Phenology/Degree-Day and Climate Suitability Model - June 2024

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Japanese beetle — ***Popillia japonica*** **Newman (Coleoptera: Scarabaeidae)**

Invasive pest of: turf, fruits, ornamentals — **native to: Japan**

Goal: Implement and partially validate a simple DD model predicting major events in life cycle of JB



Phenology model summary (version V2 June 2024):

Model name/species:	**Japanese beetle**
Sci. name	**Popilla japonica**
Abbreviation for model:	**jpb**
Start Date:	**Calendar date: Jan. 1**
Calculation method:	**Single Sine (default used by UC Davis IPM program)**

	Deg. F	Deg. C	DD (F)	DD (C)
Lower temperature threshold:	50	10		
Upper temperature threshold:	92	33.3		
Event:				
Approx. begin pupation in soil:			650	361
Place traps to monitor adult activity:			920	511
Approx. 2% adult emergence:			1000	556
Approx. 10% adult emergence:			1100	611
Approx. 50% adult emergence/begin egg hatch			1540	856
Approx. 90% adult emergence:			1985	1103
Approx. 94% adult emergence:			2110	1172
Approx. last adults trapped:			2700	1500

Main sources of data used in the analysis: Ludwig 1928, Gilioli et al. 2021, Vittum 1986, Ebbenga et al. 2022, and Wawrzynski and Ascerno 1998.

Sources:

1. Ludwig, D. 1928. The effects of temperature on the development of an insect (Popillia japonica Newman). Phys. Zool. 1:358-389.

- This appears to be the major source for the existing JB model. However, the work that derived and published the model has not been found
- With more recent data, we will test the accuracy of this model, and possibly calibrate or adjust the model if needed

Figures from Ludwig (1928):

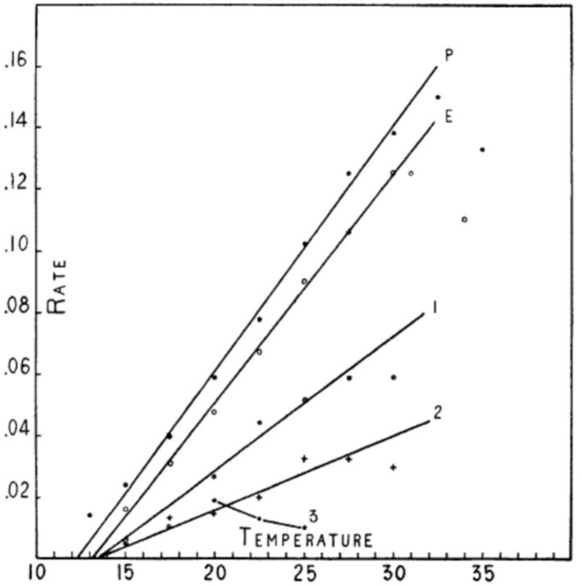


FIG. 8.—Comparison of the rates of development of each stage. *P*, pupal stage; *E*, egg; (1) first-instar larva; (2) second-instar larva; and (3) third-instar larva.

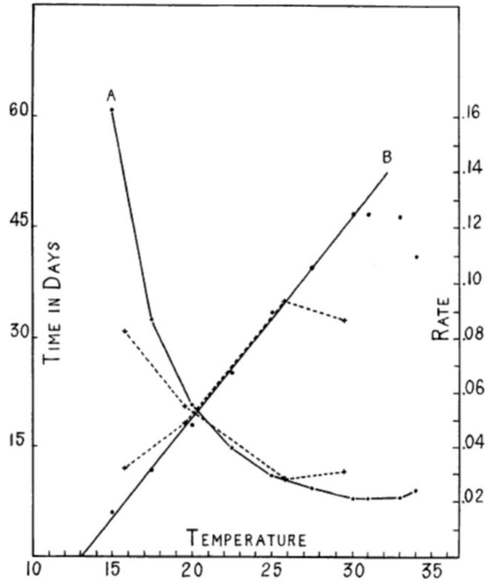
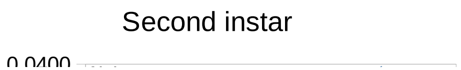


FIG. 1.—Influence of temperature on the development of the egg. *A*, time curve; *B*, rate curve. The solid line represents constant-temperature experiments, while the broken line represents alternating-temperature experiments.

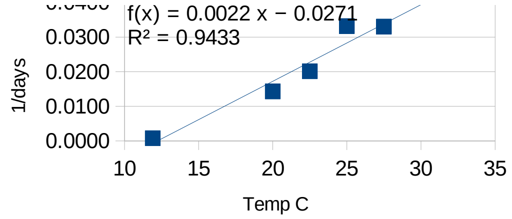
- Note Tlow tends to point to a higher value (12-13C) than current model (10C). We will compare new models using 12.22C vs 10C based on these results.

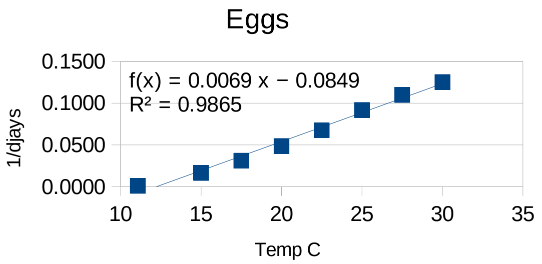
Reconstituted data from Ludwig Fig.s 2,3,4,5 using webplotdigitizer

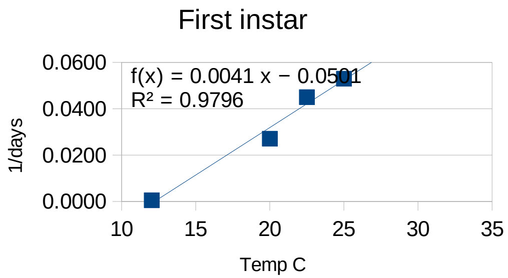
	Eggs			**1st instar**			**2nd instar**	
Temp	1/days	days	Temp	1/days	days	Temp	1/days	days
11.067	0.0010	999	12.031	0.0005	1999	11.904	0.0008	1299
15	0.0164	61	15		160			
17.5	0.0311	32.16	17.5		100.8	17.5		74.8
20	0.0486	20.58	20	0.0271	36.9	20	0.0143	70.02
22.5	0.0676	14.79	22.5	0.0450	22.22	22.5	0.0201	49.65
25	0.0918	10.89	25	0.0530	18.88	25	0.0332	30.12
27.5	0.1098	9.105	27.5		17.22	27.5	0.0330	30.26

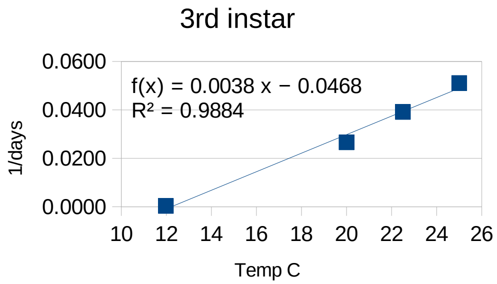


30	0.1253	7.98	30	16.9	30	33.07
	y intercept	-0.0849		-0.0501		-0.0271
	slope	0.0069		0.0041		0.0022
	Rsq	0.9865		0.9796		0.9433
	1/slope	143.9766		244.0227		451.4291
	-b/a	12.2224	54.0003	12.2222		12.2222

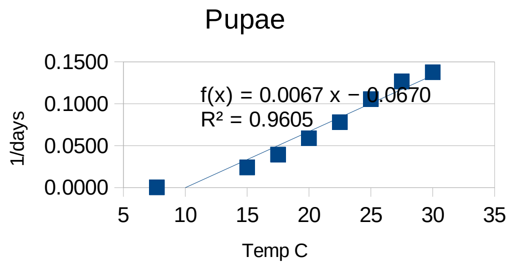








	3rd instar			**pupae**		E+1+2+pupae	
Temp	1/days	days	Temp	1/days	days	1/days	days
11.9782	0.0003	2999	7.709	0.0003	2999		
			13		70.33		291.33
15			15	0.0240	41.62		
17.5			17.5	0.0395	25.33		
20	0.0266	37.59	20	0.0589	16.98		
22.5	0.0392	25.53	22.5	0.0781	12.807		
25	0.0511	19.57	25	0.1056	9.47		
27.5			27.5	0.1266	7.9		
30			30	0.1376	7.27		
	y intercept	-0.0468			-0.0670		
	slope	0.0038			0.0067		
	Rsq	0.9884			0.9605		
	1/slope	261.0			149.3		
	-b/a	12.2222			10.0005		



Results: Good fit for eggs, larvae, and pupae using 12.22C Tlow, r-sq=0.987, 0.980, 0.943, 0.988, and 0.995 for eggs, 1st, 2nd, 3rd, and pupae. As 3rd instar is overwintering and in diapause, this result not very relevant or useful.

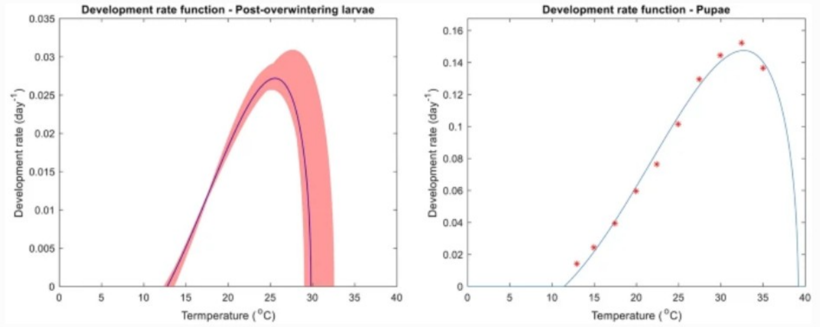
Note: changed pupal regression/graph to 10 C to determine final model (V2) pupal requirements = 149.3 DDC (269 DDF). This compares to field data results below of ca. 230 DDF (Vittum 1986 data)

For now we will use the Vittum 1986 results for model V2.

2. Gilioli, G. G. Sperandio, et al. 2021. Modelling diapause termination and phenology of the Japanese beetle, Popillia japonica. J. Pest Sci. 95: 869-880

- this paper parameterized DD model params from Ludwig **(**1928**)**

Fig. 3



Development rate function of post-overwintering larvae estimated through the parameterisation process (red hatched area reports 95% confidence interval obtained with the Jackknife procedure) (left) and development rate function of pupae estimated using data (red asterisks) extracted from Ludwig (1928) (right)

- Ludwig 1928 and sources that derive from it such as this one point to 12.5C or 12.22C as perhaps better Tlow values than 10C, pointing to a slight revision in the model. Further analysis showed that 10C will be retained as the lower threshold. Note approximate optimal near 33C (92F) that can be used as the upper temperature threshold.

3. Fleming, W. E. 1972. Biology of the Japanese beetle. USDA Tech. Bull. No. 1449. 140 pp.

- Lots of good info, e.g. pg 31: grubs will survive a while but do not feed at 10C, evidence that 10C may be slightly too low as a lower threshold for development; both 2nd and 3rd instars can overwinter.

- From pages 41-42: We could do an analysis of these general life cycle reports. Hold off because we have enough sources to analyze.

Emergence and Persistence of Adult Beetles

Along the Atlantic seaboard beetles begin to emerge from the soil the third week of May in central North Carolina, reach maximum abundance the second week of June, and then decline until only a few are found after the middle of July. In the mountainous western part of the State beetles appear the last week of June, the peak of abundance occurs about the middle of August, and beetles are still numerous in September. (Fleming and Hawley *1950*; Fleming *1963a*)

In mountainous eastern Tennessee beetles appear the first week of June and reach maximum abundance the third week of June. Only a few beetles are found early in September. (Ladd unpublished)

In central Virginia beetles appear the last week of May or the first week of June, reach maximum abundance the second week of July, and then decline until only a few are found in August (French et al. *1949*; Fleming *1963a*).

In central Maryland and in Delaware emergence begins the middle of June. The population peak is reached about the middle of July. The population then declines. A few beetles are found late in September. (Cory and Langford *1944*; Fleming *1963a*)

In southern New Jersey and southeastern Pennsylvania beetles appear the third week of June and reach the peak of abundance the last week of July. The population usually remains at a high level for about 2 weeks and then declines. A few beetles are found during September. The emergence is 1 or 2 weeks later in the mountainous parts of Pennsylvania and New Jersey and along the coast of New

In southeastern New York, Connecticut, Rhode Island, and southern Massachusetts emergence begins the last week of June and the population peak is reached the last week of July. The population usually remains at a high level for 1 or 2 weeks and then declines. A few beetles are found in September. (Stene *1929*; Britton and Johnson *1938*; Johnson *1939*; Hawley *1944*; Carruth et al. *1946*; Schread *1947*, *1953*; Adams and Matthysse *1949*; Fleming *1963a*)

In southern New Hampshire and southern Vermont beetles begin to emerge the first week of July and the population peak is reached the last week of July or the first week of August. Some years the population declines gradually until late in September, but in other years a second emergence occurs early in September and the population continues at a high level during the month. (Hawley *1944*)

In the Midwestern States between latitude 39° N. and latitude 40.5° N. the emergence and buildup of the beetle population are similar to those in southern New Jersey. Farther north along the shores of the Great Lakes the emergence of the beetle is 1 or 2 weeks later. (Denning and Goff *1944*; Hawley *1944*; Polivka *1950*, *1959*; Gould *1963*)

In central California, the only area on the west coast where the beetles became established, they begin to emerge the first week of June and reach their maximum abundance about the first week of July (Gammon *1961*).

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Jersey. (Hadley *1924*; Smith and Hadley *1926*; Guyton *1929*; Hawley *1944*; Fleming *1963a*)

4. Vittum, F.J. 1986. Biology of the Japanese beetle (Coleoptera: Scarabaeidae) in Eastern Massachusetts. J. Econ. Entomol. 79: 387-391.

- includes monitoring data which can readily be used to test models
- We used PRISM data explorer to generate relevant data to regenerate weather station data from 1983&84. Stations BOLTMA83.txt & BOLTMA84.txt
- Start comparing DD54SS data as new version of model (Tupper nominal 100F)

Table 1. Distribution of JB life stages in soil (samples collected at The International Golf Course, Bolton, Mass., 1983)

Date	n	Avg/ 0.09 m^2	% of total: Egg	First instar	Second instar	Third instar	Pupa	Adult
28 Apr.	10	11.0	0	0	33	67	0	0
5 May	5	13.0	0	0	20	80	0	0
13 May	5	7.4	0	0	27	73	0	0
20 May	5	21.2	0	0	25	75	0	0
26 May	5	18.2	0	0	22	78	0	0
2 June	5	16.0	0	0	20	80	0	0
9 June	5	27.0	0	0	5	95	0	0
15 June	10	10.3	0	0	0	100	0	0
23 June	10	10.7	0	0	0	84	16	0
29 June	5	6.8	0	0	0	38	53	9
7 July	10	4.6	0	0	0	54	33	13
14 July	10	5.7	5	0	0	49	30	16
20 July	5	1.6	12	0	0	62	12	12
29 July	5	3.0	80	0	0	20	0	0
3 Aug.	5	4.0	50	0	0	30	0	20
10 Aug.	5	8.6	14	46	23	12	2	2
17 Aug.	5	12.8	55	17	22	6	0	0
24 Aug.	10	15.6	13	22	62	4	0	0
31 Aug.	5	26.0	0	20	66	14	0	0
8 Sept.	10	20.5	0	7	64	29	0	0
14 Sept.	5	36.8	0	3	27	70	0	0
22 Sept.	5	28.4	0	6	39	55	0	0
28 Sept.	5	38.6	0	1	12	87	0	0
4 Oct.	5	27.2	0	1	7	92	0	0
13 Oct.	5	23.8	0	0	8	92	0	0
19 Oct.	5	21.4	0	0	9	91	0	0
3 Nov.	5	15.4	0	0	4	96	0	0

Table 2. Distribution of JB life stages in soil (samples collected at The International Golf Course, Bolton, Mass., 1984)

Date	n	Avg/ 0.09 m^2	% of total: Egg	First instar	Second instar	Third instar	Pupa	Adult
5 June	10	7.4	0	0	9	91	0	0
14 June	5	13.0	0	0	6	94	0	0
18 July	10	1.8	56	0	0	22	11	11
2 Aug.	5	1.6	38	25	0	12	0	25
14 Aug.[a]	5	66.6	5	81	13	1	0	0
21 Aug.	5	91.4	1	46	53	0	0	0
30 Aug.	5	79.4	1	7	92	<1	0	0
14 Sept.	5	52.4	0	1	34	65	0	0
27 Sept.	5	46.6	0	0	16	84	0	0
11 Oct.	10	33.9	0	<1	12	88	0	0

[a] Sample site moved from Fairway 18 to Fairway 11.

approx 1st pupation

	1983			1984			
date	DD50	DD54_92	date	DD50	DD54_92	DD50 Avg
06/18/83	635	422	06/15/84	662	460	648.5

approx 1st egg hatch

	1983			1984			
date	DD50	DD54_92	date	DD50	DD54_92	DD50 Avg
07/28/83	1563	1170	07/26/84	1486	1127	1524.5

Results: These can be used to add two more important events to model V2: first pupation at 630 DDF, and first egg hatch at 1525 DD (close enough to peak adult emerge)

Analysis of adults from Tables 1 and 2. Note the resolution of these data is low, expecially compared to nearby Waltham MA data (Figs 1&2) analyzed below

weather file: DD54_92 DD50/92

1983 Adult trapping data vs. models			BOLTMA83.txt			est DOY		uspest model			uspest model2	
date	DOY	beetles	cum beetles	cum. Percent	event	observed	Date	V1 predicted	Days diff	abs(days diff)	Ddaccum	
06/23/83	174	0	0	0	2% catch	177	06/26/83	185	8	8	615	829
06/29/83	180	9	9	12.5	10% catch	180	06/29/83	187	7	7	653	876
07/07/83	188	13	22	30.6								
07/14/83	195	16	38	52.8	50% catch	195	07/14/83	211	16	16	934	1217
07/20/83	201	12	50	69.4								
07/29/83	210	0	50	69.4	90% catch	212	07/31/83	232	20	20	1296	1647
08/03/83	215	20	70	97.2	94% catch	214	08/02/83	235	21	21	1346	1705
08/10/83	222	2	72	100	last beetle	223	08/11/83	268	45	45	1544	1939

		weather file:	BOLTMA84.txt									
1984 Data NOTE: small sample size should probably ignore adult trapping data						est DOY		uspest model			uspest model2	
date	DOY	beetles	cum beetles	cum. Percent	event	observed	Date	predicted	Days diff	abs(days diff)	Ddaccum	
06/05/84	157	0	0	0	2% catch	183	07/01/84	186	3	3	686	922
07/01/84	183	1	1	2.8	10% catch	185	07/03/84	189	4	4	728	962
07/18/84	200	10	11	30.6	50% catch	204	07/22/84	214	10	10	1081	1391
07/25/84	207	15	26	72.2	90% catch	209	07/27/84				1175	1505
08/02/84	215	10	36	100.0	94% catch	210	07/28/84				1181	1515
08/21/84	234	0	36	100.0	last beetle	215	08/02/84				1272	1626

Analysis of adults trapped daily for 2 months in July and Aug 1983 & 1984 (Figs 1 & 2)

Note that this is the most complete adult trapping data set published thus far. Used webplotdigitizer online to extract values from the figures

Again used PRISM data explorer to obtain temperature data for Waltham, MA: WALTHMA83.txt & WALTHMA84.txt

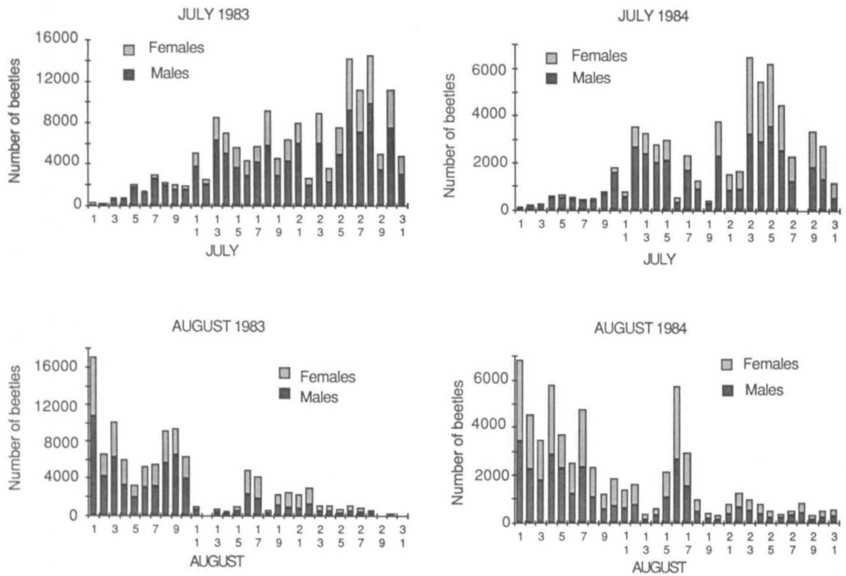

Fig. 1. Number of Japanese beetle adults recovered from eight traps (Bag-a-Bug) in daily collections, July (top) and August (bottom) 1983, Waltham, Mass.

Fig. 2. Number of Japanese beetle adults recovered from eight traps (Bag-a-Bug) in daily collections, July (top) and August (bottom) 1984, Waltham, Mass.

Date	# Beetles	Cum Beetles	Cum Percent	DDSS5092	Event	USPEST model V2 Predicted Dat	Diff Days
07/01/83	322	322	0.12	914.9			
07/02/83	276	598	0.22	939.6			
07/03/83	782	1379	0.51	967.3			
07/04/83	920	2299	0.84	998.6			
07/05/83	2069	4368	1.60	1030.6			
07/06/83	1379	5747	2.11	1055.9	2% emerg	07/05/83	-1
07/07/83	2989	8736	3.21	1076.5			
07/08/83	2299	11034	4.05	1093.2			
07/09/83	1977	13011	4.78	1116.3			
07/10/83	1931	14943	5.49	1132.4			
07/11/83	5103	20046	7.36	1146.6			
07/12/83	2575	22621	8.31	1167.6			
07/13/83	8506	31126	11.43	1192.2	10% emerge	07/09/83	-4
07/14/83	7034	38161	14.02	1217.9			
07/15/83	5609	43770	16.08	1242.8			
07/16/83	4414	48184	17.70	1271.7			
07/17/83	5793	53977	19.83	1300.3			
07/18/83	9241	63218	23.22	1326.2			
07/19/83	4598	67816	24.91	1354.2			
07/20/83	6391	74207	27.26	1381.8			
07/21/83	8000	82207	30.20	1407.9			
07/22/83	2667	84874	31.18	1433.8			
07/23/83	8920	93793	34.45	1453.4			
07/24/83	3586	97379	35.77	1479.3			
07/25/83	7586	104966	38.56	1491.3			
07/26/83	14161	119126	43.76	1510.8			
07/27/83	11080	130207	47.83	1531.4			
07/28/83	14529	144736	53.17	1554	50% emerge	07/28/83	0
07/29/83	4920	149655	54.97	1582.4			
07/30/83	11126	160782	59.06	1609.9			
07/31/83	4782	165563	60.82	1637.6			
08/01/83	17067	182630	67.09	1664.2			
08/02/83	6642	189272	69.53	1693.1			
08/03/83	10085	199357	73.23	1718			
08/04/83	6012	205369	75.44	1746.1			
08/05/83	3200	208569	76.62	1771.5			
08/06/83	5236	213806	78.54	1798.1			
08/07/83	5479	219284	80.55	1825.2			
08/08/83	9164	228448	83.92	1853			
08/09/83	9406	237854	87.37	1882.6			
08/10/83	6303	244157	89.69	1903.2			
08/11/83	970	245127	90.04	1923	90% emerge	08/17/83	6
08/12/83	242	245369	90.13	1936			
08/13/83	727	246097	90.40	1941.5			

Date	# Beetles	Cum Beetles	Cum percent	DDSS5092	Event	USPEST model V2 Predicted	Diff Days
07/01/84	130	130	0.11	922.8			
07/02/84	241	372	0.30	945.2			
07/03/84	279	650	0.53	973			
07/04/84	613	1263	1.02	996.5			
07/05/84	669	1932	1.56	1023.5			
07/06/84	557	2489	2.01	1049.9	2% emerg	07/05/84	-1
07/07/84	464	2954	2.39	1073.4			
07/08/84	502	3455	2.79	1089.5			
07/09/84	780	4235	3.43	1100.7			
07/10/84	1820	6056	4.90	1117.3			
07/11/84	799	6854	5.54	1139.2			
07/12/84	3529	10384	8.40	1160.7			
07/13/84	3251	13635	11.03	1186.1	10% emer	07/09/84	-4
07/14/84	2768	16402	13.27	1210.8			
07/15/84	2954	19356	15.65	1240.2			
07/16/84	520	19876	16.07	1270.4			
07/17/84	2322	22198	17.95	1293.9			
07/18/84	1226	23424	18.94	1316.6			
07/19/84	409	23833	19.27	1335.8			
07/20/84	3752	27585	22.31	1356			
07/21/84	1505	29090	23.53	1379.3			
07/22/84	1635	30724	24.85	1400.8			
07/23/84	6483	37207	30.09	1426.6			
07/24/84	5443	42650	34.49	1455.1			
07/25/84	6167	48817	39.48	1477.9			
07/26/84	4440	53257	43.07	1494.5			
07/27/84	2248	55505	44.89	1514.6			
07/28/84	-37	55467	44.86	1525			
07/29/84	3325	58793	47.55	1540.4			
07/30/84	2712	61505	49.74	1560.2	50% emer	07/29/84	-1
07/31/84	1115	62619	50.64	1581.9			
08/01/84	6844	69463	56.18	1607.1			
08/02/84	4550	74014	59.86	1634.6			
08/03/84	3486	77500	62.68	1659.9			
08/04/84	5780	83280	67.35	1686.2			
08/05/84	3725	87005	70.37	1714.5			
08/06/84	2514	89518	72.40	1743.3			
08/07/84	4771	94289	76.26	1773.3			
08/08/84	2330	96619	78.14	1801.3			
08/09/84	1211	97830	79.12	1826.5			
08/10/84	1890	99720	80.65	1846.9			
08/11/84	1358	101078	81.75	1871.2			
08/12/84	1633	102711	83.07	1894.4			
08/13/84	349	103060	83.35	1915.3			

08/14/83	533	246630	90.60	1952.4				08/14/84	606	103665	83.84	1937			
08/15/83	921	247551	90.93	1964.8				08/15/84	2147	105812	85.58	1961.8			
08/16/83	4848	252400	92.72	1981.2				08/16/84	5743	111555	90.22	1989.3	90% emer	08/16/84	0
08/17/83	4121	256521	94.23	2004.7	94% emerge	08/22/83	5	08/17/84	2954	114509	92.61	2017.1			
08/18/83	582	257103	94.44	2031.5				08/18/84	972	115482	93.40	2035.6			
08/19/83	2230	259333	95.26	2049.5				08/19/84	404	115885	93.72	2053			
08/20/83	2521	261854	96.19	2078.3				08/20/84	312	116197	93.98	2071.4			
08/21/83	2182	264036	96.99	2105.1				08/21/84	789	116986	94.61	2084.8	94% emer	08/23/84	2
08/22/83	2909	266945	98.06	2122.7				08/22/84	1248	118234	95.62	2101			
08/23/83	1018	267963	98.43	2140.7				08/23/84	991	119225	96.42	2122.5			
08/24/83	1018	268981	98.81	2159				08/24/84	789	120014	97.06	2143.3			
08/25/83	582	269563	99.02	2175.1				08/25/84	514	120527	97.48	2160.9			
08/26/83	1018	270581	99.39	2195.6				08/26/84	367	120894	97.77	2175.6			
08/27/83	776	271357	99.68	2222.2				08/27/84	495	121390	98.17	2194.5			
08/28/83	533	271890	99.88	2251.6				08/28/84	844	122234	98.86	2217			
08/29/83	-48	271842	99.86	2278.2				08/29/84	349	122582	99.14	2241.2			
08/30/83	194	272036	99.93	2294.3				08/30/84	514	123096	99.55	2268.7			
08/31/83	194	272230	100.00	2314.4				08/31/84	550	123647	100.00	2296			
09/01/83		272230						09/01/84		123647					

Summary of above results

	1983			1984			
Event	Observed	Predicted	days diff	Observed	Predicted	days diff	Avg Days diff
2%/1st emerg	07/06/83	07/05/83	-1	07/06/84	07/05/84	-1	-1
10% emerge	07/13/83	07/09/83	-4	07/13/84	07/09/84	-4	-4
50% emerge	07/28/83	07/28/83	0	07/30/84	07/29/84	-1	-0.5
90% emerge	08/11/83	08/17/83	6	08/16/84	08/16/84	0	3
94% emerge	08/17/83	08/22/83	5	08/21/84	08/23/84	2	3.5

Results: When you trap 123,000 to 272,000 beetles then “1st emerge” no longer has the same meaning as “2% emerge”. Besides that, the V2 model does an excellent job matching these key events, with Predicing 2% emergence on average 1 day too early, 10% emergence on average 4 days early, 50% emergence ½ day early, 90% emergence on average 3 days late, and 94% emergence 3.5 days late. Since these data were not used to construct model V2, they offer a strong validation data set.

Additional analysis of uspest V1, V2, and UMN models for this data set (marginally useful considering resolution of nearby WALTAM MA data analyzed below)

	wfl=	**BOLTMA83.txt**			wfl=	**BOLTMA84.txt**			
	uspest model V1 predictions (spp=jpb):								
		model	Text and Table 1		model	Text and Table 2		mean	mean abs
	Dds (uspest)	1983	1983	days diff	1984	1984	days diff	error (days)	error (days)
1st adult emerg	970	07/04/83	06/29/83	5	07/04/84	07/06/84	-2	1.5	3.5
10% adult emerg	1050	07/06/83	06/29/83	7	07/06/84	07/06/84	0	3.5	3.5
peak adult em	1600	07/30/83	07/20/83	10	08/01/84	08/02/84	-1	4.5	5.5
90% adult emerge	2080	08/20/83	08/20/83	0					
end main per adult activ	2150	08/23/83	08/20/83	3	08/25/84	08/22/84	3	3	3
last adults trapped	2790	09/25/83	09/15/83	10	10/27/84	09/29/84	28	19	19

Ebbenga et al (UMN) model predictions (tlow=59, thi=71, Corn growing Dds; cal=G):

model	Table 1	model	Table 2	mean	mean abs

	Dds (UMN)	1983	1983	days diff	1984	1984	days diff	error (days)	error (days)
1st adult emerg			06/29/83			07/06/84			
10% adult emerg	463	07/16/83	06/29/83	17	07/15/84	07/06/84	9	13	13
peak adult em (ca. 50% emerg)	623	08/03/83	07/20/83	14	08/04/84	08/02/84	2	8	8
end main per adult activ ca. 90%	837	08/31/83	08/20/83	11	08/29/84	08/22/84	7	9	9
last adults trapped			09/15/83			09/29/84			

V2 uspest model predictions (spp=jpb revised June 2024):

		model	Text and Table 1		model	Text and Table 2		mean	mean abs
	Dds (uspest)	1983	1983	days diff	1984	1984	days diff	error (days)	error (days)
1st adult emerg	1000	07/05/83	06/29/83	6	07/05/84	07/06/84	-1	2.5	3.5
10% adult emerg	1100	07/09/83	06/29/83	10	07/10/84	07/06/84	4	7	7
peak adult em	1540	07/28/83	07/20/83	8	07/30/84	08/02/84	-3	2.5	5.5
90% adult emerge	1985	08/16/83	08/20/83	-4	08/16/84				
end main per adult activ	2110	08/21/83	08/20/83	1	08/23/84	08/22/84	1	1	1
last adults trapped	2700	09/20/83	09/15/83	5	10/14/84	09/29/84	15	10	10

Results: These data show earlier activity vs. other data sets and vs. uspest model v1. 1983 data should be usable in revising the uspest model, perhaps pointing to using e.g. the 10th or 20th percentile rather than the mean or median estimate so that early emerging beetles are not missed.

- Results (UMN model): This model produced results that were biased relatively late compared to observed events; both ME and MAE were 7.5 for 10% adult emergence, both ME and MAE were 8 days for 50% adult emergence, and both ME and MAE were 9 days for 90% adult emergence.
These results may indicate that the thresholds, derived from trapping data in MN only, may not be as geographically robust as the thresholds derived for the older model implemented at uspest.org.

- Conclusion: Overall, the V1 and V2 uspest models performed much better for this data set collected in Massachusetts. The UMN model choices for lower and upper thresholds, and unusual calculation method (simple average with substitutions, which was developed for corn and not for insects), appear to be questionable and should be re-evaluated.
The V2 model improved performance slightly for some events, but not for others. As the nearby Waltham MA data is of higher resolution, these results are relatively less important.

5. Ebbenga, D., A Hanson, E. Burkness, and W. Hutchison. 2022. A degree-day model for forecasting adult phenology of Popillia japonica (Coleoptera: Scarabaeidae) in a temperate climate. Frontiers in Insect Sci. 2: 1-11. DOI 10.3389/finsc.2022.1075807

Resulting model from Table 4 and implemented at: https://vegedge.umn.edu/degree-days-midwest-insects/japanese-beetle
Tlow=59F, Tupper=71F, start Jan 1st, corn or modif. Growing Dds (substitution method: if Tmin less than Tlow, subs Tlow, if Tmax greater than Tupper, use Tupper)

Dds	percent emerg
463	10
537	25
623	50
722	75
837	90

Results: Ignore this source as it was repeated using easier to interpret methods in next source

6. https://blog-fruit-vegetable-ipm.extension.umn.edu/2021/04/new-forecasting-model-for-japanese.html
- This model differs (from same authors) vs Ebbenga et al 2022. Here, simple average DDs are used with Tlow=50F, Tupper=88F (SA5088)
-Method: determine dates of events using their model (SA5088) and find DD values using potential new models (SS5092 and SS5492)
- Use data from PRISM data explorer for Rosemount in 2019 and 2020

		Fig1&Table 1	SA5088	SS5492 (dds on date SA508	Fig1&Table 1	SA5088	SS5492		SS5492
DDs SA5088	percent emerg	2019	ROSEMOUN	ROSEMOUNT19	2020	ROSEMOUN	ROSEMOUNT20		average
990	2	07/08/19	07/08/19	758	07/04/20	07/04/20	824		791
1190	10	07/15/19	07/16/19	928	07/07/20	07/12/20	1008		968

	1610	50	07/25/19	08/04/19	1269			07/28/20	07/31/20	1351		1310		
	2110	90	08/19/19	09/01/19	1656			08/18/20	08/24/20	1744		1700		

Section I. Extracting key events from Fig.s 1-4.

- Data in Fig.s 1-4 suitable to test current model. Also test their VegEdge model
- Methods: extract raw data using webplotdigitizer online, convert to cumul. percentages, estimate 1st emerg (ca. 2%), peak emerg (ca. 50%), and approx. end of main period of adult activity (ca. 94%), skip last event (last adult captured) as too variable.
- To test model, we need to 1) determine comparable DDs for events of 2%, 10%, 50%, and 90% emergence
- Find nearest weather station(s) going back to 2019, run current model for comparison, calc days diff, abs days diff, compile results
- Ended up using PRISM data explorer tool for these locations and years

Location: Rosemont, MN (S. of St. Paul within metro area)
Lat/Long
44.716667, 93.083333

USPEST model V1 (50/100 Single sine)

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2019 Fig 1a				Cumulative			est DOY	Est Date	ROSEMN19	Date est.	VegEdge		uspest	uspest
	DOY	Catch	Cumultive	Percent	Event	Dds	Observed	Observed	Predicted	50 percent ca	Predicted		model2	model2
	183	3.4	3.4	0.0						200	w/ROSEMN		DD54_92	DD50
	189	525.4	528.8	1.9	1st adult emer	970	190	07/09/19	188	37			774	1019
	196	4155.9	4684.7	16.6	10% ad emerg	1050	192	07/11/19	192		197		809	1062
	203	5650.8	10335.5	36.6										
	210	6433.9	16769.4	59.4	peak adult em	1600	207	07/26/19	216		217		1105	1418
	217	3918.6	20688	73.3										
	224	3016.9	23704.9	83.9										
	230	1427.1	25132	89.0	90% emerg	2080	233	08/21/19	243		250		1527	1944
	238	893.2	26025.2	92.2										
	246	359.3	26384.5	93.4	94% emerg	2150	248	09/05/19	248				1684	2160
	253	406.8	26791.3	94.9										
	259	762.7	27554	97.6										
	268	430.5	27984.5	99.1										
	274	228.8	28213.3	99.9	last adult trapped		278	10/05/19					1962	2532
	280	27.1	28240.4	100										

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2020 Figure 1b							est DOY	Est Date	Date est. ROSEMN20	50 percent ca	VegEdge		uspest	uspest
Day of Year		Trap Catch	Cumulative	Percentile	Event	Dds	Observed	Observed	Predicted	205	Predicted		model2	model2
	175	0	0	0							w/ROSEMN		DD54	DD50
	182	381	381	2.2713724	1st adult emerg	970	182	06/30/20	183	51.6575			718	954
	189	2428.6	2809.6	16.749732	10% ad emerg	1050	184	07/02/20	186		193		768	1011
	197	2142.9	4952.5	29.52486										
	203	2261.9	7214.4	43.009419										
	210	2738.1	9952.5	59.332896	peak adult em	1600	205	07/23/20	209		214	195	1182	1510
	217	2059.5	12012	71.610826										
	224	1381	13393	79.843806										
	231	1904.8	15297.8	91.199475	90% emerg	2080	231	08/18/20	234		242		1603	2032
	238	1238.1	16535.9	98.580541	94% emerg	2150	236	08/23/20	237				1693	2142
	251	190.5	16726.4	99.716227										
	255	47.6	16774	100	last adult trap	2790	255	09/11/20	314				1918	2427

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2021 Figure 1c

Day of Year	Trap Catch	Cumulative	Percentile	Event	Dds	est DOY Observed	Est Date Observed	ROSEMN21 Predicted	50 percent ca 198	VegEdge Predicted w/ROSEMN	uspest model2 DD54	uspest model2 DD50
173	27.1	27.1	0.1									
179	644.1	671.2	3.5	1st adult emer	970	177	06/26/21	174	51.2786		825	1052
188	4939	5610.2	29.1	10% ad emerg	1050	180	06/29/21	177		187	877	1115
193	1379.7	6989.8	36.2									
200	3301.7	10291.5	53.4	peak adult em	1600	198	07/17/21	203		209	1171	1481
207	2969.5	13261	68.8									
214	1996.6	15257.6	79.1									
221	1284.7	16542.4	85.8	90% emerg	2080	225	08/13/21	223		236	1706	2124
228	1664.4	18206.8	94.4	94% emerg	2150	228	08/16/21	227			1749	2179
235	715.3	18922	98.1									
241	193.2	19115.2	99.1									
248	122	19237.3	99.7									
256	50.8	19288.1	100.0	last adult trap	2790	256	09/13/21	263			2156	2692

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2019 Figure 2a

Lat/Long 45.21666 92.8833 near Forest Lake, MN

PRISM Data Expl station:

Day of Year	Trap Catch	Cumulative	Percentile	Event	Dds Uspest m	est DOY Observed	Est Date Observed	FORLKMN19	VegEdge Predicted w/FORLKMN19	uspest model2 DD54	uspest model2 DD50
183	9	9	0.1930714								
189	63.1	72.1	1.5444225	1st adult emer	970	190	07/09/19	191		721	957
196	549.5	621.6	13.320482	10% ad emerg	1050	194	07/13/19	195	198	792	1044
203	612.6	1234.2	26.447892								
211	882.9	2117.1	45.366807								
217	1054.1	3171.2	67.953675	peak adult em	1600	212	07/31/19	220	220	1114	1437
222	738.7	3909.9	83.783787								
231	279.3	4189.2	89.768342	90% emerg	2080	232	08/20/19	251	258	1425	1827
239	153.2	4342.3	93.050195	94% emerg	2150	240	08/28/19	258		1510	1944
246	126.1	4468.5	95.752897								
253	36	4504.5	96.525097								
260	63.1	4567.6	97.876448								
267	72.1	4639.6	99.42085								
276	27	4666.7	100	last adult trap	2790	275	10/02/19	NA		1839	2393

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2020 Figure 2b

Day of Year	Trap Catch	Cumulative	Percentile	est DOY Observed	Est Date Observed	FORLKMN20	VegEdge Predicted	uspest model2	uspest model2

175	9	9	0.1506757						w/FORLKMN20	DD54	DD50
182	225.2	234.2	3.9171534	1st adult emer	970	181	06/29/20	184		683	907
189	1000	1234.2	20.640314	10% ad emer	1050	184	07/02/20	187	193	752	988
195	932.4	2166.7	36.233532								
202	1038.3	3205	53.596995	peak adult em	1600	202	07/20/20	210	215	1121	1430
210	1144.1	4349.1	72.730701								
217	783.8	5132.9	85.838044								
223	423.4	5556.3	92.919022	90% emerg	2080	221	08/08/20	235	242	1412	1795
234	189.2	5745.5	96.082863	94% emerg	2150	230	08/17/20	238		1565	1984
239	135.1	5880.6	98.34275								
245	81.1	5961.7	99.698682								
252	18	5979.7	100	last adult trap	2790	250	09/06/20	NA	UMN model Tlow=59F, Tup	1879	2374
									10%=463DD, 50%=623DD, 90%=837DD		
									VegEdge		

2021 Figure 2c

Day of Year	Trap Catch	Cumulative	Percentile			DOY Observed	Date Observed	FORLKMN21	Predicted w/FORLKMN21	uspest model2	uspest model2
173	18	18	0.1571993							DD54	DD50
179	423.4	441.4	3.8550808	1st adult emer	970	177	06/26/21	176		784	1006
188	2441.4	2882.9	25.176908	10% ad emer	1050	182	07/01/21	180	189	872	1115
193	982	3864.8	33.752846								
200	2459.5	6324.3	55.23203	peak adult em	1600	198	07/17/21	205	210	1132	1438
207	2153.2	8477.5	74.036151								
213	1324.3	9801.8	85.601866								
221	369.4	10171.2	88.827677	90% emerg	2080	223	08/11/21	226	238	1628	2034
228	824.3	10995.5	96.026744	94% emerg	2150	227	08/15/21	229		1686	2107
235	279.3	11274.8	98.465773								
241	90.1	11364.8	99.252556								
247	58.6	11423.4	99.763965								
254	27	11450.4	100	last adult trap	2790	248	09/05/21	270		2025	2528
									UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1,		
									10%=463DD, 50%=623DD, 90%=837DD		
									VegEdge	uspest	uspest

2019 Figure 3a 44.68333, 92.8666 Hastings, MN

Day of Year	Trap Catch	Cumulative	Percentile		DOY Observed	Date Observed	HASTMN19 HASTMN19	Predicted w/HASTMN19	model2 DD54	model2 DD50
183	4.6	4.6	0.0640865							
189	17.6	22.2	0.3098478	1st adult emerg.	190	07/09/19	189		767	1013
203	661.6	683.8	9.54071	10% ad emerg	198	07/17/19	192	197	936	1214
210	2298.8	2982.6	41.616342							
217	1920.1	4902.7	68.408182	peak adult em	212	07/31/19	216	216	1186	1520
224	821.7	5724.5	79.874021							
231	490.9	6215.3	86.722993							
239	325.6	6541	91.266404	90% emerg	237	08/25/19	242	248	1584	2018

247	224.1	6765	94.392682	94% emerg	246	09/03/19	246		1681	2150
253	96.9	6862	95.745427							
259	173.6	7035.6	98.168277							
267	97.6	7133.2	99.529638							
274	21.5	7154.7	99.829509							
281	12.2	7166.9	100	last adult trapped	280	10/07/19	NA		1989	2565

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2020 Figure 3b

Day of Year	Trap Catch	Cumulativ e	Percentil e		DOY Observed	Date Observed	HASTMN20	VegEdge Predicted w/HASTMN20	uspest model2 DD54	uspest model2 DD50
177	9.6	9.6	0.2649248							
182	3.2	12.8	0.3527198	1st adult emerg.	184	07/02/20	182		798	1044
189	283.4	296.2	8.1664713	10% ad emerg	190	07/08/20	185	191	951	1221
196	461.8	758	20.896741							
203	767.5	1525.5	42.055326	peak adult em	207	07/25/20	207	210	1275	1612
210	678.3	2203.9	60.755653							
217	703.8	2907.7	80.158339							
224	321.7	3229.4	89.02563	90% emerg	225	08/12/20	230	239	1572	1980
231	334.4	3563.8	98.244101	94% emerg	228	08/15/20	234		1627	2048
245	47.8	3611.5	99.561025							
256	15.9	3627.4	100	last adult trapped	255	09/11/20	285		2005	2521

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2021 Figure 3c

Day of Year	Trap Catch	Cumulativ e	Percentil e		DOY Observed	Date Observed	HASTMN21	VegEdge Predicted w/HASTMN21	uspest model2 DD54	uspest model2 DD50
173	4.1	4.1	0.0641579							
179	106.3	110.4	1.7239962	1st adult emerg.	179	06/28/21	171		885	1127
188	1463.4	1573.9	24.568247	10% ad emerg	182	07/01/21	176	185	946	1199
193	501.9	2075.7	32.402427							
201	616.9	2692.6	42.031721	peak adult em	203	07/22/21	202	206	1308	1645
207	1655.4	4348	67.872339							
214	1158.9	5506.8	85.962479							
221	299.3	5806.1	90.634917	90% emerg	220	08/08/21	221	232	1652	2058
228	395.2	6201.3	96.803678	94% emerg	226	08/14/21	224		1761	2191
235	96.1	6297.5	98.304398							
240	58.2	6355.6	99.21227							
248	36.2	6391.8	99.777471							
255	14.3	6406.1	100	last adult trapped	252	09/09/21	259		2166	2698

Lat/Long: 44.8666, 93.6333

not using nearest uspest station: E2706

using PRISM data: LANDARBMN19

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837DD

2019 Figure 4a

Day of Year	Trap Catch	Cumulative	Percentile		DOY Observed	Date Observed	LANDARBMN19 Predicted	VegEdge Predicted w/LANDARBMN19	uspest Model2 Dd54 DD54	uspest model2 DD50
187	0	0	0.0004964							
196	28.7	28.7	1.424701	1st adult emerg.	191	07/10/19	188		897	1058
203	135.2	163.9	8.138808	10% ad emerg	197	07/16/19	191	195	940	1216
210	819.7	983.6	48.830366							
216	647.5	1631.2	80.976697	peak adult em	211	07/30/19	215	213	1206	1538
224	213.1	1844.3	91.556502							
231	32.8	1877.1	93.184164							
239	36.9	1913.9	95.015284	90% emerg	223	08/11/19	238	242	1424	1803
247	0	1913.9	95.015284	94% emerg	237	08/25/19	244		1628	2063
253	18.4	1932.4	95.930844							
259	36.9	1969.3	97.761964							
267	36.9	2006.2	99.593084							
274	4.1	2010.3	99.796542	last adult trapped	274	10/01/19	NA		2026	2600
278	4.1	2014.4	100							

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837D

2020 Figure 4b

Day of Year	Trap Catch	Cumulative	Percentile		DOY Observed	Date Observed	LANDARBMN20 Predicted	VegEdge Predicted w/LANDARBMN20	uspest Model2 Dd5	uspest model2 DD50
182	0	0	0	1st adult emerg.	184	07/02/20	181		816	1064
189	114.8	114.8	14.873838	10% ad emerg	187	07/05/20	184	190	893	1153
196	168	282.8	36.653386							
203	221.3	504.1	65.338645	peak adult em	200	07/18/20	206	209	1166	1478
210	106.6	610.7	79.150066							
217	69.7	680.3	88.180611							
224	32.8	713.1	92.430279	90% emerg	221	08/08/20	228	236	1528	1924
231	24.6	737.7	95.61753	94% emerg	228	08/15/20	232		1658	2082
238	16.4	754.1	97.742364							
243	11.3	765.4	99.203187							
249	6.1	771.5	100	last adult trapped	245	09/01/20	281		1977	2469

UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1, 10%=463DD, 50%=623DD, 90%=837D

2021 Figure 4c

Day of Year	Trap Catch	Cumulative	Percentile		DOY Observed	Date Observed	LANDARBMN21 Predicted	VegEdge Predicted w/LANDARBMN21	uspest Model2 Dd5	uspest model2 DD50
169	0	0	0.000272							
179	4.1	4.1	0.1117544	1st adult emerg.	181	06/30/21	174		892	1132
188	688.5	692.6	18.8408	10% ad emerg	183	07/02/21	178	187	931	1179

193	340.2	1032.8	28.093841							
200	1188.5	2221.3	60.423742	peak adult em	197	07/16/21	203	208	1159	1462
207	739.8	2961.1	80.546318							
214	291	3252.1	88.46157	90% emerg	217	08/05/21	223	232	1562	1946
221	168	3420.1	93.032349	94% emerg	222	08/10/21	227		1659	2062
228	184.4	3604.5	98.049058							
235	24.6	3629.1	98.717952							
243	19.5	3648.6	99.247494							
251	14.3	3662.9	99.637682							
258	9.2	3672.1	99.888518	last adult trapped	258	09/15/21	261		2207	2752
266	4.1	3676.2	100							

Compare potential V2 models	Dds Tlow=12.2 2 (54F) 1st Emergence	10% emerg	50% emerg	90% emerg	94% emerg	last adult	Dds Tlow=10 (50F) 1st Emergence	10% emerg	50% emerg	90% emerg	94% emerg	last adult
1983 BOLTMA	615	653	934	1296	1346	1544	829	876	1217	1647	1705	1939
2019 ROSEMN	774	809	1105	1527	1684	1962	1019	1062	1418	1944	2160	2532
2020 ROSEMN	718	768	1182	1603	1693	1918	954	1011	1510	2032	2142	2427
2021 ROSEMN	825	877	1171	1706	1749	2156	1052	1115	1481	2124	2179	2692
2019 FORLKMN	721	792	1114	1425	1510	1839	957	1044	1437	1827	1944	2393
2020 FORLKMN	683	752	1121	1412	1565	1879	907	988	1430	1795	1984	2374
2021 FORLKMN	784	872	1132	1628	1686	2025	1006	1115	1438	2034	2107	2528
2019 HASTMN	767	936	1186	1584	1681	1989	1013	1214	1520	2018	2150	2565
2020 HASTMN	798	951	1275	1572	1627	2005	1044	1221	1612	1980	2048	2521
2021 HASTMN	885	946	1308	1652	1761	2166	1127	1199	1645	2058	2191	2698
2019 LANDARBMN	807	940	1206	1424	1628	2026	1058	1216	1538	1803	2063	2600
2020 LANDARBMN	816	893	1166	1528	1658	1977	1064	1153	1478	1924	2082	2469
2021 LANDARBMN	892	931	1159	1562	1659	2207	1132	1179	1462	1946	2062	2752
1994 COONISDAM	780	928	1217	1409	1484	1939	1020	1207	1576	1830	1925	2514
1995 COONISDAM	777	809	1304	1752	1830	2057	1022	1061	1657	2189	2283	2567
1996 COONISDAM			1363	1694	1759	1862			1745	2156	2233	2373
1997 COONISDAM			1314	1621	1681				1694	2094	2175	

Note: Do not include BOLTMA83 results – all are "too early" outliers

potential outliers							1st Emergence	10% emerg	50% emerg	90% emerg	94% emerg	last adult
mean	787.6	871.7	1207.7	1568.7	1665.9	2000.5	1026.8	1127.5	1540.1	1984.6	2108.0	2533.7
stdev	58.2	71.8	81.0	108.9	91.0	110.7	61.8	82.2	103.2	126.0	100.8	117.6
CV	7.4	8.2	6.7	6.9	5.5	5.5	6.0	7.3	6.7	6.4	4.8	4.6
33rd Percentile	774.9	827.3	1165.7	1528.0	1656.5	1953.3	1014.7	1077.4	1477.2	1943.0	2063.0	2496.9

10^{th} Percentile	768.8	809.0	1152.3	1501.5	1627.8	1928.5	1007.8	1061.3	1456.0	1900.5	2058.5	2448.0
Old uspest model (V1):							**970**	**1050**	**1600**	**2080**	**2150**	**2790**
New uspest model (V2):							**1000**	**1100**	**1540**	**1985**	**2110**	**2700**

Results: The new proposed Tlow of 54F resulted in higher CV values, so we will retain the 50F Tlow for uspest model V2.
Notes: The old (V1) model is pretty close to the mean of the sources used here. To be conservative on 2% emergence, the value was decreased to be close to the 10^{th} percentile (of 2%). Also, the last adult activity was increased to be closer to the original model, based on many of the data sets arising from northerly locations where fall/colder weather ends the season abruptly, whereas more southern locations would remain favorable for longer.

Section II. Some partial cross validations (using same data sets). Key events (first or 2% emergence, peak or 50% emergence, comparing days difference for UMN model and uspest models V1 and V2.

:Model V1	1st Emergence (2%)				Peak (50%)					Old uspest model (V1)
	Observed	Expected	Difference	Abs. Difference	Observed	Expected	Difference	Abs. Difference	1st adult emerg.	970
2019 ROSEMN	187	190	-3	3	207	218	-11	11	10% ad emerg	1050
2020 ROSEMN	181	182	-1	1	205	209	-4	4		
2021 ROSEMN	177	174	3	3	197	203	-6	6	peak adult em	1600
2019 FORLKMN	184	191	-7	7	202	220	-18	18		
2020 FORLKMN	183	184	-1	1	204	211	-7	7		
2021 FORLKMN	176	175	1	1	194	206	-12	12	90% emerg	2080
2019 HASTMN	189	187	2	2	211	214	-3	3	94% emerg	2150
2020 HASTMN	183	181	2	2	203	206	-3	3		
2021 HASTMN	178	170	8	8	197	200	-3	3		
2019 LANDARBMN	194	188	6	6	212	215	-3	3	last adult trapped	2790
2020 LANDARBMN	185	180	5	5	200	206	-6	6		
2021 LANDARBMN	176	172	4	4	195	202	-7	7		
		avg:	1.5833333			avg:	-6.916667			
		abs avg:	3.5833333			abs avg:	6.9166667			

Overall, the average differences in our model and the values found in Minnesota are within a week, showing our model to be moderately accurate. First emergence date is more accurate than peak.

Day difference observed vs. predicted (re-analysed by Len using PRISM data and revised (V2) uspest model):

UMN MODEL

	10%-- 463				Peak (50%)-- 623				90%-- 837			
	Observed DOY	Predicted DOY	Difference	Abs. Difference	Observed DOY	Predicted DOY	Difference	Abs. Difference	Observed DOY	Predicted DOY	Difference	Abs. Difference
2019 ROSEMN	192	197	5	5	207	217	10	10	233	250	17	17
2020 ROSEMN	184	193	9	9	205	214	9	9	231	242	11	11
2021 ROSEMN	180	187	7	7	198	209	11	11	225	236	11	11
2019 FORLKMN	194	198	4	4	212	220	8	8	232	258	26	26
2020 FORLKMN	184	193	9	9	202	215	13	13	221	242	21	21
2021 FORLKMN	182	189	7	7	198	210	12	12	223	238	15	15
2019 HASTMN	192	197	5	5	212	216	4	4	237	248	11	11
2020 HASTMN	190	191	1	1	207	210	3	3	225	239	14	14
2021 HASTMN	182	185	3	3	203	206	3	3	220	232	12	12
2019 LANDARBMN	197	195	-2	2	211	213	2	2	223	242	19	19
2020 LANDARBMN	187	190	3	3	200	209	9	9	221	236	15	15
2021 LANDARBMN	183	187	4	4	197	208	11	11	217	232	15	15
		avg:	4.6			avg:	7.9			avg:	15.6	
		abs avg:	4.9			abs avg:	7.9			abs avg:	15.6	

USPEST MODEL V1

	10%-- 1108				Peak (50%)				90%-- 2124			
	Observed DOY	Predicted DOY	Difference	Abs. Difference	Observed DOY	Predicted DOY	Difference	Abs. Difference	Observed DOY	Predicted DOY	Difference	Abs. Difference
2019 ROSEMN	192	192	0	0	207	216	9	9	233	243	10	10
2020 ROSEMN	184	186	2	2	205	209	4	4	231	234	3	3
2021 ROSEMN	180	177	-3	3	198	203	5	5	225	223	-2	2
2019 FORLKMN	194	195	1	1	212	220	8	8	232	251	19	19
2020 FORLKMN	184	187	3	3	202	210	8	8	221	235	14	14
2021 FORLKMN	182	180	-2	2	198	205	7	7	223	226	3	3
2019 HASTMN	198	192	-6	6	212	216	4	4	237	242	5	5
2020 HASTMN	190	185	-5	5	207	207	0	0	225	230	5	5
2021 HASTMN	182	176	-6	6	203	202	-1	1	220	221	1	1
2019 LANDARBMN	197	191	-6	6	211	215	4	4	223	238	15	15

2020 LANDARBMN	187	184	-3	3	200	206	6	6	221	228	7	7
2021 LANDARBMN	183	178	-5	5	197	203	6	6	217	223	6	6
		avg:	-2.5			avg:	5.0			avg:	7.2	
		abs avg:	3.5			abs avg:	5.2			abs avg:	7.5	

USPEST MODEL V2

	10%-- 1100				Peak (50%) - 1540				90%-- 1985			
	Observed DOY	Predicted DOY	Difference	Abs. Difference	Observed DOY	Predicted DOY	Difference	Abs. Difference	Observed DOY	Predicted DOY	Difference	Abs. Difference
2019 ROSEMN	192	194	2	2	207	214	7	7	233	236	3	3
2020 ROSEMN	184	188	4	4	205	207	2	2	231	229	-2	2
2021 ROSEMN	180	180	0	0	198	201	3	3	225	219	-6	6
2019 FORLKMN	194	197	3	3	212	217	5	5	232	244	12	12
2020 FORLKMN	184	188	4	4	202	208	6	6	221	231	10	10
2021 FORLKNM	182	182	0	0	198	203	5	5	223	222	-1	1
2019 HASTMN	198	194	-4	4	212	214	2	2	237	235	-2	2
2020 HASTMN	190	186	-4	4	207	204	-3	3	225	226	1	1
2021 HASTMN	182	178	-4	4	203	199	-4	4	220	217	-3	3
2019 LANDARBMN	197	193	-4	4	211	212	1	1	223	233	10	10
2020 LANDARBMN	187	186	-1	1	200	203	3	3	221	224	3	3
2021 LANDARBMN	183	180	-3	3	197	201	4	4	217	219	2	2
		avg:	-0.6			avg:	2.6			avg:	2.3	
		abs avg:	2.8			abs avg:	3.8			abs avg:	4.6	

Results have been added to summaries further up in this spreadsheet.

6. Wawrzynski, R. P., and M. E. Ascerno. 1998. Mass trapping for Japanese beetle (Coleoptera: Scarabaeidae) suppression in isolated areas. J. Arboriculture 24:303-307.

- Location: "Minneapolis city park along the Mississippi River", approx 15 acres
- using PRISM data explorer set on "Boom Island Park": COONISDAM94.txt etc.
- As this effort was primarily for mass trapping, and was rather successful, the 3 later years relatively small sample size may be questioned (as to how much weight should be considered in model performance).
- The location may not be accurate; if the data were better I might try an alternate location.

1) Year 1 (1994) data

Table 1. Japanese beetle captures, 1994.

Date	Beetle captures	Date	Beetle captures

6/21	3	8/23	297
6/28	31	8/30	114
7/5	112	9/6	15
7/12	329	9/13	36
7/19	329	9/20	15
7/26	622	9/27	2
8/2	1,138	10/4	1
8/9	961	10/11	0
8/16	456	10/18	0
		Total	**4,451**

Date	DOY	Beetles	Cum. Beetles	Cum. Percent	Event	Observed DOY	Predicted V1 uspest mo COONISDAM	54/92 V2 uspest mo same Dds on obs da	50/92 V2 uspest Dds on obs date	UMN model 10%=463DD,	V2 uspest pred DOY	V1 uspest e days	UMN error days	V2 uspest err days
06/21/94	172	3	3	0.1										
06/28/94	179	31	34	0.8	2%	182	180	780	1020		181	-2		-1
07/05/94	186	112	146	3.3										
07/12/94	193	329	475	10.6	10%	192	185	928	1207	193	187	-7	1	-5
07/19/94	200	329	804	18.0										
07/26/94	207	622	1426	32.0										
08/02/94	214	1138	2564	57.5	50 % or peak	212	213	1217	1576	217	211	1	5	-1
08/09/94	221	961	3525	79.0										
08/16/94	228	456	3981	89.2	90%	228	240	1409	1830	254	236	12	26	8
08/23/94	235	297	4278	95.9	94 % or end o	233	248	1484	1925		243	15		10
08/30/94	242	114	4392	98.5										
09/06/94	249	15	4407	98.8										
09/13/94	256	36	4443	99.6										
09/20/94	263	15	4458	99.9										
09/27/94	270	2	4460	100.0	last beetles c	270	NA	1939	2514		NA			
10/04/94	277	1	4461	100.0										
10/11/94	284	0	4461	100.0										

2. Table 2 – 1995

Table 2. Japanese beetle captures, 1995.

Date	Beetle captures	Date	Beetle captures
7/6	1	8/24	5
7/13	11	8/31	3
7/20	5	9/7	0
7/27	9	9/14	3
8/3	13	9/21	0
8/10	12	9/28	0
8/17	16	**Total**	**78**

Date	DOY	Beetles	Cum. Beetles	Cum. Percent	Event	Observed DOY	COONISDAM95 V1 uspest model Predicted DOY	54/92 Dds on obs da	50/92 V2 uspest Dds on obs d	UMN model 10%=463DD,	V2 uspest pred DOY	V1 uspest e days	UMN error days	V2 uspest err days
07/06/95	187	1	1	1.3	2%	188	185	777	1022		187	-3		-1
07/13/95	194	11	12	15.4	10%	190	190	809	1061	196	192	0	6	2
07/20/95	201	5	17	21.8										
07/27/95	208	9	26	33.3										
08/03/95	215	13	39	50.0	50 % or peak	215	212	1304	1657	216	210	-3	1	-5

08/10/95	222	12	51	65.4										
08/17/95	229	16	67	85.9										
08/24/95	236	5	72	92.3	90%	236	232	1752	2189	238	228	-4	2	-8
08/31/95	243	3	75	96.2	94 % or end o	240	235	1830	2283		234	-5		-6
09/07/95	250	0	75	96.2										
09/14/95	257	3	78	100.0	last beetles c	256	293	2057	2567		275	37		19
09/21/95	264	0	78	100.0										

Note: smallest total catch sample date may be less precise

3. Year 3 (1996) data

Table 3. Japanese beetle captures, 1996.

Date	Beetle captures	Date	Beetle captures
7/17	4	8/28	26
7/24	18	9/4	13
7/31	13	9/11	11
8/7	21	9/18	3
8/14	32	9/25	0
8/21	37	10/2	0
		Total	**178**

Date	DOY	Beetles	Cum. Beetles	Cum. Percent	Event	Observed DOY	COONISDAM96 Predicted uspest model	54/92 V2 uspest model Dds on obs da	50/92 V2 uspest Dds on obs d	UMN model 10%=463DD,	V2 uspest pred DOY	V1 uspest e days	UMN error days	V2 uspest err days
07/17/96	199	4	4	2.2	2%	199	190	878	1148		192	-9		-7
07/24/96	206	18	22	12.4	10%	205	195	988	1283	205	198	-10	0	-7
07/31/96	213	13	35	19.7										
08/07/96	220	21	56	31.5										
08/14/96	227	32	88	49.4	50 % or peak	227	221	1363	1745	227	218	-6	0	-9
08/21/96	234	37	125	70.2										
08/28/96	241	26	151	84.8										
09/04/96	248	13	164	92.1	90%	247	244	1694	2156	257	239	-3	10	-8
09/11/96	255	11	175	98.3	94 % or end o	250	247	1759	2233		246	-3		-4
09/18/96	262	3	178	100.0	last beetles c	261	NA	1862	2373		NA			
09/25/96	269	0	178	100.0										
10/02/96	276	0	178	100.0										

4. Year 4 (1996) data

Table 4. Japanese beetle captures, 1997.

Date	Beetle captures	Date	Beetle captures
6/28	1	8/26	25
7/2	0	9/2	6
7/9	0	9/9	8
7/15	1	9/16	4
7/22	2	9/23	3
7/29	5	9/30	1

7/29	5	9/30	1
8/5	23	10/7	0
8/12	36	10/14	0
8/19	14	**Total**	**129**

Date	DOY	Beetles	Cum. Beetles	Cum. Percent	Event	Observed DOY	V1 uspest model Predicted uspest model COONISDAM97	V2 uspest model 54/92	50/92 V2 uspest Dds on obs d	UMN model 10%=463DD,	V2 uspest pred DOY	V1 uspest err days	UMN error days	V2 uspest err days
06/28/97	179	1	1	0.8										
07/02/97	186	0	1	0.8										
07/09/97	193	0	1	0.8										
07/15/97	199	1	2	1.6	2%	201	193	NA	1197		194	-8		-7
07/22/97	206	2	4	3.1										
07/29/97	213	5	9	7.0										
08/05/97	220	23	32	24.8	10%	212	196	NA	1484	201	198	-16	-11	-14
08/12/97	227	36	68	52.7	50 % or peak	225	220	1314	1694	220	217	-5	-5	-8
08/19/97	234	14	82	63.6										
08/26/97	241	25	107	82.9										
09/02/97	248	6	113	87.6	90%	249	249	1621	2094	255	243	0	6	-6
09/09/97	255	8	121	93.8	94 % or end o	255	253	1681	2175		250	-2		-5
09/16/97	262	4	125	96.9										
09/23/97	269	3	128	99.2							NA			
09/30/97	276	1	129	100.0	last beetles c	275	NA							
10/07/97	283	0	129	100.0										

Note: small total catch sample date may be less precise - first events are outliers so exclude.

Summary of V2 Model over all data sets:	54/92 V2 model						50/92 V1 model					
	2%/1st emerg	10% emerg	50% emerg	90% emerg	94% emerg	last adult	2%/1st emerg	10% emerg	50% emerg	90% emerg	94% emerg	last adult
Wawrzy. 94	780	928	1217	1409	1484	1939	1020	1207	1576	1830	1925	2514
Wawrzy. 95	777	809	1304	1752	1830	2057	1022	1061	1657	2189	2283	2567
Wawrzy. 96			1363	1694	1759	1862			1745	2156	2233	2373
Wawrzy. 97			1314	1621	1681				1694	2094	2175	
results this study only:												
mean	778.5	868.5	1299.5	1619	1688.5	1952.7	1021.0	1134.0	1668.0	2067.3	2154.0	2484.7
stdev	2.1	84.1	60.7	149.9	149.3	98.2	1.4	103.2	71.2	163.0	158.9	100.3
CV	0.3	9.7	4.7	9.3	8.8	5.0	0.1	9.1	4.3	7.9	7.4	4.0
results this and other studies combined												
mean	787.6	871.7	1207.7	1568.7	1665.9	2000.5	1026.8	1127.5	1540.1	1984.6	2108.0	2533.7
stdev	58.2	71.8	81.0	108.9	91.0	110.7	61.8	82.2	103.2	126.0	100.8	117.6
CV	7.4	8.2	6.7	6.9	5.5	5.5	6.0	7.3	6.7	6.4	4.8	4.6

Results: Overall adding the Wawrzynski 94-97 data worsens CV slightly for early events and improves CV for most later events. 50/92 results in lower CV values than 54/92.

Performance of uspest V1 model vs UMN and updated uspest V2 model for the Wawrzynski 94-97 data set:

USPEST V1 MODEL	10% catch				Peak (50%) catch				90% catch			
	Observed ODY	Predicted DOY	Difference	Abs. Difference	Observed ODY	Predicted DOY	Difference	Abs. Difference	Observed ODY	Predicted DOY	Difference	Abs. Difference
1994	192	185	-7	7	212	213	1	1	228	240	12	12
1995	190	190	0	0	215	212	-3	3	236	232	-4	4
1996	205	195	-10	10	227	221	-6	6	247	244	-3	3
1997	214	196	-18	18	225	220	-5	5	249	249	0	0
		average:	-8.75			average:	-3.25			average:	1.25	
		abs avg:	8.75			abs avg:	3.75			abs avg:	4.75	

	2% catch			
	Observed ODY	Predicted DOY	Difference	Abs. Difference
1994	182	180	-2	2
1995	188	185	-3	3
1996	199	190	-9	9
1997	201	193	-8	8
		average:	-5.5	
		abs avg:	5.5	

USPEST V2 MODEL	10% catch				Peak (50%) catch				90% catch			
	Observed	Predicted	Difference	Abs. Difference	Observed	Predicted	Difference	Abs. Difference	Observed	Predicted	Difference	Abs. Difference
1994	192	187	-5	5	212	211	-1	1	228	236	8	8
1995	190	192	2	2	215	210	-5	5	236	228	-8	8
1996	205	198	-7	7	227	218	-9	9	247	239	-8	8
1997	214	198	-16	16	225	217	-8	8	249	243	-6	6
		average:	-6.5			average:	-5.75			average:	-3.5	
		abs avg:	7.5			abs avg:	5.75			abs avg:	7.5	

	2% catch			
	Observed	Predicted	Difference	Abs. Difference
1994	182	181	-1	1
1995	188	187	-1	1
1996	199	192	-7	7
1997	201	194	-7	7

	average:		-4
	abs avg:		4

UMN MODEL	10% catch				Peak (50%) catch				90% catch			
	Observed	Predicted	Difference	Abs. Difference	Observed	Predicted	Difference	Abs. Difference	Observed	Predicted	Difference	Abs. Difference
1994	192	193	1	1	212	217	5	5	228	254	26	26
1995	190	196	6	6	215	216	1	1	236	238	2	2
1996	205	205	0	0	227	227	0	0	247	257	10	10
1997	214	201	-13	13	225	220	-5	5	249	255	6	6
		average:	-1.5			average:	0.25			average:	11	
		abs avg:	5			abs avg:	2.75			abs avg:	11	

Results: Using this 25-30 year old data set as additional validation, all three models performed well in most cases. The UMN model (which was derived from these data) performed well for 10% and 50% catch, with average difference of -1.5 and 0.25 days, but as well for 90% catch with average 11 days later than predicted. The uspest V1 and V2 models performed well for 2% catch, with 5.5 days early (V1) and 4.0 days early (V2), on average. Note model error is best when slightly early, so 4 days is very good overall.
Similarly, 10% and 50% catch were predicted early by 8.75 and 3.25 days on average (V1), and 6.5 and 5.75 days early (V2).