

Spotted Lanternfly (*Lycorma delicatula*) Phenology/Degree-Day and Climate Suitability Model Analysis – June 2023

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

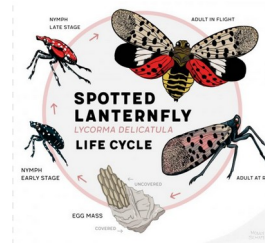
Goal: Develop a phenology model and temperature-based climate suitability model using available literature and weather data analysis



Adult



Nymphs

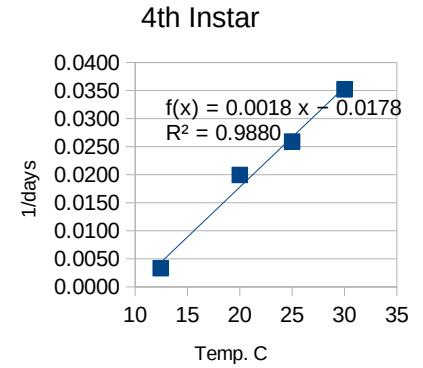
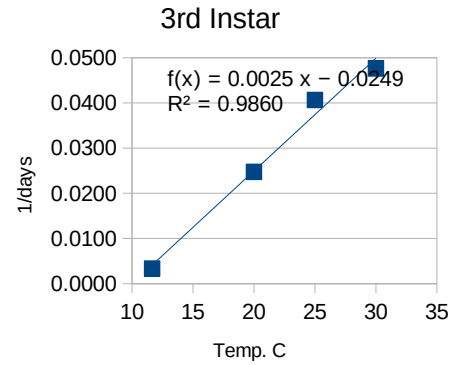
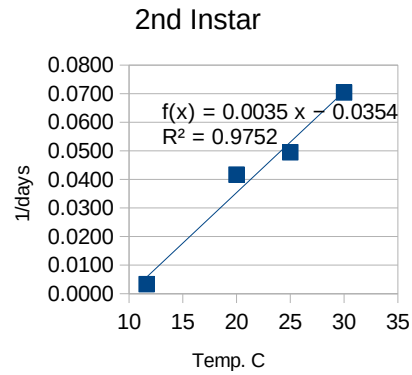
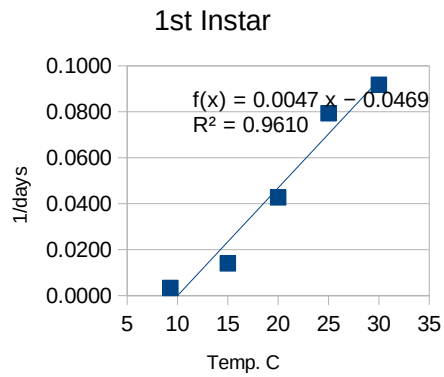


Life cycle diagram

Spotted lanternfly degree-day model parameters:		
start date: Jan 1st Calc m January 1 (nominal)		
	Celsius/DD (C)	Fahr. /DD (F)
Lower threshold:	10	50
Upper threshold:	35	95
First Egg hatch	202	364
Peak Egg hatch	293	527
Peak first instars	386	695
Peak second instars	550	990
Peak third instars	733	1320
Peak fourth instars	994	1789
First Adults	1074	1934
Peak Adults	1470	2646
First egg-laying	1728	3111
Peak egg-laying	1828	3290

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.

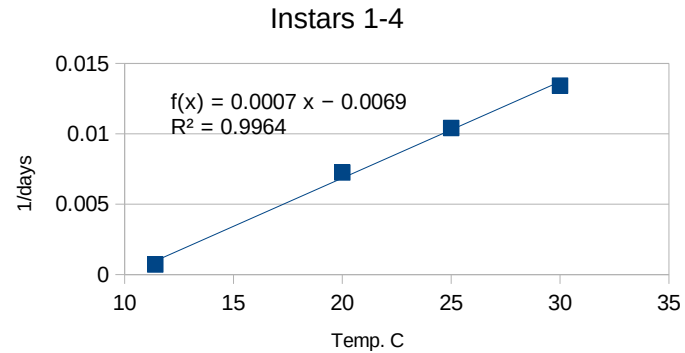
Table 2.	L1=1st Instar		L2=2nd Instar		L3=3rd Instar		L4=4th Instar		females only			
Temp. C	1/days L1	Days L1	Temp. C	1/days L2	Days L2	Temp. C	1/days L3	Days L3	Temp. C	1/days L4	Days L4	
	9.29	0.0033	300	11.642	0.0033	300	11.649	0.0033	300	12.444	0.0033	300
	15	0.0140	71.3	15		15			15			85.5
	20	0.0427	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		-0.0469			-0.0354			-0.0249			-0.0178	sum L1-4
slope		0.0047			0.0035			0.0025			0.0018	
1/slope		213			283			401			562	1459
-b/a		10.00			10.00			10.00			10.00	
R-SQ		0.96			0.98			0.99			0.99	



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. Ent.* 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

Stage	Date	Station D9872, 2017			nearby stations to compare	
		ADDs10CJan	ADDs10CJan1	Elev 427 ft	Comp. E3190 Reading PA Elev 1115 ft	Comp. C3157 Boyertown PA Elev 689 ft
		ca. from Table	uspest rerun	S1DDs10CJan	S1DDs10CJan	S1DDs10CJan1
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

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).

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	Elev 728 ft	Elev 823 ft	Elev 666	PA	Elev 1115 ft	Average	Average
	Date	KOKV	E8890	E5449	Date	E3190		
		S1DDs10CJa	S1DDs10CJa	S1DDs10CJa		S1DDs10CJan1	KOKV&E3190	E8890&E5449&E3190
First L1	05/10/19	252	280	321	05/28/19	270	261	290
Peak L1	05/23/19	336	369	422	06/05/19	338	337	376
End L1	06/07/19	497	532	607	07/02/19	620	559	586
First L2	05/24/19	348	380	436	06/06/19	350	349	389
Peak L2	06/06/19	486	521	594	06/19/19	462	474	526
End L2	06/22/19	649	686	784	07/12/19	754	702	741
First L3	06/15/19	561	597	683	06/15/19	418	490	566
Peak L3	06/28/19	728	766	873	07/03/19	634	681	758
End L3	07/10/19	899	940	1060	07/27/19	962	931	987
First L4	07/04/19	818	854	971	07/10/19	729	774	851
Peak L4	07/12/19	927	969	1090	07/21/19	887	907	982
End L4	08/01/19	1216	1262	1408	08/28/19	1375	1296	1348
First Adult	07/23/19	1104	1144	1279	08/01/19	1035	1070	1153
Peak Adult	08/15/19	1400	1452	1619	08/27/19	1365	1383	1479
End Adult	11/02/19	2075	2137	2389	11/08/19	1788	1932	2105

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.

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?](https://oup.silverchair-cdn.com/oup/backfile/Content_public/Journal/ee/49/6/10.1093_ee_nvaa126/1/nvaa126_suppl_supplementary_material.pdf?Expires=1687287607&Signature=lvloBO05-JEaI0QKGw4cm6st6rWlxANSomlJOx8vcDj-msbVTWVTPXKKluTFbh-b3VOR85grvgScO1fabZ5nMouDdmPTbZMGg1t-l-tCuyI5vs5bfE8fc3hcLlx9oH7iUucuM2)

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- 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	C3157		C3157		C3157		C3157		Average	
	Date	ADDs10CJan	Boyertown PA	ADDs10CJan	Boyertown PA	ADDs10CJan	Boyertown PA	ADDs10CJan	Boyertown PA	S1DDs10CJan	S1DDs10CJan1
	2015	uspest rerun	S1DDs10CJan	2016	uspest rerun	S1DDs10CJan	2017	uspest rerun	S1DDs10CJan	S1DDs10CJan1	
First Egg hatch	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	06/08/17	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.

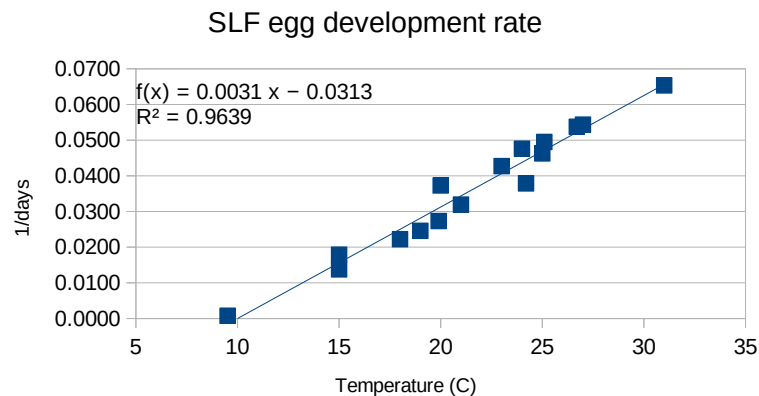
5. Smyers, E. C., J. M. Urban, A. C. Dechaine, et al. 2021. Spatio-Temporal model for predicting spring hatch of the spotted lanternfly (Hemiptera: Fulgoridae). *Env. Ent.* 50:126-137.
 - collected eggs from field and reared at constant temperatures, built model and compared to field hatch data. Found 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	
	27.0	0.0556	18.0	
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	

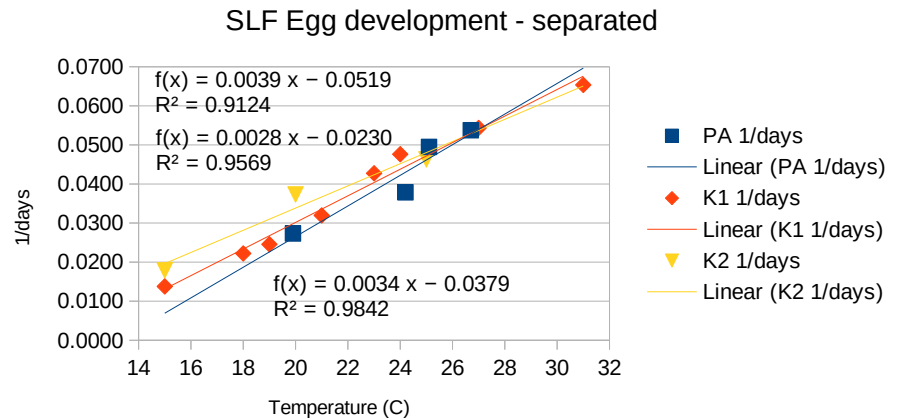
intercept	-0.0313
slope	0.0031
R-sq	0.9639
1/slope	320
-b/a (x-intercept)	10.000



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-intercept)		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 255 DD.

2) Field data: observed egg hatch near Oley, PA 2017 N=35 observation dates, and near Winchester, VA 1019 N=8 observation dates. Methods: extract ADD10.4 values from Figs 2b and 3b, use nearby weather for each location year to estimate dates of events, then calculate S1DD10 values on those dates.

Oley, PA 2017 (station E5860 elev 384 ft)					Winchester, VA (station E5449 elev 666 ft)					Avg PA&VA		
Percent hatch	DOY	Date	rough approx			DOY	Date	rough approx			S1DD10Jan1	S1DD10Jan1
			ADD10.4Jan1	ADD10Jan1	S1DD10Jan1			ADD10.4Jan1	ADD10Jan1	S1DD10Jan1		
			(Fig. 2)				(Fig. 3)					
2	118	05/01/17	152	168	213	124	04/30/19	155	171	223	218	
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	
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.

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

From Fig. 3 and as reported in results:

Stage	Approx Date	Checking: KOKV		Using: E8890		Checking: KOKV		Using: E8890		Average 2019 & 2020
		ADDs10CJan	uspest rerun	Winchester VA	S1DDs10CJan1	ADDs10CJan	uspest rerun	Winchester VA	S1DDs10CJan1	
First Egg hatch	05/01/19				199	05/07/20		190	195	
Peak egg hatch	05/08/19				260	05/16/20		228	244	
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	
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	
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	
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	
End L4	08/03/19				1291	08/14/20		1386	1339	
First Adult	07/09/19		835		925	07/20/20	887	1013	969	
Peak Adult	09/05/19				1714	09/15/20		1764	1739	
End Adult	11/06/19				2141	11/04/20		1988	2065	
First oviposition	09/11/19		1634		1785	09/15/20	1612	1764	1775	

Results: These field results is in good accord with other field sampling studies.

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:

Stage	Approx Date	Using: D6615 Breinigsville SSDD10CJan1
First Egg hatch		
Peak egg hatch	06/01/19	385
End egg hatch		
First L1	05/23/19	290
Peak L1	06/07/19	440
End L1	06/22/19	586
First L2	06/10/19	467
Peak L2	06/19/19	552
End L2	06/29/19	680
First L3	06/29/19	680
Peak L3	07/01/19	705
End L3	07/13/19	878
First L4	06/29/19	680
Peak L4	07/18/19	953
End L4	08/05/19	1215
First Adult	08/12/19	1300
Peak Adult	09/14/19	1680
End Adult	11/02/19	1971
First oviposition		

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 Albutis, PA where studies were conducted)
- studies in Albutis, 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 to use 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)

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

From Fig. 2-6: Combined TOH, TOH+Cabernet Franc, TOH+Concord

	Average	Lower percentile	Upper percentile	Station: AR98 DdsAug30-Oct10		DdsAug31-Oct11		DdsSept1-Oct12	
				AvgDDs10.4CS1DDs10.0C	AvgDDs10.4CS1DDs10.0C	AvgDDs10.4CS1DDs10.0C	AvgDDs10.4CS1DDs10.0C	AvgDDs10.4CS1DDs10.0C	AvgDDs10.4CS1DDs10.0C
Days	42.5	38	49	374	394	366	385	358	377
DD10.4 C	365	335	440						

Results: Our estimate for pre-oviposition is calculated as 385 DD (Tlow=10C, single sine). This is rather less than field results of Liu 2019

Other references not used in this analysis:

- Maino et al. 2021.

- 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 et al. 2023.

- 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 C; single sine method used for field data

Stage	2. Liu 2019	3. Nixon et al.	4. Murman et	5. Smyers et	6. Dechaine e	7. Leach&Leach	Averages	Standard Dev	C.V.
	PA 2017	VA&PA 2019	PA 2015&201	VA2017&PA 2	VA 2019&202	PA 2019			
	1 site year	2 site years	2 site years	2 site years	2 site years	1 site year			
First Egg hatch	189		208	218	195		202	13.1	6.5
Peak egg hatch	232			309	244	385	293	70.3	24.0
End egg hatch	381			446	327		385	59.6	15.5
First L1	198	290	208		197	290	237	49.1	20.8
Peak L1	381	376	422		310	440	386	50.3	13.0
End L1	707	586	830		479	586	638	134.6	21.1
First L2	397	389	420		288	467	392	65.7	16.8
Peak L2	574	526	617		481	552	550	50.9	9.3
End L2	939	741	1048		705	680	823	162.1	19.7
First L3	616	566	628		448	680	588	87.9	15.0
Peak L3	745	758	778		682	705	733	39.4	5.4
End L3	1078	987	1017		969	878	986	73.1	7.4
First L4	796	851	785		711	680	764	68.9	9.0
Peak L4	1078	982	1024		933	953	994	58.2	5.9
End L4	1309	1348	1256		1339	1215	1293	56.7	4.4
First Adult	939	1153	1011		969	1300	1074	150.4	14.0
Peak Adult	1331	1479	1120		1739	1680	1470	254.1	17.3
End Adult	1878	2105			2065	1971	2005	101.3	5.1
First oviposition	1682				1775		1728	65.4	3.8
Peak oviposition	1828						1828		
End oviposition	1858						1858		

2) Estimated stage Durations using first to first and peak to peak vs. Kreitman lab results.

Stage	Estim. Stage	Estim. Stage	1. Kreitman	5. Smyers et	8. Laveaga 2022
	Durations fro	Durations fro	lab data	field → lab	Field
	first to first	peak to peak			
Egg				320	
L1	156	164	213		
L2	195	184	283		
L3	177	260	401		
L4	310	476	562		
Pre-OV	654	497		385	
Total L1-L4	838	1084	1459		

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. The two estimates for pre-oviposition differ somewhat (497-654 DD from Liu and Dechaine vs 385 DD from Laveaga) so other studies should be sought out to resolve this difference.