Phenology/Degree-Day Model Analysis – May 2023

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Boxwood leafminer — *Monarthropalpus flavus syn. Monarthropalpus buxi*

Hosts: boxwood (Buxus spp.) Native to: Europe

Goal: Develop a phenology model using available literature and weather data analysis

Extension links: **https://www.newgenboxwood.com/boxwood-leafminer-1**
https://pnwhandbooks.org/insect/hort/landscape/hosts-pests-landscape-plants/boxwood-buxus-boxwood-leafminer



Model summary for Boxwood Leafminer:

		Celsius	Fahrenheit	
Model abbrev.:	bxlm			
Start Date:	Jan. 1st			
Calc. Method:	single sine (SS)			
lower threshold:		6.7	44	
upper threshold:		35.0	95	(nominal; there is evidence that they do not tolerate high temps)
Event:	DDC6.7		DDF44	
1st pupation in spring		127	229	
1st Adults		430	775	
Peak Adults		507	912	
1st egg hatch		682	1228	
Peak egg hatch		988	1778	
Peak 2nd, first 3rd instar larvae		1894	3410	
Peak third instar larvae		2511	4521	

General notes on methodology: The original model source (1&2) do not include dates of events, forcing us to reverse engineer dates. This allowed converting the start date and lower threshold to more plausible and robust values. The use of Mar. 1st and a 50F lower threshold and use of the simple average calculation methods may have provided a good fit of their data, but are unlikely to allow usage of the model in regions to the south of the study region (Maryland). One reason is that this species is noted to NOT have an overwintering diapause, and can develop prior to March 1. And, for this species, the simple average calculation method will often not pick up spring time highs that exceed the lower threshold, since they are averaged out. The single sine and other more complex calculation methods, will accumulate these springtime heat units that the species is responding to. The final selection

of a lower threshold of 44F is based on a review of other gall forming midges (see appendix). Of course, more research on rates of development vs. temperature are needed to confirm a more precise threshold for this species. We found one other data source (3) to partially validate the original and revised models, also from Maryland from 1913 to 1924. This older data set does not reveal which model performs best, as both seem about equal overall. Again, data such as first adult emergence from other regions, especially south of this latitude, would greatly help in validating or improving the model.
The upper threshold was selected based on notes on other pod gall midges that extreme summer heat can limit survival, and because the pine needle and blueberry pod gall midges cannot develop through all stages at or above 86 F (30 C). This estimate for an upper threshold of 95 F also requires further research.

Source 1: d'Eustachio, G.J. 1999. Integrated management of the boxwood leafminer. M.S. Thesis. U. MD.
Source 2: d'Eustachio, G.J. and M.J. Raupp. 2001. Application of systemic insecticides in relation to boxwood leafminer's life history. J. of Arboriculture 27:255-262.
- late Aug/Sept molt to 3rd instar; continue to develop slowly without diapause throughout winter months
- March molt to 4th instar (when most economic damage occurs); form pupal cells and pupate in mid- April
- Adults emerge, mate, and oviposit in 1 to a few days, very short lived. Adults not observed to feed
- used Mar 1 starting date and simple GDD formula; Tlow=50F
- raw data not included so it would be hard to do an exact reproduction of this model (so goal is to replicate using Jan 1 and Single Sine DDs if possible)
- I used PRISM Data Explorer weather from Longwood Gardens, PA and US Nat. Arboretum in Wash., DC for 1994 and 1995. The approach was to reconstruct the dates of key events. For example at Longwood Gardens, peak adult emergence using simple average DDs with a March 1 start date and 50F lower threshold, from table 1, 440 DDF50Mar1, would have occurred on April 20. Then, using these predicted dates, develop a model that is presumed to be more robust by 1) Using Jan 1 as the start date, which seems appropriate as this insect does not appear to diapause and so should respond to temperatures above the threshold earlier than March 1; 2) Using the Single Sine calculation method, because this method is standard at uspest.org due to the improved ability to record heat on days when the Tmax exceeds the Tlow, but the Tmean might not (a common occurrence in the Spring). So, through this "reverse engineering" appraoch, we can build a model that may be more robust than the original model. It would have been desirable to have the original data that d'Eustachia and Raupp used, but it is not available in the thesis or the peer reviewed publication.

Table 1. Table of boxwood leafminer stadia correlated with Growing Degree Days (average measurements for the years 1994-1995). The peak emergence is shown with the standard error.

GDD TABLE

Stadia	1st Appearance (GDD)	Peak emergence GDD (SE)	Number of GDD in stadia	Approximate Dates
4th	0	80 (27)	80	early March- mid April
Pupa	46	310 (66)	230	mid April – May
Adult	352	440 (127)	N/A	May
Egg	352	748 (104)	308	mid-late May
1st	679	1106 (258)	358	early June
2nd	1236	2459 (270)	1353	late June – July
3rd	2443	3287 (161)	828*	August – March

* The boxwood leafminer overwinters in the third instar. This number reflects the number of GDDs spent in the late summer.

Filenames in uspest.org:		1st Adult = 352 DD (Simple Avg from Mar.1)					
Station and year		**DOY**	**Date**	**ADDs50F**	**SSDDs45**	**SSDDs44FJ**	**SSDDs46FJa**
LNGWDGPA94.txt		144	05/25/94	369	701	756	647
LNGWDGPA95.txt		148	05/29/95	358	781	847	719
NATARBMD94.txt		120	05/01/94	361	633	680	588
NATARBMD95.txt		129	05/10/95	353	751	816	689
	mean	135.3		360.3	716.5	774.8	660.75
	SD	13.0		6.7	64.7	73.6	56.78
	CV	9.65		1.9	9.0	9.5	8.59

peak Adult = 440 DD (Simple Avg from Mar. 1)				
DOY	**Date**	**ADDs50FI**	**SSDDs45F**	**SSDDs44FJan1**
151	06/01/94	459	828	890
153	06/03/95	449	898	968
131	05/12/94	453	780	838
136	05/17/95	447	880	953
142.8		452	846.5	912.3
10.9		5.29	53.4	59.9
7.6		1.17	6.3	6.6

			1st Adult (cont.)		
Station and year		**DOY**	**Date**	**SSDDs50**	**SSDDs42FJan1**
LNGWDGPA94.txt		144	05/25/94	462	848
LNGWDGPA95.txt		148	05/29/95	497	988
NATARBMD94.txt		120	05/01/94	431	782
NATARBMD95.txt		129	05/10/95	481	958
	mean	135.3		467.8	894.0
	SD	13.0		28.4	95.9
	CV	9.6		6.1	10.7

peak Adult (cont.)			
DOY	**Date**	**SSDDs50F**	**SSDDs48FJan1**
151	06/01/94	559	658
153	06/03/95	588	704
131	05/12/94	528	621
136	05/17/95	576	686
142.8		562.8	667.3
10.9		26.0	36.2
7.6		4.6	5.4

		first egg Hatch = 679 DD (Simple Avg from Mar. 1)				
01/01/94		**DOY**	**Date**	**ADDs50F**	**SSDDs45**	**SSDDs44FJan1**
01/01/95		164	06/14/94	680		1203
01/01/94		166	06/16/95	680		1287
01/01/95		147	05/28/94	680		1161
		148	05/29/95	680		1261
	mean	156.3		680.0	#DIV/0!	1228.0
	SD	10.1		0.0	#DIV/0!	56.8
	CV	6.5		0.0	#DIV/0!	4.6

peak 2nd instar = 2459 DD				
DOY	**Date**	**ADDs50FI**	**SSDDs45F**	**SSDDs44FJan1**
233	08/22/94	2462	3240	3385
238	08/27/95	2474	3348	3503
210	07/30/94	2461	3183	3320
214	08/03/95	2459	3282	3432
223.8		2464.0	3263.3	3410.0
13.8		6.8	69.6	77.2
6.2		0.3	2.1	2.3

	peak egg Hatch = 1106 DD (Simple Avg from Mar. 1)				
	DOY	**Date**	**SSDDs50**	**SSDDs48**	**SSDDs44FJan1**
	180	06/30/94	1232	1389	1736
	186	07/06/95	1259	1440	1837
	166	06/16/94	1207	1367	1723
	168	06/18/95	1248	1422	1817
mean	175		1236.5	1404.5	1778.3
SD	9.6		22.6	32.7	57.1
CV	5.5		1.8	2.3	3.2

peak 2nd instar = 2459 DD & first 3rd instar = 2443			
DOY	**Date**	**SSDDs50F**	**SSDDs48FJan1**
233	08/22/94	2563	2825
238	08/27/95	2613	2898
210	07/30/94	2540	2788
214	08/03/95	2587	2853
223.8		2575.8	2841.0
13.8		31.4	46.4
6.2		1.2	1.6

Station and year		peak egg Hatch (cont.) DOY	Date	ADDs50F	SSDDs45FJan1	peak 3rd instar = 3287 DD DOY	Date	ADDs50F	SSDDs45F	SSDDs44FJan1
LNGWDGPA94.txt		180	06/30/94	1131	1645	305	11/02/94	3183		4547
LNGWDGPA95.txt		186	07/06/95	1119	1733	307	11/04/95	3287		4735
NATARBMD94.txt		166	06/16/94	1128	1736	244	09/02/94	3291		4354
NATARBMD95.txt		168	06/18/95	1119	1712	243	09/01/95	3298		4446
	mean	175.0		1124.3	1706.5	274.8		3264.8		4520.5
	SD	9.6		6.2	42.4	36.1		54.7		163.3
	CV	5.5		0.6	2.5	13.1		1.7		3.6

Station and year		first pupation = 46 DD (Simple Avg from Mar. 1) DOY	Date	SSDDs50	SSDDs44FJan1	peak pupation = 310 DD (Simple Avg from Mar. 1) DOY	Date	SSDDs50F	SSDDs44FJan1
LNGWDGPA94.txt		104	04/15/94	47	184	141	05/22/94		680
LNGWDGPA95.txt		109	04/20/95	51.1	305	145	05/26/95		795
NATARBMD94.txt		92	04/03/94	46.1	198	118	04/29/94		631
NATARBMD95.txt		78	03/20/95	47.6	228	125	05/06/95		758
	mean	95.8			228.8	132.3			716.0
	SD	13.8			54.0	12.8			74.2
	CV	14.4			23.6	9.7			10.4

Source 3: The boxwood leafminer. Clyde C. Hamilton. 1925. U. Maryland AES Bulletin No. 272

Summarizing the life history we find that the adults usually emerge about the second week in May and lay their eggs at once. The egg stage lasts on an average of about three weeks. The third larval instar is attained by fall in which instar the winter is passed. The larvae molt into the fourth instar in March and pupate in April. The dates for the beginning of emergence of the boxwood leaf miner in the vicinity of Baltimore, Maryland, during the years it has been observed are as follows: 1913, May 15; 1916, May 10; 1920, May 21; 1921, April 22; 1922, May 8; 1923, May 15, and 1924, May 16.

Methods for calculating approximate Dds for 1913-1924: We found historical monthly average temps for Baltimore from weather.gov:
https://www.weather.gov/media/lwx/climate/bwitemps.pdf
Using this data, we compared each year in the older data with a more modern year (1981-2020) that we might use as a proxy or close surrogate. First we found closest year(s) based on Jan-Mar and Apr-Jun averages, then used r-sq values to help narrow down which year(s) to select as closest correlate. Next, we used PRISM data explorer to obtain the surrogate year data to use for the validation analysis. The reason for all this is that PRISM data is not available prior to 1981.

Baltimore MD temperatures:

Data yrs	Jan	Feb	Mar	Apr	May	Jun	Jan-Mar Avg	Apr-Jun Avg	Totals	Similar year or years (monthly match if needed)
1913	43.5	36.2	48.8	55.6	64.9	73.7	42.8	64.7	107.6	1995
1916	39.5	33.6	37	52.6	66.6	69.4	36.7	62.9	99.6	(use combination of years from 1984, 1986, 1995, and 2000)

	1920	28.6	32.8	44.8	52.8	60.8	72.6	35.4	62.1	97.5	1996							
	1921	37	39	54.6	58.6	63.1	75	43.5	65.6	109.1	(use combination of years from 1993, 1994, 2003, and 2012)							
	1922	32.2	38.4	44.8	55.8	67.2	75.1	38.5	66.0	104.5	2000							
	1923	36.6	32.4	44.5	53.6	63.8	76.7	37.8	64.7	102.5	1986							
	1924	34.8	34.6	43	52.2	60.2	71.2	37.5	61.2	98.7	1992	**R-square values**						
Avail. Years												1913	1916	1920	1921	1922	1923	1924
	1981	27.9	38.8	41.9	57	62.2	74.3	41.4	64.5	105.9		0.852	0.831	0.956	0.912	0.967	0.903	0.940
	1982	25.5	35.8	42.9	50.7	66.1	69.4	38.7	62.1	100.8	1920	0.862	0.847	0.952	0.907	0.974	0.896	0.925
	1983	34.6	34.7	45.4	51.8	61.5	72.1	41.6	61.8	103.4		0.965	0.891	0.981	0.959	0.968	0.984	0.987
	1984	28.5	41.7	38.2	51.5	61.3	73.4	40.0	62.1	102.0	1920	0.811	0.832	0.910	0.838	0.947	0.873	0.912
	1985	29.3	38.7	46	57.9	65.1	70.4	43.0	64.5	107.4	1923	0.851	0.822	0.958	0.926	0.965	0.888	0.923
	1986	33.2	32.9	45	53.5	66.7	74.4	41.2	64.9	106.0	1923	0.965	0.917	0.974	0.944	0.974	0.977	0.981
	1987	32.5	34.3	46.2	53.1	65	74.5	41.5	64.2	105.7	1923	0.954	0.887	0.984	0.960	0.977	0.973	0.981
	1988	28.7	35.9	45.1	52	64	73	40.4	63.0	103.4	1916	0.907	0.853	0.983	0.952	0.983	0.942	0.963
	1989	37.9	36.5	43.8	52.5	62	73.9	42.7	62.8	105.5		0.968	0.923	0.956	0.917	0.956	0.987	0.987
	1990	42	42.3	47.6	54.8	62.3	73.3	46.7	63.5	110.1	1913	0.954	0.906	0.959	0.919	0.959	0.981	0.985
	1991	35.5	40.7	46.7	55.9	70.6	74.6	44.7	67.0	111.7	1913	0.913	0.913	0.957	0.903	0.985	0.938	0.957
	1992	34.6	37.1	41.3	52	60.8	70.1	41.3	61.0	102.2	1924	0.938	0.925	0.964	0.912	0.980	0.969	0.983
	1993	37.9	31.4	39.4	52.5	65	72.2	40.3	63.2	103.5	1916	0.972	0.975	0.909	0.857	0.928	0.969	0.960
	1994	27.1	34	43	59.6	60.6	77.2	40.9	65.8	106.7		0.879	0.815	0.964	0.945	0.946	0.920	0.947
	1995	39	33.2	47.8	55.2	64.5	74.5	43.8	64.7	108.5	1922	0.987	0.903	0.953	0.942	0.932	0.985	0.973
	1996	31.7	35.7	39.9	54	60.6	73.3	40.3	62.6	103.0	1920	0.921	0.900	0.963	0.916	0.973	0.958	0.977
	1997	32.8	41	45.5	51.6	59.5	70.1	42.7	60.4	103.1		0.873	0.819	0.970	0.934	0.970	0.923	0.951
	1998	40.9	41.7	45.9	55.2	66.5	71.7	45.9	64.5	110.4	1913	0.945	0.956	0.945	0.886	0.975	0.964	0.973
	1999	35.1	37.6	41.8	53.2	64.2	71.5	41.9	63.0	104.9		0.937	0.941	0.957	0.899	0.982	0.963	0.977
	2000	32.5	38.1	48.5	52.9	64.7	72.8	43.0	63.5	106.5		0.913	0.843	0.982	0.960	0.975	0.943	0.960
	2001	33.1	38.5	41.8	55.4	63.4	74.1	42.2	64.3	106.5		0.911	0.903	0.963	0.910	0.981	0.950	0.973
	2002	39.1	39.3	45	56.7	62.2	73.8	45.0	64.2	109.3		0.949	0.913	0.961	0.922	0.962	0.976	0.985
	2003	28.3	30.2	43.9	52.7	59.3	69.8	38.8	60.6	99.4		0.936	0.847	0.985	0.979	0.961	0.956	0.967
	2004	27.6	34.8	45.6	54.7	69.8	70.9	40.7	65.1	105.8		0.880	0.859	0.951	0.915	0.967	0.901	0.925
	2005	34.1	36.7	40.6	55.2	59.2	73.6	41.7	62.7	104.3		0.917	0.889	0.951	0.908	0.954	0.954	0.971
	2006	41.6	36.1	45.6	57.5	63.4	73.1	45.2	64.7	109.9		0.977	0.933	0.935	0.907	0.929	0.979	0.971
	2007	38.7	29.1	45.2	51.5	65.5	73.8	41.1	63.6	104.7		0.989	0.921	0.916	0.897	0.904	0.974	0.951
	2008	35.4	37.1	45	55.8	60.5	75.3	43.3	63.9	107.2		0.938	0.869	0.973	0.948	0.957	0.969	0.981
	2009	29.3	37.5	43.1	54.9	63.7	71.4	41.2	63.3	104.5		0.886	0.865	0.972	0.929	0.985	0.925	0.955
	2010	32.7	30.9	48.5	57.2	67.4	78.9	42.3	67.8	110.2		0.964	0.874	0.978	0.971	0.954	0.973	0.974
	2011	30.3	38.5	44.4	57.7	67.2	75.7	42.7	66.9	109.6		0.893	0.875	0.972	0.927	0.986	0.931	0.959
	2012	38.3	41.6	53.7	55.3	69	73.6	47.2	66.0	113.2		0.916	0.840	0.964	0.947	0.957	0.932	0.941
	2013	36.9	35	40.7	55.4	63.7	73.9	42.0	64.3	106.3		0.957	0.952	0.941	0.890	0.956	0.974	0.978
	2014	27.4	32.9	38.5	53	64.9	73.2	38.0	63.7	101.7		0.919	0.917	0.966	0.913	0.988	0.950	0.971
	2015	30.8	25.3	39.7	54.6	69.1	74.1	37.6	65.9	103.5		0.967	0.948	0.937	0.902	0.947	0.963	0.960
	2016	31.9	37.4	50	54	61.5	73	43.3	62.8	106.2		0.899	0.788	0.983	0.982	0.951	0.931	0.948
	2017	39	44.2	43.9	60.3	62.3	73.7	46.9	65.4	112.3		0.860	0.871	0.919	0.861	0.940	0.906	0.936
	2018	32	41.8	40.2	52.1	69.6	72.6	41.5	64.8	106.3		0.839	0.900	0.898	0.814	0.957	0.879	0.909
	2019	33.5	37.8	43	59.5	68.3	75.3	43.5	67.7	111.2		0.912	0.919	0.956	0.904	0.979	0.940	0.963

2020	40.2	42	50.9	53	62.1	75.1	46.5	63.4	109.9	0.930	0.828	0.961	0.944	0.938	0.960	0.963

uspest.org weather data

file name	Emerg	Date of 352 Dds			Date of 467 Dds			Date of 774 Dds			Date of 894 Dds		
	Date	SADDs50Mar1	days diff	abs(daysc	SSDDs50Jar	days diff	abs(daysdiff	SSDDs44J	days diff	abs(daysdi	SSDDs42	days diff	abs(daysdiff)
BALT13	05/15/13	05/15/13	0	0	05/14/13	-1	1	05/12/13	-3	3	05/12/13	-3	3
BALTC16	05/10/16	05/17/16	7	7	05/18/16	8	8	05/17/16	7	7	05/16/16	6	6
BALT20	05/21/20	05/12/20	-9	9	05/17/20	-4	4	05/17/20	-4	4	05/16/20	-5	5
BALTE21	04/22/21	04/26/21	4	4	04/27/21	5	5	04/26/21	4	4	04/26/21	4	4
BALT22	05/08/22	05/13/22	5	5	05/15/22	7	7	05/16/22	8	8	05/16/22	8	8
BALT23	05/15/23	05/08/23	-7	7	05/11/23	-4	4	05/12/23	-3	3	05/12/23	-3	3
BALT24	05/16/24	05/19/24	3	3	05/22/24	6	6	05/19/24	3	3	05/19/24	3	3
	average/MAE		0.43	5.00		2.43	5.00		1.71	4.57		1.43	4.57

Notes: SSDDs45FJan1 means: Single sine DDs base 45 F and Jan 1st as start date

SSDDs50Jan1 means: Base 50F Dds using Single Sine calculations and Jan 1 as start date, etc.

Results: All methods tested seem acceptable, DDs44 Single Sine Jan 1 appears to work well, and best matches Tlow for other gall midges mentioned below
The average days difference for these settings were 1.7 days, mean absolute error was 4.6 days.

Source 4: https://entnemdept.ufl.edu/creatures/ORN/SHRUBS/boxwood_leafminer.html

The adult emergence period typically occurs in the spring as temperatures warm and lasts only about two weeks once it begins (Barnes 1948). Adults emerge through circular windows on blisters, leaving behind a pupal case (exuvia), which remains protruding from the lower surface of the previously infested leaf (Figure 4) (Brewer et al 1984). Adult emergence is synchronized with sunlight level, resulting in more adults emerging during early morning hours (Brewer 1981). These midges have one generation per year and complete their entire juvenile development within the leaf before emerging as adults (Brewer et al. 1984).

Source 5. Brewer JW, Skuhravÿ V, Skuhravá M. 1984. Biology, distribution and control of Monarthropalpus buxi (Laboulbéne) (Diptera, Cecidomyiidae). Zeitschrift für Angewandte Entomologie 97: 167-175.

In Prague, Czechoslovakia, the emergence period of Monarthropalpus buxi begins in early May and lasts until about the first of June.

Notes: climate in Prague is similar to much of New England including Baltimore; these results are consistent with expectations

Appendix. Evidence of low threshold values for other gall midges:

From the four studies below, the average lower threshold was 5.9 C (42.7 F), ranging from 3.9 to 7.2 C (39 to 44.9 F)

Study	Tlow ©	Tlow (F)
1. Douglas fir needle midge (jan 1 to adult	3.9	39.0
2. pine needle gall midge (larvae, pupae)	5.9	42.6
3. Blueberry gall midge (pupae)	6.8	44.2
4. Pod gall midge (eggs, larvae, pupae)	7.2	44.9
Average	**5.9**	**42.7**

1. Douglas fir needle midge: https://uspest.org/wea/model_DNM_v1.pdf

- Solved for Tlow of **39F (3.9C)**, using Jan 1 start date.

2.Temperature-dependent post-diapause development and prediction of spring emergence of the pine needle gall midge (Dipt., Cecidomyiidae)
Y. Son, J.-H. Lee, Y.-J. Chung
First published: 20 November 2007
https://doi.org/10.1111/j.1439-0418.2007.01214.x

From Abstract: “In a linear model, the lower threshold temperatures were **5.1, 7.1 and 5.9°C** for larvae, pupae, and larvae to adults respectively"
Note that pupae did not complete development at 30 C (86 F), which indicates that the upper developmental threshold may be between this value and, say 100 F.

Data from Table 1:

Temp (°C)	n*	Development stage (n†)		
		Larvae	Pupae	Larvae to adults
12	216	142.6 ± 2.3 (74)	43.0 (1)	239.0 (1)
15	212	114.5 ± 1.1 (136)	25.3 ± 1.0 (15)	140.9 ± 2.0 (15)
18	220	83.9 ± 1.1 (159)	25.1 ± 1.0 (48)	102.8 ± 1.8 (48)
21	225	67.3 ± 0.8 (176)	16.5 ± 0.3 (112)	81.8 ± 1.0 (112)
24	257	53.0 ± 0.6 (219)	12.3 ± 0.3 (146)	63.8 ± 0.6 (146)
27	226	50.3 ± 0.8 (165)	11.3 ± 0.3 (84)	59.9 ± 0.9 (84)
30	290	47.9 ± 1.3 (42)	_‡ (0)	_ (0)

*Initial number of insects.

†Number of individuals surviving to next stage.

‡No observation was made due to 100% pupal mortality.

3. Pupation and Emergence of Blueberry Gall Midge, Dasineura oxycoccana (Diptera: Cecidomyiidae), Under Varying Temperature Conditions
Authors: Roubos, Craig R., and Liburd, Oscar E. 2010
Source: Florida Entomologist, 93(2) : 283-290

From table 3 – the lower threshold ranged from 4.7 to 8.9 depending on rearing method for the pupal stage. Overall average: **6.8 C (44.2 F)**
Note that pupae did not complete development for two methods at 30 C, suggesting that the upper threshold is somewhat close to, but higher than this value.

TABLE 3. ESTIMATES OF THE THERMAL CONSTANT FOR *DASINEURA OXYCOCCANA* PUPATION UNDER CONSTANT TEMPERATURES, WITH THERMAL CONSTANTS REPORTED IN DEGREE-DAYS.

			Thermal Constant (K)[a]			
Model	Method	Threshold (°C)	15°C	20°C	25°C	30°C
Linear	5-mL vial 4[b]	6.1	195.8	164.0	165.9	217.5
	5-mL vial 3[c]	8.9	134.2	131.0	133.6	192.0
	Deli cup 4[b]	4.7	207.0	171.4	174.6	177.1
	Deli cup 3[c]	7.4	152.8	141.1	151.4	158.2
Nonlinear	5-mL vial	6.9	178.2	154.6	150.2	210.2

[a] Formula for calculating $K = D_{Ti}(T_i - c)$.
[b] Four temperatures used (15-30°C).
[c] Three temperatures used (15-25°C).

4. The developmental time of the pod gall midge, Dasyneura brassicae Winn. (Dipt., Cecidomyiidae)
J. Axelsen
First published: January/December 1992
https://doi.org/10.1111/j.1439-0418.1992.tb01125.x

Reported a Tlow of **6.7 C (44.1 F)** for egg+larval development, **8.1 C (46.6 F)** for pupal development in the soil