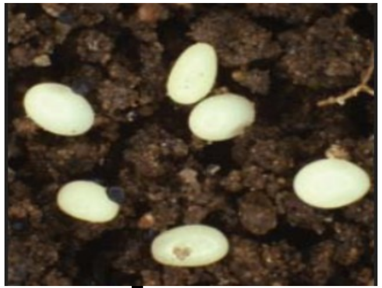
Phenology/Degree-Day and Climate Suitability Model – Dec 2024

by Len Coop & Brittany Barker, Oregon IPM Center, Oregon State University

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



Egg

Larva

Adult

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

Parameter abbr.	Description	degF	degC	DDF	DDC
eggLDT	egg lower dev threshold	50.0	10.0	-	-
eggUDT	egg upper dev threshold	92.0	33.3	-	-
larvaeLDT	larvae lower dev threshold	50.0	10.00	-	-
larvaeUDT	larvae upper dev threshold	92.0	33.3	-	-
pupaeLDT	pupae lower dev threshold	50.0	10.00	-	-
pupaeUDT	pupae upper dev threshold	92.0	33.3	-	-
adultLDT	adult lower develpmental threshold	50.0	10.00	-	-
adultUDT	adult upper dev threshold	92.0	33.3	-	-
eggDD	duration of egg stage in Dds	-	-	310	172
larvaeDD	duration of larval instars 1-3 (assuming mulitvoltine) in D	-	-	2066	1148
pupaeDD	duration of pupal stage in DDs	-	-	270	150
adultDD	duration of adult stage from emerge to first OV in DDs	-	-	238	132
OwlarvaeDD	DDs until OW first pupation	-	-	650	361
eggEventDD	DDs into egg stage when hatching begins	-	-	310	172
eggEventLabel	egg hatch	-	-	-	-
larvaeEventDD	DDs until approx first pupation	-	-	650	361
larvaeEventLabel	pupation in spring	-	-	-	-
pupaeEventDD	DDs until first adults	-	-	270	150
pupaeEventLabel	adult emergence	-	-	-	-
adultEventDD	DDs until first egg laying	-	-	238	132
adultEventLabel	egg laying	-	-	-	-
coldstress_threshold	cold stress threshold	5.0	-15	-	-
coldstress_units_max1	cold stress degree day limit when most individuals die	-	-	1260	700
coldstress_units_max2	cold stress degree day limit when all individuals die	-	-	1800	1000
heatstress_threshold	heat stress threshold	96.8	36	-	-
heatstress_units_max1	heat stress degree day limit when most individuals die	-	-	135	75
heatstress_units_max2	heat stress degree day limit when all individuals die	-	-	270	150

distro_mean	average DDs to OW egg first hatch	-	-	963	535
distro_var	variation in DDs to OW egg first hatch	-	-	2880	1600
xdist1	minimum DDs (°C) to OW egg first hatch	-	-	603	335
xidst2	maximum DDs (°C) to OW egg first hatch	-	-	1323	735
distro_shape	shape of the distribution	-	-		normal

PHENOLOGY MODEL ANALYSIS

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

Estimates for life stage durations for DDRP:

Owlarvae: Subtract estimated pupal duration (350 DDF50) from 2% adult emergence (1000 DDF50) equals 650 DDF (from field data collected by Vittum (1986), average time first pupae 1983-84 Bolton MA)

Pupae: 350 DDF50, obtained by subtraction as per Owlarvae

DDRP stage parameters				Major sources:
OwlarvaeDD	**(OW 3rd instar larvae, time to pupation in s**	**650**	**361**	**Ludwig 1928, Vittum 1986, Estimated as: avg 1st adult emergence (556 DDC) minus pupal duration (150 DDC) equals 361 DDC**
PupaeDD	**(duration of pupal stage)**	**270**	**150**	**Ludwig 1928**
AdultDD	**(from emergence to first egglaying)**	**238**	**132**	**Vittum 1986**
EggDD	**(duration of egg stage)**	**310**	**172**	**Ludwig 1928**
LarvaeDD	**(larval stage assuming multivoltine)**	**2066**	**1148**	**Ludwig 1928 This is for completeness only – JPB not known to be multivoltine**
Egg-to-adult	**(assuming multivoltine)**	**2645**	**1470**	**All**

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):

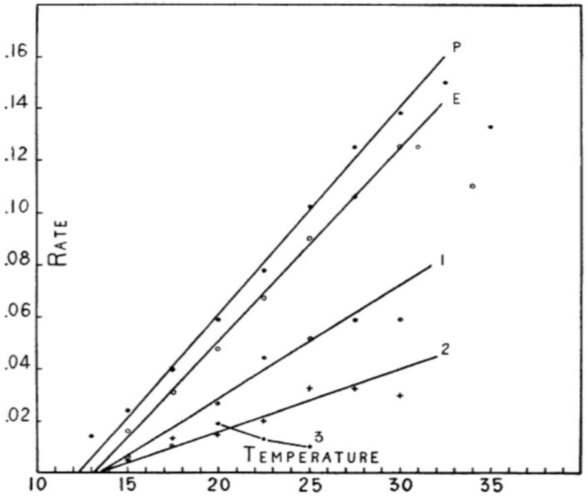


FIG. 8.—Comparison of the rates of development of each stage. *P*, pupal stage; *E*, egg; (1) first-instar larva; (2) second-instar larva; and (3) third-instar larva.

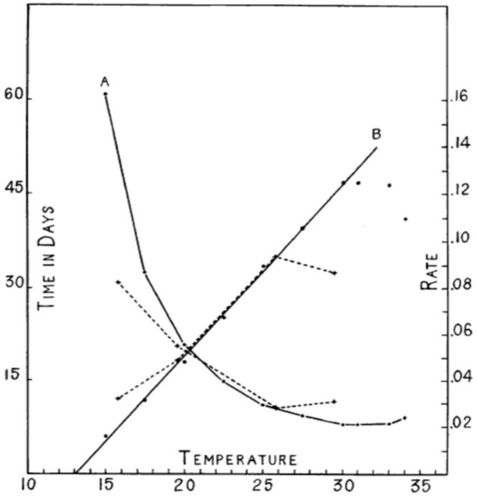


FIG. 1.—Influence of temperature on the development of the egg. *A*, time curve; *B*, rate curve. The solid line represents constant-temperature experiments, while the broken line represents alternating-temperature experiments.

- 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

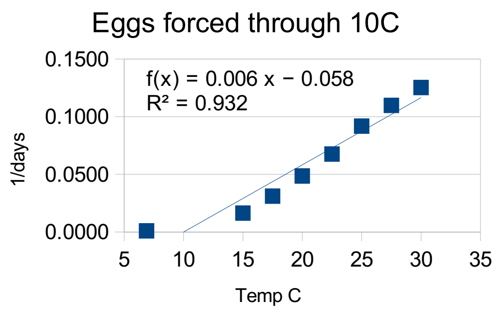
Reconstituted data from Ludwig Fig.s 2,3,4,5 using webplotdigitizer

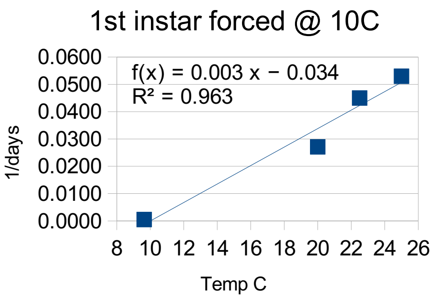
1. Use 10 C as forced common Tlow:

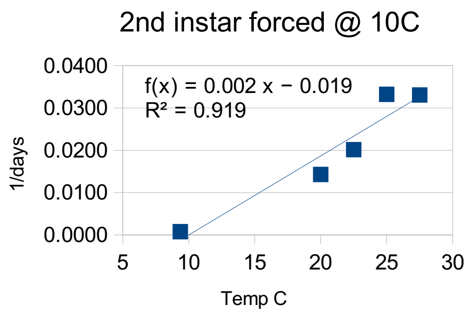
	Eggs			**1st instar**			**2nd instar**	
Temp	1/days	days	Temp	1/days	days	Temp	1/days	days
6.886	0.0010	999	9.634	0.0005	1999	9.36	0.0008	1299
15	0.0164	61	15		160			
17.5	0.0311	32.16	17.5		100.8	17.5		74.8
20	0.0486	20.58	20	0.0271	36.9	20	0.0143	70.02
22.5	0.0676	14.79	22.5	0.0450	22.22	22.5	0.0201	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
								-0.0187
								0.0019
								0.9190 Deg
								536
								10.0034

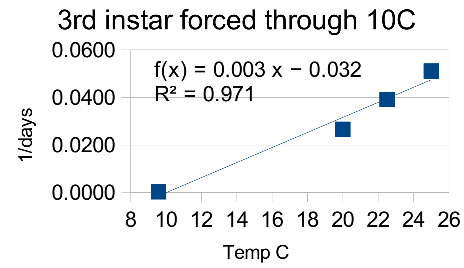
DegF

50.

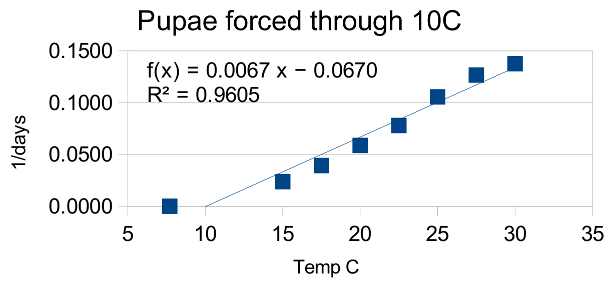








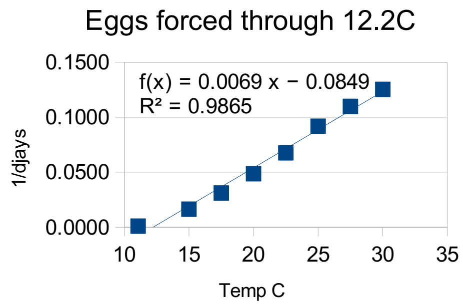
	3rd instar			pupae			Laval instars 1-3 total	
Temp	1/days	days	Temp	1/days	days		Dds	
9.575	0.0003	2999	7.709	0.0003	2999			
			13		70.33			
15			15	0.0240	41.62			
17.5			17.5	0.0395	25.33			
20	0.0266	37.59	20	0.0589	16.98			
22.5	0.0392	25.53	22.5	0.0781	12.807			
25	0.0511	19.57	25	0.1056	9.47			
27.5			27.5	0.1266	7.9			
30			30	0.1376	7.27			
						degF		
	y intercept	-0.0316			-0.0670		**Laval instars 1-3 total**	
	slope	0.0032			0.0067		(maybe useful if found to be	
	Rsq	0.9707			0.9605		multivoltine in southern regions)	
	1/slope	316.3	569		149.3	269	1148	2066
	-b/a	10.0010			10.0005			

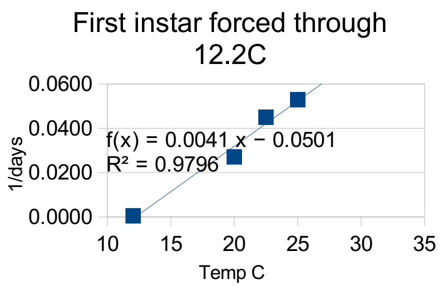


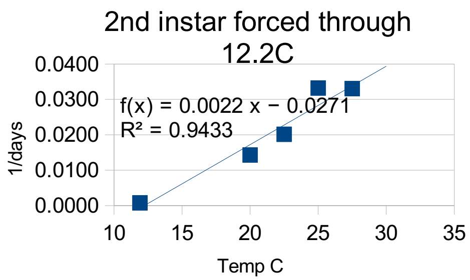
Results: regressions forced through 10C not as good fit and lowered R-sq values somewhat as compared to using 12.2C (see below).
Using these regression results for estimation of developmental times brings: 172, 1148, and 149 Dds (10C), or 309, 2066, and 269 (DDF50) for eggs, larval, and pupal development.
These values are useful in a predictive model especially in combination with field derived data.
Note: pupal regression/graph to estimate model (V2) pupal requirements = 149.3 DDC (269 DDF). This compares to field data results below of ca. 230 DDF (Vittum 1986 data)
Using the results from this study, we subtract pupal degree-days 150 DDC) from first (2%) adult emerge Dds (556 DDC) to get spring first pupation; 361 DDC.

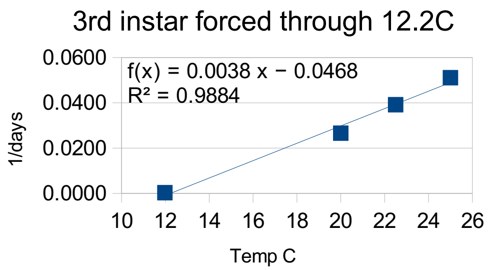
2. Use 12.2C as Tlow

	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

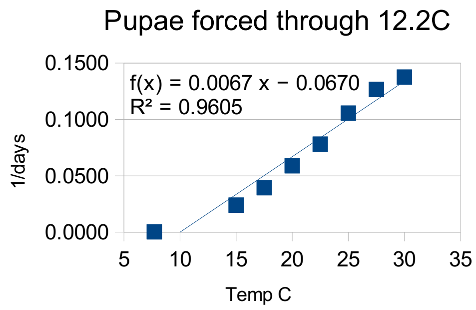








	3rd instar			pupae	
Temp	1/days	days	Temp	1/days	days
11.9782	0.0003	2999	12.1003	0.0003	2999
			13		70.33
15			15	0.0240	41.62
17.5			17.5	0.0395	25.33
20	0.0266	37.59	20	0.0589	16.98
22.5	0.0392	25.53	22.5	0.0781	12.807
25	0.0511	19.57	25	0.1056	9.47
27.5			27.5	0.1266	7.9
30			30	0.1376	7.27
	y intercept	-0.0468			-0.0971
	slope	0.0038			0.0079
	Rsq	0.9884			0.9947
	1/slope	261.0			125.9
	-b/a	12.2222			12.2222

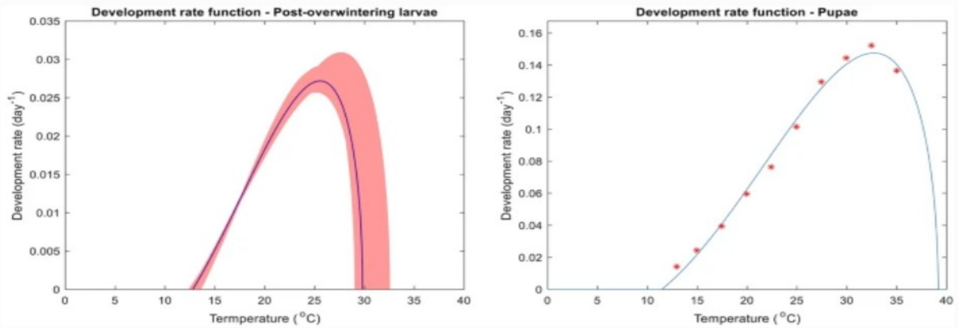


Results: Good fit for eggs, larvae, and pupae using 12.22C Tlow, R-sq=0.987, 0.980, 0.943, 0.988, and 0.995 for eggs, 1st, 2nd, 3rd, and pupae. As 3rd instar is overwintering and in diapause, this result not very relevant or useful. While 12.2C provides a better fit for this lab data, we have not found a strong case with field data (below) for revising the the lower threshold to 12.2, so 10C will be retained in 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 of field data showed that 10C is best 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

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

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*).

Note: mention of a "second emergence" in early Sept. in southern NH and Vermont. As these are northern states, it is presumed that this pattern reflects bimodel activity, perhaps due to semi-voltinism, rather than evidence of bivoltinism. Bivoltinism may be possible but thus far we have not seen good evidence for it.

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)

820

Date	n	Avg/ 0.09 m²	% 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 m²	% 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.

Estimated population cohort spread using DD10C

Using adults:		1983 DDC10
ca 1st adults:	06/27/83	467
ca last adults:	08/11/83	1077
Difference		610
subtract adult longev. (guess: 240)		370

note: use for partial validation, do not use for estimate

Using pupae:		1983 DDC10
ca 1st pupation:	06/18/83	352
ca last pupae:	07/30/83	899
	(ignore outliers)	
Difference		547
subtract pupal duration (150)		397

Using eggs:		1983 DDC10
ca 1st eggs:	07/12/83	648
ca last eggs:	08/25/83	1219
Difference		571
subtract egg duration (172)		399

So consider using ca 400 DDC10 as the cohort spread initial value (as a starting maximum)

Using 1st Instars:		1983 DDC10
ca. 1st L1	07/30/83	899
ca last L1	10/04/83	1589
Difference		690
subtract L1 duration (296)		394

note: use for partial validation, do not use for estimate

approx 1st pupation

1983			1984			
date	DD50F	DD54_92	date	DD50F	DD54_92	DD50F Avg
06/18/83	635	422	06/18/84	662	460	648.5
DD10C	352			367.7		360

approx mating+pre-oviposition period (DD first eggs – DD first adults)

	1983		1984		
	date	DD50	date	DD50	DD50 Avg
First eggs	07/12/83	1166	07/11/84	1129	1147.5
First adults	06/27/83	841	06/30/84	892	866.5
Difference	15	325	8	237	281
		DDC10		DDC10	DDC10
		181		132	156

<- the avg is 156 DDC10. As this is a rough estimate, for better fit with other data, we will select the lower of the two estimate
Equals 132 DDC

approx 1st egg hatch

1983			1984		
date	DD50	DD54_92	date	DD50	DD50 Avg
07/25/83	1496		07/25/84	1468	1482

823 ← DDC10 Avg
← We can subtract egg devel time (172 DDC) and adult mating+pre-OV time (132 DDC) from 823 DDC = 519 DDC to cross-check with avg adult 1st emerge time (556 DDC)
519 ← vs 556 DDC is a 37 DD difference (would be larger if we used the average mating+pre-OV

approx egg development time (DD first hatch/instars – DD first eggs)

		1983		1984		
		date	DD50	date	DD50	DD50 Avg
07/26/84	First hatch	07/25/83	1496	07/25/84	1468	1482
	First eggs	07/12/83	1166	07/11/84	1129	1147.5
	Difference		330		339	334.5

This compares to 310 DDF for egg stage from Ludwig (1928), close (use Ludwig result not these)

Results: These can be used to add two more important events to model V2: first pupation at 649 DDF, and first egg hatch at 1482 DDF. (close to peak adult emerge)
Also estimated mating + pre-oviposition at 281 DDF, and egg development time at 335 DDF. Note these are very rough estimates that rely on interpolation between sample intervals ranging from 6 to 34 days. This study had emergence rather earlier than most all others, so we will keep that in mind for the analysis.

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

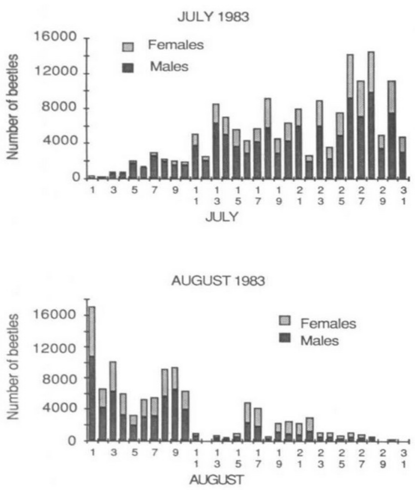


Fig. 1. Number of Japanese beetle adults recovered from eight traps (Bag-a-Bug) in daily collections, July (top) and August (bottom) 1983, Waltham, Mass.

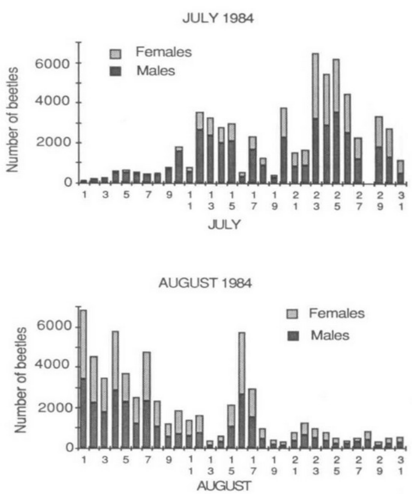


Fig. 2. Number of Japanese beetle adults recovered from eight traps (Bag-a-Bug) in daily collections, July (top) and August (bottom) 1984, Waltham, Mass.

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			
08/14/83	533	246630	90.60	1952.4			
08/15/83	921	247551	90.93	1964.8			
08/16/83	4848	252400	92.72	1981.2			
08/17/83	4121	256521	94.23	2004.7	94% emerge	08/22/83	5
08/18/83	582	257103	94.44	2031.5			
08/19/83	2230	259333	95.26	2049.5			

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			
08/14/84	606	103665	83.84	1937			
08/15/84	2147	105812	85.58	1961.8			
08/16/84	5743	111555	90.22	1989.3	90% emer	08/16/84	0
08/17/84	2954	114509	92.61	2017.1			
08/18/84	972	115482	93.40	2035.6			
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			
		DD5092			DD5092		
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 WALTHAM 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% e	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):

	Dds (uspest)	model 1983	Text and Table 1 1983	days diff	model 1984	Text and Table 2 1984	days diff	mean error (days)	mean abs 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 (vs V1) 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

last accessed: 9/27/2024 by LC

- 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

DDs SA5088	percent emerg	Fig1&Table 1 2019	SA5088 ROSEMOUN	SS5492 (dds on date SA508 ROSEMOUNT19	Fig1&Table 1 2020	SA5088 ROSEMOUN	SS5492 ROSEMOUNT20	SS5492 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

- Data in Fig 1 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 their model, we need to 1) determine comparable DDs for their 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

- Could also use PRISM data using data explorer tool, for now not apparently needed

		Location: Rosemont, MN (S. of St. Paul within metro area)				USPEST model V1 (50/100 Single sine)					UMN model Tlow=59F, Tupper=71F, corn gdd, start Jan 1,			
Lat/Long:		44.716667, 93.083333									10%=463DD, 50%=623DD, 90%=837DD			
2019 Fig 1a				Cumulative			est DOY	Est Date	ROSEMN19	DOY est. 50	VegEdge		uspest	uspest
	DOY	Trap Catch	Cumultive	Percent	Event	Dds	Observed	Observed	Predicted DOY	catch	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,			

									Date est.	DOY est. 50	10%=463DD, 50%=623DD, 90%=837DD			
2020 Figure 1b							est DOY	Est Date	ROSEMN20	catch	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	2.271372362	1st adult emer	970	182	06/30/20	183	51.6575			718	954
	189	2428.6	2809.6	16.74973173	10% ad emerg	1050	184	07/02/20	186		193		768	1011
	197	2142.9	4952.5	29.5248599										
	203	2261.9	7214.4	43.00941934										
	210	2738.1	9952.5	59.33289615	peak adult em	1600	205	07/23/20	209		214	195	1182	1510
	217	2059.5	12012	71.61082628										
	224	1381	13393	79.84380589										
	231	1904.8	15297.8	91.19947538	90% emerg	2080	231	08/18/20	234		242		1603	2032
	238	1238.1	16535.9	98.58054131	94% emerg	2150	236	08/23/20	237				1693	2142
	251	190.5	16726.4	99.71622749										
	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							est DOY	Est Date	ROSEMN21	50 percent ca	VegEdge		uspest	uspest
Day of Year		Trap Catch	Cumulative	Percentile	Event	Dds	Observed	Observed	Predicted	198	Predicted		model2	model2
	173	27.1	27.1	0.1							w/ROSEMN		DD54	DD50
	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 Day of Year	Lat/Long 45.21666 92.8833 Trap Catch	near Forest Lake, MN Cumulative	Percentile		Dds Uspest m	est DOY Observed	Est Date Observed	PRISM Data Expl station: FORLKMN19	VegEdge Predicted w/FORLKMN19	uspest model2 DD54	uspest model2 DD50
183	9	9	0.193071388								
189	63.1	72.1	1.544422452	1st adult emer	970	190	07/09/19	191		721	957
196	549.5	621.6	13.32048173	10% ad emer	1050	194	07/13/19	195	198	792	1044
203	612.6	1234.2	26.44789207								
211	882.9	2117.1	45.36680697								
217	1054.1	3171.2	67.95367476	peak adult em	1600	212	07/31/19	220	220	1114	1437
222	738.7	3909.9	83.78378723								
231	279.3	4189.2	89.76834194	90% emerg	2080	232	08/20/19	251	258	1425	1827
239	153.2	4342.3	93.05019453	94% emerg	2150	240	08/28/19	258		1510	1944
246	126.1	4468.5	95.75289665								
253	36	4504.5	96.52509726								
260	63.1	4567.6	97.87644833								
267	72.1	4639.6	99.42084954								
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 w/FORLKMN20	uspest model2 DD54	uspest model2 DD50
175	9	9	0.150675681								
182	225.2	234.2	3.9171534	1st adult emer	970	181	06/29/20	184		683	907
189	1000	1234.2	20.64031447	10% ad emer	1050	184	07/02/20	187	193	752	988
195	932.4	2166.7	36.23353222								
202	1038.3	3205	53.59699451	peak adult em	1600	202	07/20/20	210	215	1121	1430
210	1144.1	4349.1	72.73070132								
217	783.8	5132.9	85.83804378								
223	423.4	5556.3	92.91902189	90% emerg	2080	221	08/08/20	235	242	1412	1795
234	189.2	5745.5	96.08286317	94% emerg	2150	230	08/17/20	238		1565	1984
239	135.1	5880.6	98.3427498								
245	81.1	5961.7	99.69868178								
252	18	5979.7	100	last adult trap	2790	250	09/06/20	NA	UMN model Tlow=59F, Tu	1879	2374

10%=463DD, 50%=623DD, 90%=837DD

2021 Figure 2c Day of Year	Trap Catch	Cumulative	Percentile			DOY Observed	Date Observed	FORLKMN21	VegEdge Predicted w/FORLKMN21	uspest model2 DD54	uspest model2 DD50
173	18	18	0.157199303								
179	423.4	441.4	3.855080811	1st adult emer	970	177	06/26/21	176		784	1006
188	2441.4	2882.9	25.17690822	10% ad emer	1050	182	07/01/21	180	189	872	1115
193	982	3864.8	33.75284619								
200	2459.5	6324.3	55.23203026	peak adult em	1600	198	07/17/21	205	210	1132	1438
207	2153.2	8477.5	74.03615112								
213	1324.3	9801.8	85.60186562								
221	369.4	10171.2	88.82767715	90% emerg	2080	223	08/11/21	226	238	1628	2034
228	824.3	10995.5	96.02674434	94% emerg	2150	227	08/15/21	229		1686	2107
235	279.3	11274.8	98.46577257								
241	90.1	11364.8	99.25255587								
247	58.6	11423.4	99.76396501								
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

2019 Figure 3a	44.68333, 92.8666	Hastings, MN			DOY	Date	HASTMN19	VegEdge	uspest	uspest
Day of Year	Trap Catch	Cumulative	Percentile		Observed	Observed	HASTMN19	Predicted w/HASTMN19	model2 DD54	model2 DD50
183	4.6	4.6	0.064086482							
189	17.6	22.2	0.309847815	1st adult emerg.	190	07/09/19	189		767	1013
203	661.6	683.8	9.540709954	10% ad emerg	198	07/17/19	192	197	936	1214
210	2298.8	2982.6	41.61634242							
217	1920.1	4902.7	68.40818182	peak adult em	212	07/31/19	216	216	1186	1520
224	821.7	5724.5	79.87402109							
231	490.9	6215.3	86.72299342							
239	325.6	6541	91.26640402	90% emerg	237	08/25/19	242	248	1584	2018
247	224.1	6765	94.39268163	94% emerg	246	09/03/19	246		1681	2150
253	96.9	6862	95.74542697							
259	173.6	7035.6	98.16827701							
267	97.6	7133.2	99.5296376							
274	21.5	7154.7	99.82950874							
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					DOY	Date		VegEdge Predicted	uspest model2	uspest model2
Day of Year	Trap Catch	Cumulative	Percentile		Observed	Observed	HASTMN20	w/HASTMN20	DD54	DD50
177	9.6	9.6	0.264924805							
182	3.2	12.8	0.352719766	1st adult emerg.	184	07/02/20	182		798	1044
189	283.4	296.2	8.166471256	10% ad emerg	190	07/08/20	185	191	951	1221
196	461.8	758	20.89674054							
203	767.5	1525.5	42.05532603	peak adult em	207	07/25/20	207	210	1275	1612
210	678.3	2203.9	60.75565263							
217	703.8	2907.7	80.15833891							
224	321.7	3229.4	89.02562993	90% emerg	225	08/12/20	230	239	1572	1980
231	334.4	3563.8	98.24410079	94% emerg	228	08/15/20	234		1627	2048
245	47.8	3611.5	99.5610252							
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					DOY	Date		VegEdge Predicted	uspest model2	uspest model2
Day of Year	Trap Catch	Cumulative	Percentile		Observed	Observed	HASTMN21	w/HASTMN21	DD54	DD50
173	4.1	4.1	0.064157883							
179	106.3	110.4	1.723996151	1st adult emerg.	179	06/28/21	171		885	1127
188	1463.4	1573.9	24.56824743	10% ad emerg	182	07/01/21	176	185	946	1199
193	501.9	2075.7	32.40242704							
201	616.9	2692.6	42.03172105	peak adult em	203	07/22/21	202	206	1308	1645
207	1655.4	4348	67.87233889							
214	1158.9	5506.8	85.96247924							
221	299.3	5806.1	90.6349172	90% emerg	220	08/08/21	221	232	1652	2058
228	395.2	6201.3	96.8036784	94% emerg	226	08/14/21	224		1761	2191
235	96.1	6297.5	98.3043981							
240	58.2	6355.6	99.21227011							
248	36.2	6391.8	99.77747075							
255	14.3	6406.1	100	last adult trapped	252	09/09/21	259		2166	2698

not using nearest uspest station: E2706

using PRISM data:

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

2019 Figure 4a Day of Year	Lat/Long 44.8666, 93.6333 Trap Catch	Cumulative	Percentile		LANDARBMN19 DOY Observed	Date Observed	LANDARBMN19 Predicted	VegEdge Predicted w/LANDARBMN19	uspest Model2 Dd5 DD54	uspest model2 DD50
187	0	0	0.000496437							
196	28.7	28.7	1.424700964	1st adult emerg.	191	07/10/19	188		897	1058
203	135.2	163.9	8.138808019	10% ad emerg	197	07/16/19	191	195	940	1216
210	819.7	983.6	48.83036593							
216	647.5	1631.2	80.97669668	peak adult em	211	07/30/19	215	213	1206	1538
224	213.1	1844.3	91.55650173							
231	32.8	1877.1	93.18416405							
239	36.9	1913.9	95.01528416	90% emerg	223	08/11/19	238	242	1424	1803
247	0	1913.9	95.01528416	94% emerg	237	08/25/19	244		1628	2063
253	18.4	1932.4	95.93084421							
259	36.9	1969.3	97.76196431							
267	36.9	2006.2	99.59308442							
274	4.1	2010.3	99.79654221	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	14.87383798	10% ad emerg	187	07/05/20	184	190	893	1153
196	168	282.8	36.65338645							
203	221.3	504.1	65.33864542	peak adult em	200	07/18/20	206	209	1166	1478
210	106.6	610.7	79.1500664							
217	69.7	680.3	88.18061089							
224	32.8	713.1	92.43027888	90% emerg	221	08/08/20	228	236	1528	1924
231	24.6	737.7	95.61752988	94% emerg	228	08/15/20	232		1658	2082
238	16.4	754.1	97.74236388							
243	11.3	765.4	99.20318725							
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	0.000272017							
179	4.1	4.1	0.111754434	1st adult emerg.	181	06/30/21	174		892	1132
188	688.5	692.6	18.84080048	10% ad emerg	183	07/02/21	178	187	931	1179
193	340.2	1032.8	28.09384108							
200	1188.5	2221.3	60.42374199	peak adult em	197	07/16/21	203	208	1159	1462
207	739.8	2961.1	80.54631825							
214	291	3252.1	88.46156985	90% emerg	217	08/05/21	223	232	1562	1946
221	168	3420.1	93.03234894	94% emerg	222	08/10/21	227		1659	2062
228	184.4	3604.5	98.0490577							
235	24.6	3629.1	98.71795221							
243	19.5	3648.6	99.24749369							
251	14.3	3662.9	99.63768214							
258	9.2	3672.1	99.88851758	last adult trapped	258	09/15/21	261		2207	2752

266	4.1	3676.2	100

Compare potential V2 models	Dds Tlow=12.22 (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 COONISDA	780	928	1217	1409	1484	1939	1020	1207	1576	1830	1925	2514
1995 COONISDA	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	

potential outliers			Note: Do not include BOLTMA83 results – all are "too early" 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
10th 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) (DD50F):	**970**	**1050**	**1600**	**2080**	**2150**	**2790**
New uspest model (V2) (DD50F):	**1000**	**1100**	**1540**	**1985**	**2110**	**2700**
DD10C:	**556**	**611**	**856**	**1103**	**1172**	**1500**

Results: The new proposed Tlow of 54F resulted in higher error (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 10th 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 III. 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.

Old uspest model

1st adult eme	970
10% ad eme	1050
peak adult	1600
90% emerg	2080
94% emerg	2150
last adult tr	2790

USPest model V2:

	1st Emergence				Peak			
	Observed	Expected	Difference	Abs. Difference	Observed	Expected	Difference	Abs. Difference
2019 ROSEMN	187	190	-3	3	207	218	-11	11
2020 ROSEMN	181	182	-1	1	205	209	-4	4
2021 ROSEMN	177	174	3	3	197	203	-6	6
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
2019 HASTMN	189	187	2	2	211	214	-3	3
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
2020 LANDARBMN	185	180	5	5	200	206	-6	6
2021 LANDARBMN	176	172	4	4	195	202	-7	7
		avg:	1.58			avg:	-6.92	
		abs avg:	3.58			abs avg:	6.92	

Results: 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 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	

Old USPEST MODEL:

	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	

New USPEST MODEL:

	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 mod same Dds on obs dat	50/92 V2 uspest Dds on obs date	UMN model 10%=463DD,	V2 uspest pred DOY	V1 uspest e days	UMN erroi 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	V2 uspest model Dds on obs dat	50/92 V2 uspest Dds on obs d	UMN model 10%=463DD,	V2 uspest pred DOY	V1 uspest e days	UMN erroi 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	V2 uspest model Dds on obs dat	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 (1997) 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
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 mod	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
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 V2 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.
This provides further validation for the V2 50/92 model.

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 not 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).

CLIMATE SUITABILITY MODEL

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

Borner, L., D. Martinetti, and S. Poggi. 2023. A new chapter of the Japanese beetle invasion saga: predicting suitability from long-invaded areas to inform surveillance strategies in Europe. Entomol. Gen. 43:951-960.
- Used presence-only and pseudo-absence data and a Random Forest method to produce a climate suitability model for JB for Europe.
- Their dataset included presence records from JB's worldwide range and was used for model development for this study as well.
- Main finding was that Cental Europe is generally suitable whereas Northern European countries are at lower risk.
- Areas with high suitability in Europe included Balkan countries bordering the Mediterranean, lower elevation areas in the Alps, and coastal areas of the eastern Black Sea region
- Their model for North America doesn't seem accurate at all (excludes all of W. US, and most of the upper Midwest, where the pest occurs).
- Low precipitation seasonality and high temperature seasonality were found to be favorable.
- Actual evapotranspiration and vapour pressure were also important, which is related to soil suitability for adult oviposition.

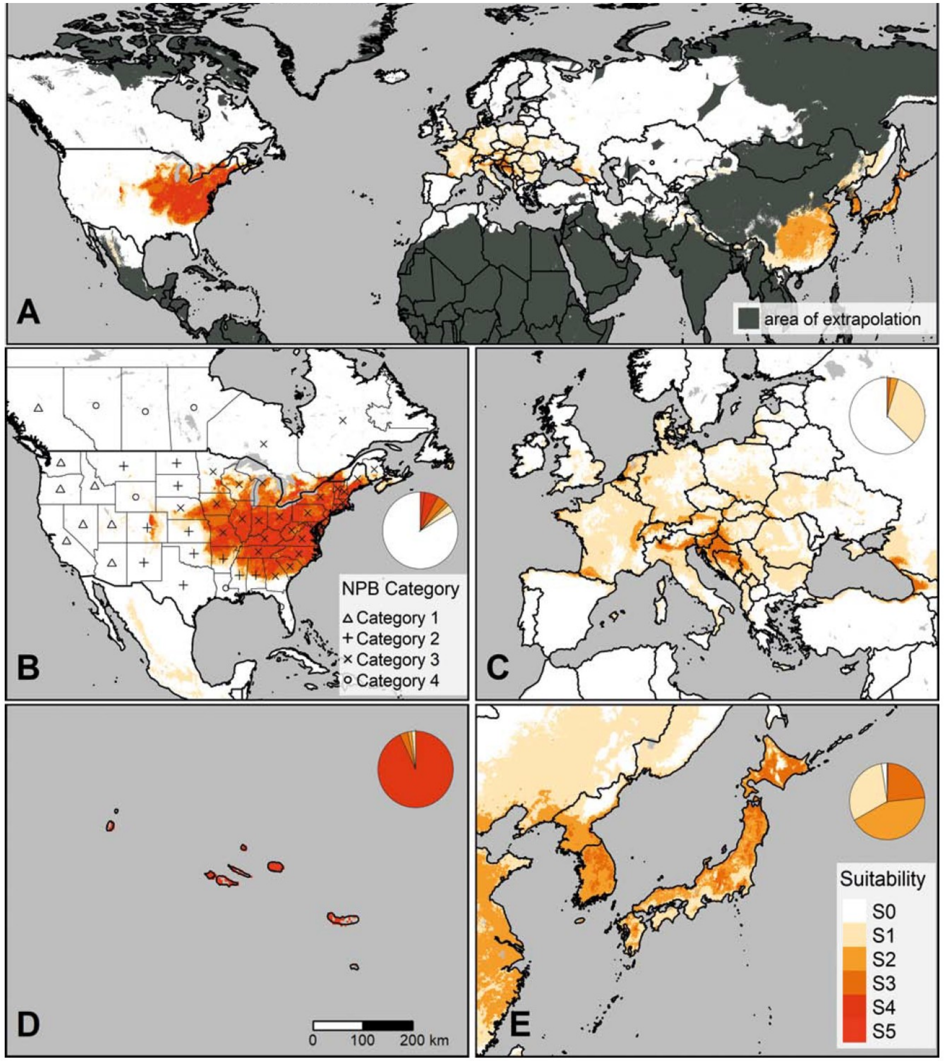


Fig. 3. Suitability maps for the Japanese beetle and composition of predicted suitability. **A** Northern Hemisphere, displaying areas of extrapolation in dark grey (Appendix 4), **B** North America, Japanese beetle-infested areas reported by the NPB (2016) are displayed by categories, **C** Continental Europe, **D** Azores archipelago, **E** Japan. In each panel, a pie chart depicts the composition of suitability, i.e. the proportion of total area covered by each suitability class. Darker colours correspond to greater suitability for the Japanese beetle. Pj infested areas categories according to NPB (2016): Category 1 = "Uninfested/ Quarantine Pest", Category 2 = "Uninfested or Partially Infested", Category 3 = "Partially or Generally Infested" and Category 4 = "Historically not known to be infested / Unlikely to Become Established".

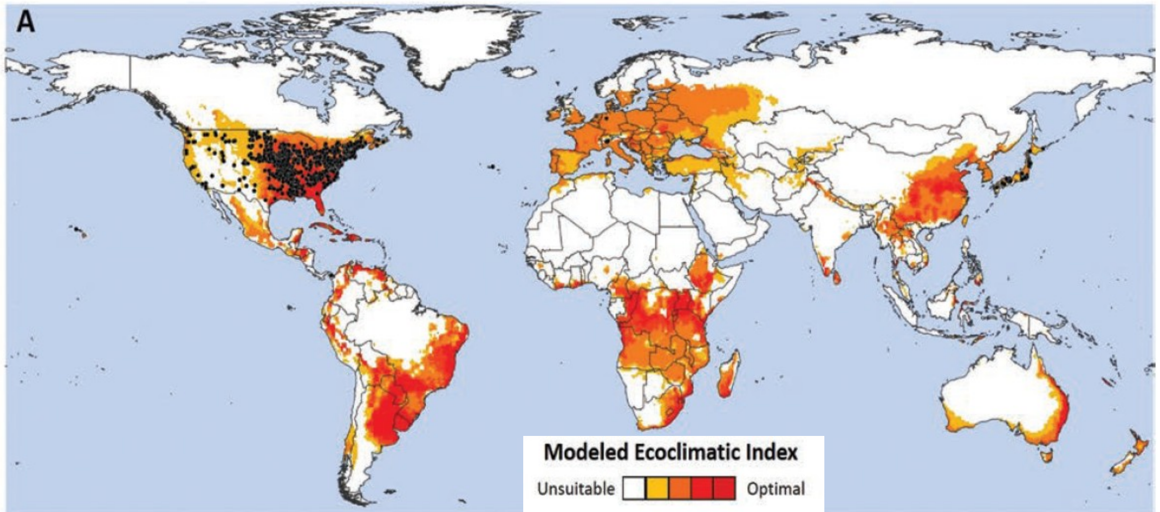
Kistner-Thomas, E.J. 2019. The potential global distribution and voltinism of the Japanese beetle (Coleoptera: Scarabaeidae) under current and future climates. J. Ins. Sci. 16: https://doi.org/10.1093/jisesa/iez023

- Model fitted to the known distribution in Asia (Japan and far eastern Russian island of Kunashir) and validated using North America and Europe records.
- Soil moisture is important for this pest - larvae are vulnerable to dessication.
- A threshold temperature cold stress of −15°C (TTCS) and a stress accumulation of −0.007 wk−1 (THCS) allowed the northernmost records to be included in distribution.
- This threshold is much lower than what larvae actually experience when snow cover is present, which can keep soil temps from falling below 0C
- No explanation was given regarding the choice of the heat stress threshold (34C) and rate (0.01 wk-1)
- Hot-wet stress parameters were applied because it may affect the pest in wet tropical regions.
- PDD represented the minimum heat sum required each year to complete the life cycle.
- The EI was very low in northernmost areas either due to the PDD or the temperature index parameter values.
- Results for future climates indicated potential for further range expansion in Europe and North America

Table 1. CLIMEX parameter values for *Popillia japonica*

Index	Parameter	Values
Temperature	DV0 = limiting low average weekly temperature	10°C
	DV1 = lower optimal average weekly minimum temperature	27.5°C
	DV2 = upper optimal average weekly maximum temperature	31°C
	DV3 = limiting high average weekly temperature	34°C
Threshold Annual Heat Sum	PDD = minimum heat sum required each year in order to complete its life cycle	525°C degree-days
Moisture[a]	SM0 = lower soil moisture threshold	0.2
	SM1 = lower optimal soil moisture	0.5
	SM2 = upper optimal soil moisture	1
	SM3 = upper soil moisture threshold	1.5
Cold Stress	TTCS = cold stress threshold (average minimum weekly temperature)	−15°C
	THCS = rate of cold stress accumulation	−0.007 wk^{-1}
Heat Stress	TTHS = heat stress threshold (average maximum weekly temperature)	34°C
	THHS = rate of heat stress accumulation	0.01 wk^{-1}
Dry Stress	SMDS = dry stress threshold (average weekly minimum soil moisture)	0.2
	HDS = rate of dry stress accumulation	−0.008 wk^{-1}
Wet Stress	SMWS = wet stress threshold (average weekly maximum soil moisture)	1.5
	HWS = rate of wet stress accumulation	0.007 wk^{-1}
Hot–Wet Stress	TTHW = hot–wet temperature threshold (average maximum weekly temperature)	27°C
	MTHW = hot–wet moisture threshold (average weekly maximum soil moisture)	1.4
	PHW = rate of hot–wet stress accumulation	0.01 wk^{-1}

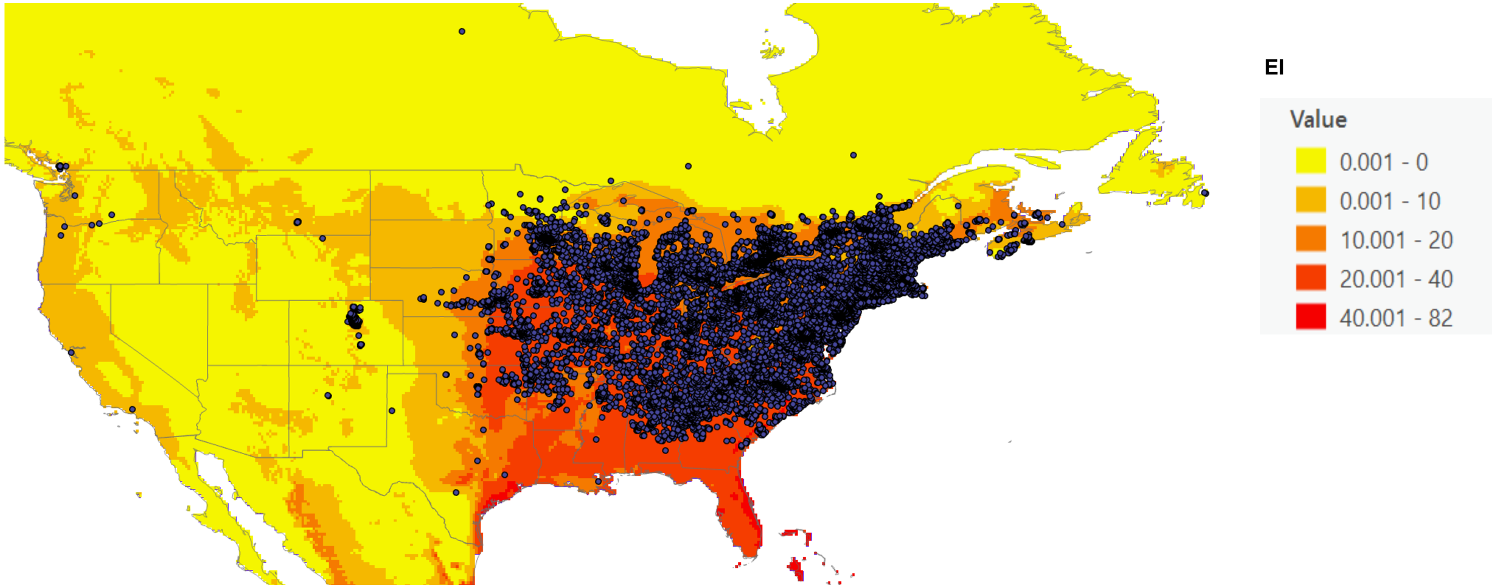
[a]Values without units are dimensionless indices of available soil moisture, scaled from 0 (oven dry), with 1 representing field capacity.

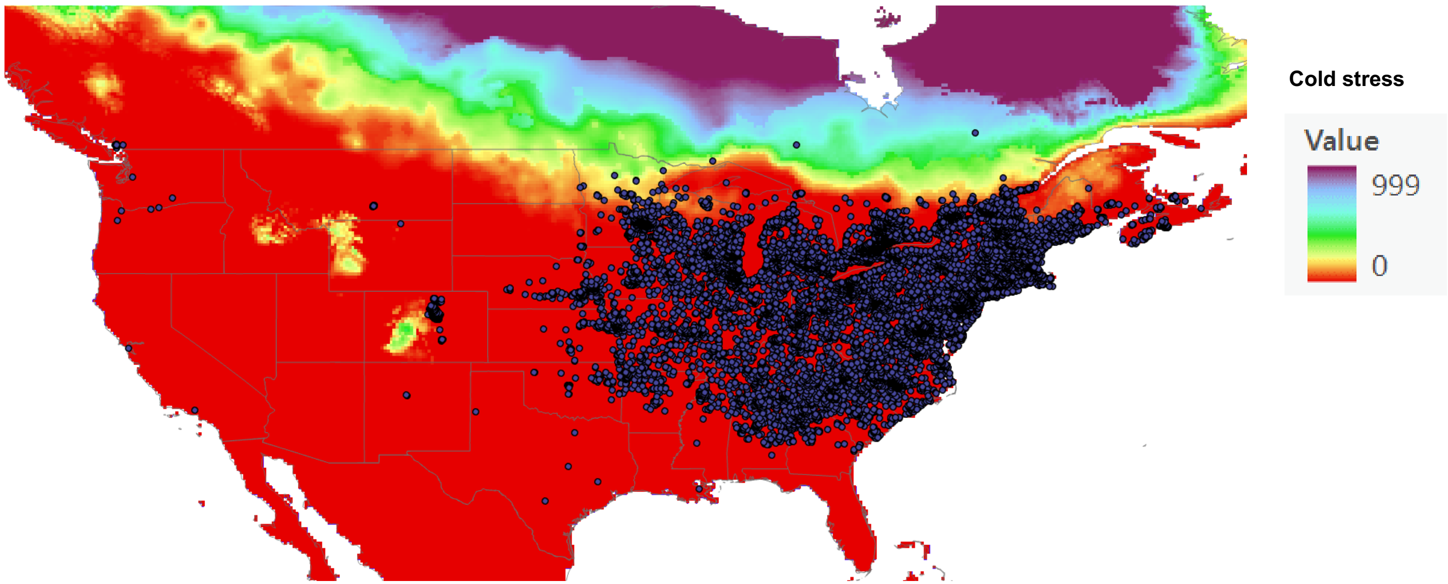


Global potential distribution of JB based on current climate conditions (1961-1990 normals in CLIMEX)

Re-analysis of the CLIMEX model using some more updated records

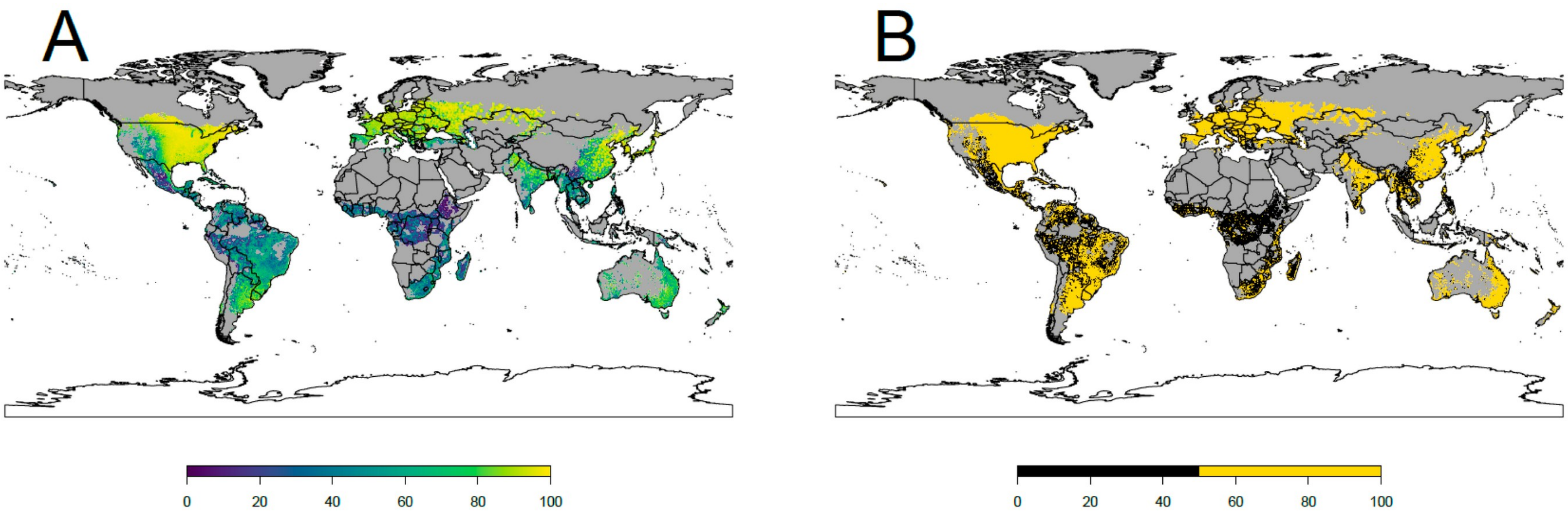
- Extracted EI values for 40,038 records for North America - many of these were collected after the publication of this CLIMEX model
- 205 had EI values of 0 (see top map below) but most were due to non-cold-stress related factors
- Some N. Minnesota records were possibly excluded due to cold stress, but these establishments are recent and CLIMEX data are 1961-1990.
- Thus it's unclear if the CLIMEX model should be adjusted (lower TTCS or THCS) or if warmer temperatures explain the discrepancy.





Della Rocca, F., and P. Milanesi. 2022. The new dominator of the world: modeling the global distribution of the Japanese beetle under land use and climate change scenarios. Land. 11:657.

- Used presence-only and pseudo-absence data and a Bayesian method to model the global distribution of JPB under current and future conditions.
- Model included 34 predictors (2 topographic, 10 land cover, 19 bioclimatic, and 3 anthropogenic) to represent the habitat characteristics of JB.
- Found that current distribution was primarily influenced by % of croplands, annual range of temperature, habitat diversity, % human settlements, and human population density.
- Distribution predicted to increase under 2050 climatic and land-use change scenarios.
- Distribution is larger than Borner et al's (2023) model, and seems more realistic for North America given JPB's actual distribution there.
- Areas with high annual temperatures and low daily temp fluctuations were highly suitable.
- Contrary to previous work, precipitation had little effect on the modeled distribution, but this may be because soil moisture data should have been used instead.
- Their model results for North America are generally similar to Kistner-Thomas (2019), but the northern range of suitability extends farther.



DDRP model (this study)

Final parameters reported below

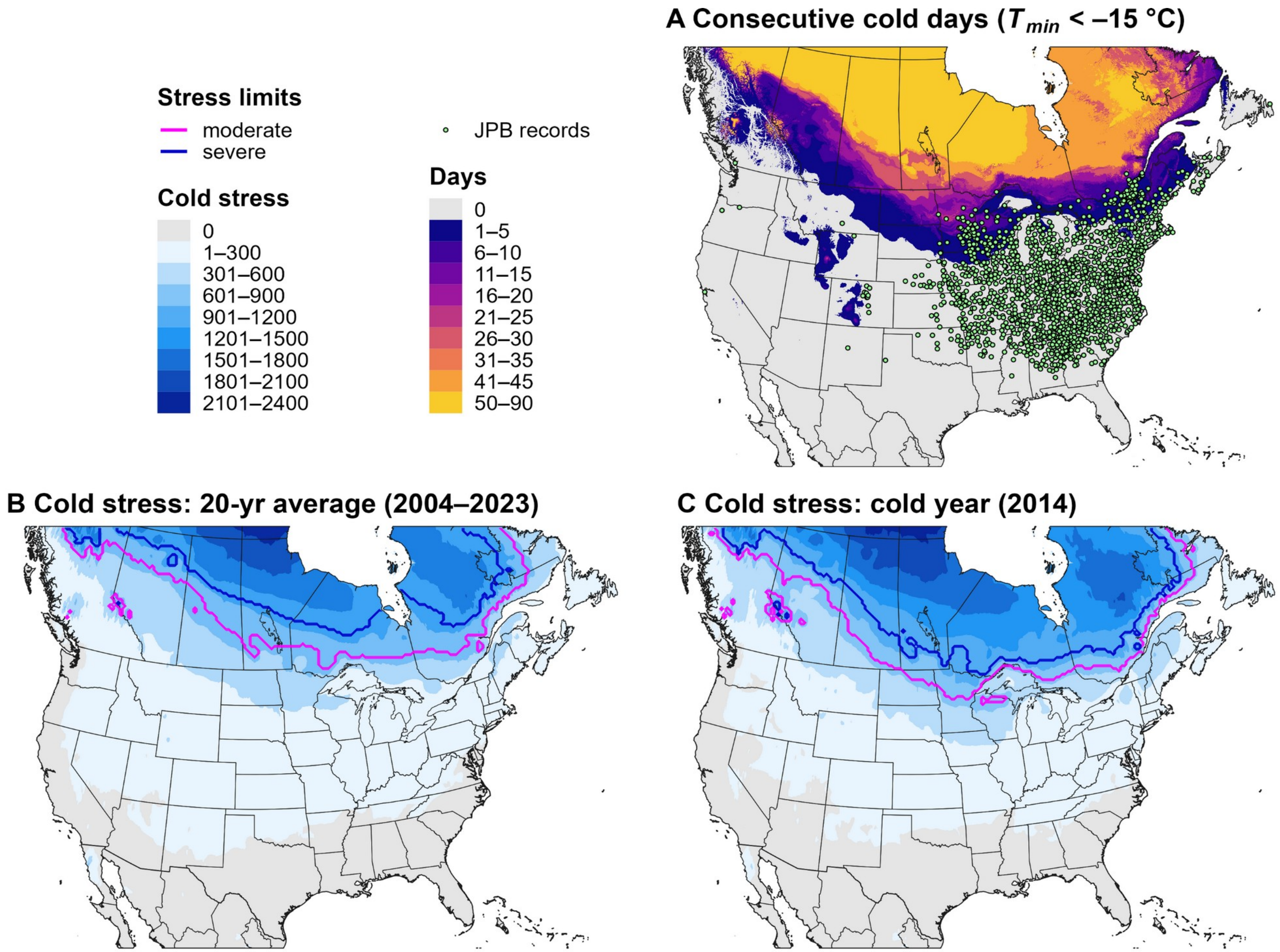
DDRP Cold Stress	Value	Units
cold stress threshold	-15	C
limit 1 (mod. cold stress)	700	DDC
limit 2 (sev. cold stress)	1000	DDC

DDRP Heat Stress	Value	Units
heat stress threshold	36	C
limit 1 (mod. heat stress)	75	DDC
limit 2 (sev. heat stress)	150	DDC

Methods overview

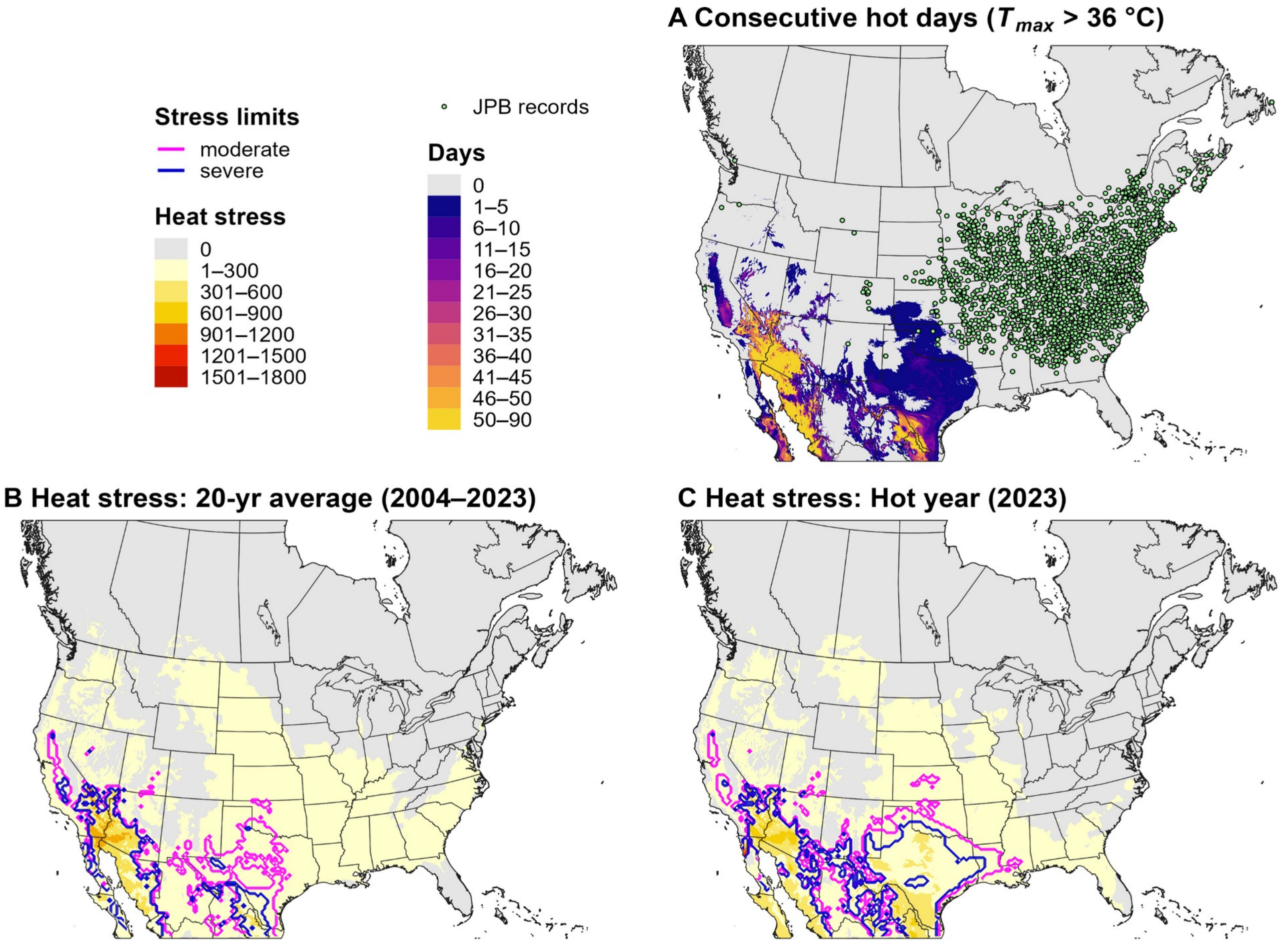
Cold stress parameters

- Subset record dataset (N=39,993) for North America for calibration (75%) and validation (25%)
- Analyzed coldest average daily temperatures experienced in northern CONUS and southern Canada (20 yr averages, 2004-2023)
- Analyses used tmin data from Daymet (1 km resolution)
- 99% of records occurred in areas with average weekly Tmin values ≥ -15C
- Daily average Tmin for records fell below −15°C for < 5 consecutive days during winter months
- Next, fine-tuned cold stress limits to include majority of records in the potential distribution (model runs used Daymet data at 4 km resolution for 2004-2023)
- Predictions for each record were for years after the record collection date (e.g., 2022 and 2023 for a record collected on 6/1/2021)
- Thus, years in which a population may have not been present at a location weren't considered when fine-tuning stress limits
- Below maps (B and C) show averages of cold stress accumulation between 2004 and 2023 and accumulations for a cold year (2014)
- Total area excluded by heat stress was highest in 2023

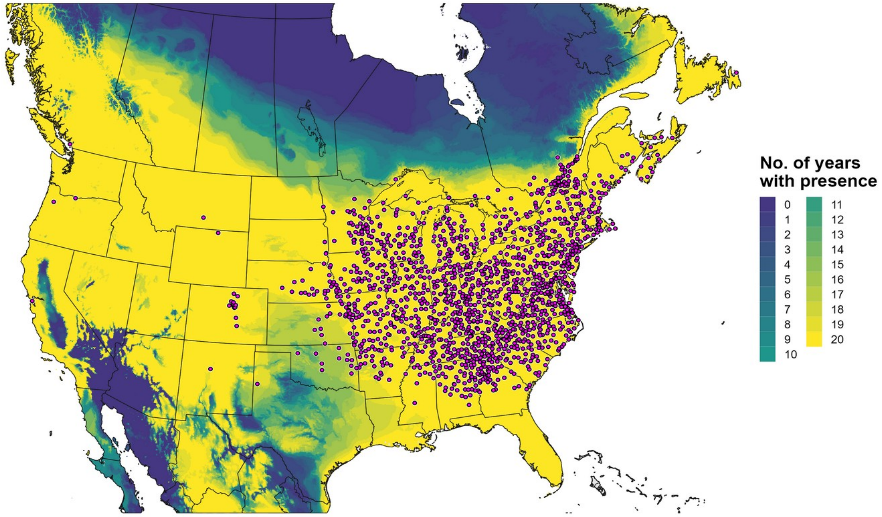


Heat stress parameters

- Analyzed hottest average daily temperatures experienced in North America (20 yr averages, 2004-2023)
- Analyses used tmax data from Daymet (1 km resolution)
- >99% of records occurred in areas with average weekly Tmax values ≤ 36C
- Daily average Tmax for records did not exceed 36C for > 5 consecutive days during summer months (except 1 record) (A in below map)
- Fine-tuned heat stress limits to include majority of records in the potential distribution
- Below maps (B and C) show averages of heat stress accumulation between 2004 and 2023 and accumulations for a hot year (2023)
- Total area excluded by heat stress was highest in 2023



Analysis using cold and heat stress parameters above
- Estimated presence as areas not under moderate or severe stress exclusions for the 20 years (2004-2023)
- Areas that experienced at least 1 years of exclusuions were in Calififornia, the Southwest, and the coldest parts of the Midwest



Notes for discussion: possibility of presence records that are influenced by human activity (artificial environments largely impacted by irrigation). If this is the case, then the distribution predicted by DDRP may be much more liberal than under just natural conditions. But this would be the case for all other methods that make use of climate data. E.g. a golf course in Central Washington has turf and irrigation (providing good conditions for establishment), whereas the high desert conditions outside the golf course may be unfit.