance of each component index. Areas that have a CMI ≥ 0.7 are considered to have similar climates to 'Home' locations (Kriticos 2012).

Maxent model.—We generated a climate suitability model using a correlative approach in the Maxent software version 3.4.1 (Accessed from https://biodiversityinformatics.amnh.org/open_source/maxent/ on 2020-3-11). Climate data included 19 Bioclim variables from the CliMond database (https://www.climond.org/BioclimRegistry.aspx#Table1), which are derived from monthly averages of daily minimum and maximum temperatures and monthly precipitation for 1961−1990. We estimated the first two principal components (PCs) of Bioclim variables with a standardized PCA in the "RStoolbox" in R 3.6.1, which captured 78% of the variability in the full dataset. PC data are often used to estimate climate suitability models in Maxent to avoid model over-fitting due to correlations among variables (Kriticos et al. 2014).

Maxent models were trained using PC data that were cropped to the extent (bounding box) of the native range localities. We created 50 replicate models for each variable using a random 80% subset of localities to train the model and 20% reserved for testing using the area under the receiver operating curve (AUC) statistic for each replicate. Model replicates were then projected at the scale of CONUS using the same variables. Other settings were left as default. The native range Maxent models performed adequately based on AUC values (average AUC_{test} over 50 replicate runs was 0.88 ± 0.074).

DDRP model.—A summary of DDRP parameters used for climate suitability modeling is reported in Table 1. 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 and Maxent. We attempted to set the cold and heat stress thresholds and limits so that the species was excluded only from areas where the other three modeling approaches also predicted unsuitable conditions.

Results

All four modeling approaches predicted suitable conditions throughout eastern CONUS. CLIMEX and DDRP both predicted that high cold stress in most of North Dakota and northern parts of Minnesota, Wisconsin, and Michigan lowered suitability (Figs. 2 and 3). These areas were also deemed to be unsuitable according to the CLIMEX-CMR model (CMI < 0.5) and the Maxent model (log suitability < 0.05; Fig. 2). In contrast, results in western CONUS varied widely according to the modeling approach. CLIMEX-CMR and Maxent predicted low suitability in the West (approximately west of Oklahoma) except in some coastal areas of the Pacific Northwest, whereas CLIMEX predicted suitability only throughout the Southwest and southern California (Fig. 2). DDRP excluded *P. quercivorus* only from the hottest areas of the Southwest (southeastern California and southwestern Arizona; Figs. 2 and 3).

Suggested applications

The DDRP model may be run to test where *P. quercivorus* may become established and reproduce in CONUS 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 emergence 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 CONUS showing (a) the average date of the beginning of the first generation egg hatch (Fig. 4), and (b) potential voltinism (number of generations; Fig. 5).

Improvements needed

DDRP's climate suitability model predicted a much wider potential distribution for *P. quercivorus* in the West compared to the other three models. This finding is likely due in part to DDRP's absence of moisture factors in the modeling process. However, all four climate suitability models presented here should be used with caution because 1) there is a scarcity of locality data outside of Japan, which hinders model-fitting and could bias estimates of suitability; and 2) there is virtually no information on the climatic tolerances of *P. quercivorus*. Users should also consider whether suitable hosts for the species exist in an area when considering risk of establishment. For example, oak forests (*Quercus* species) occur in high densities throughout the same areas of the East where our climate suitability models also predicted suitable conditions (Fig. 1), so they are likely at high risk of establishment (USDA-APHIS 2011).

References

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Table 1. DDRP parameter values for *Platypus quercivorus*.

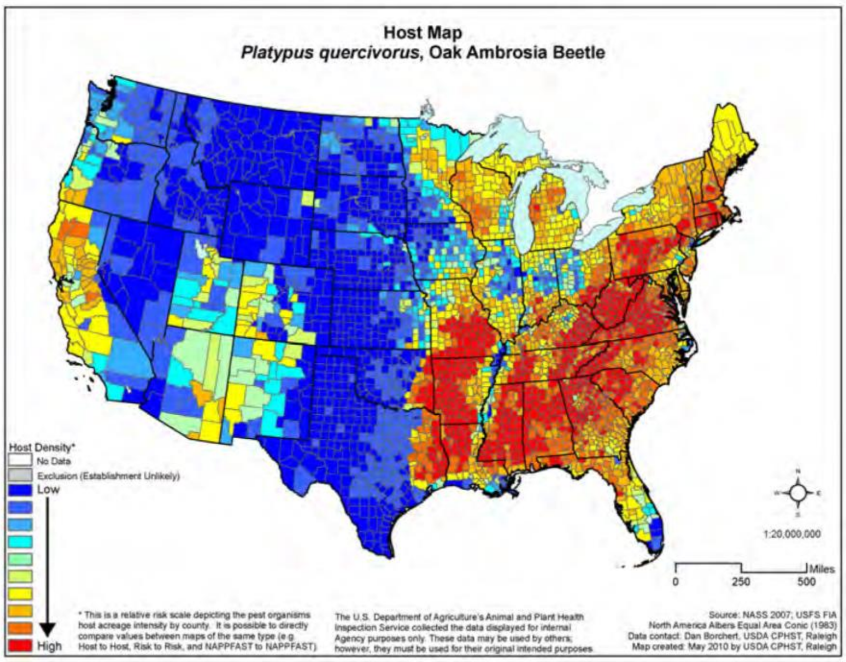
Parameter	Code	Value
Lower developmental thresholds (°C)		
Egg	eggLDT	11.1
Larvae	larvaeLDT	11.1
Pupae	pupaeLDT	11.1
Adult	adultLDT	11.1
Upper developmental thresholds (°C)		
Egg	eggUDT	38.0
Larvae	larvaeUDT	38.0
Pupae	pupaeUDT	38.0
Adult	adultUDT	38.0
Stage durations (°C degree-days)		
Egg	eggDD	125
Larvae	larvaeDD	805
Pupae	pupDD	218
Adult	adultDD	339
Pest events (°C degree-days)		
Egg event (egg-hatch)	eggEventDD	122
Larva event (end of adult emergence)	larvaeEventDD	251
Pupa event (mid-pupae development)	pupaeEventDD	109
Adult event (first adult emergence)	adultEventDD	2
Cold stress		
Cold stress temperature threshold (°C)	coldstress_threshold	-10
Cold degree-day (°C) limit when most individuals die	coldstress_units_max1	100
Cold degree-day (°C) limit when all individuals die	coldstress_units_max2	250
Heat stress		
Heat stress temperature threshold (°C)	heatstress_threshold	38
Heat stress degree-day (°C) limit when most individuals die	heatstress_units_max1	180
Heat stress degree-day (°C) limit when all individuals die	heatstress_units_max2	300
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 *Platypus quercivorus.*

CLIMEX parameter	Code	Value
Temperature		
Lower temperature threshold (°C)	DV0	11.1
Lower optimal temperature (°C)	DV1	15
Upper optimal temperature (°C)	DV2	30
Upper temperature threshold (°C)	DV3	38
Degree-days per generation (°C days)	PDD	1486
Moisture		
Lower soil moisture threshold	SM0	0.1
Lower optimal soil moisture	SM1	0.3
Upper optimal soil moisture	SM2	1.6
Upper soil moisture threshold	SM3	2.5
Cold stress		
Cold stress temperature threshold (°C)	TTCS	–10
Cold stress temperature rate ($week^{-1}$)	THCS	–0.001
Heat stress		
Heat stress temperature threshold (°C)	TTHS	38
Heat stress temperature rate ($week^{-1}$)	THHS	0.0001
Dry stress		
Dry stress threshold	SMDS	0.1
Dry stress rate ($week^{-1}$)	HDS	–0.01
Wet stress		
Wet stress threshold	SMWS	2.5
Wet stress rate ($week^{-1}$)	HWS	0.0001

Fig. 1. Previously published risk maps for *Platypus quercivorus* (OAB) in CONUS. (a) The risk assessment of USDA-APHIS (2011) is based on the relative density of susceptible host trees (scale of 1 to 10; warm colors indicate higher risk). (b) Davis et al. (2005) identified biomes in CONUS that were similar to those in the species' native range (pink shading).

(a)



(b)

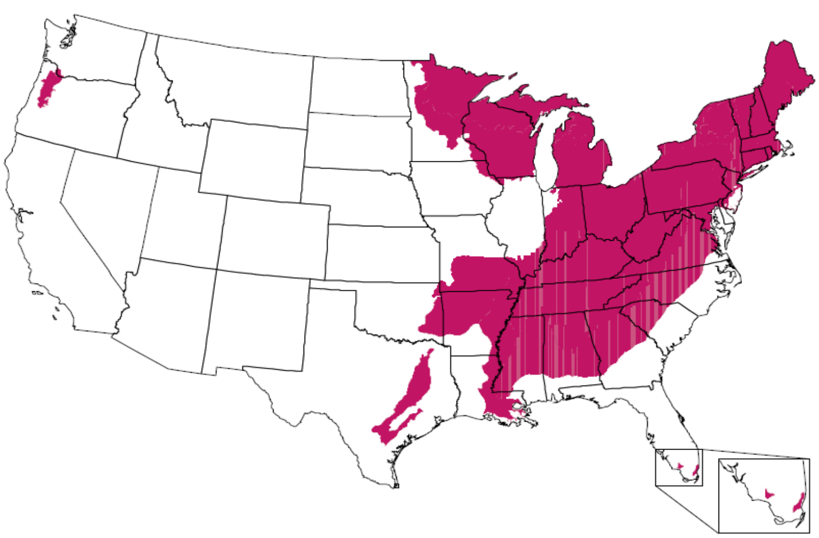


Fig. 2. Comparison of climate suitability models based on (a) climate matching (CLIMEX-MCR), (b) CLIMEX, (c) Maxent, and (d) DDRP for *Platypus quercivorus* (OAB) in the native range and in CONUS.

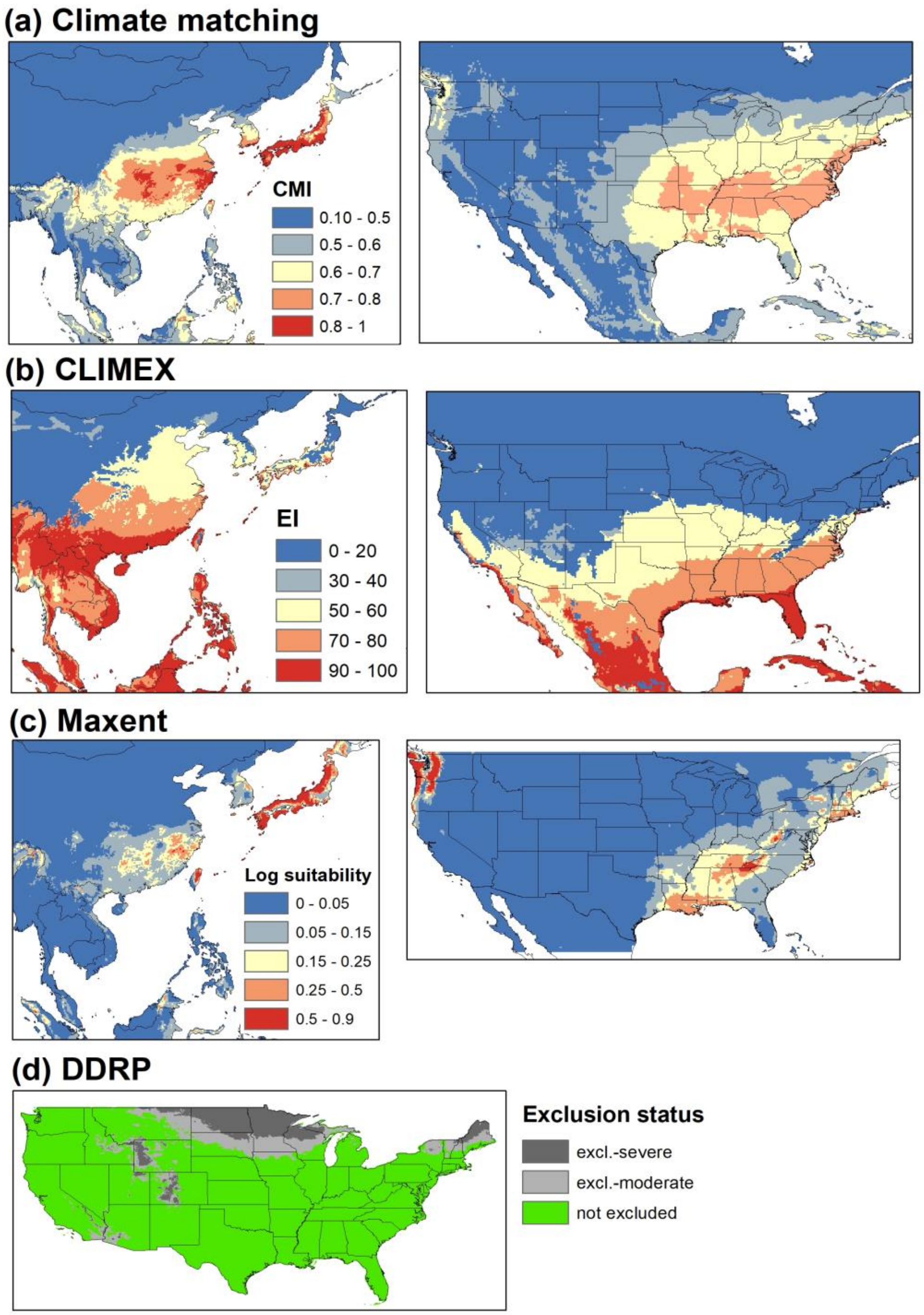


Fig. 3. Maps of (a) cold stress units and (b) heat stress units for *Platypus quercivorus* (OAB) produced by DDRP and CLIMEX. Reference climate data for DDRP were from 1961–1990 Normals (matched to available CLIMEX data). The pink and black lines in DDRP maps depict the stress unit limits 1 and 2 (Table 1).

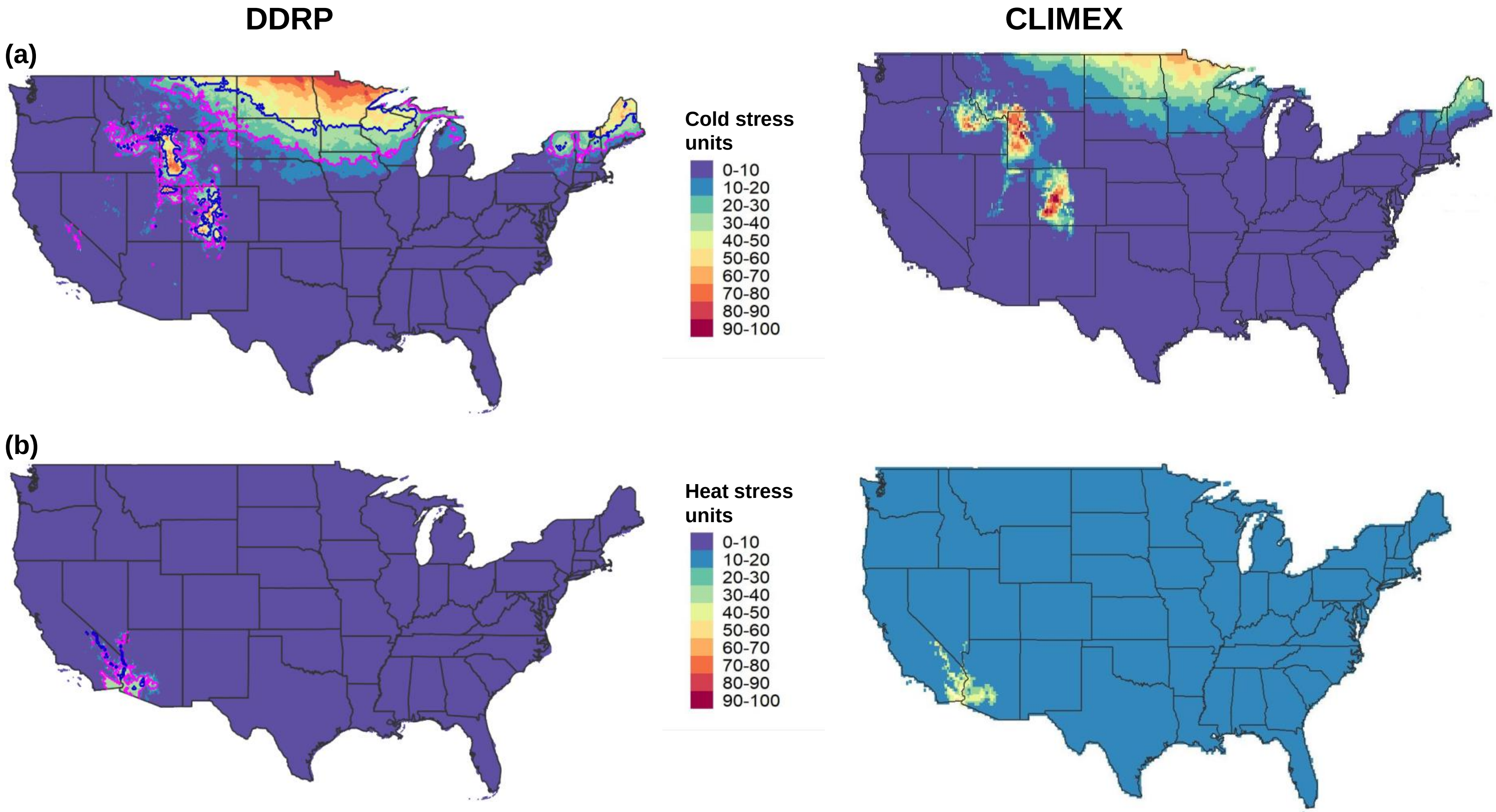


Fig. 4. Map depicting the average date of the beginning of the first generation egg hatch with severe climate stress exclusion (based on cold and heat stress units) for *Platypus quercivorus* (OAB) for 2012 produced by DDRP.

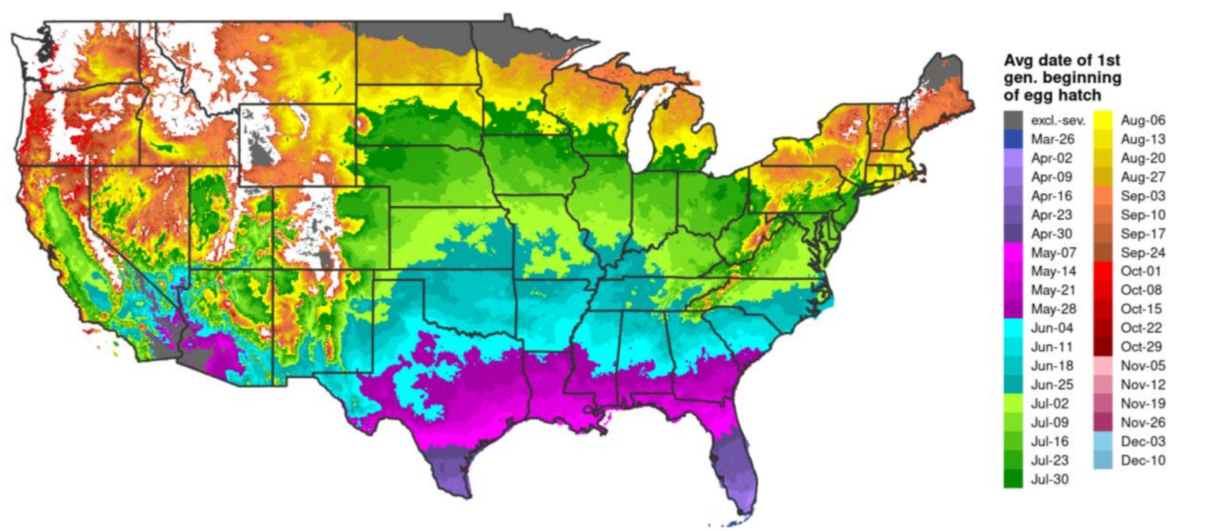


Fig. 5. Map showing the voltinism (number of generations) of *Platypus quercivorus* (OAB) with severe climate stress exclusion (based on cold and heat stress units) for 2012 produced by DDRP.