Spotted Lanternfly (Lycorma delicatula) Phenology/Degree-Day and Climate Suitability Model Analysis – Feb 2024

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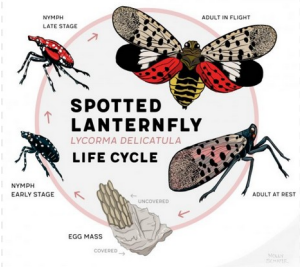
Hosts: tree of heaven (*Ailanthus* spp.), many commercial perrenials including wine grapes, tree fruits, black walnut, willow, etc.

Goal: Develop a phenology model and temperature-based climate suitability model using available literature and weather data analysis

Adult

Nymphs



Life cycle diagram

Key stages: 1. Egg Hatch 2. Early nymph - appearance of second or third instar. 3. 1st emergence of adults

Thresholds, degree-days, events and climate suitability params used in spotted lanternfly model:

Parameter abbr.	Description	degF	degC	DDF	DDC
eggLDT	egg lower dev threshold	50.0	10.00	-	-
eggUDT	egg upper dev threshold	95.0	35.0	-	-
larvaeLDT	larvae lower dev threshold	50.0	10.00	-	-
larvaeUDT	larvae upper dev threshold	95.0	35.0	-	-
pupaeLDT	pupae lower dev threshold	50.0	10.00	-	-
pupaeUDT	pupae upper dev threshold	95.0	35.0	-	-
adultLDT	adult lower develpmental threshold	50.0	10.00	-	-
adultUDT	adult upper dev threshold	95.0	35.0	-	-
eggDD	duration of egg stage in spring in DDs	-	-	364	202
larvaeDD	duration of 1st through 4th instars in DDs	-	-	1602	890
pupaeDD	duration of pre-oviposition period in DDs	-	-	1134	630
adultDD	duration of adult stage from 1st to 50% OV in DDs	-	-	263	146
OWeggDD	DDs until OW egg first hatch	-	-	varies	varies
OWEventLabel	egg hatch	-	-	-	-
eggEventDD	DDs into egg stage when diapause begins	-	-	180	100
eggEventLabel	diapausing eggs	-	-	-	-
larvaeEventDD	DDs until approx midpoint of nymphal development	-	-	796	442
larvaeEventLabel	nymphs halfway developed	-	-	-	-
pupaeEventDD	DDs until first adults	-	-	2	1
pupaeEventLabel	first adults	-	-	-	-
adultEventDD	DDs until first egg laying	-	-	2	1
adultEventLabel	first egg laying	-	-	-	-
coldstress_threshold	cold stress threshold	3.2	-16	-	-
coldstress_units_max1	cold stress degree day limit when most individuals die	-	-	540	300
coldstress_units_max2	cold stress degree day limit when all individuals die	-	-	855	475
heatstress_threshold	heat stress threshold	98.6	37	-	-
heatstress_units_max1	heat stress degree day limit when most individuals die	-	-	207	115
heatstress_units_max2	heat stress degree day limit when all individuals die	-	-	315	175
distro_mean	average DDs to OW egg first hatch	-	-	342	190
distro_var	variation in DDs to OW egg first hatch	-	-	27000	15000
xdist1	minimum DDs (°C) to OW egg first hatch	-	-	180	135
xidst2	maximum DDs (°C) to OW egg first hatch	-	-	648	360
distro_shape	shape of the distribution	-	-		normal

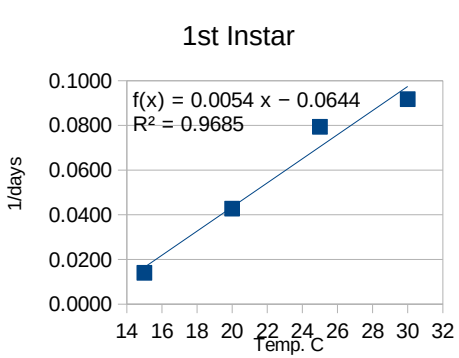
PHENOLOGY MODEL ANALYSIS

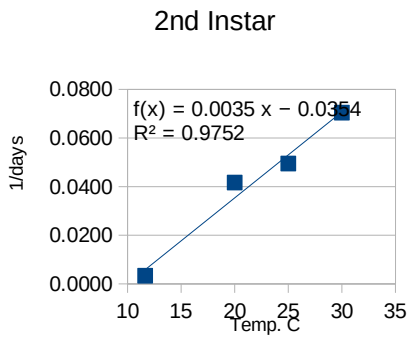
Phenology Model Summary:

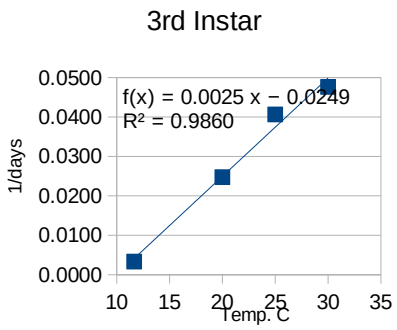
Model for uspest.org/dd/model_app		
Spotted lanternfly degree-day model parameters:		
start date: Jan 1st (nominal)		
Calc. method: single sine		
	Celsius/DD (C)	Fahr. /DD (F)
Lower threshold:	10	50
Upper threshold:	35	95
First Egg hatch	202	364
Peak Egg hatch	279	503
Peak first instars	375	674
Peak second instars	541	974
Peak third instars	726	1307
Peak fourth instars	991	1784
First Adults	1045	1881
Peak Adults	1463	2633
First egg-laying	1675	3015
Peak egg-laying	1821	3278

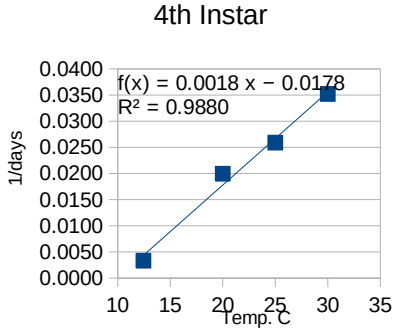
Sources: 1. Kreitman, D. M., A. Keena, A. L. Nielsen, and G. Hamilton. 2020. Effects of temperature on development and survival of nymphal *Lycorma delicatula*. Env. Entomol. 50:183-191.

Table 2.	L1=1st Instar			L2=2nd Instar			L3=3rd Instar			L4=4th Instar	females only	
Temp. C	1/days L1	Days L1	Temp. C	1/days L2	Days L2	Temp. C	1/days L3	Days L3	Temp. C	1/days L4	Days L4	
	0.0033	300	11.642	0.0033	300	11.649	0.0033	300	12.444	0.0033	300	
15	0.0140	71.3	15			15			15		85.5	
20	0.0427	23.4	20	0.0417	24	20	0.0248	40.4	20	0.0200	50.1	
25	0.0794	12.6	25	0.0495	20.2	25	0.0407	24.6	25	0.0259	38.6	
30	0.0917	10.9	30	0.0704	14.2	30	0.0476	21	30	0.0352	28.4	
intercept	-0.0644			-0.0354			-0.0249			-0.0178		sum L1-4
slope	0.0054			0.0035			0.0025			0.0018		
1/slope	185			283			401			562		1431
-b/a	11.94			10.00			10.00			10.00		
R-SQ	0.968			0.975			0.986			0.988		





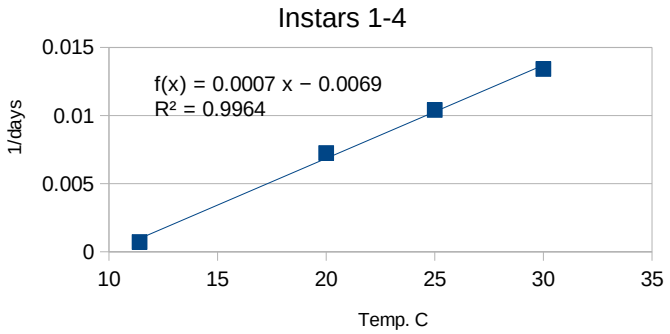




Nymphs (L1-4 total)

Temp. C	1/days L1-4	Days total
11.409	0.000714286	1400
15		NA
20	0.007251632	137.9
25	0.010416667	96
30	0.013422819	74.5
35		NAS

Intercept	-0.0069
Slope	0.0007
1/slope	1459
-a/b	10.000
R-SQ	0.996



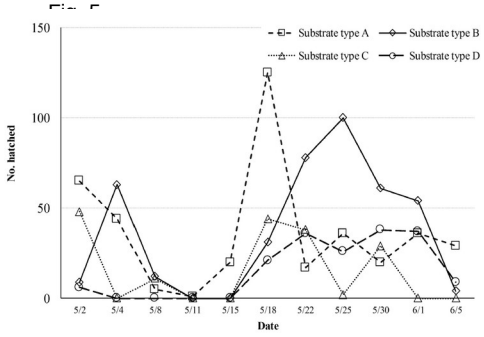
Results: A lower developmental threshold of 10C appears to provide an excellent fit to the data, with R-sq values ranging from 0.96 – 0.99 for instars 1-4. Associated Degree-days for development were 213, 283, 401, 562, and 1,459 for instars 1, 2, 3, 4, and for instars 1-4 total. However, as Maino et al. 2021 pointed out, these development times are too slow compared to other works, including the several studies that tracked development in the field. Therefore, these development times in DDs are not usable.

2. Liu, H. 2019. Oviposition substrate selection, egg mass characteristics, host preference, and life history of the spotted lanternfly (Hemiptera: Fulgoridae) in North America. Env. Entomol. 48:1452-1468.

- Study sites in Banks Co., Pennsylvania 2016-17
- Seasonal development site known as OD South, weather station DW9872 (5m NE of Oley, SW of Allentown, PA), 2017
- S1DD10 = single sine DDs 10C lower threshold

From Table 5&Fig 7. Life history table and degree-days Station D9872, 2017

Stage	Date	ADDs10CJan ca. from Table	ADDs10CJan Elev 427 ft uspest rerun	Elev 427 ft S1DD10C Jan1	nearby stations to compare Comp. E3190 Reading PA Elev 1115 ft S1DD10CJan	Comp. C3157 Boyertown PA Elev 689 ft S1DD10CJan1
First Egg hatch	05/01/17	160	144	189	147	178
Peak egg hatch	05/15/17		178	232	173	216
End egg hatch	06/05/17	340	325	381	306	358
First L1	05/02/17	160	153	198	153	187
Peak L1	06/05/17		325	381	306	358
End L1	07/03/17	738	644	707	620	678
First L2	06/08/17		338	397	319	373
Peak L2	06/22/17		512	574	493	546
End L2	07/20/17	900	881	939	836	902
First L3	06/25/17	600	558	616	529	584
Peak L3	07/06/17		682	745	654	715
End L3	07/31/17	1050	1020	1078	962	1037
First L4	07/10/17		738	796	701	763
Peak L4	07/31/17	1050	1020	1078	962	1037
End L4	08/20/17		1251	1309	1183	1259
First Adult	07/20/17	900	881	939	836	902
Peak Adult	08/22/17		1265	1331	1211	1286
End Adult	11/15/17		1795	1878	1712	1811
First oviposition	10/01/17	1644	1620	1682	1543	1627
Peak oviposition	10/22/17	1795	1755	1828	1679	1764
End oviposition	10/31/17		1778	1858	1699	1792



Site Model CALIB 2 sta D9872	days diff
05/04/17	3
05/20/17	5
06/05/17	0
06/20/17	-2
07/05/17	-1
07/24/17	-7
07/28/17	8
09/09/17	18
09/29/17	-2
10/21/17	-1

Results: With 1 location year, rather complete phenology data that should carry more weight perhaps vs. Murman et al. Data. The suggested weather station was D9872, which was warmer than two other nearby weather stations (that are at slightly higher elevations). Weight: 1.0

3. Nixon, L.J., H. Leach, C. Barnes, J. Urban, et al. 2020. Development of behaviorally based monitoring and biosurveillance tools for the invasive spotted lanternfly (Hemiptera: Fulgoridae). Environ. Entomol. 49: 1117-1126.

- Primarily testing new traps and attractants; work done in Virginia and Pennsylvania

Location 1: A community park in Winchester, VA (39°12′22″N, 78°9′18″W): uspest.org station E8890 or KOKV
Location 2: A memorial park in Reading, PA (40°20′50.3″N, 75°54′08.1″W): uspest.org station E3190
Note: KOKV is much cooler than most all stations surrounding it – better to use E8890 & E5449 (average) as representative of the area

From Fig. 5. Stages present in VA and PA 2019

Stage	VA Date	Elev 728 ft KOKV S1DDs10CJa	Elev 823 ft E8890 S1DDs10CJa	Elev 666 E5449 S1DDs10CJa	PA Date	Elev 1115 ft E3190 S1DDs10CJa	extra col. To match weight	Average KOKV&E3190	Average E8890&E5449&E3190
First L1	05/10/19	252	280	321	05/28/19	270	270	261	285
Peak L1	05/23/19	336	369	422	06/05/19	338	338	337	367
End L1	06/07/19	497	532	607	07/02/19	620	620	559	595
First L2	05/24/19	348	380	436	06/06/19	350	350	349	379
Peak L2	06/06/19	486	521	594	06/19/19	462	462	474	510
End L2	06/22/19	649	686	784	07/12/19	754	754	702	745
First L3	06/15/19	561	597	683	06/15/19	418	418	490	529
Peak L3	06/28/19	728	766	873	07/03/19	634	634	681	727
End L3	07/10/19	899	940	1060	07/27/19	962	962	931	981
First L4	07/04/19	818	854	971	07/10/19	729	729	774	821
Peak L4	07/12/19	927	969	1090	07/21/19	887	887	907	958
End L4	08/01/19	1216	1262	1408	08/28/19	1375	1375	1296	1355
First Adult	07/23/19	1104	1144	1279	08/01/19	1035	1035	1070	1123
Peak Adult	08/15/19	1400	1452	1619	08/27/19	1365	1365	1383	1450
End Adult	11/02/19	2075	2137	2389	11/08/19	1788	1788	1932	2026

Site model calib 2
Sta E5449

VA	PA	days diff VA	days diff PA
04/27/19	05/20/19	-13	-8
05/19/19	06/09/19	-4	4
06/01/19	06/26/19	-5	7
06/18/19	07/10/19	-10	7
07/06/19	07/29/19	-6	8
07/10/19	08/02/19	-13	1
08/05/19	09/07/19	-10	11

Results: With two site-years that are rather similar as to DD totals for each stage, average results are in good accord with other studies. Weight: 1.0

4. Murman, K., G. Setliff, et al. 2020. Distribution, survival, and development of spotted lanternfly on host plants found in North America. Env. Entomol. 49: 1270-1281.
Accessing supplemental material from:
https://oup.silverchair-cdn.com/oup/backfile/Content_public/Journal/ee/49/6/10.1093_ee_nvaa126/1/nvaa126_suppl_supplementary_material.pdf?

- Compared host preference and other traits between tree of heaven and other hosts, Burks Co, PA 2015-2016
- Phenology not major objective, so dates at least for 2015 are very approximate, much better for 2016

Stage	Approx Date 2015	C3157 ADDs10CJan uspest rerun	C3157 Boyertown PA S1DDs10CJa	Date 2016	C3157 ADDs10CJan uspest rerun	C3157 Boyertown PA S1DDs10CJa	2017	C3157 ADDs10CJan uspest rerun	C3157 Boyertown PA S1DDs10CJa	Average S1DDs10CJan1
First Egg hatc	05/15/15	169	200	05/23/16	148	215				208
Peak egg hatch				06/05/16	303	370				370
End egg hatch										
First L1	05/15/15	169	200	05/23/16	148	215				208
Peak L1	06/12/15	411	447	06/08/16	329	397				422
End L1				07/15/16	759	830				830
First L2	06/12/15	411	447	06/07/16	326	393				420
Peak L2	06/25/15	574	610	06/29/16	555	623				617
End L2				07/30/16	972	1048				1048
First L3	07/01/15	629	665	06/26/16	521	590				628
Peak L3	07/10/15	735	771	07/12/16	715	785				778
End L3	07/20/15	860	897	08/06/16	1059	1136				1017
First L4	07/15/15	795	832	07/08/16	667	737				785
Peak L4	08/02/15	1021	1058	07/26/16	913	989				1024
End L4				08/14/16	1177	1256				1256
First Adult	08/15/15	1167	1203	07/25/16	898	974	07/17/17	798	856	1011
Peak Adult							08/08/17	1060	1120	

Results: Degree-day accumulations generally agree well with Liu 2019 study. Weight: 0.7

Site model CALIB 3

2015	2016	2017	days diff 2015	days diff 2016	days diff 2017
05/16/15	05/20/16		1	-3	
05/26/15	05/29/16			-7	
06/06/15	06/06/16		-6	-2	
06/20/15	06/22/16		-5	-7	
07/07/15	07/08/16		-3	-4	
07/28/15	07/26/16		-5	0	
08/01/15	07/30/16	08/01/17	-14	5	15
09/05/15	08/29/16	09/16/17			39

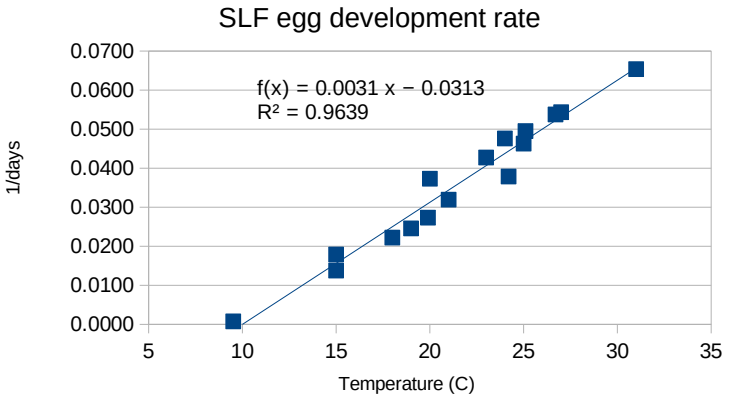
5. Smyers, E. C., J. M. Urban, A. C. Dechaine, et al. 2021. Spatio-temporal model for predicting spring hatch of the spotted lanternfly (Hemiptera: Fulgoridae). Env. Entomol. 50:126-137.
- collected eggs from field and reared at constant temperatures, built model and compared to field hatch data. Found Tlow of 10.4 C from all data combined.

From Table 2 Temperature vs. time to egg hatch for PA and two Korean populations

A) First Lump them all in one group:

	Temp C	1/days	Days to hatch
forcing point	9.513	0.0008	1299
PA	19.9	0.0273	36.6
	24.2	0.0379	26.4
	25.1	0.0495	20.2
	26.7	0.0538	18.6
Park (K1)	15	0.0138	72.6
	18	0.0222	45
	19	0.0246	40.7
	21	0.0319	31.3
	23	0.0427	23.4
	24	0.0476	21
	27	0.0543	18.4
	31	0.0654	15.3
Choi (K2)	15	0.0179	55.9
	20	0.0373	26.8
	25	0.0463	21.6

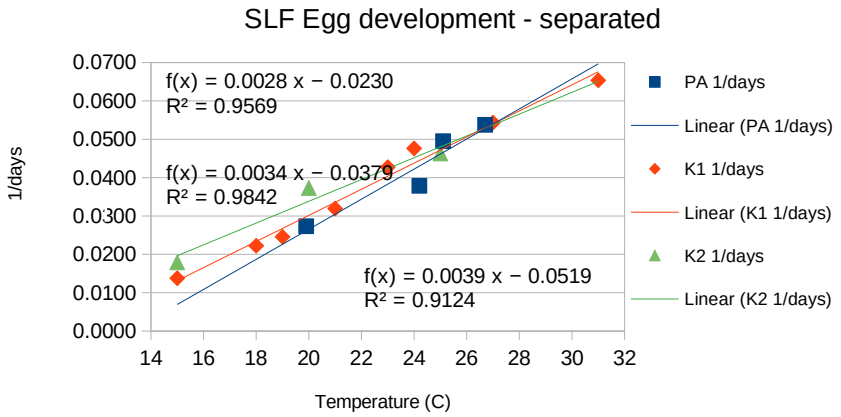
intercept	-0.0313
slope	0.0031
R-sq	0.9639
1/slope	320
-b/a (x-intercept)	10.000



Results: The three sources combine well (R-SQ=0.96); 10 C is a good lower threshold for the combined data (with 1 forcing point), resulting in 320 DD for egg hatch.

B) Second: compare separately with no forcing of x-intercept:

	Temp C	PA 1/days	K1 1/days	K2 1/days	Days to hatch
PA	19.9	0.0273			36.6
	24.2	0.0379			26.4
	25.1	0.0495			20.2
	26.7	0.0538			18.6
Park (K1)	15		0.0138		72.6
	18		0.0222		45
	19		0.0246		40.7
	21		0.0319		31.3
	23		0.0427		23.4
	24		0.0476		21
	27		0.0543		18.4
	31		0.0654		15.3
Choi (K2)	15			0.0179	55.9
	20			0.0373	26.8
	25			0.0463	21.6
					Average
intercept		-0.0519	-0.0379	-0.0230	-0.03758982
slope		0.0039	0.0034	0.0028	0.003388317
R-sq		0.9124	0.9842	0.9569	0.951158861
1/slope		255.1	293.8	352.0	300.3
-b/a (x-interce		13.2	11.1	8.1	10.8



Results: Individual and the average of the three unforced regression parameters do not differ greatly from the combined (forced) model, with averaged Tlow of 10.8 and 300 DD. Also the strongest data set (Park K1) has a Tlow of 11.1 and 294 DD. These DD values are high compared to the field data (see next). Perhaps they were brought into the lab before diapause was complete?

2) Field data: observed egg hatch near Oley, PA 2017 N=35 observation dates, and near Winchester, VA 2019 N=8 observation dates.
Methods: extract ADD10.4 values from Fig.s 2b and 3b, use nearby weather for each location year to estimate dates of events, then calculate S1DD10 values on those dates.
ADD10.4 = simple average DD with 10.4C lower threshold S1DD10 = Single sine DD with 10C lower threshold

		Oley, PA 2017 (station E5860 elev 384 ft)					Winchester, VA (station E5449 elev 666 ft)					Avg PA&VA	Site Model Calib 3 sta		days diff
			rough approx					rough approx					E5860	E5449	
Percent hatch	DOY	Date	ADD10.4Jan1 (Fig. 2)	ADD10Jan1	S1DD10Jan1	DOY	Date	ADD10.4Jan1 (Fig. 3)	ADD10Jan1	S1DD10Jan1	**S1DD10Jan1**	PA	2017	2019	PA 2017
2	118	05/01/17	152	168	213	124	04/30/19	155	171	223	218		04/30/17	04/27/19	-1
10	122	05/05/17	165	182	231	127	05/04/19	192	213	265	248				
20	131	05/16/17	190	208	264	128	05/06/19	205	229	281	273				
50	139	05/23/17	245	270	327	134	05/07/19	220	239	291	309		05/18/17	05/06/19	-5
75	148	05/28/17	280	305	362	138	05/09/19	238	257	309	336				
90	151	06/01/17	305	334	391	142	05/15/19	260	281	336	364				
98	158	06/10/17	365	398	456	146	05/24/19	345	394	436	446				

Results: With 2 location years, and fairly complete sampling of egg hatch, first hatch (ca. 2%) averaged 218 DD (Single sine Tlow 10C, start date Jan 1).
With 50 and ca. 98% hatch at 309 and 446 DD, respectively. Weight: 1.0

days diff VA 2019
-3
-1

6. Dechaine et al. 2021. Phenology of *Lycorma delicatula* (Hemiptera: Fulgoridae) in Virginia, USA. Environ. Entomol.50:1267-1275.
- used KOKV weather station; already determined that this station tends to be "cooler" than most other nearby stations for unknown reasons
- Also E8890, also nearby and perhaps more representative of the area.

From Fig. 3 and as reported in results:

		Checking:	Using:		Checking:	Using:	Average	Site model calib 3 Sta E8890		Sta E8890	
	Approx Date	KOKV ADDs10CJan	E8890 Winchester VA		KOKV ADDs10CJan	E8890 Winchester VA	2019 & 2020	2019	2020	2019	2020
Stage	2019	uspest rerun	S1DDs10CJan1	2020	uspest rerun	S1DDs10CJa	S1DDs10CJa	VA	VA	VA	VA
First Egg hatch	05/01/19		199	05/07/20		190	195	05/02/19	05/14/20	1	7
Peak egg hatch	05/08/19		260	05/16/20		228	244	05/10/19	05/25/20	2	9
End egg hatch	05/16/19		300	06/01/20		354	327				
First L1	05/01/19	135	199	05/11/20	112	195	197				
Peak L1	05/16/19		300	05/28/20		320	310	05/24/19	06/03/20	8	6
End L1	06/02/19		488	06/10/20		469	479				
First L2	05/20/19	300	348	05/16/20	129	228	288				
Peak L2	06/03/19		493	06/10/20		469	481	06/08/19	06/19/20	5	9
End L2	06/19/19		653	07/04/20		757	705				
First L3	06/02/19	413	488	06/05/20	304	408	448				
Peak L3	06/21/19		678	06/29/20		685	682	06/26/19	07/03/20	5	4
End L3	07/09/19		925	07/20/20		1013	969				
First L4	06/26/19	649	736	06/29/20	566	685	711				
Peak L4	07/10/19		940	07/15/20		925	933	07/14/19	07/19/20	4	4
End L4	08/03/19		1291	08/14/20		1386	1339				
First Adult	07/09/19	835	925	07/20/20	887	1013	969	07/17/19	07/22/20	8	2
Peak Adult	09/05/19		1714	09/15/20		1764	1739	08/16/19	08/21/20	-20	-25
End Adult	11/06/19		2141	11/04/20		1988	2065				
First oviposition	09/11/19	1634	1785	09/15/20	1612	1764	1775	09/02/19	09/07/20	-9	-8

Results: In accord with most other studies. 195, 244, and 327 Dds from Jan1 for 1st, peak, and end of egg hatch. Other stages also in good accordance. Weight: 1.0

7. Leach, H. and A. Leach 2020. Seasonal phenology and activity of spotted lanternfly (Lycorma delicatula) in eastern US vineyards. J. Pest Sci. 93:1215-1224.

- sampled vineyards around Kutztown, PA mostly in 2019.

From Fig. 2 and as reported in results:	estimated Approx Date	Using: D6615 Breinigsville SSDD10CJan1	Site model calib 3 Sta D6615 PA 2019	days diff
Stage	2019			
First Egg hatch	05/10/19		05/10/19	0
Peak egg hatch	06/01/19	385	05/22/19	-10
End egg hatch				
First L1	05/23/19	290		
Peak L1	06/07/19	440	05/31/19	-7
End L1	06/22/19	586		
First L2	06/10/19	467		
Peak L2	06/19/19	552	06/19/19	0
End L2	06/29/19	680		
First L3	06/29/19	680		
Peak L3	07/01/19	705	07/03/19	2
End L3	07/13/19	878		
First L4	06/29/19	680		
Peak L4	07/18/19	953	07/21/19	3
End L4	08/05/19	1215		
First Adult	08/12/19	1300	07/24/19	-19
Peak Adult	09/14/19	1680	08/24/19	-21
End Adult	11/02/19	1971		

Results: perhaps weigh these results at 0.5 due to one site-year and imprecise graphics

8. Laveaga, E.. 2022. Developmental and mortality rate of spotted lanternfly (Hemiptera: Fulgoridae) on grapevines and tree of heaven. M.S. Thesis. Penn. St. Univ. 83 pp.

- compare development rates on tree of heaven (TOH) vs. wine grapes alone and together
- did not post actual raw data so may be difficult to use results
- nearest weather station in uspest.org database is AR986, Macungie, PA **(**ca 6 km from Alburtis, PA where studies were conducted**)**
- studies in Alburtis, PA conducted between May-Nov 2021
- field collected egg masses were chilled then hatched then placed in treatment cages
- Degree-day calculation methods were as follows: used different thresholds for each instar according to Kreitman et al. 2020 data: 12, 12.43, 8.48, 6,29 for instars 1-4. Modified simple avg method: so they substituted lower threshold instead of daily min temp in the simple avg formula. Dds for each instar using these different thresholds were then added together (??).
- DDs for adult oviposition used Tlow of 10.4, simple average method. - so error for this stage should be minor and results can be re-analyzed

- Results for nymphal development are therefore not usable and cannot be reconstructed from the thesis
- Results for pre-oviposition should be somewhat usable but will have error and biases that cannot be entirely corrected or estimated

- Pre-oviposition results were: range 30-50 days, 250-500 DD **(**average DDs, Tlow=10.4C**)**
- Range of dates for this study not provided. Perhaps try reconstructing Single sine DDs using start dates that best match average results (42 days = 365 DD)

	From Fig. 2-6: Combined TOH, TOH+Cabernet Franc, TOH+Concord			Sta: AR986	Pre-oviposition period: Use Avg Dds Tlow = 10.4 to find interval close to 365 Dds, then Re-calculate using uspest.org standard of Single Sine (S1) Dds, Tlow = 10.0					
	Average	Lower percentile	Upper percentile		DdsAug30-Oct10		DdsAug31-Oct11		DdsSept1-Oct12	
					AvgDDs10.4C	S1DDs10.0C	AvgDDs10.4C	S1DDs10Jan1	AvgDDs10.4C	S1DDs10.0C
Days	42.5	38	49		374	394	366	385	358	377
DD10.4 C	365	335	440							

Results: The modified estimate for pre-oviposition is calculated as 385 DD (Tlow=10C, single sine)

Other references not used in phenology model analyses:

- Maino, J.L, et al. 2021. Mapping the life history, development, and survival of spotted lanternfly in occupied and uninvaded areas. Biol. Invasions 24:2155-2167
- Used Kreitman results but re-scaled them to match development rates observed by Park et al (2009).
- Fitted Briere non-linear models to Kreitman and other data sources. Is this approach appropriate for modeling using daily average temperatures?
- Results may not be usable but perhaps could be compared to our modeling results

- Elsensohn, J., et al. 2023. Development and survivorship of Lycorma delicatula on cultivated and native Vitis spp. of the Eastern US. J. Econ. Entomol. 116:2207-2211.
- Development in cages at ambient temperatures; duration in days reported but not dates so cannot reconstruct degree-day results

9. Combine and compare results from above studies

1) Overall development results. All values in Dds using Tlow=10C after Jan 1st; single sine method used for field data

Source:	2. Liu 2019	3. Nixon et al.	4. Murman et	5. Smyers et a	6. Dechaine e	7. Leach&Leach							**Site model**
Locations:	PA 2017	VA&PA 2019	PA 2015&201	VA2017&PA 2	VA 2019&202	PA 2019							**CALIB3**
weight (peak egg hatch)	1			1	1	0.5	**unweighted**			**weighted**	**Revised**	**Estimated**	**avg diff**
Stage	**1 site year**	**2 site years**	**2 site years**	**2 site years**	**2 site years**	**1 site year**	**Average**	**St. Dev.**	**C.V.**	**Average**	**Oviposition**	**1st to 50% OV**	**days**
First Egg hatch	189		208	218	195		202	13.1	6.5	202			-1.89
Peak egg hatch	232			309	244	385	293	70.3	24.0	279			-1.00
End egg hatch	381			446	327		385	59.6	15.5	385			
weight (1st L1 to 1st adult)	1	1	0.7		1	0.5							
First L1	198	285	208		197	290	236	47.7	20.3	231			
Peak L1	381	367	422		310	440	384	50.9	13.3	375			-0.13
End L1	707	595	830		479	586	639	133.8	20.9	632			
First L2	397	379	420		288	467	390	66.0	16.9	379			
Peak L2	574	510	617		481	552	547	53.2	9.7	541			0.25
End L2	939	745	1048		705	680	823	161.7	19.6	824			
First L3	616	529	628		448	680	580	91.6	15.8	565			
Peak L3	745	727	778		682	705	727	37.0	5.1	726			0.00
End L3	1078	981	1017		969	878	985	73.1	7.4	995			
First L4	796	821	785		711	680	758	60.0	7.9	766			
Peak L4	1078	958	1024		933	953	989	60.3	6.1	991			0.13
End L4	1309	1355	1256		1339	1215	1295	58.3	4.5	1307			
First Adult	939	1123	1011		969	1300	1068	147.1	13.8	1045			-0.78
Peak Adult	1331	1450	1120		1739	1680	1464	254.2	17.4	1463			-7.11
End Adult	1878	2026			2065	1971	1985	80.8	4.1	1985			
First oviposition	1682				1775		1682	65.4	3.9	1682	1675	146	-6.33
Peak oviposition	1828						1828			1828	1821		
End oviposition	1858						1858			1858	1858		

Notes: In PA sites, egg-laying is at very end of season – may need to lower the devel. threshold temp. for PreOV adults, otherwise temps could drop too quickly to allow egg-laying to happen or finish. Since these bugs sun themselves, likely they can utilize lower temps than 10C for pre-OV and egg-laying Consider this idea in further calibrations.

Results: Some stages with excellent concordance (low St. Dev. and C.V.), especially first egg hatch and first oviposition.
The oviposition estimates were revised to be more conservative – otherwise egg laying would not occur in much of the Northern US due to onset of cold temperatures in the fall.

2) Estimated stage Durations (Tlow=10C, DDs after Jan 1) using first to first and peak to peak vs. Kreitman lab results.

Stage	Cumulative Dds to first Event	Cumulative Dds to Peak Event	Estim. Stage Durations fro first to first	Estim. Stage Durations fro peak to peak	Average of first to first and peak to peak	Cumulative	1. Kreitman lab data	5. Smyers et a field→lab	8. Laveaga 2022 Field	
Egg	202	279	202	279	241	241		320		8.699095023
L1	231	375	148	166	157	398	185			
L2	379	541	186	185	186	584	283			462.4
L3	565	726	201	265	233	817	401			
L4	766	991	279	472	376	1192	562			
Total L1-L4	766	991	814	1088	890		1459			
Adults (pre OV)	1045	1463	637	365	630	1822			370	(range 168 (grapes) to 370 (Tree of Heaven))
Oviposition	1682	1828								
End oviposition	1858									

Results: These field results (Liu, Nixon, Murman, Smyers, Dechaine) are fairly similar with moderate C.V. values and representing a range of 4-9 site-years depending on stage.
These instar durations derived from first (Ln) to first (Ln+1) and peak to peak instars should be more useful than the lab findings of Kreitman et al.
For the pre-oviposition interval, we will use the average of peak 1st adult to peak 1st OV (365) and Laveaga results for TOH (370) as a conservative value (368 DD), but this estimate is in need of further study. First to 50% oviposition is estimated as 1828 (peak OV) minus 1728 (1st OV), equal to 100 DD

CLIMATE SUITABILITY MODEL

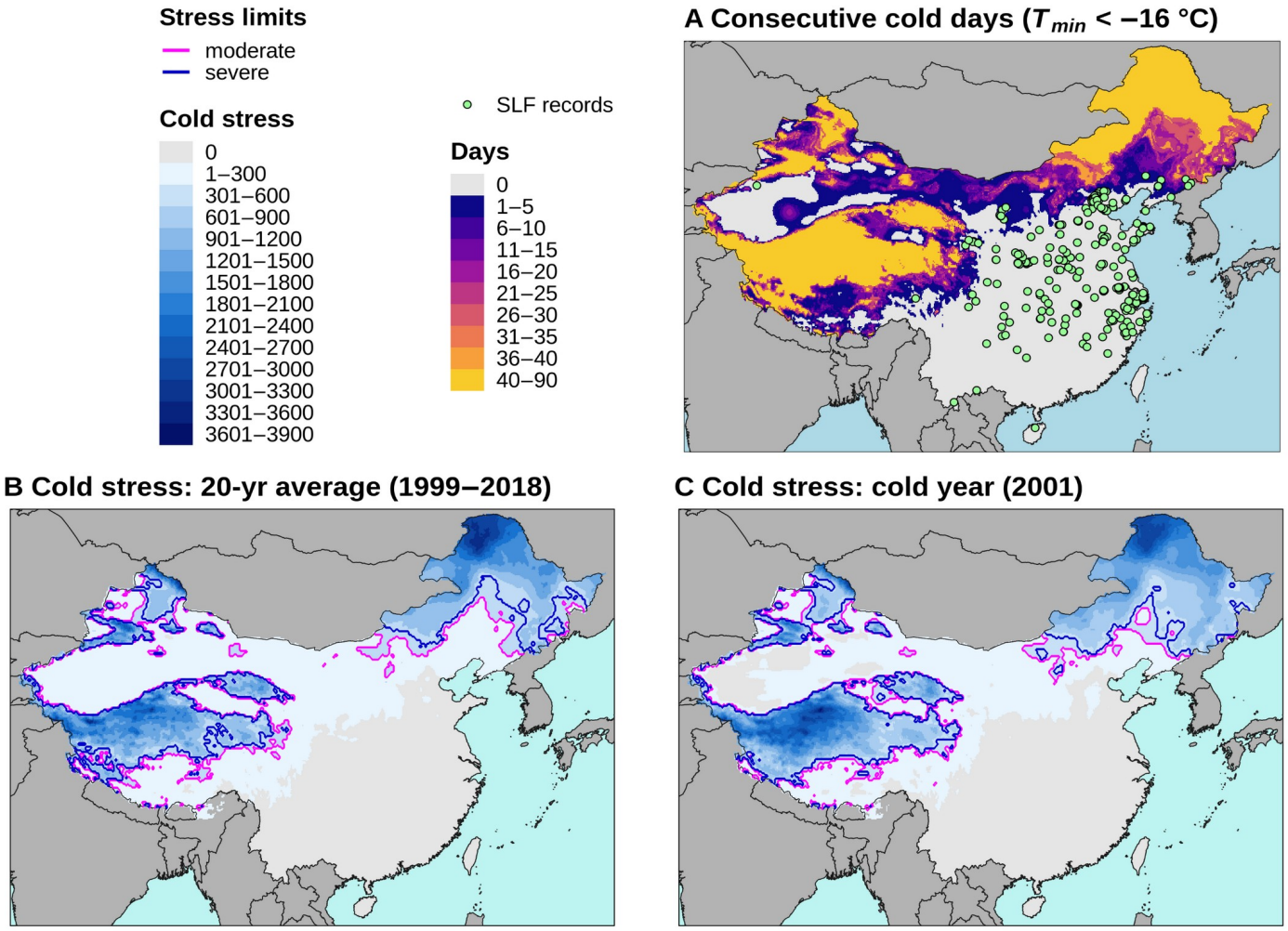
See white paper for a detailed description of methods used to develop the climate suitability model
Final parameters reported below

DDRP Cold Stress	Value	Units
cold stress threshold	-16	C
limit 1 (mod. cold stress)	300	DDC
limit 2 (sev. cold stress)	475	DDC

DDRP Heat Stress	Value	Units
heat stress threshold	37	C
limit 1 (mod. heat stress)	115	DDC
limit 2 (sev. heat stress)	175	DDC

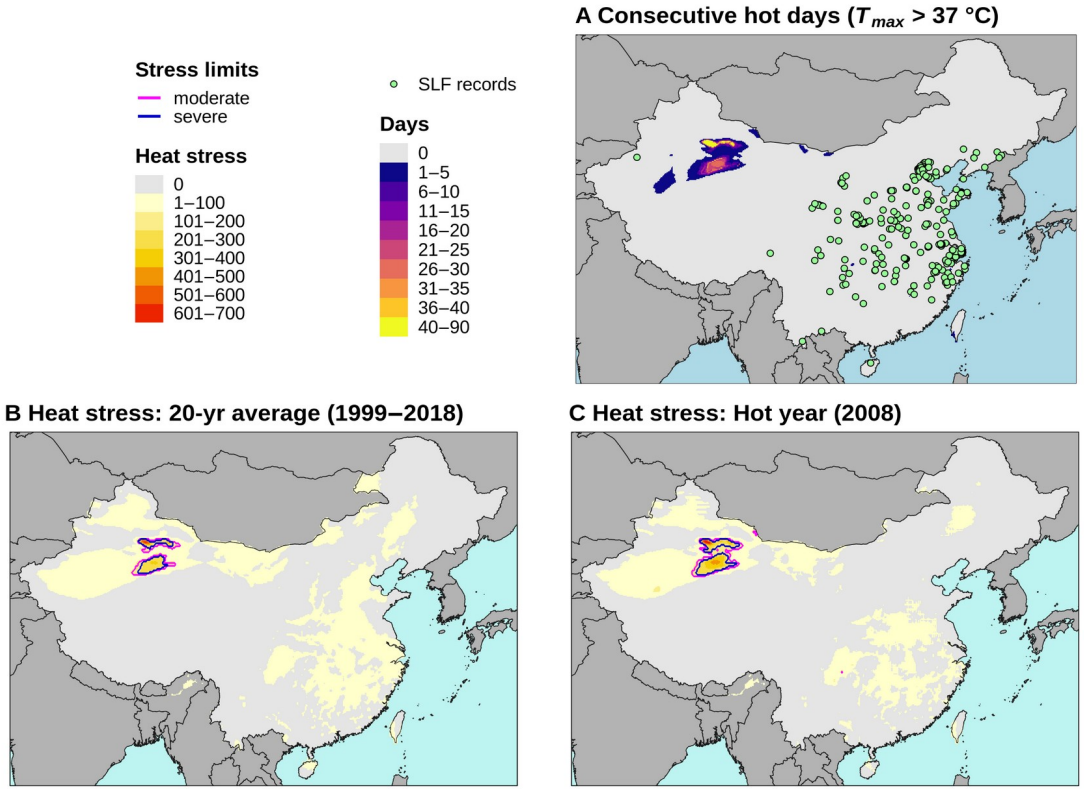
Methods overview

Cold stress parameters
- Analyzed coldest temperatures experienced at locations with 392 presence records in China for each year between 1999 and 2018
- Analyses used tmax and tmin data from CDAT dataset (0.1 degree resolution)
- 98% (385/392) of records occurred in areas with average weekly Tmin values ≥ -16C
- Fine-tuned cold stress limits to include majority of records for most extreme years in terms of cold stress accum (B,C in below map)



Heat stress parameters

- Analyzed hottest temperatures experienced at locations with 392 presence records in China for each year between 1999 and 2018
- 99% (389/392) of records occurred in areas with average weekly Tmax values ≤ 37C
- Fine-tuned heat stress limits to include majority of records for most extreme years in terms of heat stress accum (B,C in below map)



Analysis using cold and heat stress parameters above for CONUS plus

- Ran DDRP for invaded range using climate data for 20 recent years (i.e., 1/1 to 12/31 for each year)
- Analysis used Daymet data for 2002-2021 (1 km2 resolution), cropped to S. Canada and N. Mexico
- Estimated presence as areas not under moderate or severe stress exclusions
- Results indicate that presence predicted across all years in most of CONUS