DDRP: Modeling Degree-Days, Risk of Establishment, and Phenological Event Maps

Leonard Coop[1], Brittany Barker[1], Tyson Wepprich[2], and Fritzi Grevstad[2]

[1]Integrated Plant Protection Center & Dept. of Horticulture, Oregon State University, Corvallis OR
[2]Dept. Botany and Plant Pathology, Oregon State University, Corvallis OR

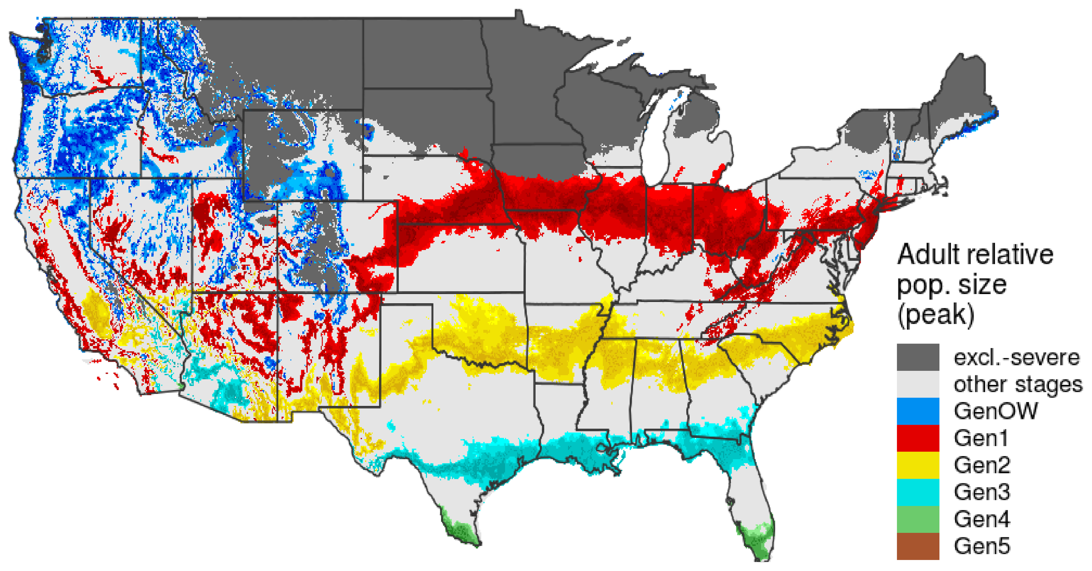


Fig. 1. DDRP map of adults (by generation) of old world bollworm, *Helicoverpa armigera*, for July 29, 2019.

ABSTRACT

We highlight development of a new multi-species spatial modeling platform that can be used to predict phenology and climate suitability (risk of establishment) of insects for the 48-state US. Platform development is funded by a series of grants from the USDA APHIS (Animal Plant Health Inspection Service) PPQ (Plant Protection and Quarantine), for decision support for CAPS (Cooperative Agricultural Pest Survey) programs, and by the US Dept. of Defense (DoD) SERDP (Strategic Environmental Research and Development Program), for management of weed biological control organisms. Model parameters can be derived from temperature-development studies, field data, and geographic survey reports. The model is written in R and uses a variety of gridded weather and climate data types across past, present, and future time frames. CAPS pests include over a dozen species, including Asian long-horned beetle (*Anoplophora glabripennis*), light brown apple moth (*Epiphyas postvittana*), old world bollworm (*Helicoverpa armigera*), small tomato borer (*Neoleucinodes elegantalis*), common or cotton cutworm (*Spodoptera litura*), false codling moth (*Thaumatotibia leucotreta*), oak ambrosia beetle (*Platypus quercivorus*), silver Y moth,(*Autographa gamma*), and tomato leafminer (*Tuta absoluta*). We plan to place a version of the model online, and to share the source code as open source software.

CREDITS

IPPC works closely with and gives thanks and appreciation to: funding agencies USDA NIFA CPPM ARDP (Applied Research and Development Program), W. IPM Center, APHIS PPQ CPHST & CAPS, DoD SERDP, NOAA NWS, MESOWEST UTAH, and the OSU PRISM Group. We thank numerous sources of free and public weather data including WSU AgWeatherNet, AGRIMET, ADCON, CIMIS, Daymet, and numerous other public and agricultural networks. The system was built using open source software tools such as GNU/LINUX, GRASS GIS, and the Perl and R programming languages.

DDRP model data and parameters

Weather/climate data: Gridded weather and climate data may include PRISM, NWS National Digital Forecast Database (NDFD), Daymet, and extended forecasts from the North American Multi-model Ensemble (NMME).

Developmental thresholds and degree day parameters: Upper and lower temperature thresholds and number of degree days for different life stages (egg, larvae, pupae, adult), and degree days at which stage-specific pest events occur (e.g., first adult flight, first egg laying).

Climate stress parameters (optional): Chill and heat stress temperature thresholds and stress unit limits can be supplied to model climate suitability. Stress units accumulate when daily temperatures exceed defined thresholds. Moderate and severe stress limits can depict a zone of uncertainty, or temporary vs. long-term establishment.

DDRP features and highlights

- Intended to serve as a relatively easy-to-parameterize platform for many IPM, invasive, and biocontrol species
- Uses NMME 7-month climate forecasts
- New multiple cohorts feature, in which overwintering insects can emerge across a time span rather than at a single time point
- Output maps include proportion of each life stage and generations present, voltinism, real-time climate exclusion, and phenological/pest event maps (Figs. 1 and 2)
- Option for photoperiod response to trigger diapause (Fig. 3)

Table 1. Species currently running or in development to run on the DDRP modeling platform. Model products will assist CAPS and US DoD SERDP with planning and survey activities across space and time.

Species	Common Name	Project	Status
Agrilus planipennis	Emerald ash borer	CAPS	In devel.
Anoplophora glabripennis	Asian longhorned beetle	CAPS	Running
Autographa gamma	Silver Y moth	CAPS	Running
Chilo suppressalis	Asiatic rice borer	CAPS	In devel.
Cryptoblabes gnidiella	Christmas berry webworm	CAPS	In devel.
Dendrolimus pini	Pine-tree lappet moth	CAPS	Running
Epiphyas postvittana	Light brown apple moth	CAPS	Running
Eurygaster integriceps	Sunn pest	CAPS	In devel.
Helicoverpa armigera	Old world bollworm	CAPS	Running
Monochamus alternatus	Japanese pine sawyer beetle	CAPS	Running
Neoleucinodes elegantalis	Small tomato borer	CAPS	Running
Platypus quercivorus	Oak ambrosia beetle	CAPS	Running
Spodoptera littoralis	Egyptian cottonworm	CAPS	In devel.
Spodoptera litura	Common or cotton cutworm	CAPS	Running
Thaumatotibia leucotreta	False codling moth	CAPS	Running
Tuta absoluta	Tomato leaf miner	CAPS	In devel.
Aphalara itadori	Japanese knotweed psyllid	SERDP	Running
Galerucella calmariensis	Black-margined loosestrife beetle	SERDP	Running
Diorhabda carinulata	Northern tamarisk beetle	SERDP	Running

Applications for invasive pests

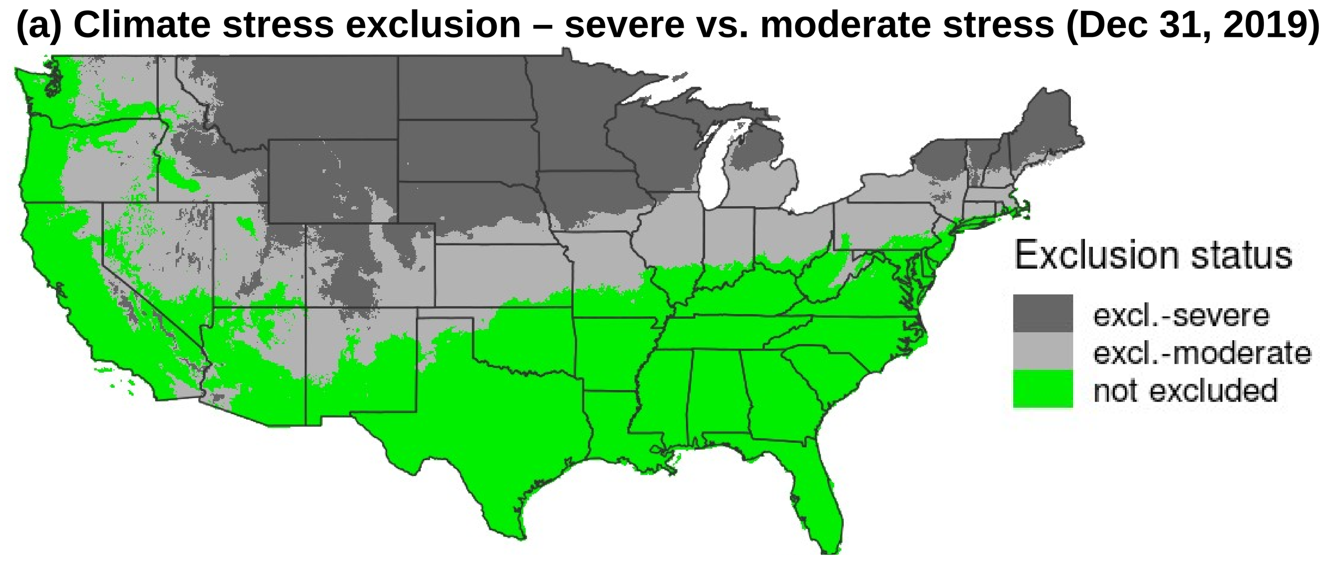
We are using the DDRP modeling platform in combination with CLIMEX climate suitability modeling to guide CAPS trapping programs for 16 insect species (Table 1).

Example: *Helicoverpa armigera* (old world bollworm)
Establishment of old world bollworm, *H. armigera*, in the US could result in significant economic losses. It can attack more than 180 plant species, including corn, cotton, small grains, soybean, peppers, and tomatoes. *H. armigera* was detected in Puerto Rico in 2014 and Florida in 2015. Hybridization between *H. armigera* and *H. zea* in South America is an additional threat.

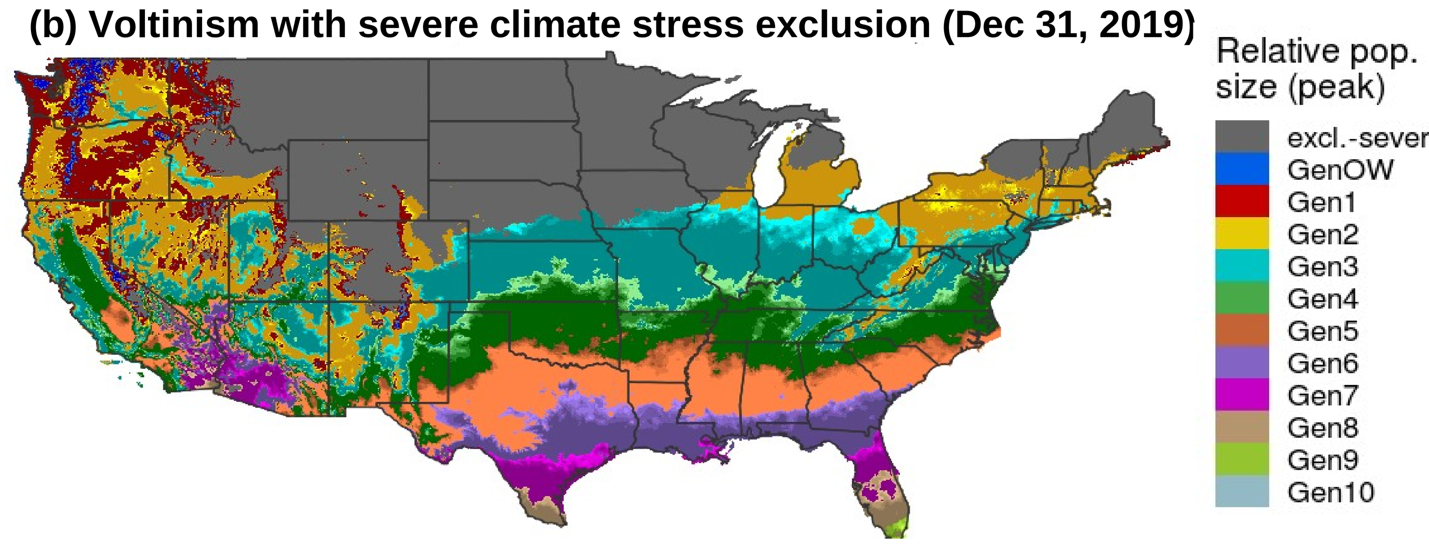
DDRP output maps for *H. armigera* in 2019 predict that unsuitable climate conditions may exclude the species from several northern states, although the extent of stress exclusion depends on user-defined stress unit limits (Fig. 2a). A voltinism map predicts up to 10 generations by the end of the year (Fig. 2b). A pest event map depicts first flight of the overwintering generation as early as Jan/Feb (Florida) to as late as Oct/Nov (Pacific Northwest; Fig. 2c).

Fig. 2. DDRP output maps for old world bollworm, *Helicoverpa armigera*, for 2019.

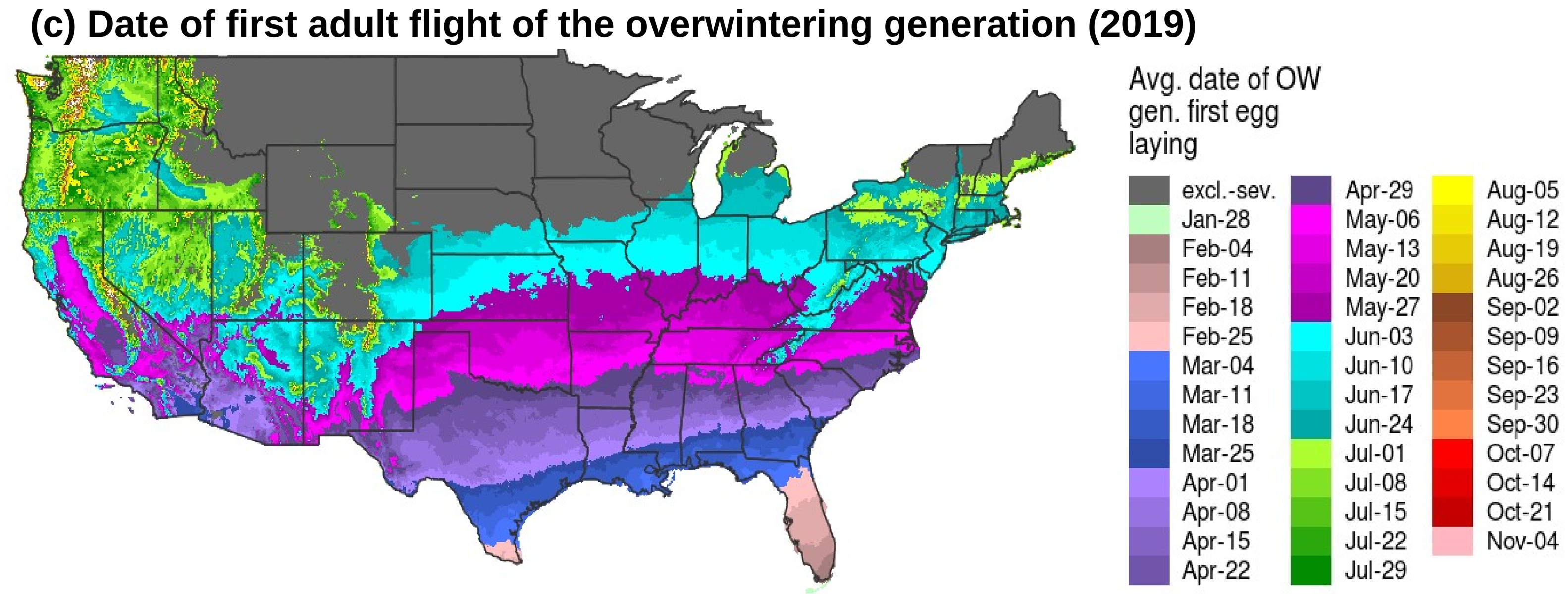
(a) Climate stress exclusion – severe vs. moderate stress (Dec 31, 2019)



(b) Voltinism with severe climate stress exclusion (Dec 31, 2019)



(c) Date of first adult flight of the overwintering generation (2019)



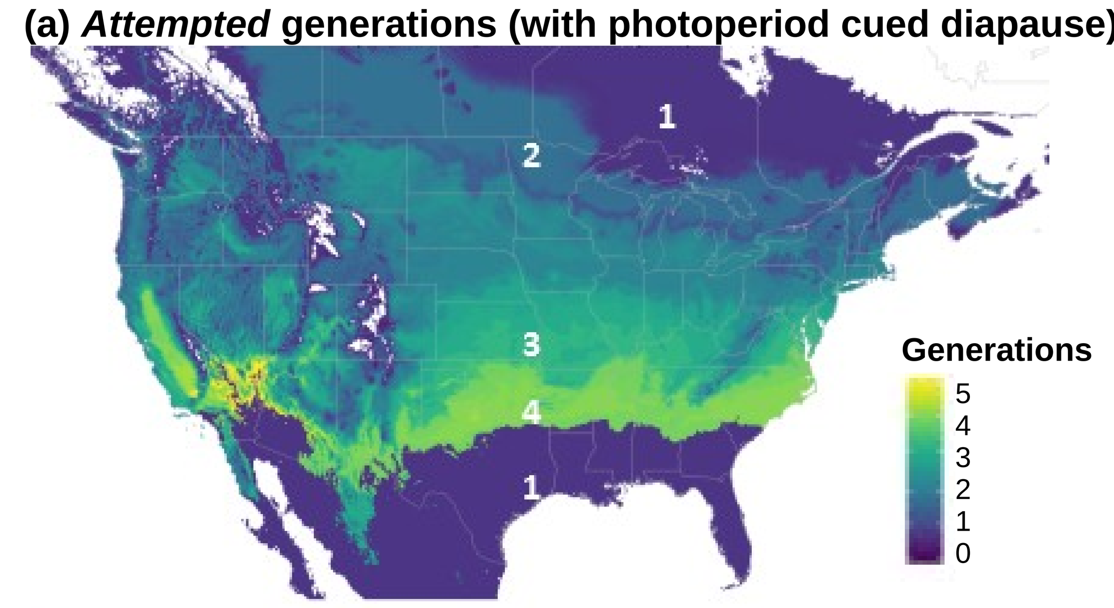
Applications for biocontrol

The DDRP model for the US DoD SERDP, which incorporates photoperiod-induced diapause parameterized by lab experiments, predicts voltinism and phenology match of three biocontrol agents (Table 1) introduced to attack invasive Japanese knotweed, purple loosestrife, and tamarisk.

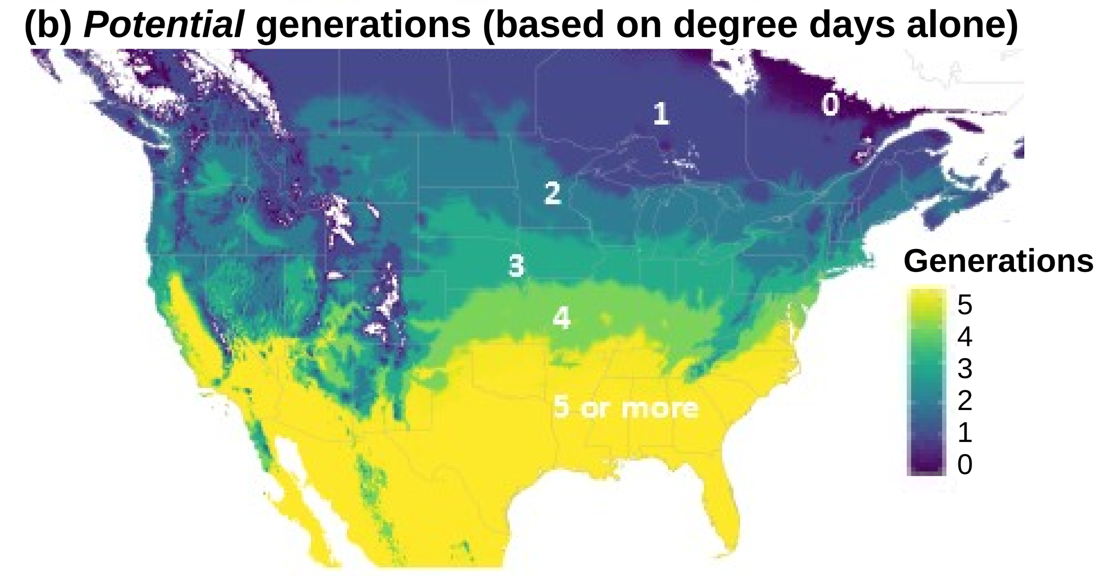
Example: *Aphalara itadori* (Japanese knotweed psyllid)
We compared 2017 maps of the number of expected *attempted* generations (given the photoperiod response, Fig. 3a) to the number of *potential* generations (based on degree days, Fig. 3b) for the Japanese knotweed psyllid, *A. itadori*, which is under review for a introduction to the US. The degree of mismatch (= *attempted* minus *potential* generations) is shown in Fig. 3c. The psyllid, with a photoperiod response adapted to its native Japan, is likely to attempt the correct number of generations across much of the northern states where knotweed is a problem, but may attempt one too many generations is some northern regions and too few generations in southern regions (Fig. 3c)

Fig. 3. Maps of voltinism modeled for the Japanese knotweed psyllid, *Aphalara itadori*, for 2017.

(a) *Attempted* generations (with photoperiod cued diapause)



(b) *Potential* generations (based on degree days alone)



(c) Degree of mismatch (*attempted - potential*)