IPPC Model Analysis Summary – June 27, 2017; updates Dec. 17, 2018 vers. 1.1

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

Developed for APHIS PPQ CAPS and CPHST

Asian Longhorned Beetle Phenology (degree-day) Model *Anoplophora glabripennis (Motschulsky)*

Model based on numerous sources outlined below

note significant data used in final model in salmon color

note points added to force x-intercept method in yellow

Asian Longhorned Beetle Model Parameters:	**Fahrenheit**	**Celsius**
Lower threshold:	**50**	**10**
Upper threshold:	**95**	**35**

Start Date: **January 1st**

Calculation Method: **single sine**

Region of Known use: **Developed using data and models from sources including China, Italy, US, England, Finland.**

Validation status: **Based solely on analysis of sources below including lab and field data; with some cross-checks. More validation needed.**

Events and degree-days used in Asian longhorned beetle model:

Stage	DDs50 (F)	DDs10 (C)
Egg	432	240
Instars 1-8 (univoltine climates)	3888	2160
Instars 1-10 (semivoltine climates)	4680	2600
Pupae	468	260
Teneral adult (post-pupae, pre-exit)	224	124
Immature "chewing" adult (post-pupae, use to estimate 1st flight)	238	132
Egg to Egg w/8 instars (min gen. time: univoltine climates)	5249	2916
Egg to Egg w/10 instars (min gen. time: semivoltine climates)	6041	3356

Adult emergence (based on overwintering final stage larvae ready to pupate):

% emerg.	DDs50 (F)	DDs10 (C)
1	795	442
10	992	551
25	1173	652
50	1593	885
75	2162	1201
95	2735	1519
99	3003	1668

% emergence (Ranges) (Fahrenheit only)

Start	End	DDs50 (F) Start	DDs50 (F) End
0	0.9	0	794
1	9.9	795	991
10	24.9	992	1172
25	49.9	1173	1592
50	74.9	1593	2161
75	94.9	2162	2734
95	98.9	2735	3002

99	100	3003	>2963

Final DD model: (start date Jan 1; single sine Dds; Tlower=50F (10C), Tupper=95F (35C)

	DDs50 (F)	DDs10 (C)	
OW larvae begin pupation	**104**	**58**	←Major change from V1.0
1% Adult emergence	**795**	**442**	
10% Adult emergence, 1st egg-laying	**992**	**551**	
25% Adult emergence	**1173**	**652**	
1st Egg hatch	**1424**	**791**	
50% Adult emergence	**1593**	**885**	
75% Adult emergence	**2162**	**1201**	
1st 5th instar larvae	**2500**	**1389**	
95% Adult emergence	**2735**	**1519**	
99% Adult emergence	**3003**	**1668**	
1st 8th instar larvae (could be univoltine if reached by Oct)	**4110**	**2283**	

Sources of Analysis:

1 Smith, M.T., P.C. Tobin, J. Bancroft, G. Li, and R. Gao. 2004. Dispersal and Spatiotemporal dynamics of asian longhorned beetle (Coleoptera: Cerambycidae) in China. Environ. Entomol. 33:435-442.

- data from Gansu Province of N. Central China 1999 & 2000

- in China, 50% emergence occurred after 950 DDC10 (base Temp 10 Celsius)
- fitted a simple model to % emergence (tested by Faccoli et al 2014 and Trotter and Keena 2016 below).

Approx results from Fig. 1:

Date	DD10(C)	DDs50(F)	% emerg	
06/08/99	450	810	2	
06/28/99	700	1260	20	
07/12/99	850	1530	38	approx peak capture at 800-900 DD
07/17/99	950	1710	50	
07/21/99	1050	1890	60	
08/14/99	1225	2205	80	
08/22/99	1430	2574	90	
09/28/99	1700	3060	98	

2 Zhao and Naliaki 1999. (As cited in ref. 1 and 3 above and below; not directly accessed)

- in China, 90% emerg. occurred by 7/23/1995, 7/22/1996, and 7/22/1997 (Zhao & Naliaki 1999) with a DD accum. of 1450 DDs by mid-July (Tlow=10C, start Jan 1)

Date	DD10 (C)	% emerg
07/22/96	1450	90

3 Keena, M.A. and P.M. Moore. 2010. Effects of temperature on Anoplophora glabripennis (Col.: Cerambycidae) larvae and pupae. Environ. Entomol. 39:1323-1335.

Table 1 (IL population)	Temp Celsius		Day Devel. Time:		Leave out	
Stage	10	15	20	25	25yr2	30
1		15.7	8.5	5.3	4.5	4.1
2		33.6	12.8	7.6	7.4	5.5
3		97.5	17	9.9	10.6	7.8

4	40.4	24.8	15.6	15.3	12
5	56.4	29.2	19	19.4	14.9
6	111.1	44.6	23	24.3	20.7
7	127.4	74.3	28	37.3	22.5
8	98.6	107.1	33.3	46.2	23.8
9	104.6	57.5	31.1	40.1	24.7
10	31	47.2	38	54.4	29.7
11	56		32.2	59.4	26.2
12	165		32.3	26.1	26.9
13	53		44.3	23.3	26.8
14	55		43.3	22.3	30
Instars 1-4	187.2	63.1	38.4	37.8	29.4
Instars 5-10	529.1	359.9	172.4	221.7	136.3
Instars 11-14	329	0	152.1	131.1	109.9
Instars 1-8	580.7	318.3	141.7	165	111.3
Larval Totals	1045.3	423	362.9	390.6	275.6
pupa	47.4	26.4	17.5	17.8	12.4
adults	703.9	409	358.3	245.4	299.9

Instars 1-8

days	TempC	1/days
1000	10.41	0.0010
580.7	15	0.0017
318.3	20	0.0031
141.7	25	0.0071
111.3	30	0.0090
	r2	0.9441
	slope	0.0004
	intercept	-0.0043
X-intercept	-a/B	10.0004
DDReq.	1/slope	2301.1461

Instars 1-10

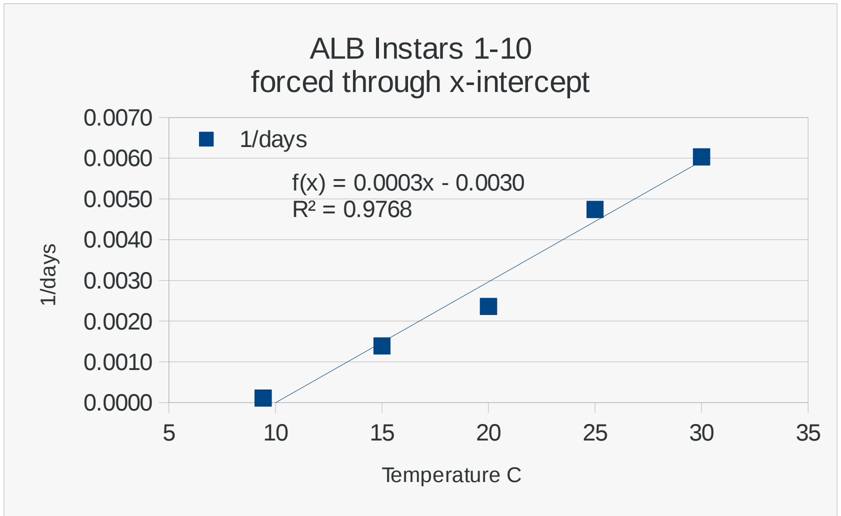
days	TempC	1/days
9000	9.4232	0.0001
716.3	15	0.0014
423	20	0.0024
210.8	25	0.0047
165.7	30	0.0060
	r2	0.9768
	slope	0.0003
	intercept	-0.0030
X-intercept	-a/B	10.0000
DDReq.	1/slope	3373.5778

Instar 8 only

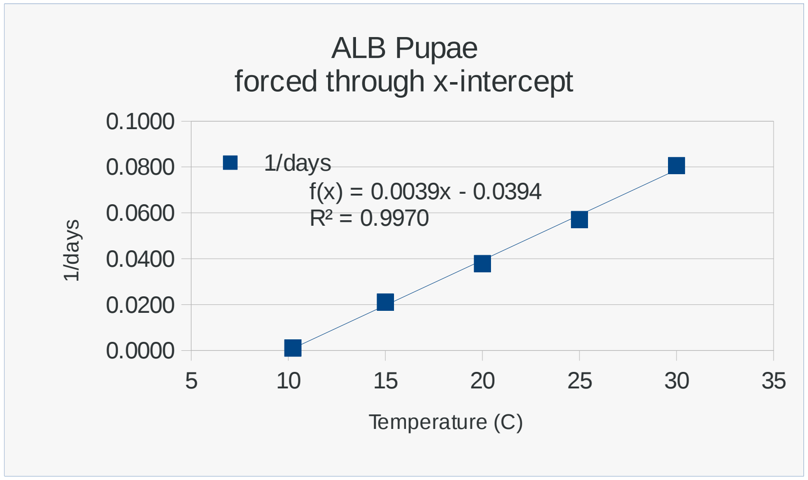
days	TempC	1/days
300	9.548	0.0033
98.6	15	0.0101
107.1	20	0.0093
107.1	25	0.0093
23.8	30	0.0420
	r2	0.6091
	slope	0.0015
	intercept	-0.0150
X-intercept	-a/B	10.0005
DDReq.	1/slope	668.0362

Instars 1-4

days	TempC	1/days
500	9.7313	0.0020
187.2	15	0.0053
63.1	20	0.0158
38.4	25	0.0260
29.4	30	0.0340
	r2	0.9766
	slope	0.0017
	intercept	-0.0167
X-intercept	-a/B	10.0001
DDReq.	1/slope	597.4017



Pupae	days	TempC	1/days
	900	10.2328	0.0011
	47.4	15	0.0211
	26.4	20	0.0379
	17.5	25	0.0571
	12.4	30	0.0806
		r2	0.9970
		slope	0.0039
		intercept	-0.0394
	X-intercept	-a/B	10.0000
	DDReq.	1/slope	253.8625



- Larvae survived short periods at temps > 30C; some instars molted at 35C; given Thermal insulation of larvae; Tupper may be ca. 36-38
-Posit hypothesis that 7-8 instars required for univoltinism, 10+ for 2, 3, etc gen/yr
-Larvae found to need to weigh at least 500 mg to pupate
-Larvae at 25 C and especialy 30 C tended to need chilling (20 C or lower??) before pupation
-Most larvae pupated w/o molting or after a single molt following chilling
-cited supercooling point at -25.8 C from Roden et al. 2008; therefore northern (cold) limits may be due to lack of heat units (e.g. Finland pops may take 4 yr/generation)
-in Florida suggest that chilling requirement would not be met
-Extended warm/hot temps may be limiting in South; suggest 2-4 wk above 35C to kill larvae; I would conservatively increase this upper lethal temp to 40 C

4 Keena, M. 2006. Effects of temperature on Anoplophora glabripennis (Col.: Cerambycidae) adult survival, reproduction, and egg hatch. Environ. Entomol. 35:912-921.
-populations from Chicago, IL and Queens, NY reared at constant temps using artificial diet
Thresholds for life history params (celsius):

	longevity	Fecun. (IL)	Fecun. (NY)	Pre-OV	Egg hatch
Tupper	39	35	34	30	32
Tlower	-3	11	14	10	10
Optimum	18	24	23		
Adult longevity in Days:		78 Max at 18C	56 At 30 C		
		40 At 3 C	0 At -2 and 40C		

Pre-Oviposition (time to 1st egg-laying)	days	TempC	1/days	
	283	13	0.0035	
	32.9	15	0.0304	
	23.6	20	0.0424	
	16.9	25	0.0592	
	15	30		(removed)
		r2	0.8893	
		slope	0.0041	
		intercept	-0.0411	
	X-intercept	-a/B	10.0022	
	DDReq.	1/slope	243.5256	

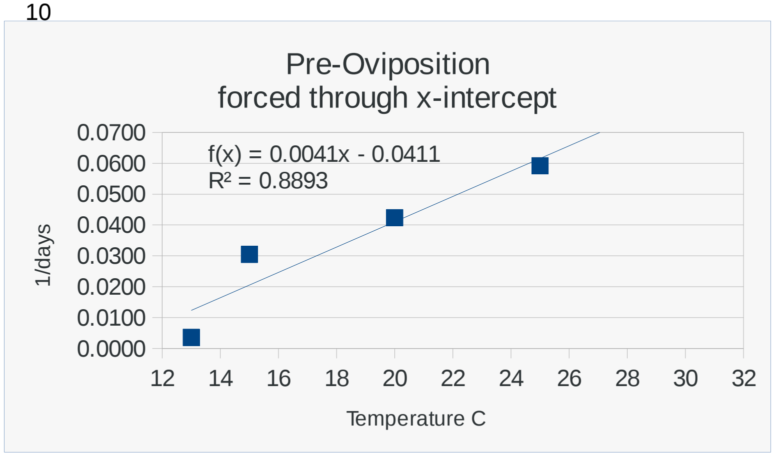
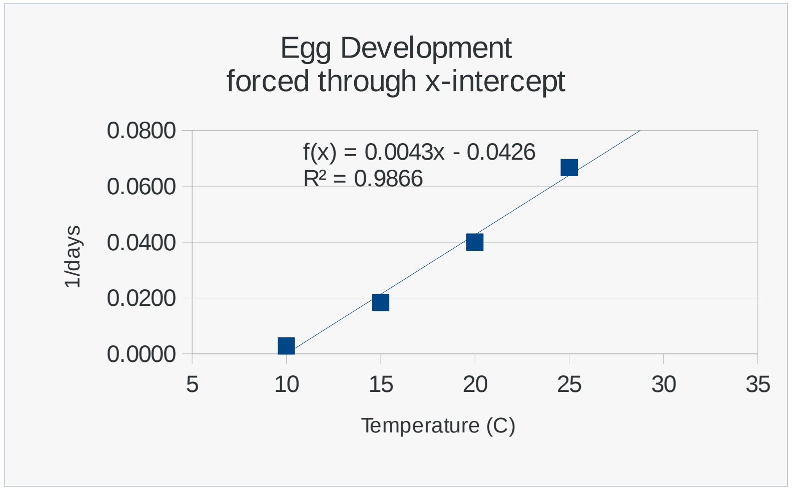


Table 3.	days	TempC	1/days
Egg Development	354	10	0.0028
	54.4	15	0.0184
	25	20	0.0400
	15.0	25	0.0667
	13.3	30	
		r2	0.9866
		slope	0.0043
		intercept	-0.0426
	X-intercept	-a/B	10.0007
	DDReq.	1/slope	234.5842



Tlower for eggs – evidence that it is somewhat higher than 10C
-upper threshold for eggs somewhere between 30 and 35 C; set at 34 C
Accounting for thermal insulation in egg pits 34C "=93.2F

5 Faccoli, M., R. Favaro, M.T. Smith, and J. Wu. 2014. Life history of the Asian longhorn beetle Anoplophora glabripennis (Coleoptera: Cerambycidae) in southern Europe. Agric. and For. Entomol. 17:188-196.
Model tested was from Smith et al 2004; DDs were simple AVG method Tlower=10C
-Italy study was beginning after a suspected 5-year establishment in the area.
-Italy study w/newly cut logs stored under natural near-field conditions 2010-2012.

From Fig. 3. Approx. avg emergence w/Cumul. DdsC (actual; not predicted by Smith model) in Cornuda Italy 2010-2012

% emerg.	DDs 2010	DDs 2011	DDs 2012	DDs Average
1	450	400	500	450
10	650	525	670	615
25	725	580	770	692
50	820	685	870	792
75	860	850	925	878
95	1150	1250	1100	1167
99	1260	1350	1250	1287

^---- Final emergence less than other studies: due to using cut logs?

- Main emergence period was end of June to July
- Mean longevity of adults was 30 days (sexes not signif. different) held in cages w/o mating at 22C
- Max longevity of females (from Fig. 4) was 60 days at 22C held in cages without mating
-in Italy study, 50% emerg between 931 and 989 DD over 3 years (2010-2012)
Fig. 5. ca. 65% OW as larvae in xylem; 5% larvae in phloem, 5% eggs
- My assessment: emergence may have ended early relative to other works due to methodology of using cut logs rather than allowing larvae to develop in living trees.
this assessment could be tested by comparing adult size/weights: the Italian beetles would be smaller if development was cut short

6 Straw, N.A., C. Tilbury, N.J. Fielding, D.T. Williams, and T. Cull. 2015. Timing and duration of the life cycle of Asian longhorn beetle Anoplophora glabripennis (Coleoptera: Cerambycidae) In southern England: Agric. For. Entomol. 17:400-411.
-S. England studied infested trees felled as part of an eradication programme; 366 larvae recovered
-results indicated 1 to 2 gen/year; OW as eggs or mid-instar larvae; analysis by Trotter and Keena (below) suggest semivoltine in England.
- OW as eggs produce 1st and 2nd instars by June/July; no adults emerged yet (so 1 gen/2 years=semivoltine)
- OW as larvae produce adults August/Sept (probably also be semi-voltine if eggs deposited Sept or later)
- used same Smith (2004) model 800-900 DD range for estimation of peak emergence; not directly monitored

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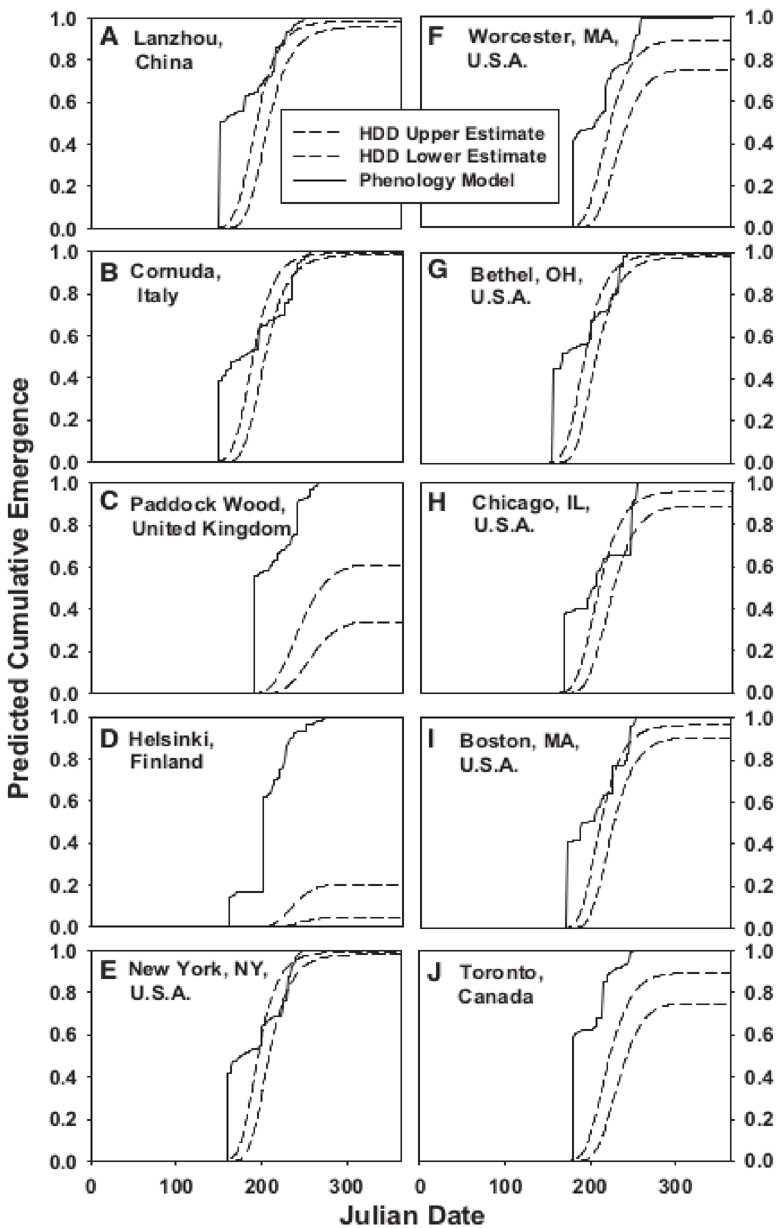


Fig. 4. (A–J) Panels show the patterns of cumulative adult emergence over

the growing season for populations at 10 locations known to have reproducing populations of the Asian longhorned beetle. The dotted lines denote the upper and lower confidence bounds calculated using the degree day model described by Smith et al. (2004). The solid lines represent the predicted cumulative adult emergence based on the described phenology model. Note the abrupt initiation of emergence that is likely driven by a lack of variation in the simulated system.

7a. Summary of selected params from Tables 1&2 (modified values):

Stage	Tlower	Tupper	DDs C	notes
Egg	12	34	248	
Instars 1-8	11.0	30	1899	Tupper for instar 1 listed as 40C based on Keena and Moore 2010
Instars 1-10	10.9	30	2565	
Pupae	9.8	30	263	
Imm. Adult I	-4	30	124	sclerotizing adult or teneral adult
Imm. Adult II			132	Emerging (chewing adult)

-gleaned data from all above sources; not as useful as would be expected (e.g. Fig. 4 used Julian date on x-axis and compared w/Smith model not actual data)
-for most stages used upper development threshold (Tupper) of 30C
-Tlow varied between 8.7 and 13C for immature stages
-Tended to verify/validate Smith DD model for 1st emergence; but in cooler climates 50% and 100% emergence occur much earlier than Smith.
-Tended to verity/validate Smith model at least for New York, Ohio, and Chicago, but 25% and 50% emergence always earlier than Smith
-But some of this fast emergence attributed to simulation model design deficiencies
-supported fact that populations can be univoltine in warmer climates, 1 gen/2 or 3 yr in cool climates, and 1 gen/4+ years in cold climates such as Helsinki, Finland
-may be best to try to estimate life stage params from orig sources **(**Keena 2006 and Keena and Moore 2010**)**

7b. Degree-Day analysis based on Fig. 4. Run a recent range of years for dates of %emergence to estimate avg DD values
Revised using Single Sine Dds on July 19 2017

		A) New York NY		Predicted	**SimpAVG**	KJFK					
		Julian Date	Date	%emerg	Mean DD10C	2010	2011	2012	2013	2014	2015
Adj. using	-->	168	06/17/00	1	476	546	483	516	386	442	484
Ref. 10 below	-->	186	07/05/00	25	733	834	727	791	631	684	729
		200	07/19/00	50	962	1083	958	1023	884	883	941
		220	08/08/00	75	1272	1409	1294	1321	1168	1161	1277
		240	08/28/00	90	1553	1686	1568	1612	1437	1426	1590
		258	09/15/00	99	1786	1917	1785	1840	1661	1659	1853

B) Chicago IL		Predicted	**SimpAVG**	KMDW					
Julian Date	Date	%emerg	Mean DD10C	2010	2011	2012	2013	2014	2015
154	06/03/00	1	342	385	262	472	282	330	322
165	06/14/00	25	459	499	382	600	381	435	457
202	07/21/00	50	996	1055	930	1238	912	928	911
240	08/28/00	75	1531	1622	1482	1795	1389	1441	1459
260	09/17/00	90	1762	1836	1679	2044	1635	1647	1729
265	09/22/00	99	1802	1888	1713	2067	1681	1686	1775

C) Bethel, OH		Predicted	**SimpAVG**	KLUK					
Julian Date	Date	%emerg	Mean DD10C	2010	2011	2012	2013	2014	2015
150	05/30/00	1	398	412	400	530	353	321	369
160	06/10/00	25	518	553	558	626	467	436	467
185	07/04/00	50	841	895	855	982	774	750	792
210	07/29/00	75	1211	1295	1285	1396	1115	1043	1132
245	09/02/00	90	1686	1820	1792	1876	1563	1508	1557
255	09/10/00	99	1781	1900	1871	1974	1660	1605	1673

D) Boston, MA		Predicted	**SimpAVG**	KOWD					
Julian Date	Date	%emerg	Mean DD10C	2010	2011	2012	2013	2014	2015
165	06/15/00	1	329	341	334	399	302	277	318
175	06/25/00	25	431	452	425	501	424	372	412
190	07/09/00	50	608	643	595	681	632	549	545
245	09/02/00	75	1264	1326	1273	1380	1280	1119	1203
265	10/22/00	90	1524	1571	1634	1648	1484	1342	1463
295		99	not reached						

Single Sine	KJFK					
Mean DD10C	2010	2011	2012	2013	2014	2015
510	582	511	561	420	477	509
766	870	755	835	664	720	754
996	1119	986	1068	918	919	966
1305	1445	1321	1365	1202	1196	1302
1587	1722	1596	1656	1470	1461	1616
1820	1953	1812	1885	1694	1694	1879

Single Sine	KMDW					
Mean DD10C	2010	2011	2012	2013	2014	2015
377	416	296	507	317	362	361
493	530	416	635	415	467	496
1030	1087	963	1273	947	960	950
1566	1653	1516	1830	1423	1473	1498
1797	1868	1714	2078	1669	1682	1768
1837	1919	1748	2102	1716	1721	1814

Single Sine	KLUK					
Mean DD10C	2010	2011	2012	2013	2014	2015
461	479	452	599	413	392	430
581	620	610	694	527	506	529
905	962	907	1050	834	821	853

1274	1362	1337	1464	1175	1114	1193
1749	1887	1843	1944	1623	1579	1618
1844	1967	1923	2043	1721	1676	1735

Single Sine KOWD

Mean DD10C	2010	2011	2012	2013	2014	2015
388	381	380	475	376	340	376
491	492	471	580	497	437	471
668	684	641	760	705	615	605
1325	1369	1319	1459	1355	1187	1263
1627	1652	1699	1763	1617	1463	1568

E) Average of US Locs		Predicted	SimpAVG		Single Sine	
Julian Date	Date	%emerg	Mean DD10C		Mean DD10C	
159	06/07/00	1	386		434	←-Using the single sine results vers. 1.1
172	06/20/00	25	535		583	
194	07/13/00	50	852		900	
229	08/17/00	75	1319		1368	
253	09/08/00	90	1631		1690	
268	09/25/00	99	1789		1833	

Reports used as limited validations:

8 Asian Longhorned Beetle. Ohio State University Extension Ohioline
http://ohioline.osu.edu/factsheet/ent-75

-Adults emerge in late spring through late summer with peak emergence typically occurring in late June to early August; however, adults can be present in the fall.

-This report matches well with analysis C) above

9 USDA – Asian Longhorned Beetle – About
https://www.aphis.usda.gov/aphis/resources/pests-diseases/asian-longhorned-beetle/About-ALB
While adult beetle activity is most obvious during the summer and early fall, adults have been seen from April to December.
Adults can fly for 400 yards or more to search for a host tree or mate. However, they usually remain on the tree from which they emerged, resulting in infestation by future generations.

-Not enough detail but generally agrees with analysis above

10 Auclair, A.N.D., G. Fowler, M.K. Hennessey, A.T. Hogue, M. Keena, D.R. Lance, R. M. McDowell, D. O. Oryang, and A. J. Sawyer. 2005. Assessment of the risk of introduction of Anoplophora glabripennis (Coleoptera: Cerambycidae) in municipal solid waste from the quarantine area of New York City to landfills outside or the quarantine area: A pathway analysis of the risk of spread and establishment. J. Econ. Entomol. 98:47-60.

10a. First beetles emerg. In NY NY 2003: 06/26/03 DDS10C 441 (single sine method; simple avg method=408)

10b. Fig. 5. it took 6-8 weeks at 20C before first beetles emerged for logs collected in April 1999

Dds April 5 1999:		34	
Dds April 25 1999:		80	
	Lab: 10DD/day		
6 wks at 20C	420	454	min DDC10
8wks at 20C	560	640	max DDC10
		547	avg DDC10

Conclusion: Estimated first adult emerg in 2003 was 6/26 at 441 DD and in 1999 was ca. 6/13 at 454 DD (single sine method)

Table 7b part A) NY NY was therefore adjusted to reflect these estimates

11 http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/Anoplophora%20glabripennis.html

-Adult emergence in NY and IL appears to range from July to Nov.

-This report from 2004 does not quite match analysis A) and B) above, which has first emerg. in June most Years

12 Summary table for life stage parameters

Notes: Tlower was forced to presumptive value of 10 C for sources 3 & 4; could have forced to Tlower of 10.55 or 11.0 C

Tupper not well studied; these tend to be interpolated from ranges cited in sources 3 & 4

	Source #:	4	3	7	**Average (or selected value)**	
Tlower	Author Abbr.	K. 2006	K. & M. 2010	T. & K. 2016		**notes**
Egg		10.0		12	10	as noted already; 10 or 10.55 or 11 might all suffice as
Instars 1-8			10.0	11.0	10	a good overall Tlower; based on discussion of thermal
Instars 1-10			10.0	10.9	10	environment for this spp; the lower (10C) may be
Pupae			10.0	9.8	10	best value as phloem temperatures are always higher
Immature adult		10.0		-4	10	than ambient except during extreme hot periods
Overall Egg to Egg (min generation time)					10	
Tupper						
Egg		34		34	34	Considering that most stages are protected from
Instars 1-8			34	30	34	extreme heat in logs/bark/trees; can use a relatively
Instars 1-10			34	30	34	high Tupper which would be the ambient (not within tree)
Pupae				30	34	actual temperature
Immature adult/PreOV				30	34	
Overall Egg to Egg (min generation time)					34	
DD Req.						
Egg		235		248	240	
Instars 1-8			2301	1899	2160	
Instars 1-10			3374	2565	2600	
Pupae			254	263	260	
Schlerotizing/teneral adult				124	124	
"Chewing" adult				132	132	← using this as greater value not both combined
Total Pre-Oviposition		244		256.2	256	
Overall Egg to Egg using 8 instars (min gen. time for univoltine climates)					2916	
Overall Egg to Egg using 10 instars (min gen. time for bi tor tri-voltine climates)					3356	
First emergence estimated below					442	
Estimated post-winter larvae develop time					50	

13 Summary of adult emergence

13a. 1st emergence based on life stage analysis:

-assume in most all climates that mature larvae are ready to molt with temps above 10C in spring
-therefore pupal duration (260 DD) + some pre-pupation time ca. 40 DDC + teneral adult "sclerotization" time (Table 2: 124 DDC) needed before flight & capture in traps
Therefore: minimum time to emergence in spring/summer estimated as:

40	Nominal "post-diapause"/pre-pupal time
260	Pupal duration
124	Sclerotizing/teneral adult
424	Total ← Compare to 442 DD 1st Emerg below

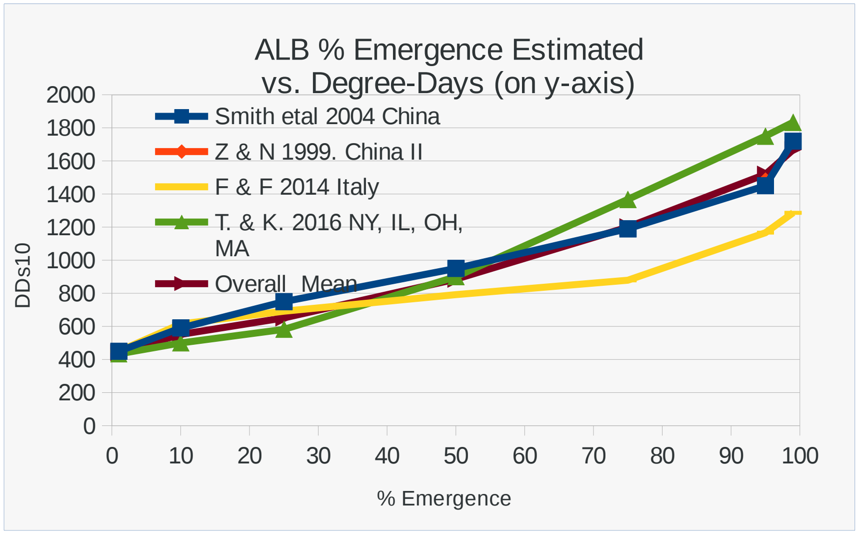
Conclusion: Rather similar; use average value below of 442 DD10C

13b. Emergence summary based on analysis of sources listed from above:

Degree-Days (Base 10 C)

% emerg.	1 Smith etal 20 China	2 Z & N 1999. China II	5 F & F 2014 Italy	7 T. & K. 2016 NY, IL, OH, M	Overall Mean
1	450		450	434	442
10	590		615	500	551
25	750		692	583	652
50	950		792	900	885
75	1190		878	1368	1201
95	1450	1480	1167	1750	1519
99	1720		1287	1833	1668

^---given double weight



ALB Estimated Emergence (for graph)

DDsC10 Overall Mean	DDsF50	% emerg.
442	795	1
551	992	10
652	1173	25
885	1593	50
1201	2162	75
1519	2735	95
1668	3003	99