IPPC Model Analysis Summary – Apr. 2, 2018 vers. 1.1

Old world bollworm (OWBW) (Helicoverpa armigera) Phenology (degree-day) Model

By Len Coop for use at Oregon State University's Integrated Plant Protection Center website http://uspest.org

Developed for APHIS PPQ CAPS program

Pest status: high risk of US invasion; polyphagous pest throughout Australia, Africa, India, much of Europe and Asia especially on cotton, soybean and vegetables; known long-distance migratory behavior

Model abbrev: owbw

note significant data used in final model in salmon background

note points added to force x-intercept method in yellow

Parameter		Celsius	Fahrenheit
Lower Threshold:		10.56	51
Upper Threshold:		38	100.4 (based on some survival egg-adult at 35C)
Start Date:	Jan. 1st		
Calculation type:	single sine (UC Davis default)		
Region of known use:	Developed for use in the continental U.S.		
Validation status:	Version 1.1 based on analysis of sources listed; emphasis on regions w/winter diapause		
Notes on biology:	Working assumption that below ca. 20 deg. Lat. (tropics): no diapause, 25-40 deg. Lat: OW pupae in diapause in soil, above 40 deg. Lat.: fail to survive cold (except Mediterranean and marine-influence climates can have milder winters), but migratory colonization can occur.		

Event	DDs10.56 (C)	DDs51 (F)	notes
First flight (winter diapause; not contin. devel or migrants)	240	432	← first flight for migrant populations likely to occur later than this; ca. 400 DD (C) in S. Hungary
Peak flight	569	1024	
Approx peak larvae 1st Gen (peak flight+Pre-OV+Egg+0.5*Larvae)	808	1454	
1st Generation first flight	845	1521	← using 1st flight in spring + avg generation time (Egg to 25% OV)
1st Generation peak flight	1174	2113	
2nd Generation peak larvae	1413	2543	
2nd Generation first flight	1450	2610	
2nd Generation peak flight	1779	3202	
3rd Generation first flight	2055	3698	
3rd Generation peak flight	2384	4290	
4th Generation first flight	2660	4787	
4th Generation peak flight	2988	5379	
5th Generation peak flight	3593	6468	
6th Generation peak flight	4198	7557	

1. Jallow, M.F.A., M. Matsumura. 2001. Influence of temperature on the rate of development of Helicoverpa armigera (Hubner)(Lepidoptera:Nocturidae). Appl. Entomol. Zool. 36:427-430.

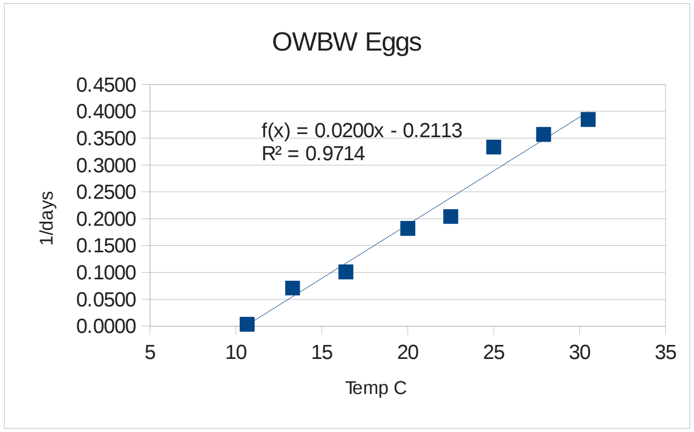
-Reared on tomato collected from diff hosts in Kumamoto Prefecture, Japan (32.4 Deg North). Photoperiod 12L:12D. Relative Humidity unspecified.

2. Jallow, M.F.A., M. Matsumura, and Y. Suzuki. 2001. Oviposition perference and reproductive performance of Japanese Helicoverpa armigera (Hubner)(Lepidoptera:Nocturidae). Appl. Entomol. Zool. 36:419-426.

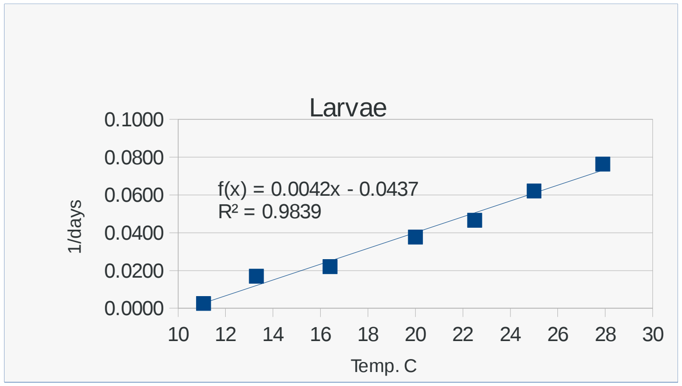
-Studies included Pre-OV time on various hosts

Table 1.

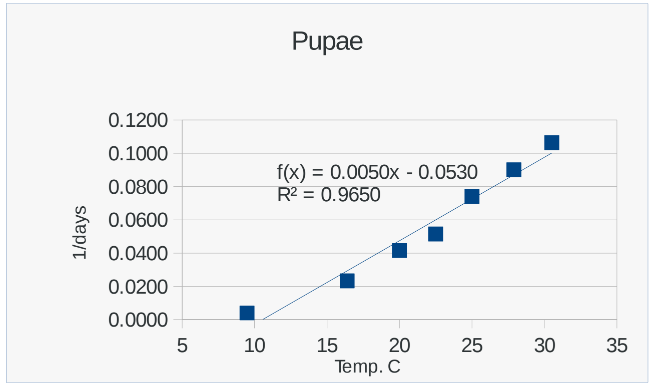
Eggs	Temp. C	1/days	Days
	10.653	0.0033	300
	13.3	0.0709	14.1
	16.4	0.1010	9.9
	20	0.1818	5.5
	22.5	0.2041	4.9
	25	0.3333	3
	27.9	0.3571	2.8
	30.5	0.3846	2.6
	32.5		2.5
	Slope=b	0.0200	
	intercept=a	-0.2113	
Tlow	X-interc -a/b	10.5596	
DD-req	1/slope	49.98	
	RSQ	0.9714	0.9688



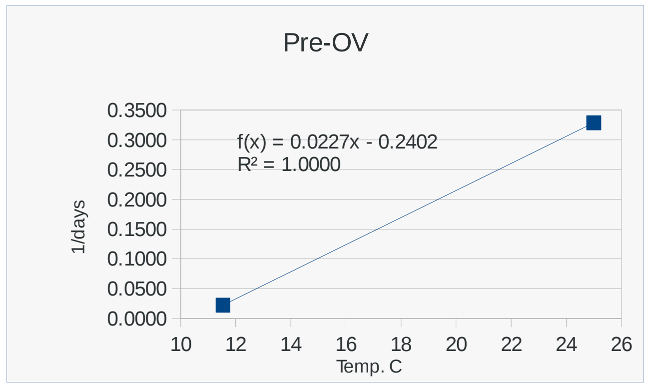
Larvae	Temp. C	1/days	Days
	11.075	0.0025	400
	13.3	0.0169	59.1
	16.4	0.0221	45.3
	20	0.0377	26.5
	22.5	0.0465	21.5
	25	0.0621	16.1
	27.9	0.0763	13.1
	30.5	0.0870	11.5
	32.5		10.9
	Slope=b	0.0043	
	intercept=a	-0.0451	
Tlow	X-interc -a/b	10.5601	
DD-req	1/slope	234.07	
	RSQ	0.9886	0.9859



Pupae	Temp. C	1/days	Days
	9.484	0.0040	250
	13.3		
	16.4	0.0233	43
	20	0.0415	24.1
	22.5	0.0515	19.4
	25	0.0741	13.5
	27.9	0.0901	11.1
	30.5	0.1064	9.4
	32.5		9
	Slope=b	0.0050	
	intercept=a	-0.0530	
Tlow	X-interc -a/b	10.5608	
DD-req	1/slope	199.21	
	RSQ	0.9650	0.9756



Pre-OV	Temp. C	1/days	Days
	11.5371	0.0222	45
	25	0.3284	3.045
	Slope=b	0.0227	
	intercept=a	-0.2402	
Tlow	X-interc -a/b	10.5600	
DD-req	1/slope	43.97	
	RSQ	1.0000	



Studies with different host plants (Tables 2&3, Jallow, Matsumura & Suzuki 2001)

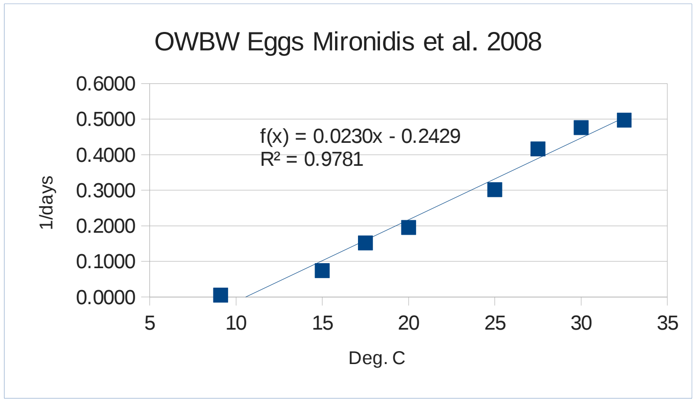
	Larval Duration			**Pupal Duration**		**Pre-OV**	
Larval Duration	**Days**	**Tempc**	**DD10.56**	**Days**	**DD10.56**	**Days**	**DD10.56**
Artif. Diet	12.2	25	176.2	13.3	192.1	2.68	38.7
Eggplant	19.85	25	286.6	14.01	202.3	2.72	39.3
Pepper	20.17	25	291.3	14.26	205.9	3.29	47.5
Maize	14.5	25	209.4	14.19	204.9	3.21	46.4
OKRA	14.76	25	213.1	14.13	204.0	3.27	47.2
Tomato	16.2	25	233.9	13.46	194.4	3.1	44.8
AVERAGE	16.28	25	235.1	13.9	200.6	3.045	44.0

3. Mironidis, G.K., and M. Savopoulou-Soultani. 2008. Development, survivorship, and reproduction of H. armigera under constant and alternating temperatures Env. Entomol. 37:16-28.

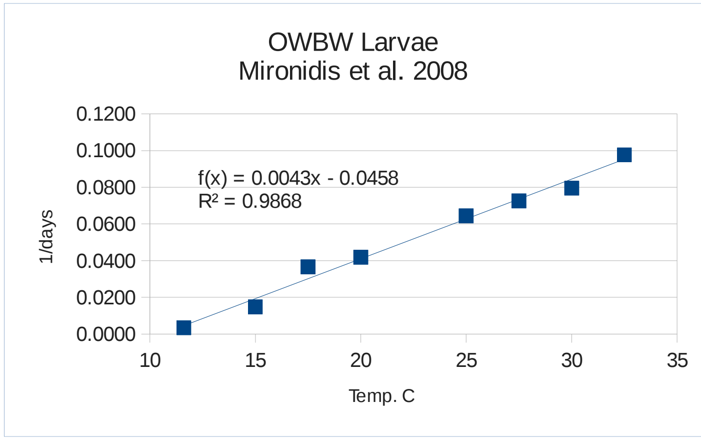
-Studied using populations from cotton fields in N. Greece. Reared on artificial diet at 25C and 16:8 L:D.

Table 1.

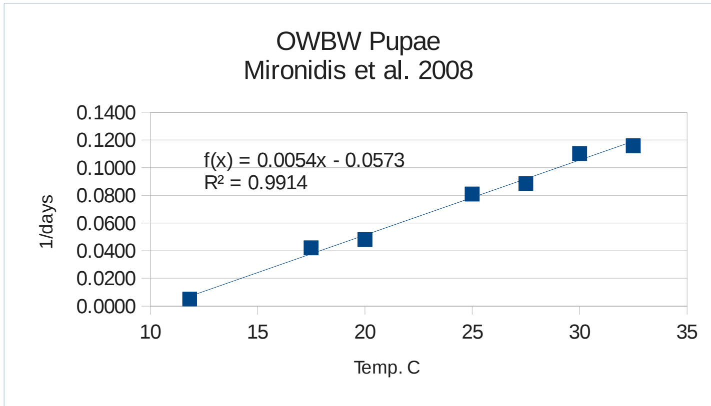
Eggs	Temp. C	1/days	Days
	9.1	0.0050	200
	15	0.0737	13.57
	17.5	0.1515	6.6
	20	0.1953	5.12
	25	0.3021	3.31
	27.5	0.4167	2.4
	30	0.4762	2.1
	32.5	0.4975	2.01
	35		2.04
	Slope=b	0.0230	
	intercept=a	-0.2429	
Tlow	X-interc -a/b	10.5620	
DD-req	1/slope	43.49	
	RSQ	0.9781	



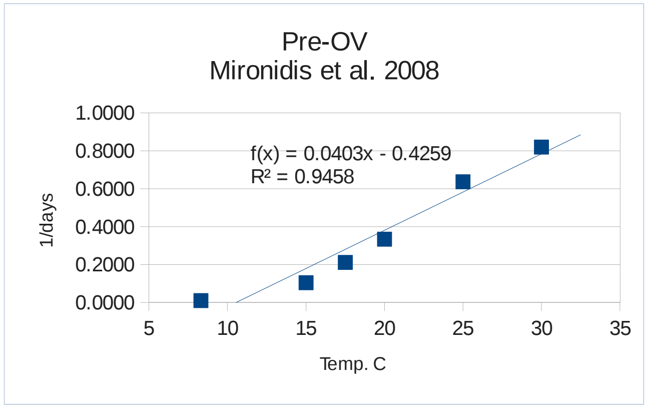
Larvae	Temp. C	1/days	Days
	11.61	0.0033	300
	15	0.0147	68
	17.5	0.0366	27.3
	20	0.0419	23.87
	25	0.0644	15.52
	27.5	0.0726	13.78
	30	0.0795	12.58
	32.5	0.0977	10.24
	35		10.36
	Slope=b	0.0043	
	intercept=a	-0.0458	
Tlow	X-interc -a/b	10.5604	
DD-req	1/slope	230.40	
	RSQ	0.9868	



Pupae	Temp. C	1/days	Days
	11.84	0.0050	200
	17.5	0.0420	23.81
	20	0.0481	20.8
	25	0.0810	12.35
	27.5	0.0886	11.29
	30	0.1103	9.07
	32.5	0.1159	8.63
	35		8.56
	Slope=b	0.0054	
	intercept=a	-0.0573	
Tlow	X-interc -a/b	10.5614	
DD-req	1/slope	184.23	
	RSQ	0.9914	



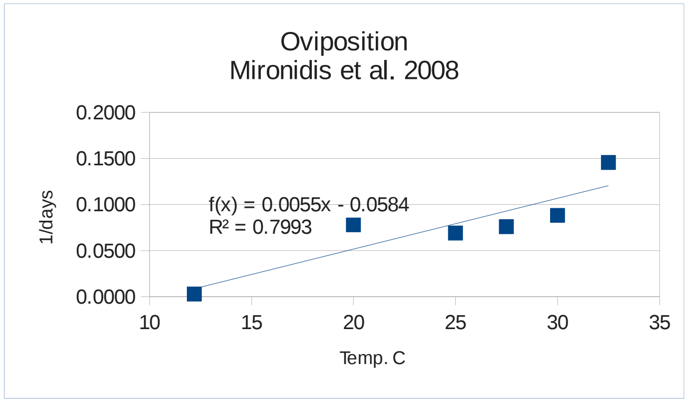
Pre-OV	Temp. C	1/days	Days
	8.311	0.0100	100
	15	0.1042	9.6
	17.5	0.2110	4.74
	20	0.3333	3
	25	0.6369	1.57
	27.5		1.95
	30	0.8197	1.22
	32.5		1.71
	35		2
	Slope=b	0.0403	
	intercept=a	-0.4259	
Tlow	X-interc -a/b	10.5603	
DD-req	1/slope	24.80	
	RSQ	0.9458	



Use weighting approach to emphasize favorable temps

Oviposition	Temp. C	1/days	Days	DDs10.56 ©	Wt.	Dds x Wt.
	12.2	0.0029	350			
	15		13.5	60	0.1	6.0
	17.5		12.11	84	0.3	25.2
	20	0.0778	12.85	121	0.4	48.5
	25	0.0690	14.5	209	1	209.4
	27.5	0.0760	13.16	223	0.8	178.3
	30	0.0883	11.33	220	0.7	154.2
	32.5	0.1458	6.86	151	0.14	21.1
	35		4.71			
	Slope=b	0.0055	sum		3.44	642.7
	intercept=a	-0.0584	avg	153		186.8
Tlow	X-interc -a/b	10.6107			wtd avg	-----------^
DD-req	1/slope	181.73				
	RSQ	0.7993				

40% of Oviposition time = 0.4 x 186.8 = 75



4. Liu, Z., D. Li, P. Gong, and K. Wu. 2004. Life table studies of the cotton bollworm, H. armigera on different host plants. Environ. Entomol. 33:1570-1576.

Table 1 / **Table 4**

Host	**Temp. C**	**Egg Days**	**DD10.56**	**Larvae Days**	**DD10.56**	**Pupae Days**	**DD10.56**	**Adult Female Longevity Days**	**DD10.56**
Cotton	27	3.0	49.3	22.32	367	10.1	166	9.79	161
Corn	27	3.0	49.3	14.05	231	9.55	157	10.61	174
Common Bea	27	3.0	49.3	15.21	250	9.75	160	12.2	201
Tomato	27	3.0	49.3	22.72	374	9.35	154	10.84	178
Hot Pepper	27	3.0	49.3	21.02	346	9.79	161	12.11	199
Tobacco	27	3.0	49.3	19.77	325	10.14	167	7.65	126
Average			49.3		315.3		160.8		173.2
Average Cotton, Corn, Bean only			49.3		282.7		161.1		178.6

←-- assume same as oviposition

40% of Oviposition time = 0.4 x 178.6 = 71

Notes:
-in China, 3-5 generations per year
-best hosts for fitness such as survival, devel rate, pupal size, fecundity etc, generally: cotton > corn > bean >> tobacco, tomato, hot pepper
-In China, is a key pest of cotton, rarely found on tobacco and hot pepper
-Serious pest of China, Australia, and India

5. Venette, R.C., E.E. Davis, J. Zaspel, H. Heisler, M. Larson. 2003. Mini Risk Assessment Old World Bollworm, H. armigera.
https://www.aphis.usda.gov/plant_health/plant_pest_info/owb/downloads/mini-risk-assessment-harmigerapra.pdf

-Distribution based on eco-biome matching of US with similar biomes in countries included in global distribution
-Range includes tropical, dry, and temperate climates.
-may be most closely assoc. with deserts and xeric shrublands, Mediterranean scrub, temperate broadleaf and mixed forsts, tropical and subtropical moist broadleaf forest.

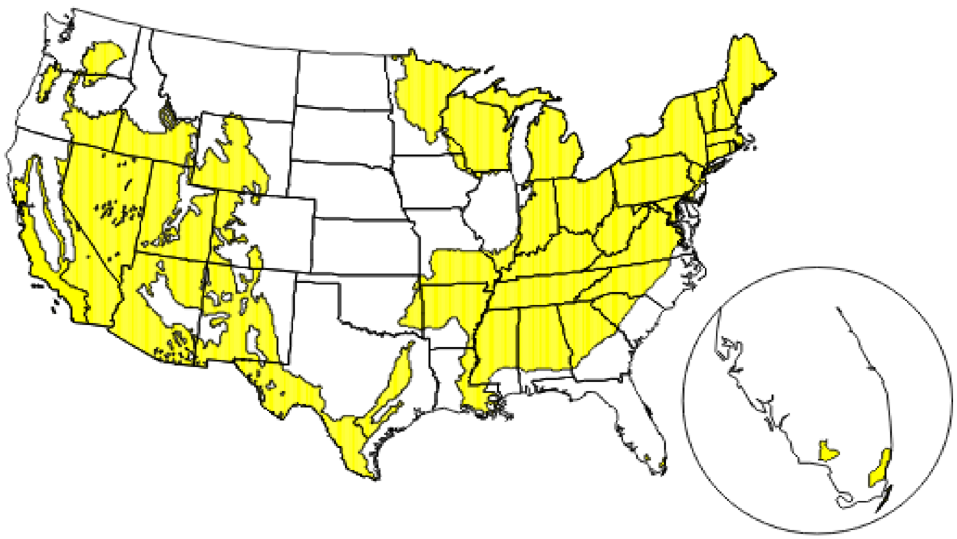


Figure 2. Predicted distribution of *Helicoverpa armigera* in the continental US. Southern Florida is enlarged for detail.

6. Kriticos, D, N. Ota, W. D. Hutchison, J. Beddow, T. Walsh, W. Tek Tay, D. Borchert, S. Paula-Moraes, C. Czepak, M. Zalucki. 2015. The potential distribution of invading Helicoverpa Armigera in North America: Is it just a matter of time? Plos One 10(7): e0133224.

Summary of Climex Parameters:

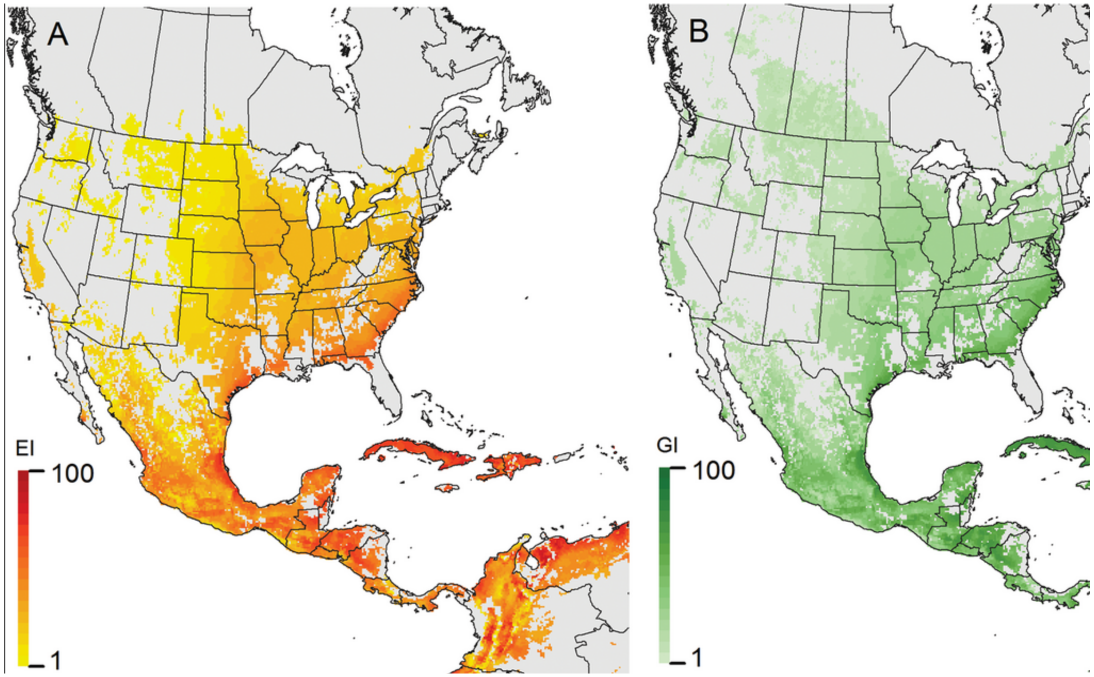
Index	Parameter	Previous Values	New Value[a]
Temperature	DV0 = lower threshold	11°C	11°C
	DV1 = lower optimum temperature	20°C	20°C
	DV2 = upper optimum temperature	31°C	31°C
	DV3 = upper threshold	37°C	37°C
Moisture	SM0 = lower soil moisture threshold	0.05	**0.1**
	SM1 = lower optimum soil moisture	0.7	0.7
	SM2 = upper optimum soil moisture	2.0	**1.0**
	SM3 = upper soil moisture threshold	4.0	**2.0**
Cold stress	TTCS = temperature threshold	9	-
	TTHS = stress accumulation rate	-0.0003	-
	DTCS = degree day threshold	-	**5°C days**
	DHCS = stress accumulation rate	-	**−0.0005 week^{-1}**
Heat stress	TTHS = temperature threshold	37°C	37°C
	THHS = stress accumulation rate	0.0005 Week^{-1}	**0.001 Week^{-1}**
Dry stress	SMDS = soil moisture threshold	0.1	0.1
	HDS = stress accumulation rate	-0.005 Week^{-1}	**−0.004 Week^{-1}**
Wet Stress	SMWS = soil moisture threshold	2	2
	HWS = stress accumulation rate	0.005 Week^{-1}	0.005 Week^{-1}
Diapause Index	DPD0 = Diapause induction daylength	11 h	11 h
	DPT0 = Diapause induction temperature	15°C	**10°C**
	DPT1 = Diapause termination temperature	16°C	**10°C**
	DPD = minimum days in diapause	69	**0**
	DPSW = summer/winter switch	0 (winter)	0 (winter)

Model parameters were adapted from Zalucki and Furlong [12]. Changed values are indicated in bold.

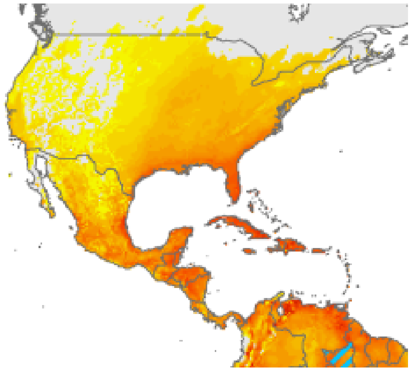
[a] Values without units are dimensionless indices of soil moisture for a 100 mm single bucket model (0 = oven dry, 1 = field capacity).

doi:10.1371/journal.pone.0119618.t001

Climex predicted distrib. In US & part of S. America: A) Ecoclimatic index, B) Annual growth index indicating the potential for population growth:



Notes: Fig A in supplemental material has a much broader potential distribution in US:



Pers commun. With one of the authors: The reason Florida was originally excluded was due to lack of cotton there….the climate is probably not the factor limiting success there.

7. Baker, G.H., C.R. Tann, G.P. Fitt. 2011. A tale of two trapping methods: Helicoverpa spp. In pheromone and light traps in Australian cotton production systems. Entomol. Research 101:9-23.

-growing season of cotton ca. weeks 18-43

-monitored light and pheromone traps for 11 seasons

Fig. 4:

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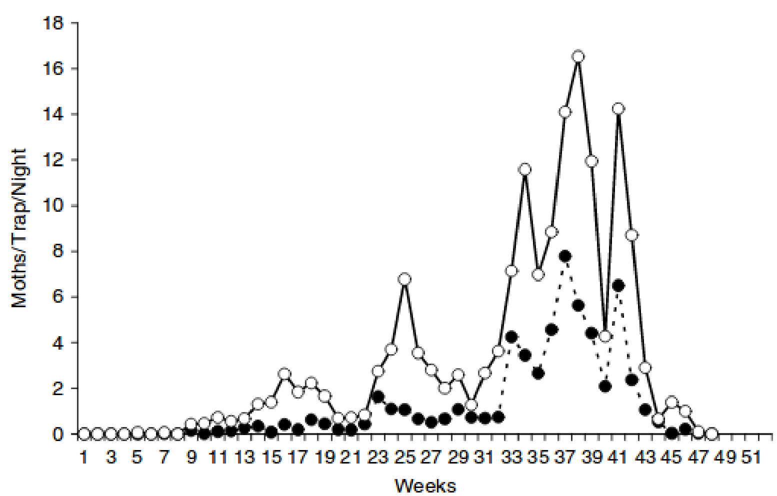


Fig. 4. Long-term average catches of *H. armigera* female and male moths in light traps at ACRI, Narrabri, New South Wales from 1992–93 to 2001–02 (–●–, female; –○–, male).

<table>
<tr><td>Extracted from Fig. 4 and climate data:</td><td></td><td></td><td>Simple Avg Dds</td><td></td><td></td><td>←- weather data from</td><td></td><td>http://www.bom.gov.au/climate/data/</td><td>30-31S Latitude</td><td></td><td></td></tr>
<tr><td>Date (convert to</td><td></td><td>Cumul %</td><td>DD10.56</td><td>DD10.56</td><td></td><td>for station 053030 Narrabri West Post Office NSW from 1995</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>N. Hemis)</td><td>Week</td><td>Trap Catch</td><td>1995</td><td>1997</td><td>Avg</td><td></td><td>Data available at uspest.org/data/NARRABRI95.txt</td><td></td><td>and NARRABRI96.txt</td><td></td><td></td></tr>
<tr><td>01/01/95</td><td>1</td><td>0</td><td>1.7</td><td>5.1</td><td>3</td><td></td><td>←-----|</td><td></td><td>Estimated female</td><td>Modified</td><td>Gen Time</td></tr>
<tr><td>01/28/95</td><td>4</td><td>0</td><td>16.4</td><td>40.6</td><td>29</td><td></td><td>|</td><td></td><td>peak catch from Fig. 4</td><td>Peak DD</td><td>Pk to Pk</td></tr>
<tr><td>03/07/95</td><td>9</td><td>2</td><td>191</td><td>137</td><td>164</td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>03/24/95</td><td>11</td><td>5</td><td>300</td><td>242</td><td>271</td><td>1st catch G1</td><td>←-----|</td><td>1st Catch ca. 271 DD</td><td></td><td></td><td></td></tr>
<tr><td>04/07/95</td><td>13</td><td>10</td><td>391</td><td>342</td><td>367</td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>04/21/95</td><td>15</td><td>24</td><td>533</td><td>452</td><td>493</td><td>diff=wk23-11</td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>04/29/95</td><td>16</td><td>40</td><td>618</td><td>534</td><td>576</td><td></td><td>|</td><td>1st GEN (Maelzer & A 1999)</td><td>peak catch G1</td><td>576</td><td></td></tr>
<tr><td>05/19/95</td><td>19</td><td>75</td><td>876</td><td>718</td><td>797</td><td></td><td>|</td><td>(weeks 0-20)</td><td></td><td></td><td></td></tr>
<tr><td>06/02/95</td><td>21</td><td>95</td><td>1059</td><td>1054</td><td>1057</td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>06/16/95</td><td>24</td><td>5</td><td>1332</td><td>1284</td><td>1308</td><td>1st catch G2</td><td>←-----|</td><td></td><td>peak catch G2</td><td>1308</td><td>732</td></tr>
<tr><td>06/30/95</td><td>25</td><td>50</td><td>1430</td><td>1524</td><td>1477</td><td>diff=wk40-23=</td><td>|</td><td>2nd GEN (M & Z 1999)</td><td></td><td></td><td></td></tr>
<tr><td>08/09/95</td><td>31</td><td>5</td><td>2054</td><td>2114</td><td>2084</td><td></td><td>|</td><td>(weeks 20-33)</td><td>peak catch G3</td><td>2084</td><td>776</td></tr>
<tr><td>08/24/95</td><td>33</td><td>50</td><td>2266</td><td>2362</td><td>2314</td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>09/13/95</td><td>36</td><td>5</td><td>2561</td><td>2674</td><td>2618</td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>09/27/95</td><td>38</td><td>50</td><td>2749</td><td>2848</td><td>2799</td><td>diff=wk44-</td><td>|</td><td>3rd GEN (M & Z 1999)</td><td>peak catch G4</td><td>2799</td><td>715</td></tr>
<tr><td>10/10/95</td><td>40</td><td>5</td><td>2836</td><td>2980</td><td>2908</td><td>1st catch G3</td><td>←-----|</td><td>(weeks 33-44)</td><td></td><td></td><td></td></tr>
<tr><td>10/24/95</td><td>42</td><td>50</td><td>2941</td><td>3108</td><td>3025</td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11/07/95</td><td>44</td><td>est5</td><td>3051</td><td>3232</td><td>3142</td><td></td><td>←-----|</td><td></td><td></td><td>(assume partial gen)</td><td></td></tr>
<tr><td>11/14/95</td><td>45</td><td>95</td><td>3114</td><td>3265</td><td>3190</td><td></td><td></td><td></td><td>partial peak ca. G5</td><td>3190</td><td>391</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>avg Gen Time Dds</td><td></td><td>741</td></tr>
</table>

First Catch evidence

Fig. 2 (pheromone traps = males) – ca. Weeks 11-13 (equiv March 24-Apr 7)

Fig. 4 (light traps) – ca. Weeks 11-13 (female), weeks 9-11) male

Fig. 6 (light and pheromone traps) – ca. Weeks 10-11

- First flight 3rd week Mar 270 DD; Peak flight last week Apr.,575 DD; AVG gen time between peaks/generation time ca. 740 DD

<table>
<tr><td></td><td>DD10.56</td><td></td></tr>
<tr><td>First flight</td><td>270</td><td></td></tr>
<tr><td>Peak flight</td><td>575</td><td></td></tr>
<tr><td>Gen time</td><td>740</td><td>← remove from final summary due to lack of assurance that this analysis has low enough error</td></tr>
</table>

8. Duffield, S. and M. Dillon. 2005. The emergence and control of overwintering Helicoverpa armigera pupae in southern New South Wales. Austral. J. of Entomol.

-OW as pupae in Southern NSW

-Data from caged planted populations **(**not entirely natural field conditions**)**

-females emerge before males; presumed due to pre-OV requirement for females

-Cooler climate and later emergence by ca. 2 weeks than reference #7 above

From Fig. 1 (1997 data)		% male moth		
Austral	N. Hemis	emerg	DD10.56	DDS from same site as above, 1997 DENILIQUIN97.txt NSW Austral sta 74128 note reversed seasons
10/24/97	04/24/97	2	277	
10/29/97	04/29/97	10	336	
11/07/97	05/07/97	50	395	
11/14/97	05/14/97	90	473	
11/29/97	05/29/97	98	636	

From Fig. 2 (1998 data) % male moth

Austral	N. Hemis	emerg	DD10.56	DDS from same site as above, 1998 DENILIQUIN98.txt NSW Austral sta 74128 note reversed seasons
10/24/98	04/24/98	1	306	
11/04/98	05/04/98	10	393	
11/17/98	05/17/98	50	511	
11/30/98	05/30/98	90	687	
12/06/98	06/06/98	98	772	

From Fig. 4 (model from 1990-2001 data)

		% male moth	DD10.56			
	N. Hemis	emerg	1997	1998	AVG	DDS from same site as above, 1997&98 DENILIQUIN NSW Austral sta 74128 note reversed seasons
10/18/99	04/18/98	2	253	259	256	
10/29/99	04/29/99	10	336	365	351	
11/16/99	05/16/99	50	489	508	499	
12/04/99	06/04/99	90	713	746	730	
12/17/99	06/17/99	98	881	911	896	

Average of the three above:	**DD10.56**
First flight	**280**
Peak flight	**468**
End flight	**768**

9. Kumar, G. J.. 2013. Monitoring of Insect Pest Populations of Chickpea. M.S. Thesis. ANGR Agric. University, Rajendranagar, Hyderabad India.

1) In Haryana India max activ of the males during 6th to 28th week (Feb 4-July 10 spring / summer) plus a minor peak week s 42-50 (Chickpea) (Sinha and Jain 1992)
2) In Varanasi India moths active from 2nd week Feb to last week of May (ca. weeks 6-19) w/peaks during Mar and Apr in 1989-90 and 1990-91 (Rakesh et al. 1995)
3) In Dhankuta, Nepal max moths trapped in Pheromone traps in Apr, Mar, and May in 1988, 1989, and 1990, respectively (Duwadi et al. 1996)
4) In Uttar Pradesh India, max moth catches Pheromone traps in first half of April, also during Late March.
-In Tamil Nadu 1982-83 peak pheromone and light trap catch during Feb to April and Oct to Dec.
-In Gujarat pheromone trap catch highest from Dec to Apr. (Chari et al. 1985)
-Peak catch from Mar to Apr in N. India, Nov-Dec in S. India, Mar-Apr in E. India (Dent 1985)
5) Uttar Pradesh 1982-85 catches from Mar to Apr in Pheromone traps **(**Lal et al. 1985**)**
-In Gujarat continuous trapping 1982-1983 with max males during Oct-Nov both years **(**Patel et al. 1985**)**
-In Texas highest spring catches in areas planted with wheat **(**Slosser et al. 1987**)**
6) In Nepal w/Pheromone traps in chickpea fields trapped from 1st week Jan to last week Apr., peak from last week Feb to first week Mar **(**Sah et al. 1988**)**
-In S. Italy moths trapped from July to Sept w/peak in Aug. **(**Sannino and Balbini 1989**)**
7) In Himachal Pradesh 1991 peak catch Mar to May **(**Dev et al 1991**)**
-In Pakistan 1991 peak first half of April **(**Srivastava et al. 1991**)**
-In Raichur India max activity in light and pheromone traps Oct to Dec with peak during week 50, oviposition peaked same as trapping plus next week after trap peaks (Patil and Kulkarni 1997)
8) In Andhra Pradesh 1998-99 max moths during Weeks 2-5 (Jan and Feb) (Suganthy et al. 2003)
-In ?? India populations low during 49-6th weeks increasing from week 7-13 **(**Zahid and Shahzad 2007**)**
9) In Madhya Pradesh India 1983-5 peak activity (presumed larvae) in Feb and Mar both years **(**Dubey et al. 1993**)**
10) In Syria 3 peak catches of male moths: mid-Mar weeks 10-11, April weeks 13-15, and early June weeks 21-22 **(**Tahhan and Hariri 1982**)**
11) Results from Thesis on H armigera: -peak moth catch week 6; 4 peak catches recorded: week 48, 52, 4, and 6. Major peak coincided with podding stage of chickpea

From numbered reports above: Estimates of Dds (most recent year data 2017-8 not year of study; using online DD calc at: http://www.degreedays.net/#)

exclude as not temperate / more warm tropical/subtropical where pops appear to develop year-round; also possibly migrant population trapped

Location (ref above)		First Flight Noted		First Peak Flt Noted		End Flight Noted		Notes/other data			
Weather station used for Dds		**Date**	**DD10.50**	**Date**	**DD10.50**	**Date**	**DD10.50**				
1. Haryana, India		02/05/91	122			07/10/91	2672				
42101	Patiala, PU, IN (76.45E,30.36N)										
2. Varanasi, India		02/10/90	230	03/20/90	655	05/27/90	2103				
VIBN	Varanasi / Babatpur, IN (82.86E,25.45N)										
3. Dhankuta, Nepal		03/07/88	324	04/15/88	630						
44477	Dhankuta, DH, NP (87.35E,26.98N)										
4. Uttar Pradesh (Kanpur) India				04/07/90	937						
(Station VILK)	Lucknow / Amausi, IN (80.89E,26.76N)										
5. Uttar Pradesh (Kanpur) India		03/04/83	418								
VILK	Lucknow / Amausi, IN (80.89E,26.76N)										
6. Bharatpur Nepal		01/07/87	31	02/28/87	366			Immigrants? No locality specified?			
VNPK	Pokhara Airport, GA, NP (84.00E,28.22N)										
7. Solan HP India				03/25/91	214	05/25/91	885				
IHIMACHA9	Solan, Himachal Pradesh, IN (77.10E,30.93N)										
8. Andhra Pradesh-Anantapur India				01/20/98	291			S. India – tropical no diapause			
43237	Pbo Anantapur, IN (77.63E,14.58N)										
9. Madhya Pradesh India				01/10/84	65			Larvae in Feb and Mar			
VABP	Bhopal / Bairagarh, IN (77.34E,23.29N)										
10. Damascus Syria				03/14/81	167		Peak flights:	04/05/81	251	06/06/81	975
OSDI	Damascus Int. Airport, SY (36.52E,33.41N)							difference:	724	possible generation time	
11. Hyderabad, India											
VOHY	Hyderabad Airport, India (78.47E,17.45N)			02/07/12	530						
			1st Flight		Peak Flt 1st Gen			Gen time			
Selected averages (exclude yellow shaded as probably too			273.5		688			724	← drop from final table due to being higher than expected, lack original reference.		

Comments/Interpretations:

-In tropical regions, flight occurs throughout winter; generally showing lack of diapause (typical that OW diapause weakens as populations are not under selection pressure there)

-In more temperate regions, flight usually not until Mar-April, more or less supporting results from Australia (300 DD for first flight (3rd week Mar), 620 first peak (last week Apr.)

-Closer examination of original source documents (if available) could improve this analysis

10. USDA APHIS PPQ Plant Health Pest Info – Helicoverpa armigera. 2014. Old World Bollworm Fact Sheet.
https://www.aphis.usda.gov/plant_health/plant_pest_info/owb/downloads/owb-factsheet.pdf

-OW pupae in soil; moths emerge in May to June depending on latitude.

-2 to 5 generations typical in subtropical and temperate regions; up to 11 under optimal conditions.

-cited Jallow and Twine 1978 for DD requirements; from Twine 475 DD above 11C for E-L-P development

Quoted: Helicoverpa armigera has a facultative pupal diapause, which is induced by short day lengths (11 to 14 hours per day) and low temperatures (15 to 23°C; 59 to 73°F) experienced as a larva (CABI, 2007). A summer diapause, in which pupae enter a state of arrested development during prolonged hot, dry conditions, has been recorded in the Sudan (Hackett and Gatehouse, 1982) and Burkina Faso (Nibouche, 1998).

-moths disperse 10km for non-migratory flights and hundreds of KM (up to 250 km) for migratory flights when host quality declines.

-Risk map emphasizes high risk in states incl. E. Texas, LA, MS, AL, GA, SC, N. FL,

-Med risk in states like VA, NC, TN, AR, OK, W. TX, S. CA, S. AZ, S. NM., S. KS

-Low risk in all N. States and PNW states, CO, most of UT

-Risk map considers host availability as well as climate

11. Noor-Ul-Ane, M, A. Mirhosseini, et al. 2017. Temperature-dependent development of Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae) and its larval parasitoid, Habrobracon hebetor (Say) (Hymenoptera: Braconidae): implications for species interactions. Bull Entomol Res 24:1-10.

-completed devel at 37.5C but not at 40C
-Estimated 11.6 and 513.6 DD for E-L-P development, but no access to full paper to review methodology used

12. Keszthely, S., L. Nowinszky, K. Szeoke. 2016. Different catching series from light and pheromone trapping of Helicoverpa armigera (Lepidoptera: Noctuidae) Biologia 71:818-823.
-Work done in Southern Hungary

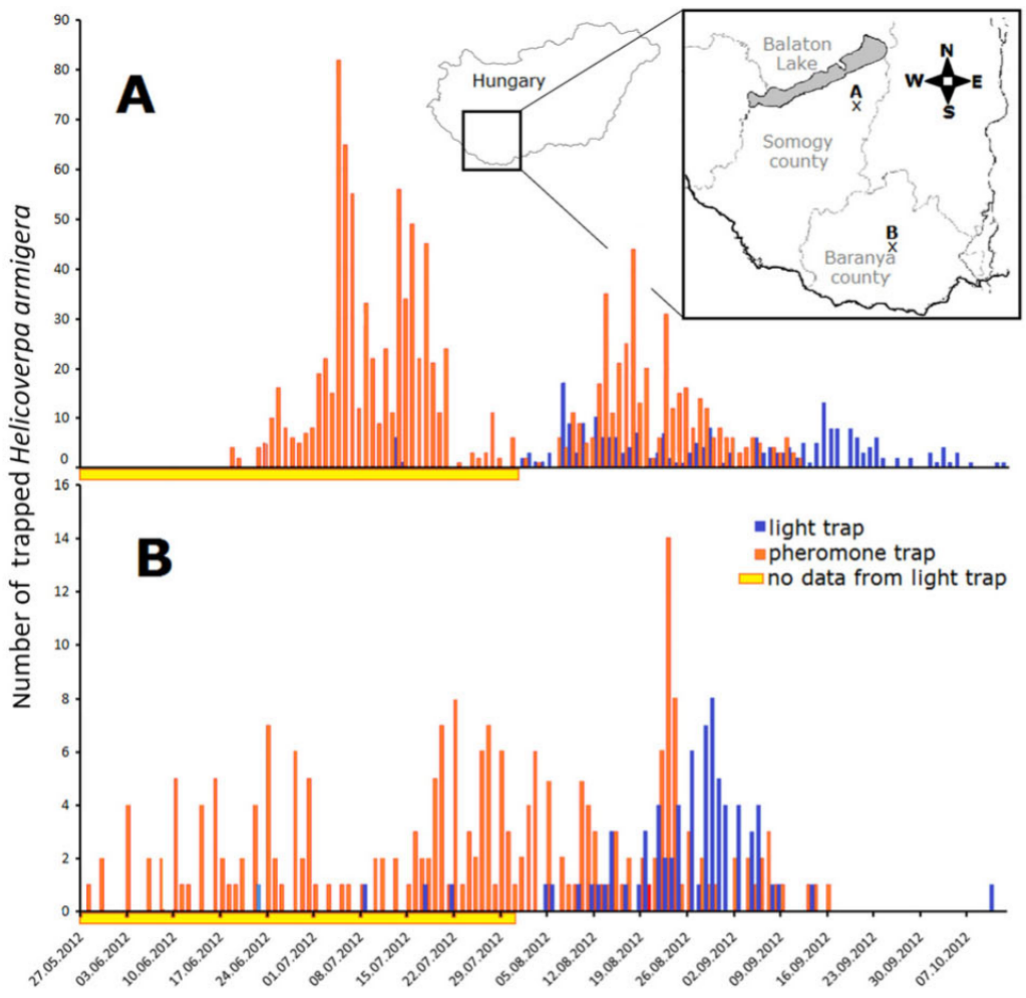


Fig. 3. Catching data from the light- and the pheromone trapping observation in 2012 and locations of the the field monitoring. A: Sárvár (Somogy county, Hungary); B: Kozármisleny (Baranya county, Hungary).

From Fig. 3.	Rough estimates of flight using pheromone traps (study found light traps not as reliable for migrant flight detection)										Diff G1-G2
	1st catch (ca. 5%)		25% catch		G1 50% catch		End catch ca 95%		G2 50% catch		50% catch
		DD10.5		DD10.5		DD10.5		DD10.5		DD10.5	
A. Sarvar/Somogy	06/22/12	553	07/02/12	677	07/08/12	761	07/20/12	913	08/19/12	1314	553
Data from degreedays.net for station LHSK (last 36 months averaged; not true to 2012) for Siofok, Hungary (18.05E,46.92N)											
B. Kozarmisleny / Pogany	06/10/12	412	06/25/12	571	07/10/12	759	08/06/12	1109	08/23/12	1313	554
Data from degreedays.net for station LHPP (last 36 months avg) Pecs / Pogany, HU (18.24E,45.99N)											

Notes:

-Migrant populations; apparently no successful OW here (45-46N Latitude)

-So most estimates (other studies) for native populations, these for more temperate climates such as US above ca. 40 Deg. Latitude

-migrant adults less predictable than local pop.s; first catch later **(**presumably are F1 or F2 from pop.s to the South**)**

-Generation times seem about right but dont use in table below since they are probably a mixture of local and migrants

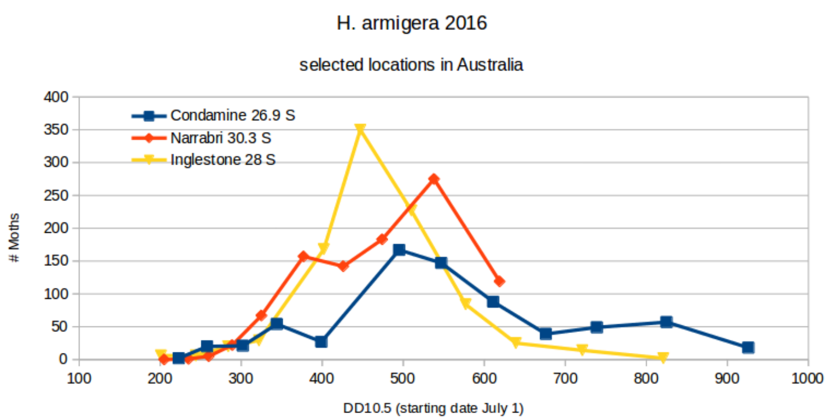
13. TheBeatSheet.Com.AU – Australian Helicoverpa trapping program

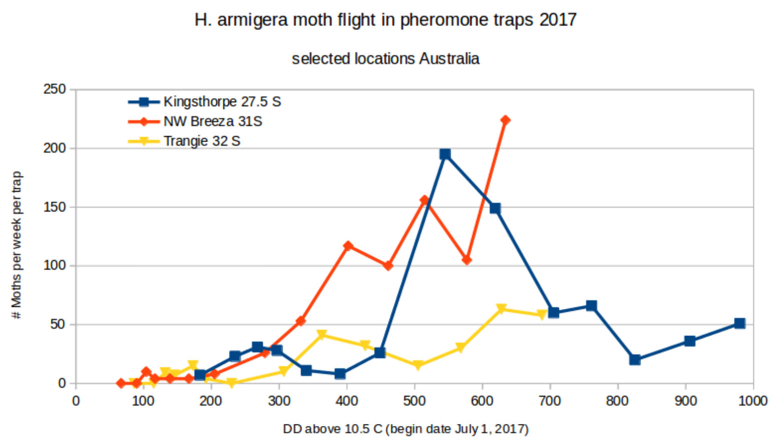
https://thebeatsheet.com.au/helicoverpa-pheromone-traps/

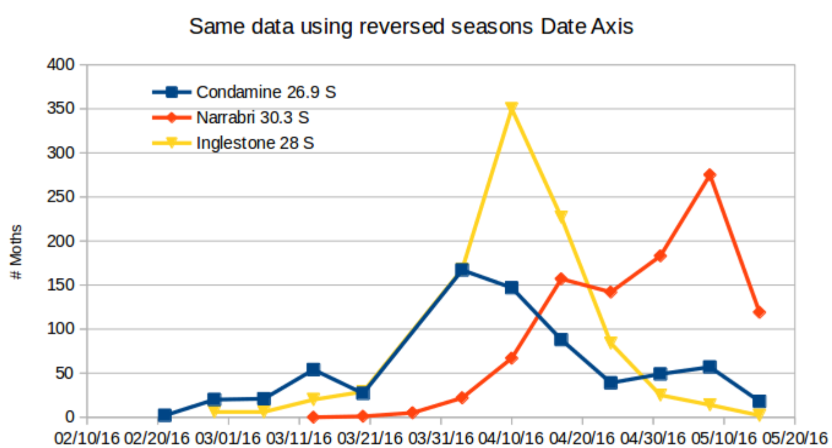
Pheromone data from website, DD calcs from degreedays.net for:

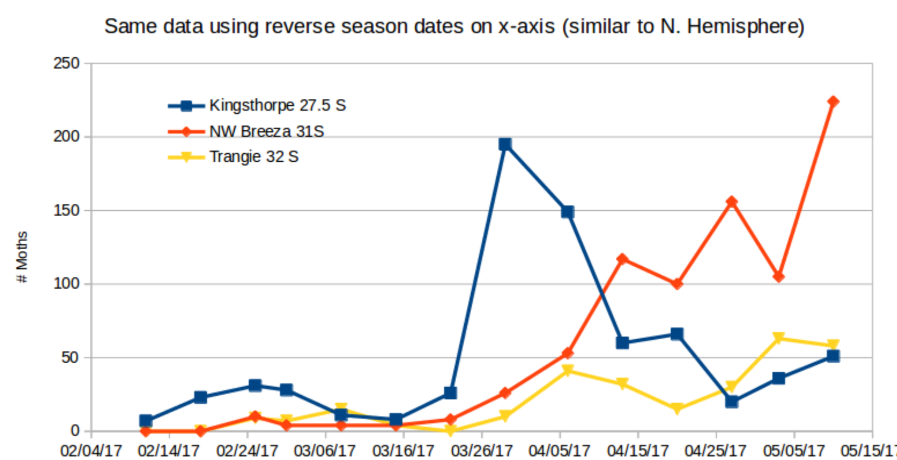
2016 - 3 Locations in Australia (Narrabri NSW 95734, St George QL, 94517 [Inglestone], Surat QL 94521 [Condamine])

2017 - 3 Locations in Australia (Kingsthorpe IKINGSTH3, Tamworth Airport YSTW, [for NW Breeza], and Trangie Res. Sta. #95710)









Notes:

Presumed these are all local (not migrant) populations which overwinter in pupal diapause in the soil: latitude is well within expected range for continental climates (25-40 deg. Lat.).

Loc/Lat	Year	1st catch (ca. 5%) DD10.5	Peak or ca. 50% catch DD10.5	End catch ca 95% DD10.5
Condamine 27 S	2016	230	500	910
Narrabri 30 S	2016	270	525	
Inglestone 28 S	2016	280	470	800
Kingsthorpe 27.5 S	2017	230	550	820
Breeza 31 S	2017	245	600	
Trangie 32 S	2017	190	620	
Average		**241**	**544**	**843**

-Reasonably good data but traps may have been sometimes missed beginning and end of flight

-Could add 2015 to the analysis, consider Brookstead and Kingaroy locations, but not as good as 16-17 data

14. Behere, G.T., W.T. Tay, D.A. Russell, D.G. Heckel, B.R. Appleton, K.R. Kranthi, and P. Batterham. 2007. Mitochondrial DNA analysis of field populations of H. armigera and of its Relationship to H. zea. BMC Evolutionary Biology 7:117-127.

- DNA sequencing supports "single species status" of H. armigera: same genetically across Africa, Asia, and Australia (due to long-distance migratory capacity).
- Very close genetically, believe from this evidence to have diverged from H. zea around 1.5 million years ago.

exclude from average (treat as outlier) in yellow

15. Summary Table for DD req.s (10.56 C lower threshold temperature) for OWBW:

Study	**Jallow, M**	**J, M &S**	**Mironidis et a**	**Liu et al.**		**DD 10.56C Average**	**S.D.**	**C.V.**
Year	**2001**	**2001**	**2008**	2004				
Loc.	**Japan**	**Japan**	**N. Greece**	**China**				
Egg	50.0		43.5	49.3		**48**	4.1	8.7
Larvae	234.1	235.1	230.4	282.7		**246**	28.9	11.8
Pupae	199.2	200.6	184.2	161.1		**195**	19.8	10.2
E+L+P	483.3	435.7	458.1	493.1		**488**	28.9	5.9
Pre-OV	44.0	44.0	24.8			**44**	13.6	30.8
40% OV			74.7	71.5		**73**	2.3	3.2
Full OV			186.8	178.6		**183**	5.8	3.2
Generation time (E+L+P+PreOV+40%OV)			558	589	**Compute by addition →**	**605**		

16. Estimates of first and peak 1st Gen flight, and generation time (DD10.56C between apparent peak flights)

Source:	**Baker et al**	**Kumar**	**Duffield**	**Keszthelyi**	**beatsheet.co**	**From Summ Table above**	**DD 10.56C Average**	**S.D.**	**C.V.**	Notes:
Year	**2011**	**various**	**2005**	**2015**	**2016-17**					
Loc.	**NSW Austral.**	**India, Nepal**	**S. NSW Au**	**Hungary**	**NSW/Queens**	**Lab various**				
Latitude	**30 S.**	**Var. 15-32N**	**35 S.**	**46 N.**	**27-31 S.**					
First flight	270	273.5	280		241		**266**	17.2	6.5	Avg 266 but use more
Peak flight	575	688	468		544		**569**	91.3	16.0	conservative 240 for
First flight (migration areas higher latitudes)				400			**400**			first emergence
Peak flight (migration areas higher lats.)				760			**760**			
End Flight			768		843		**806**	53.3	6.6	
Gen. Time						605	**605**			

17. Estimates of lethal temps for life stages

	Celsius C	Fahrenheit F	
Upper lethal temp	39	102	← From Kritocos et al. 2015 plus a margin of error
Lower lethal temp	-4	25	← Calibrated from CLIMEX map using DDRP model

18. Proposed model parameters for Helicoverpa armigera, old world bollworm (OWBW)

Parameter	Celsius C	Fahrenheit F
Lower developmental threshold	10.56	51
Upper developmental threshold	38	100

Start Date: Jan 1

Calculation type: single sine (UC Davis default)

Region of known use: Developed for use in the continental U.S.

Validation status: Version 2 based on analysis sources listed; emphasis only on regions w/successful overwintering

Life Stage DD durations	DDC	DDF
Egg	48	86
Larvae	246	442
Pupae	195	350
Egg to Adult	488	878
Pre-OV+40% OV	117	211
Generation Time (Egg to 40% OV)	605	1089

Model Events	DDC	DDF	
First flight (winter diapause; not contin. devel. as in the tropics)	240	432	First flight for migrant populations likely to occur later than this;
Peak flight	569	1024	ca. 400 DDC in S. Hungary
Approx peak larvae 1st Gen (peak flight+Pre-OV+Egg+0.6*Larvae)	808	1454	
1st generation first flight	845	1521	
1st generation peak flight	1174	2113	
2nd generation peak larvae	1413	2543	
2rd generation first flight	1450	2610	
2rd generation peak flight	1779	3202	
3rd generation first flight	2055	3698	
3rd generation peak flight	2384	4290	
4th generation first flight	2660	4787	
4th generation peak flight	2988	5379	
5th generation peak flight	3593	6468	
6th generation peak flight	4198	7557	

Phenology Stage Ranges	Begin DDC	End DDC	Begin DDF	End DDF
OW pupae in soil	0	239	0	430
OW generation flight	240	844	432	1520
1st generation flight	845	1449	1521	2609
2nd generation flight	1450	2054	2610	3697
3rd generation flight	2055	2659	3698	4786
4th generation flight	2660	3263	4787	5875
5th generation flight	3264	3868	5876	6964
6th generation flight	3869	4473	6965	8053
7th generation flight	4474	5078	8054	9141

Climate Suitability Parameters	DDC	DDF	
Heat Stress Threshold for DDRP model	39	102	Estimate based on failure to develop at 38C
Heat Stress Units preventing long term establishment	150	270	for lethal longer-term threshold
Heat Stress Units preventing short term establishment	250	450	
Chill Stress Threshold for DDRP	-4	25	Assume some thermal protection outdoors
Chill Stress Units preventing overwintering	200	360	based on calibration from CLIMEX model
Chill Stress Units restricting migration	700	1260	based on calibration and reports of regular trapping in Norway
OW Stage			pupae in diapause in soil (subtropical and temperate climates)
Photoperiod sensitivity			ca. 11 hr daylength and 10C to trigger pupal diapause (Kriticos et al. 2015)