# Phenology/Degree-Day and Climate Suitability Model Analysis – Vers. 2, Mar. 25, 2020

## Analysis by Len Coop and Brittany Barker for USPEST.ORG at Oregon State University, Oregon IPM Center

**Oak Ambrosia Beetle** *Platypus quercivorus* **(Murayama)** **[Coleoptera: Platypodidae]**

**Hosts:** ***Quercus*** **spp. (oak); may also infect chestnut, chinquapin, and stone oaks**

**Damage: wood boring beetle that vectors a pathogenic fungus (*Raffaelea quercivora*) that causes Japanese oak wilt disease**

**Goal: Develop a phenology model and temperature-based climate suitability model using available literature and weather data analysis**

**Eggs**

**Damaged wood**

**Larvae**

**Adult Males**

Source for images: http://www.rinya.maff.go.jp/tohoku/syo/asahi/siryou/kasinaga.html

### Thresholds, degree-days, events and climate suitability params used in Oak Ambrosia Beetle model:

| Parameter abbr. | Description | degF | degC | DDF | DDC | |
|---|---|---|---|---|---|---|
| eggLDT | egg lower dev threshold | 52.0 | 11.1 | - | - | |
| eggUDT | egg upper dev threshold | 100.4 | 38.0 | - | - | |
| larvaeLDT | larvae lower dev threshold | 52.0 | 11.1 | - | - | |
| larvaeUDT | larvae upper dev threshold | 100.4 | 38.0 | - | - | |
| pupaeLDT | pupae lower dev threshold | 52.0 | 11.1 | - | - | |
| pupaeUDT | pupae upper dev threshold | 100.4 | 38.0 | - | - | |
| adultLDT | adult lower develpmental threshold | 52.0 | 11.1 | - | - | |
| adultUDT | adult upper dev threshold | 100.4 | 38.0 | - | - | |
| eggDD | duration of egg stage in DDs | - | - | 224 | 125 | |
| larvaeDD | duration of larva stage in DDs | - | - | 1449 | 805 | |
| pupaeDD | duration of pupa stage in DDs | - | - | 392 | 218 | |
| adultDD | duration of teneral adult stage in DDs | - | - | 200 | 111 | |
| OWlarvaeDD | DDs until OW larvae first pupation | - | - | 423 | 235 | |
| eggEventDD | DDs into egg stage when hatching begins | - | - | 220 | 122 | |
| larvaeEventDD | DDs until end of adult emergence (event actually for adults) | - | - | 452 | 251 | |
| pupaeEventDD | DDs until mid-pupal development - time to place traps | - | - | 196 | 109 | |
| adultEventDD | DDs until first adult emergence | - | - | 4 | 2 | |
| | | | | | | |
| chillstress_threshold | chill stress threshold | 14.0 | -10.0 | - | - | |
| chillstress_units_max1 | chill stress degree day limit when most individuals die | - | - | 927 | 515 | |
| chillstress_units_max2 | chill stress degree day limit when all individuals die | - | - | 1440 | 800 | |
| heatstress_threshold | heat stress threshold | 100.4 | 38.0 | - | - | |
| heatstress_units_max1 | heat stress degree day limit when most individuals die | - | - | 324 | 180 | |
| heatstress_units_max2 | heat stress degree day limit when all individuals die | - | - | 540 | 300 | |
| | | | | | | |
| distro_mean | average DDs to OW larvae first pupation | | | 635 | 353 | = 50% emrg. - pupDD - teneral adult DD |

| | | | | |
|---|---|---|---|---|
| distro_var | variation in DDs to OW larvae first pupation | 9000 | 5000 | |
| xdist1 | minimum DDs (°C) to OW larvae first pupation | 216 | 120 | = 1st emrg. - pupDD - teneral adult DD |
| xdist2 | maximum DDs (°C) to OW larvae first pupation | 1512 | 840 | = end emerg. - pupDD - teneral adult DD |
| distro_shape | shape of the distribution | | normal | |

## Sources and Data:

**(Note significant data used in final model highlighted in Salmon color)**

**1. APHIS PPQ pest datasheet Exotic Wood Borer/Bark Beetle Survey Reference 2013.**

-usually 1 gen. per year
-eggs hatch 1 week after oviposition
-larvae feed on the fungus
-30 to 40% of broods reach adulthood between Aug and Oct **(**Sone et al 1998**)**
-remainder OW in the 5th instar and emerge mid-June **(**Sone et al 1998**)**
-CAPS surveys should put up traps in May when adults are mating **(**Davis etal 2005**)**

**2. Sone, K, T. Mori, and M. Ide. 1998. Life history of the oak borer, Platypus quercivorus (Murayama). Appl. Entomol. Zool. 33:67-75.**

-Study site in Takakuma Exper. Forest of Tarumizu city, Kagoshima Prefecture **(**need 1994-6 weather data), latitude ca. 31 deg N, similar to San Diego or Georgia
-in Japan, greatest infestation occurs from June to early July
-most attacks within 3 weeks of first attack
-larvae usually found July and onward through OW **(**in 5th stage**)**
-pupation usually starts in May
-by Sept, 64%, by Oct, 76% and by Nov, 90% in 5th instar
-2nd gen emerg. Sept-Oct for a portion of the population
-1995 adult females emerged 8th of June, peaked mid-June, through 18 July
-1995 2nd gen. adults began to fly by end of Aug, peak in mid-Sept and early Oct, ceased in early Nov.
-1996 adults caught from 3 June to 30 July; peak in late June and early July
-prefer dibilitated trees and fresh logs to vigorous living trees
-about 30-40% reached adult stage from aug-oct, thus able to start a 2nd generation
-late fall adults may not start new broods but may help in cleaning existing galleries
-some may take 2 years to complete life cycle
-higher reproductive success in logs (40-50 per female) vs live trees **(**5-10 per female**)**
-sap production is most likely the limiting factor to success in live trees
-1995 new gallery started Oct 6-18 did not develop (only 2-3 weeks of warm weather remained in season)

Adult Emerg Data (Fig 6): (DD data Kagoshima near sea level; do not use:)

| | 1994 | | 1995 | | 1996 | |
|---|---|---|---|---|---|---|
| Medium | live trees | | prepared logs | | prepared logs | |
| notes | | | text and fig d | Cum. DDs C | | Cum. DDs C |
| approx pupation | 05/01/94 | 307 | 05/08/95 | 303 | 05/11/96 | 304.0 |
| First attack | 06/04/94 | 650 | 06/15/95 | 696 | | |
| 50% attack | 06/16/94 | 800 | 06/26/95 | 831 | | |
| end attack | 07/25/94 | 1461 | 08/15/95 | 1680 | | |
| 2nd Gen attack | NA | | 10/12/95 | | NA | |
| First emerge | | | 06/06/95 | 594 | 06/05/96 | 568.0 |
| 50% emerge | | 1423 | 06/20/95 | 761 | 06/30/96 | 925.0 |
| end emerge | | | 07/18/95 | 1182 | 07/25/96 | 1341.0 |
| peak egglaying | 07/10/94 | 1175 | 07/20/95 | 1218 | | |
| mostly 5th stage larvae by | 09/01/94 | 2136 | 09/15/95 | 2226 | | |
| 2nd Gen 1st emerge | | | 08/26/95 | 1888 | NA | |
| 2nd Gen 50% emerge | | | 09/25/95 | 2349 | NA | |
| 2nd Gen end emerge | | | 11/02/95 | 2739 | NA | |

**Use Modified Weather Data: (elevation adjustment: Tmax-1.5, Tmin-0.5), also data from Kyoto 2007 & 2010 ( Sources 5&6 below)**

| | Adult Emerg Data (Fig 6): | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1994 (Kagoshima) | | 1995 (Kagoshima) | | 1996 (Kagoshima) | | 2007 (Kyoto) | | 2010 (Kyoto) | | |
| Medium: | live trees | | prepared logs | | prepared logs | | | | | | Average |
| | | Cum. DDs C | text and fig d | Cum. DDs C | | Cum. DDs C | Date | Cum. DDs C | Date | Cum. DDs C | Cum. DDs C |
| approx pupati | 05/01/94 | 238 | 05/08/95 | 233 | 05/11/96 | 234 | | | | | 235 |
| First attack | 06/04/94 | 547 | 06/15/95 | 588 | | | | | 06/18/10 | 555 | 563 |
| 50% attack | 06/16/94 | 686 | 06/26/95 | 713 | | | | | | | 700 |
| end attack | 07/25/94 | 1308 | 08/05/95 | 1345 | | | | | | | 1327 |
| 2nd Gen attack | NA | | 10/12/95 | | NA | | | | | | |
| First emerge | 06/04/94 | 547 | 06/06/95 | 495 | 06/05/96 | 473 | 05/20/07 | 295 | | | 453 |
| 50% emerge | | | 06/20/95 | 648 | 06/30/96 | 806 | 06/18/07 | 594 | | | 683 |
| end emerge | | | 07/18/95 | 1041 | 07/25/96 | 1197 | 08/03/07 | 1264 | | | 1167 |
| peak egglayin | 07/10/94 | 1037 | 07/20/95 | 1075 | | | | | | | 1056 |
| mostly 5th stag | 09/01/94 | 1945 | 09/15/95 | 2026 | | | | | | | 1986 |
| 2nd Gen 1st emerge | | | 08/26/95 | 1709 | NA | | | | | | 1709 |
| 2nd Gen 50% emerge | | | 09/25/95 | 2139 | NA | | | | | | 2139 |
| 2nd Gen end emerge | | | 11/02/95 | 2492 | NA | | | | | | 2492 |

**Summary of stage interval DDs: (all in Celsius, Tlow = 11.1C)**

| | **1994 (Kagoshima)** | **1995 (Kagoshima)** | **1996 (Kagoshima)** | **2007 (Kyoto)** | **2010 (Kyoto)** | **Average** |
|---|---|---|---|---|---|---|
| Estimate of Jan 1-pupation: | 238 | 233 | 234 | | | 235 |
| Est. of pupal+teneral (pre-attack) | 309 | 355 | | | | 332 |
| Est. egg+larval devel | 908 | 951 | | | | 930 |
| Estimate of egg devel period: | 129 | 120 | | | | 125 |
| Estimate of larval devel period: | 779 | 831 | | | | 805 |
| Estimate of pupal devel period: | | 262 | | | | 218 |
| Estimate of teneral adult period: | | 93 | | | | 111 |
| Est. teneral adult+tunnel building+initial egglaying (0.35) | | | | | | 339 |
| Est full generation: egg+larv+pup+ten adult+tunnel building+initial egglaying: | | | | | | 1486 |
| Est. summer gen time (1st emerg-1st emerg) | | 1214 | | | | 1214 |
| Est. summer gen time (50% emerg-50% emerg) | | 1491 | | | | 1491 |
| Est. summer gen time (end emerg-end emerg) | | 1451 | | | | 1451 |
| | | | | | | |
| **Summary of events after Jan 1st:** | | | | | | |
| Est. spring pupation: | 238 | 233 | 234 | | | 235 |
| Est. first emerge: | 547 | 495 | 473 | 295 | | 453 |
| Est. 50% emerge: | | 648 | 806 | 594 | | 683 |
| Est. end emerge: | | 1041 | 1197 | 1264 | | 1167 |
| Est. first attack: | 547 | 588 | | | 555 | 563 |
| Est. 50% attack: | 686 | 713 | | | | 700 |
| Est. peak larvae develop in galleries: | | | | | | 1355 |
| Est end attack: | 1308 | 1345 | | | | 1327 |
| Est. 2nd Gen 1st emerge | | 1709 | | | | 1709 |
| Est. 2nd Gen 50% emerge | | 2139 | | | | 2139 |
| Est. 2nd Gen end emerge | | 2492 | | | | 2492 |

**Summary of cumulative degree-days for Kagoshima emergence data. In Celsius, Tlow = 11.1C**

| Kagoshima DDs 1994-96 (KAGOSHIMA94.txt, 95.txt, 96.txt) | | | | Modified to reflect higher elevation forest | | |
|---|---|---|---|---|---|---|
| Month | Cum. DDs 94 | Cum. DDs 95 | Cum. DDs 96 | 1994 | 1995 | 1996 |
| Jan | 28 | 18.9 | 19.4 | 17 | 12 | 11 |
| Feb | 49 | 41.1 | 42.8 | 28 | 24 | 26 |
| Mar | 107 | 109 | 112 | 68 | 72 | 76 |
| Apr | 307 | 259 | 229 | 239 | 196 | 169 |
| May | 616 | 542 | 517 | 518 | 448 | 427 |
| Jun | 1011 | 888 | 938 | 882 | 764 | 818 |
| Jul | 1586 | 1427 | 1477 | 1425 | 1272 | 1326 |
| Aug | 2137 | 1994 | 2028 | 1946 | 1809 | 1845 |
| Sept | 2562 | 2420 | 2488 | 2340 | 2204 | 2275 |
| Oct | 2871 | 2736 | 2801 | 2618 | 2489 | 2557 |
| Nov | 3058 | 2829 | 2967 | 2778 | 2560 | 2698 |
| Dec | 3119 | 2848 | 3013 | 2822 | 2569 | 2731 |
| | warm | cool | moderate | | | |

**3. Sone, K., K. Uto, S. Fukuyama, and T. Nagano. 2000. Effects of attack time on the development and reproduction of the oak borer, *Platypus quercivorus* (Murayama). Japanese Journal of Applied Entomology and Zoology. 44: 189–196.**

- Studies conducted near Kagoshima (Southern Japan); Latitude ca 31 Deg. N.
- Two generations possible in Kagoshima as per prior study (Sone et al. 1998)
- In 1997 attack observed from early June to early Oct.
- Galleries started June and July resulted in new adults emerging in Sept and Oct 1997
- Galleries started after late Aug seldom survive and contribute little to the population

**4. Davis, E., S. French, and R.C. Venette. 2005. Mini risk assessment. Ambrosia beetle: *Platypus quercivorus* Murayama [Coleoptera: Platypodidae]**

- common in parts of Japan and is present in India, Taiwan, Indonesia, and Papua New Guinea
- the pathogen only reported from Japan
- occurs in temperate or tropical climates w/adequate seasonal rainfall to support deciduous tree hosts.
- new adults emerge and disperse beginning in late June through early Oct or Nov (Sone etal 1998, Kinuura 2002)
- eggs laid about 2-3 weeks after gallery construction is initiated; egg hatch occurs in about one week
- larvae OW in (or not in) diapause in the larval gallery
- pupae occurs in May followed by emergence of adults in June and July
- may OW as pupa or adult; adults less likely to survive

Analysis of suitability: they estimate that 29% of CONUS would have suitable climate for establishment
- this prediction is based only on the known worldwide geographic distribution of the species
- they identified biomes (habitat types) as defined by the WWF that occurred in each country or municipality reported
- see Appendix A for more details, but essentially they matched biomes to those in the US

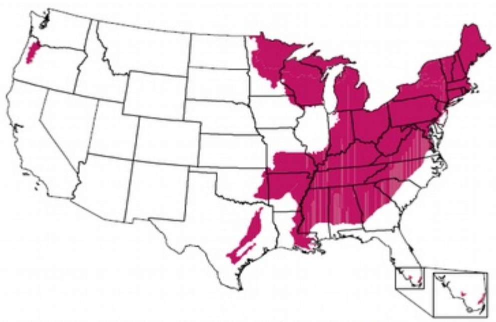


**Figure 2.** Predicted distribution (shaded pink) of *Platypus quercivorus* in the contiguous US.

**5. Yamasaki, M. H. Iizuka, and K. Futai. 2012. Reproductive success of the ambrosia beetle *Platypus quercivorus* on *Quercus laurifolia* planted in Japan For. Res. Kyoto 78:29-38.**

- emerg. from Q. laurifolia similar to Q. crispula

Fig. 4a. Male and female emergence from Q. laurifolia

Females emerg:

| Date | % Emerg | Dds Tlow=11.1C (KYOTO07.txt) |
|---|---|---|
| 05/20/07 | 3.00% | 295 |
| 06/18/07 | 50.00% | 594 |
| 08/03/07 | 97.00% | 1264 |

**6. Tarno, H. H. Qi, M. Kobayashi, and K. Futai. 2012. Two active stages of ambrosia beetle, *Platypus quercivorus* M. estimated from frass production. Agrivita 34:207-214.**

- Studies in Kyoto, latitude ca. 35 deg. N. (similar to Charlotte SC)
- assumed univoltine in Kyoto
- Tunnel blocking for protection from predators but also hypothesized to serve in microclimate control
- after attack there is a fibrous frass stage (adult feeding), an intermediate stage, and a powdery frass stage (larval feeding)
- fibrous frass (adult) stage between 5 and 21 days in lab (lab was 26C); mean duration 11.14 days +/- 4.83
- intermediate stage between 2 to 20 DAYS in lab; mean 11.95 days +/- 4.87
- start of 3rd stage (larvae) ranged from 19th to 27th days in lab; continued until day 40 (end of study?)
- in Kyoto 2010, attack began mid-June (ca. 515 DD)

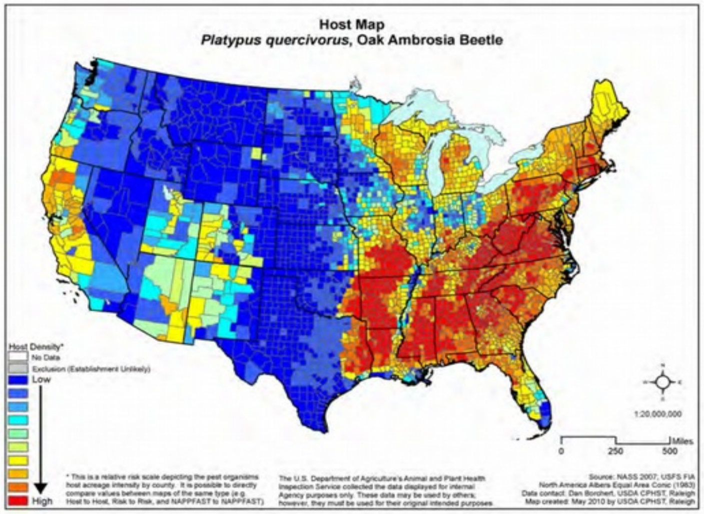
| | | |
|---|---|---|
| est. Dds fibrous stage = (26-11.11)*11.14 | 166 | (tunnel building by adults) |
| est. DDS intermed stage = (26-11.11)*11.95 | 178 | (egglaying+egg devel+1st&2nd instars) |
| est. DDS powdery stage (likely is longer due to study termination) | 194 | (3-5 instar feeding) |

using Tlow=11.1 Tupper=38, mid-June in Kyoto

Kyoto DD summary (KYOTO10.txt)

| Month | 2010 Dds | 2007 Dds | | | |
|---|---|---|---|---|---|
| Jan | 2.8 | 1.7 | | | |
| Feb | 23.3 | 17.2 | | | |
| Mar | 48.3 | 57.8 | | | |
| Apr | 127.2 | 161 | | | |
| May | 355 | 407 | | | |
| Jun | 745 | 777 | 06/18/10 | 555 | (est first attack Kyoto 2010) |
| Jul | 1273 | 1228 | | | |
| Aug | 1878 | 1800 | | | |
| Sept | 2322 | 2258 | | | |
| Oct | 2629 | 2496 | | | |
| Nov | 2691 | 2567 | | | |
| Dec | 2708 | 2576 | | | |

**7. USDA-APHIS. 2011. New Pest Response Guidelines: Exotic Wood-Boring and Bark Beetles. USDA-APHIS-PPQ-EDP-Emergency Management, Riverdale, Maryland**



-the risk map is based on relative density of susceptible hosts (scale of 1 to 10); data from National Ag Statistics Service (NASS) and Forest Inventory Analysis (FIA)

-i.e., there are no climate data that go into this model

**8. Basis for lower and upper developmental temperatures:**

1. Gaylord, ML, KK Williams, RW Hofstetter, JD McMillin, TE Degomez, and MR Wagner. 2008. Influence of temperature on spring flight initiation for southwestern Ponderosa pine bark beetles. Eniviron. Entomol. 37:57-69

- used Tlow = 11C for Ips pini in comparison to 7 other bark beetles based on Miller and Keen 1960 and Ungerer et al 1999 (D. frontalis)
- attack in Kyoto starts June = high Tlow (such as 11C); note that even by mid-May Tmax regularly exceeds an adult flight temp threshold (15C)

| C | F | |
|---|---|---|
| 11 | 51.8 | |
| 11.11 | 52 | ← use this as Tlow |
| 10.56 | 51 | |
| 38 | 100.4 | ← use for Tupper |

- phloem temps differ from ambient temps by 1 to 2 deg. C.
- study emphasized flight temps which ranged for 7 species at: 16C (I. pini), 18.6C (D. brevicomis); 16.1 (D. frontalis)
- (cont.), lowest flight temps for I. pini was 16.1 C; but beetles were captured when flight temps were as low as 11.7 C
- conclude/suggest that once a threshold flight temp reached in the spring, flight occurs at lower temps during subsequent months
- same study upper flight temps where Tmax was ca. 38.9, 37.9 (37-38C)
- only 1 spp. had lower temp thresholds (D adjunctus) where you could argue for an upper flight temp threshold (Tmax < 27 C)
- for most species, flight initiated when spring Tmax began to exceed 15C; so this might be a good Tlow for Adult stage (if needed)
- similarly in the Fall, monitoring should continue until Tmax regularly fails to reach 15C for 4 species (13 and 10C for other spp.)

## Summary of phenology model

| Start Date: Jan 1 | **Temp (C)** | **Temp (F)** |
|---|---|---|
| Tlow: | 11.1 | 52 |
| Thi: | 38.0 | 100.4 |
| | **DD (C)** | **DD (F)** |
| Estimate of egg devel period: | 125 | 224 |
| Estimate of larval devel period: | 805 | 1449 |
| Estimate of pupal devel period: | 218 | 392 |
| Estimate of teneral adult period: | 111 | 200 |
| Est egg+larv+pup+ten adult: | 1486 | 2675 |
| Est. summer gen time (1st emerg-1st emerg) | 1214 | 2185 |
| Est. summer gen time (50% emerg-50% emerg) | 1491 | 2684 |
| Est. pupation: | 235 | 423 |
| Est. first emerge: | 453 | 815 |
| Est. 50% emerge: | 683 | 1229 |
| Est. end emerge: | 1167 | 2101 |
| Est. peak larvae develop in galleries: | 1355 | 2440 |
| Est. 2nd Gen 1st emerge | 1709 | 3076 |
| Est. 2nd Gen 50% emerge | 2139 | 3850 |
| Est. 2nd Gen end emerge | 2492 | 4486 |

## Climate suitability model

**Methods:** Lacking previously published robust analyses, generate updated list of localities reporting occurrence of OAB, perform CLIMEX (Match Climate Regimes), and Maxent analyses to determine climate limits. Next develop a CLIMEX model with parameters for OAB, followed by DDRP model that is calibrated to match the CLIMEX ecoclimatic results.

**9. List and map of localities used for the regional climate matching analysis in CLIMEX (CLIMEX-MCR; #10) and the Maxent analysis (#11)**

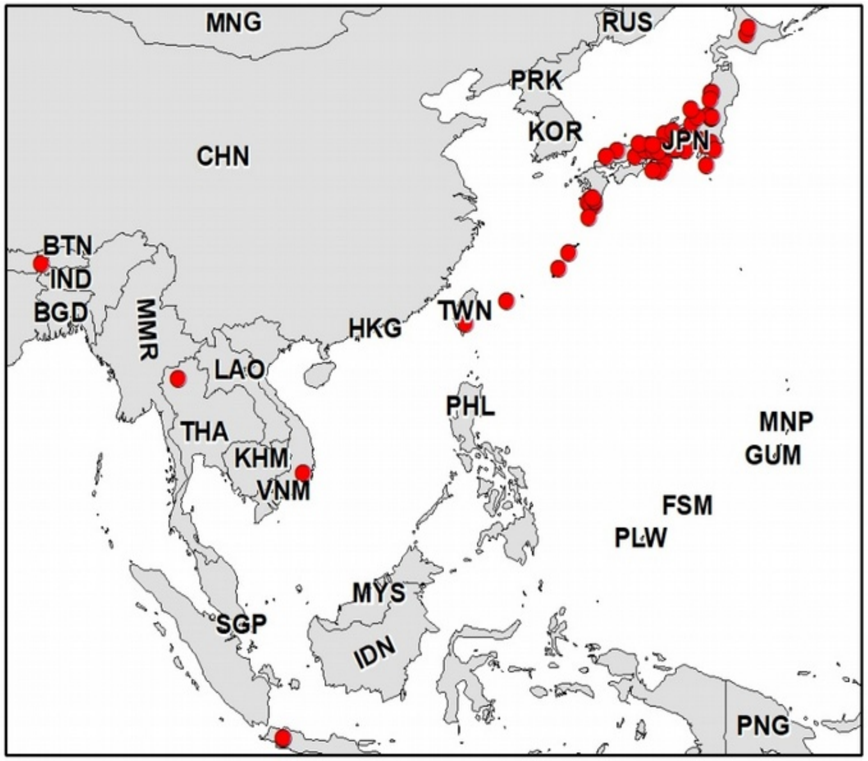
All localities used in analysis had coordinate data in at least one reference in the "References" column

We filtered out localities that occurred within 20km of another point to reduce potential effects of sampling bias
Localities that were included in the CLIMEX-MCR and Maxent analysis are indicated

| Inc. in analysis | Country | Prefect./Prov. | Locations | Latitude | Longitude | References |
|---|---|---|---|---|---|---|
| N | Japan | Fukushima | Aizu-Wakamatsu | 37.49 | 139.93 | Masahiko et a (did not use because no coordinate data) |
| N | Japan | Kagoshima | Ibusuki | 31.25 | 130.63 | Hamaguchi ar (did not use because no coordinate data) |
| N | India |  | Kalimpong |  |  | Beeson 1937 |
| N | Japan | Okinawajima Is. | Kunigami | 26.66 | 128.17 | Hamaguchi and Goto 2010 (no climate data for this point) |
| N | Japan | Miyakejima Is. | Miyake | 34.08 | 139.52 | Hamaguchi and Goto 2010 (no climate data for this point) |
| N | Indonesia |  | Mount Gede |  |  | Beeson 1937 |
| N | Japan | Aichi | Nagoya | 35.18 | 136.91 | Hamaguchi and Goto 2010 |
| N | Japan | Kyoto | Ohura Natural Park, Maizuru City | 35.55 | 135.39 | Kobayashi and Ueda 2002 |
| N | Japan | Kagoshima | Takakuma Exp. Forest, Tarumizu ( | 31.49 | 130.87 | Soné et al. 1998 |
| N | Japan | Kagoshima | Kinko, Tashirofumoto | 31.17 | 130.89 | Hamaguchi and Goto 2010 |
| N | Japan | Kagoshima | Kagoshima | 31.60 | 130.56 | Hamaguchi and Goto 2010 |
| N | Japan | Fukushima |  | 37.38 | 139.89 | Kondoh et al. 2015 |
| N | Japan | Hacchodaira |  | 35.23 | 135.83 | Yamasaki et al. 2014 |
| N | Japan | Ibuski |  | 31.24 | 130.59 | Kusumoto et al. 2013 |
| N | Japan | Nagano |  | 36.15 | 137.92 | Qi et al. 2011 |
| N | Japan | Kagoshima |  | 31.39 | 130.88 | Qi et al. 2011 |
| N | Japan | Shimane |  | 35.12 | 132.63 | Qi et al. 2011 |
| Y | Japan |  | Aichi, Tokyo University Forest | 35.22 | 137.17 | Hata et al. 2017, Sanguansub et al. 2011 |
| Y | Japan | Miyazaki | Ayase | 35.44 | 139.43 | Hamaguchi and Goto 2010 |
| Y | Taiwan | Taitung | Beinan Township | 22.75 | 121.02 | Kusumoto et al. 2013 |
| Y | Vietnam | Dalat | Bidoup-Nui Ba National Park | 12.13 | 108.53 | Kusumoto et al. 2013 |
| Y | Japan | Chiba | Chiba | 35.15 | 140.13 | Sanguansub et al. 2011 |
| Y | Japan | Saitama | Chichibu | 35.90 | 138.98 | Sanguansub et al. 2011 |
| Y | Indonesia |  | Cibodas Botanical Garden, LIPI | -6.74 | 107.01 | Kusumoto et al. 2013 |
| Y | Thailand | Chiang Mai | Dio Suthep-Pui National Park | 18.81 | 98.92 | Kusumoto et al. 2013 |
| Y | Japan | Gifu | Gifu | 35.42 | 136.76 | Hamaguchi and Goto 2010, Yamada and Ichihara |
| Y | Japan | Ishigakijima Is. | Ishigaki | 24.34 | 124.16 | Hamaguchi and Goto 2010 |
| Y | Japan | Tottori | Iwami | 35.58 | 134.33 | Hamaguchi and Goto 2010, Qi et al. 2011 |
| Y | Japan | Ishikawa | Kaga | 36.30 | 136.31 | Hamaguchi and Goto 2010, Igeta et al. 2004a, Igeta et al. 2004b, Yamada and Ichihara, Esaki et al. 2002, Kamata et al. 2002 |
| Y | Japan | Kyoto | Kamigamo Experimental Station | 35.04 | 135.46 | Iidzuka et al. 2016 |
| Y | Japan | Yakushima Is. | Kamiyaku | 30.36 | 130.51 | Hamaguchi and Goto 2010 |
| Y | Japan | Fukui | Katsuyama | 36.06 | 136.50 | Hamaguchi and Goto 2010, Yamada and Ichihara, Hijii et al. 1991, Kuroda 2001, Kamata et al. 2002, Kubono and Ito 2002 |
| Y | Japan | Kyoto | Keihoku, Kyoto city | 35.22 | 135.68 | Masahiko et al. 2007 |
| Y | Japan | Mie | Kihoku | 34.21 | 136.34 | Hamaguchi and Goto 2010 |
| Y | Japan | Kagoshima | Kinko, Kamikawa | 43.85 | 142.77 | Hamaguchi and Goto 2010 |
| Y | Japan | Kyushu | Kirishima | 31.74 | 130.76 | Hamaguchi and Goto 2010 |
| Y | Japan | Kyoto | Kitashirakawa Experimental Statio | 35.02 | 135.79 | Pham et al. 2019 |
| Y | Japan | Shimane | Masuda | 34.67 | 131.84 | Hamaguchi and Goto 2010 |
| Y | Japan | Kagoshima | Minamikyushu | 31.38 | 130.44 | Hamaguchi and Goto 2010 |
| Y | Japan | Kyoto | Miyazu | 35.54 | 135.20 | Hamaguchi and Goto 2010, Qi et al. 2011 |
| Y | Japan | Wakayama | Nachikatsuura | 33.63 | 135.94 | Hamaguchi and Goto 2010, Qi et al. 2011 |
| Y | Japan | Niigata | Nagaoka | 37.45 | 138.85 | Hamaguchi and Goto 2010 |
| Y | Japan | Toyama | Nanto | 36.51 | 136.90 | Hamaguchi and Goto 2010, Qi et al. 2011, Nakajima 2019 |

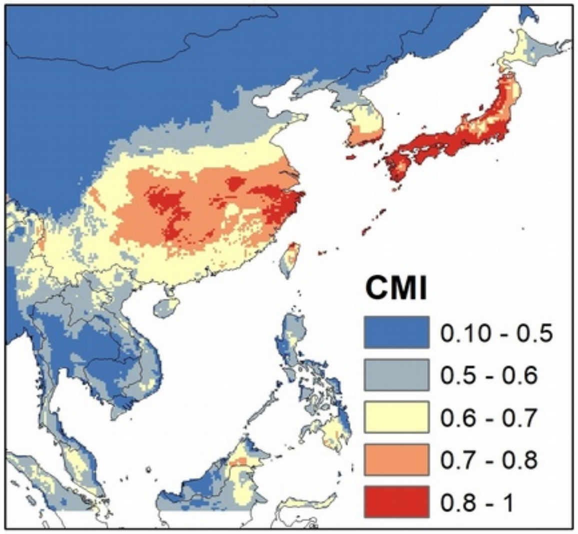
| | | | | | | |
|---|---|---|---|---|---|---|
| Y | Japan | Akita | Nikaho | 39.20 | 139.91 | Hamaguchi and Goto 2010 |
| Y | Japan | Fukushima | Nishiaizu | 37.59 | 139.65 | Hamaguchi and Goto 2010 |
| Y | Japan | Shiga | Nishikasai | 35.67 | 139.86 | Hamaguchi and Goto 2010 |
| Y | Japan | Sadogashima Is. | Sado | 38.02 | 138.37 | Hamaguchi and Goto 2010 |
| Y | Japan | Amami-Oshima Is | Setouchi | 34.66 | 134.09 | Hamaguchi and Goto 2010 |
| Y | Japan | Shiga | Takashima | 35.35 | 136.04 | Hamaguchi and Goto 2010 |
| Y | Japan | Wakayama | Tanabe | 33.73 | 135.38 | Hamaguchi and Goto 2010, Qi et al. 2011 |
| Y | Japan | Nagano | Tenryu | 35.09 | 137.88 | Hamaguchi and Goto 2010 |
| Y | Japan | Tokunoshima Is. | Tokunoshima | 27.79 | 128.97 | Hamaguchi and Goto 2010 |
| Y | Japan | Yamagata | Tsuruoka | 38.73 | 139.83 | Hamaguchi and Goto 2010, Qi et al. 2011 |
| Y | Japan | Hyogo | | 35.08 | 134.85 | Soné et al. 1998 |
| Y | Japan | Kisakata | | 39.21 | 139.92 | Kusumoto et al. 2013 |
| Y | Japan | Niigata | | 37.02 | 138.44 | GBIF (accessed 2/16/2020) |

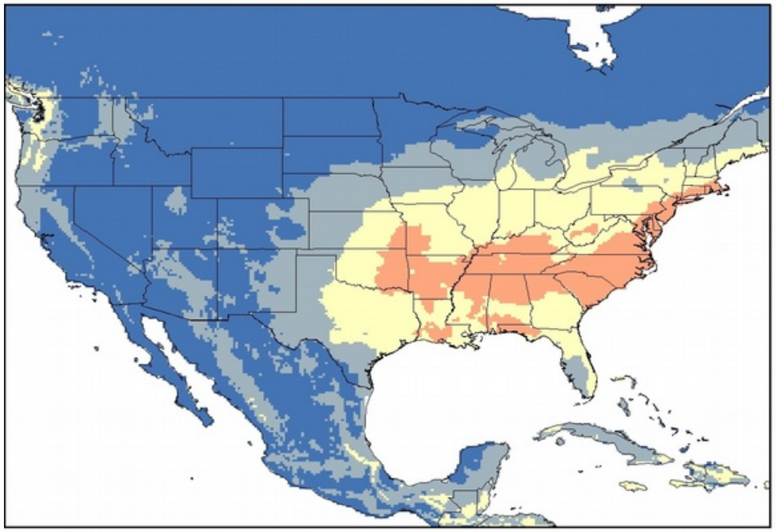
**Map of ALL localities (inc. those not included in analyses)**



### 10. Regional climate matching analysis in CLIMEX (this study)

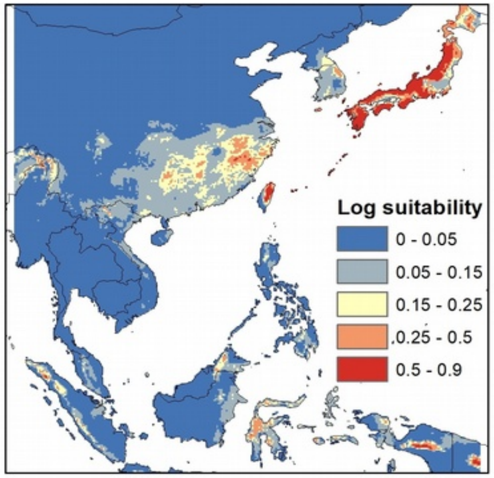
- Matched climate at 39 localities from native range ('Home' localities) to climate in North America
- Areas with a composite match index (CMI) > 0.70 are considered to have similar climate to the 'Home' locations
- See white paper for more details on methods and results

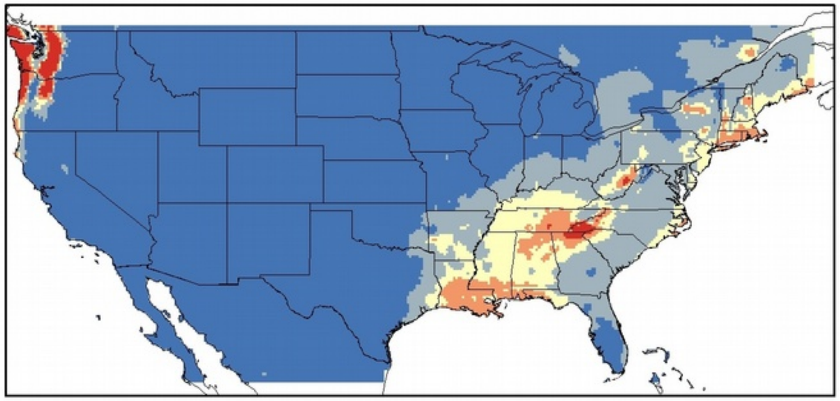




### 11. Maxent analysis (this study - see white paper for more details and results)

- Used same 39 localities to train a Maxent model in the native range, and then projected the model onto CONUS
- Methods included 50 replicates, with a random 80% of localities used to train the model and 20% reserved for testing using the AUC statistic
- Input climate data were the first 5 principal components of all 35 Bioclim variables (see https://www.climond.org/BioclimData.aspx)
- Other settings were default





## 12. CLIMEX model

**Parameters used for CLIMEX model developed for this study**

Moisture Index

| SM0 | SM1 | SM2 | SM3 |
|---|---|---|---|
| 0.1 | 0.3 | 1.6 | 2.5 |

Temperature Index

| DV0 | DV1 | DV2 | DV3 |
|---|---|---|---|
| 11.1 | 15 | 30 | 38 |

Light Index (not used)

| LT1 | LT0 |
|---|---|
| 0 | 0.01 |

Cold Stress

| TTCS | THCS | DTCS | DHCS | TTCSA |
|---|---|---|---|---|
| -10 | -0.001 | 0 | 0 | 0 |

Heat Stress

| TTHS | THHS | DTHS | DHHS |
|---|---|---|---|
| 38 | 0.0001 | 0 | 0 |

Dry Stress

| SMDS | HDS |
|---|---|
| 0.1 | -0.01 |

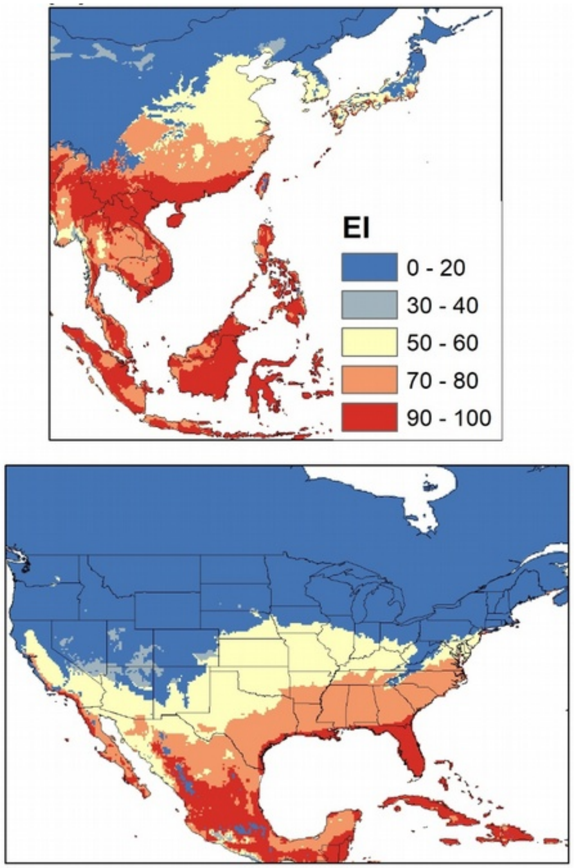
Wet Stress

| SMWS | HWS |
|---|---|
| 2.5 | 0.0003 |

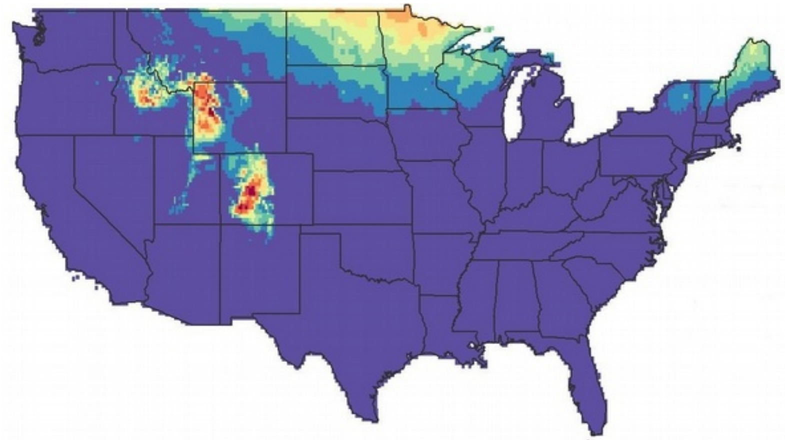
Degree-days per Generation

| PDD |
|---|
| 1486 |

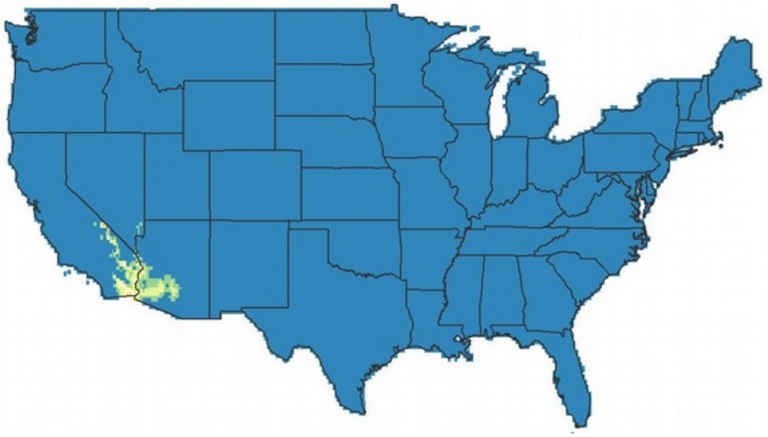
**Ecoclimatic Index (Asia and N. America)**



**CLIMEX Cold Stress (North America)**



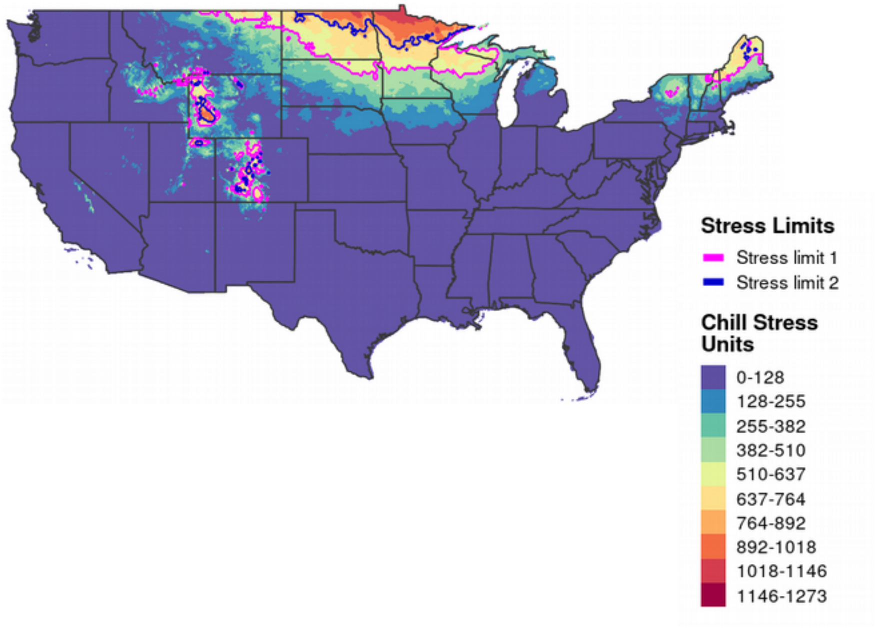
**CLIMEX Heat Stress (North America)**



**13. DDRP climate suitability model – developed in accordance with three other model outputs above (CLIMEX-MCR, Maxent, and CLIMEX)**

**DDRP Cold Stress**

| | Value | Units |
|---|---|---|
| chill stress threshold | -10 | C |
| limit 1 (mod. chill stress) | 515 | DDC |
| limit 2 (sev. chill stress) | 800 | DDC |



**DDRP Heat Stress**

| | Value | Units |
|---|---|---|
| heat stress threshold | 38 | C |
| limit 1 (mod. heat stress) | 180 | DDC |
| limit 2 (sev. heat stress) | 300 | DDC |