What Will Climate Change Bring To Bark Beetles in the Western and Southwestern US?

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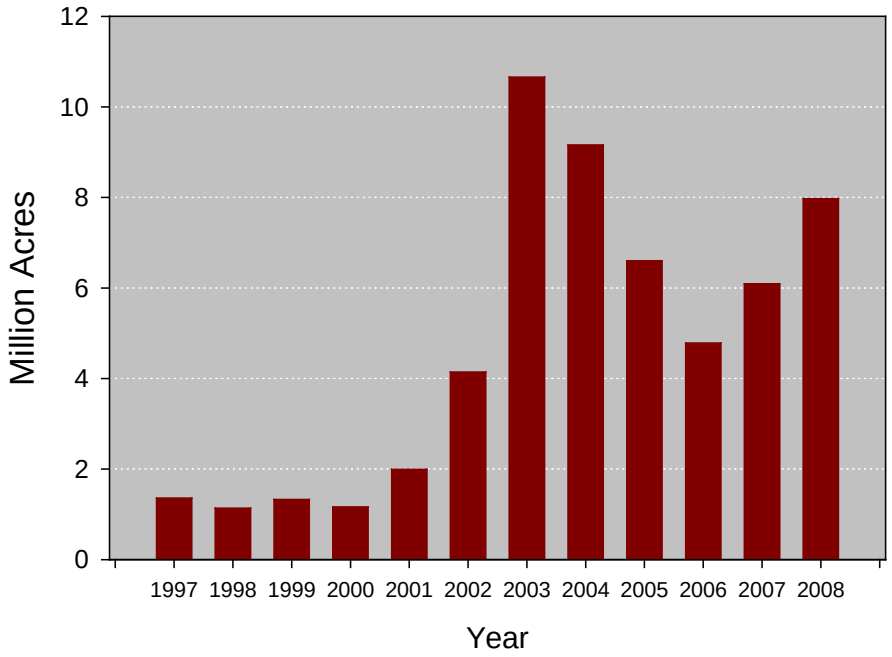
Forest and Woodland Ecosystem Research



Native bark beetles have affected > 56 million acres in the western US over the past 10 years (*USDA Forest Health Protection*).

Native Western US Bark Beetle Species That Can Cause Landscape-Wide Tree Mortality

Spruce beetle
D. rufipennis

Douglas fir beetle
D. pseudotsugae

Mountain pine beetle
Dendroctonus ponderosae

Western pine beetle
D. brevicomis

Roundheaded pine beetle
D. adjunctus

Southern pine beetle
D. frontalis

Jeffrey pine beetle
D. jeffreyi

Arizona fivespined ips
Ips lecontei

Pinyon ips
Ips confusus

Pine engraver
Ips pini

Western balsam bark beetle
Droycoetes confusus

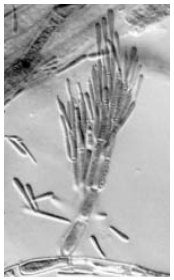
Ips calligraphus, *Ips latidens* and *Ips knausi* – *complex in the SW*

Precipitation
Atmospheric Gases
Temperature

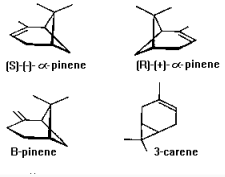
Natural Enemies

Beetle development
& survival

Host tree defenses
(inducible & constituitive),
Tree growth,
Distribution



Associated fungi
& bacteria



Pheromone production
& release

Precipitation
Atmospheric Gases
Temperature

Natural Enemies

Beetle development
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Host tree defenses
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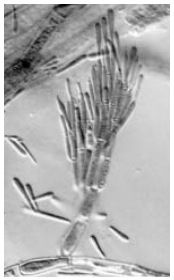

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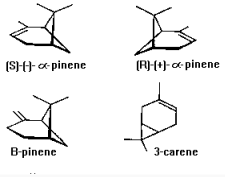


Pheromone production
& release

Temperature has a direct relationship to bark beetle development rate & survival

Powerful pheromone communication system

- Temperature-dependent ‘adaptive developmental timing’

- Evolved strategies to reduce temperature induced mortality

For the majority of bark beetle species in the western US, very little is known about temperature-dependent physiological response. Lifecycle information is limited to observations on flight timing:

Ips confusus – 2 or more generations per year

Ips leconti – 3 generations per year

Ips pini – 2 or 3 generations per year

Ips calligraphus, Ips latidens and Ips knausi - ?

Western pine beetle – 2 to 4 generations per year

Fir engraver, western balsam bark beetle – 1 generation per year

Douglas fir beetle – 1 generation per year

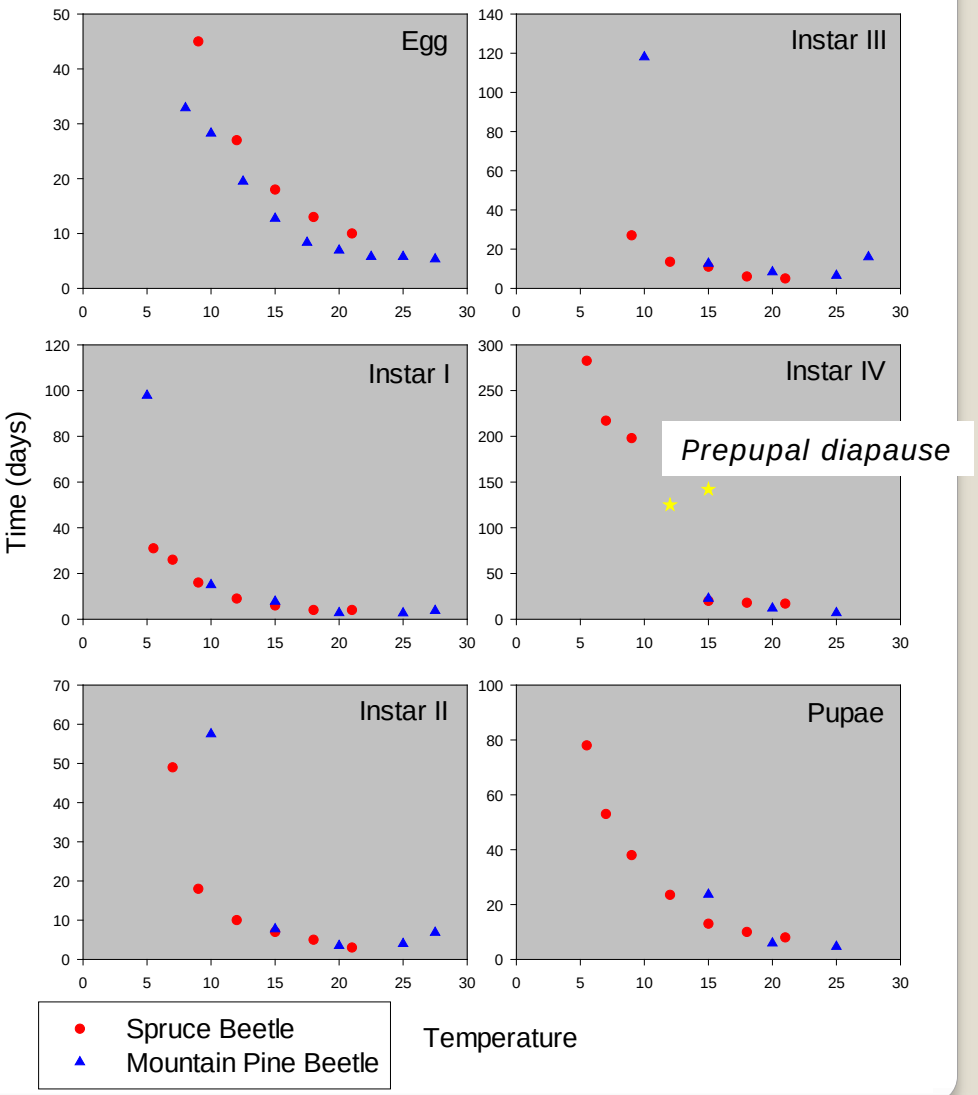
Southern pine beetle – 3 to 6? generations per year

Roundheaded pine beetle - 1 generation per year

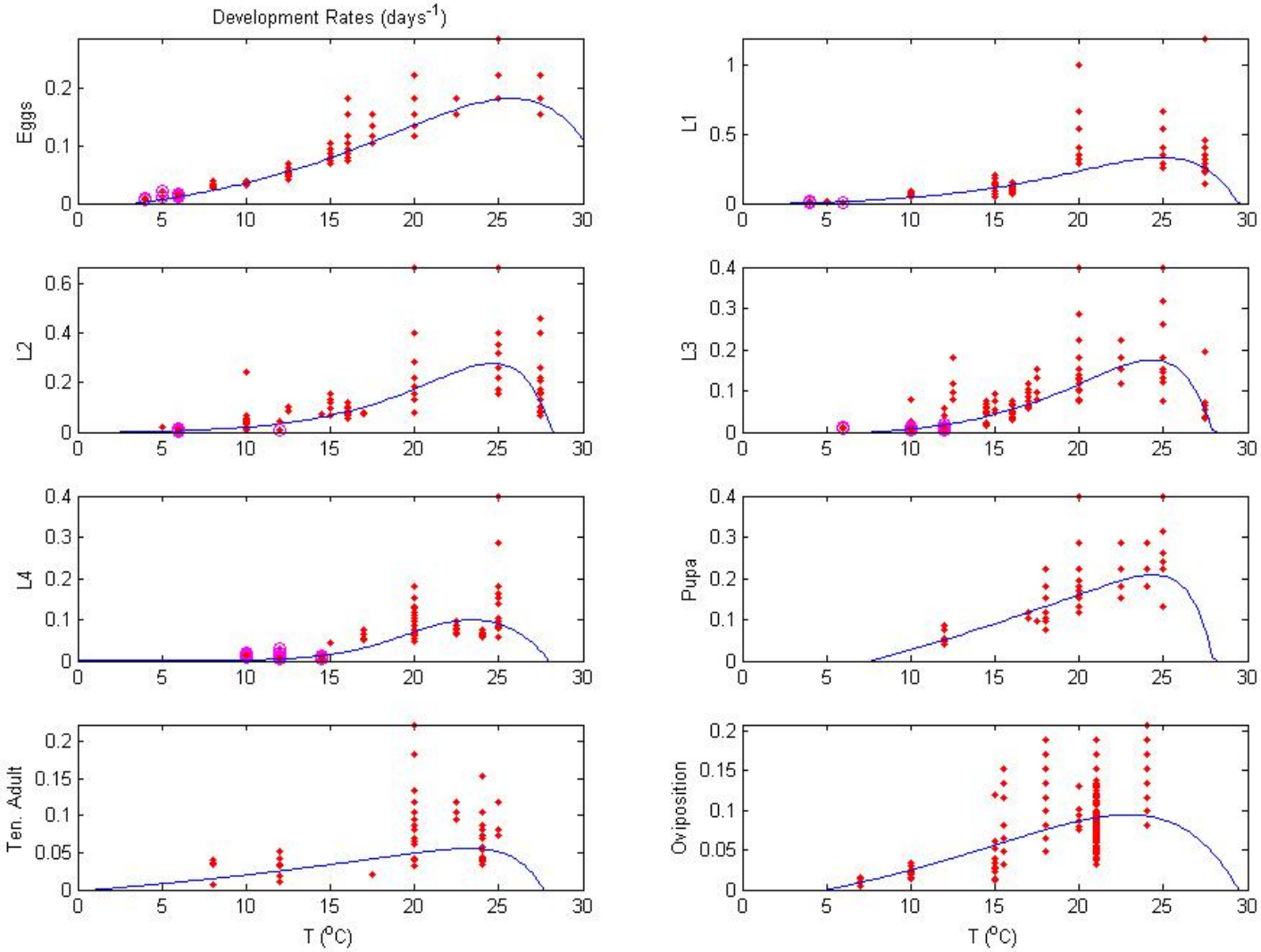
Mechanistic response to temperature - bark beetle development rate & survival

Mountain pine beetle

Spruce beetle



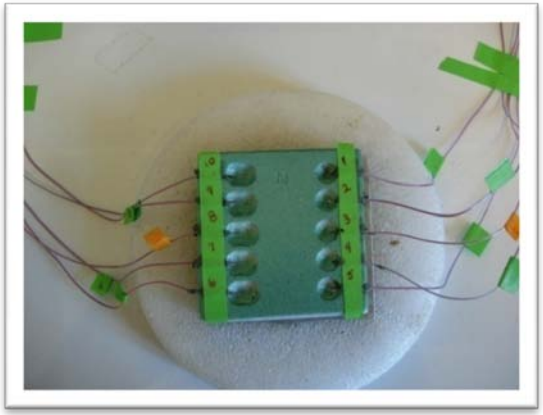
Mountain pine beetle development rate curves

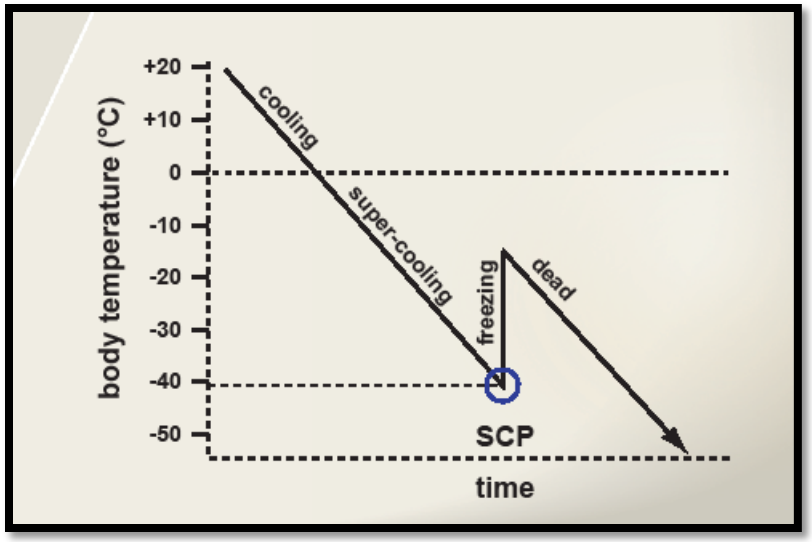


Bentz, Powell, Regniere unpublished data

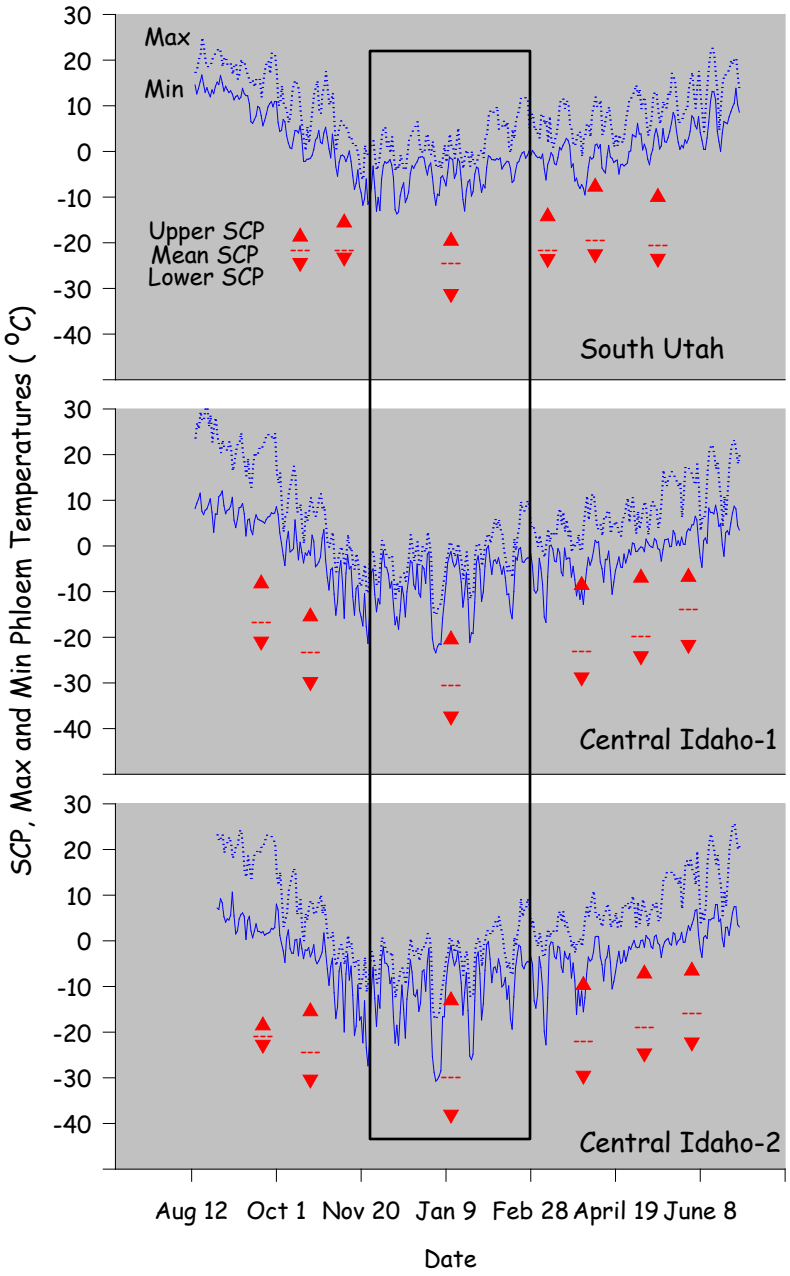
Mountain pine beetle Cold Tolerance

Lifestage-specific direct effects of cold temperature on mortality





‘Supercooling point’ is the temperature at which tissues freeze and death occurs, and can be used as the lethal temperature.



Microhabitat temperature varies within and among years and geographic locations.

Larval supercooling point (SCP) also varies.

Cold tolerance is dynamically dependent on temperature regime experienced.

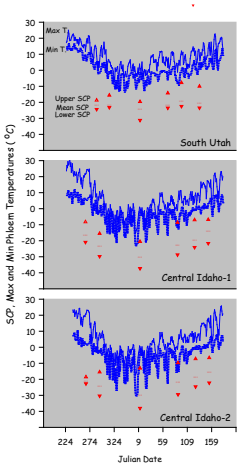
Simple low temperature threshold can not explain the role of temperature in mountain pine beetle survival/mortality.

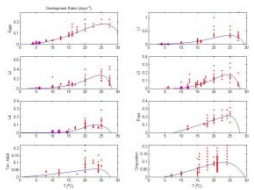
From Bentz and Mullins (1999)

- Field and lab data describing bark beetle response to temperature

$$\frac{\partial u}{\partial t} + r[T(t);\bar{\rho}]\frac{\partial u}{\partial a} = \frac{\Delta t}{2}\left(\sigma_E^2 + \sigma_G^2\right)\frac{\partial^2 u}{\partial a^2},$$

$$\lambda(t') = f(A_n(t')) = b_n \max\left(A_n(t') - a_n, 0\right)$$





$$X_i = \frac{e^{-(T-\alpha_i)/\beta_i}}{\beta_i\left[1+e^{-(T-\alpha_i)/\beta_i}\right]^2}$$

$$G(t,\tau) = \frac{1}{\sqrt{4\pi\nu(t-\tau)^3}}\exp\left[-\frac{\left(1-\int_\tau^t r(T(s))ds\right)^2}{4\nu(t-\tau)}\right]$$

$$S = R\,\rho_S\,\frac{e^{-(\tau-T_S)/\sigma_S}}{\sigma_S\left(1+e^{-(\tau-T_S)/\sigma_S}\right)^2}$$

$$L = R\,\rho_L\,\frac{e^{-(\tau-T_L)/\sigma_L}}{\sigma_L\left(1+e^{-(\tau-T_L)/\sigma_L}\right)^2}$$

$$p_{out}(t) = \int_0^t G(t,\tau)\,p_{in}(\tau)\,d\tau.$$

$$dC/dt = (1-C)\,S - C\,L$$

Jacques Régnière

Jim Powell

Temperature-driven process models – Provide a filter between temperature and beetle population success

Models Describing Beetle Response to Temperature

Mountain pine beetle

Lifestage specific development = *f* (temperature)

Logan & Amman 1986
Bentz, Logan & Amman 1991
Logan & Bentz 1999
Powell, Jenkins, Logan, & Bentz 2000
Logan & Powell 2001
Jenkins, Powell, Logan, & Bentz 2001
Gilbert, Powell, Logan & Bentz 2004
Powell & Bentz 2009

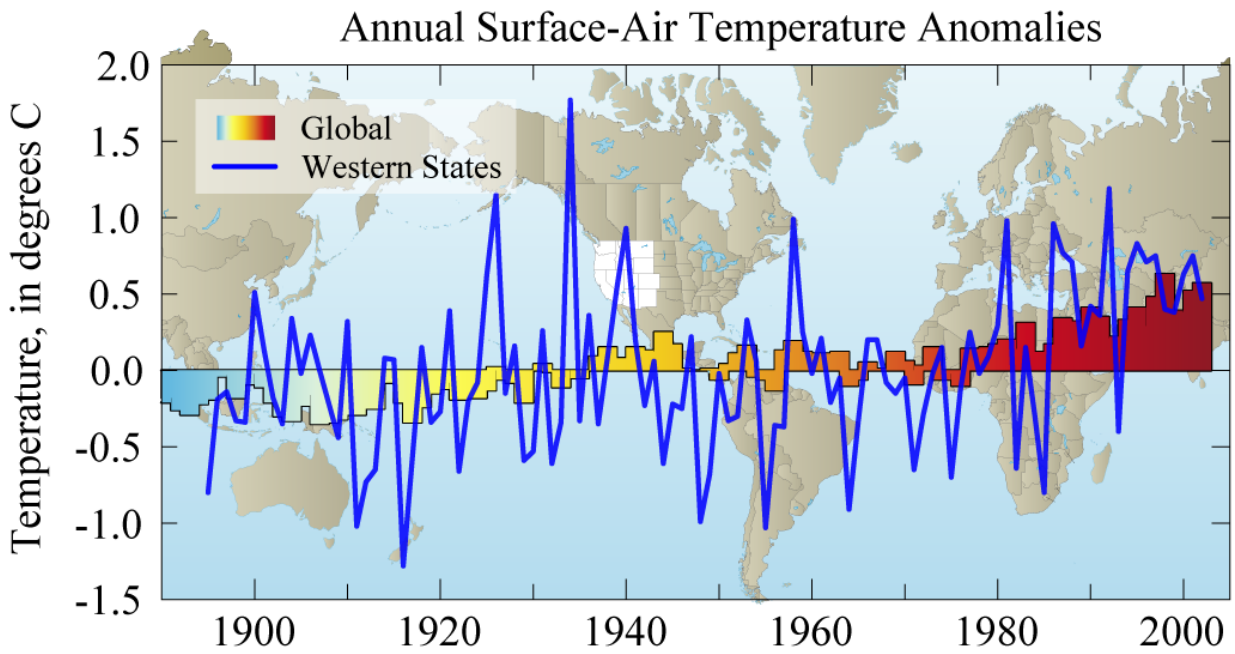
Probability of cold temperature survival = *f* (temperature)

Bentz & Mullins 1999
Régnière & Bentz 2007

Spruce beetle

Probability of univoltine lifecycle = *f* (temperature)

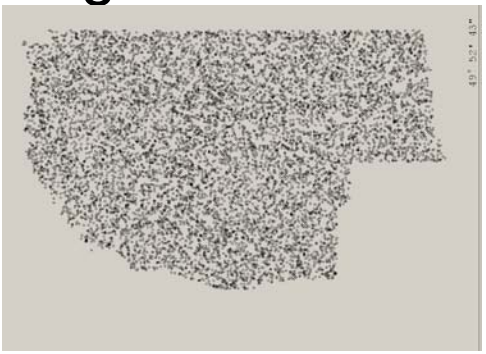
Hansen et al. 2001
Hansen & Bentz 2003



From Mike Dettinger & Dan Cayan:
http://geochange.er.usgs.gov/program/workshop/Dettinger.ppt

How will the trend in warming temperature influence trends in mountain pine beetle population success?

Landscape projections of Cold Tolerance and developmental timing across 12 contiguous western US states.

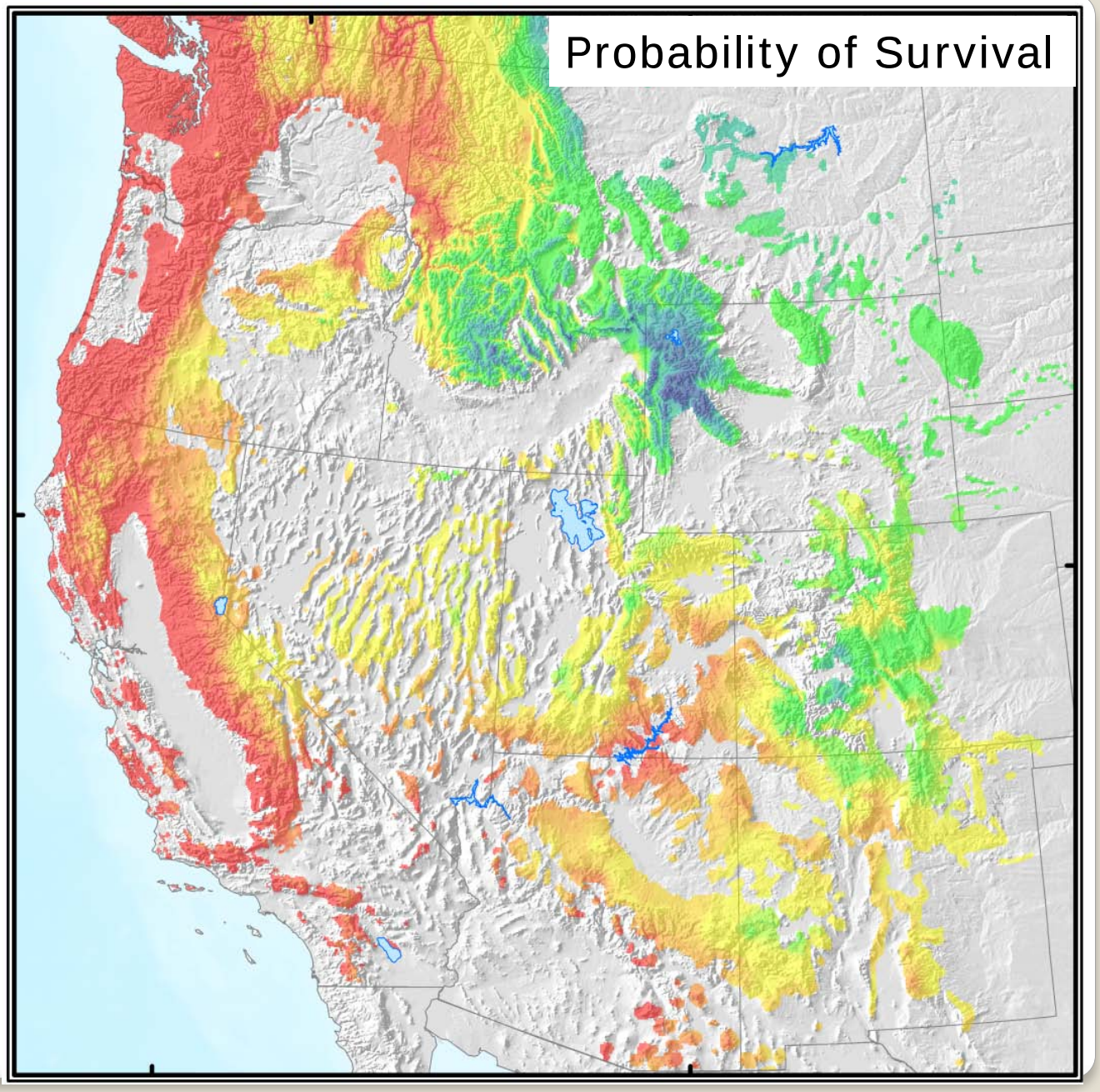


Régnière & St-Amant. 2007

- Generate 10,000 random points from a DEM of the western US.
- Climate normals were used to run the simulations:
  -actual monthly climate normals for the period 1961-1990
  -climate-changed normals for the periods 2001-2030, 2041-2070, 2071-2100 (based on CRCM, v. 4.2.0, runs ADJ and ADL, a moderate scenario).
- The model is replicated 30 times at each point using a stochastically determined normals temperature file.
- Average output for each point is spatially interpolated (krigged) back across the DEMs.

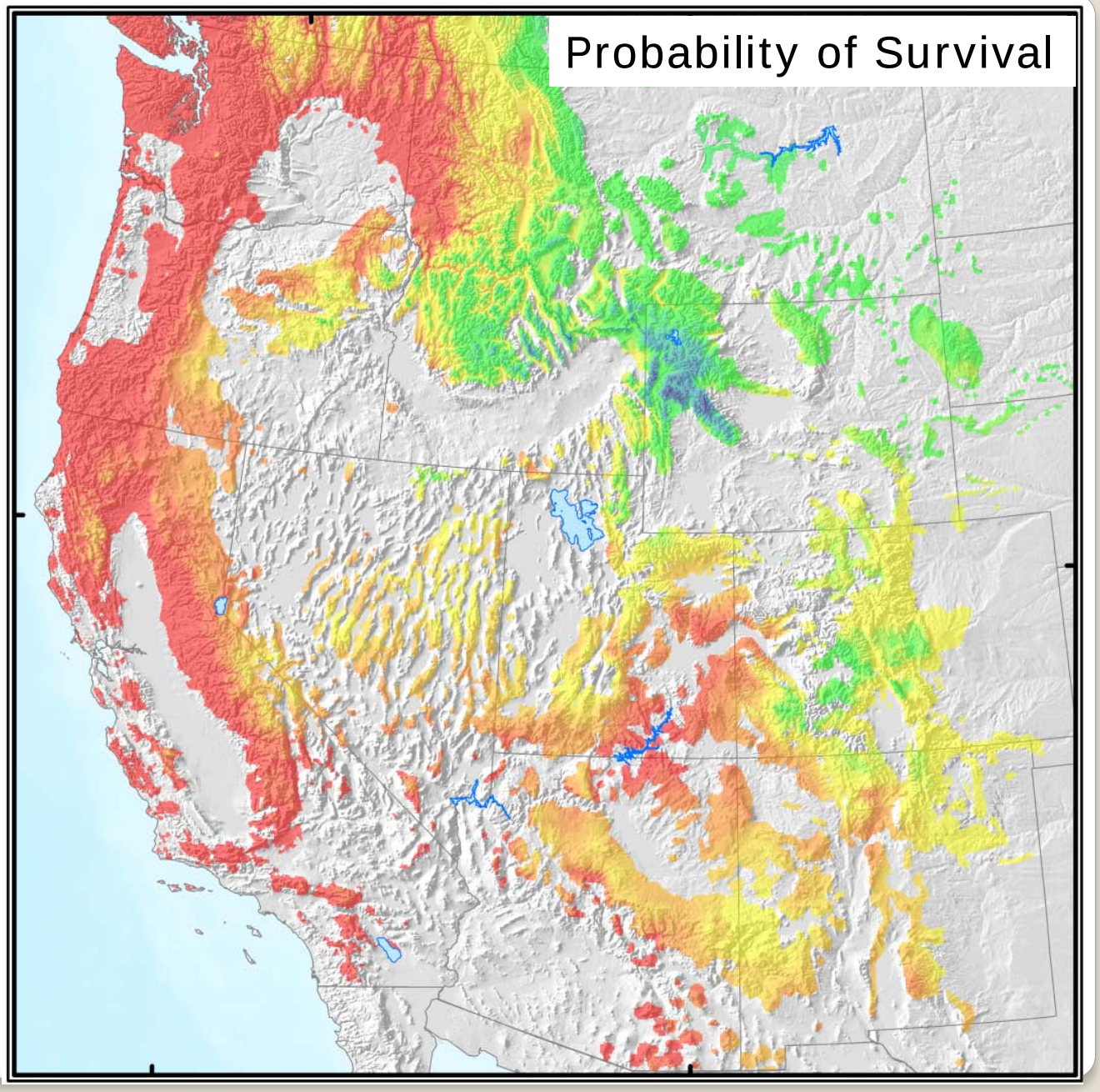
Mountain pine Beetle
Cold Tolerance

1961-1990



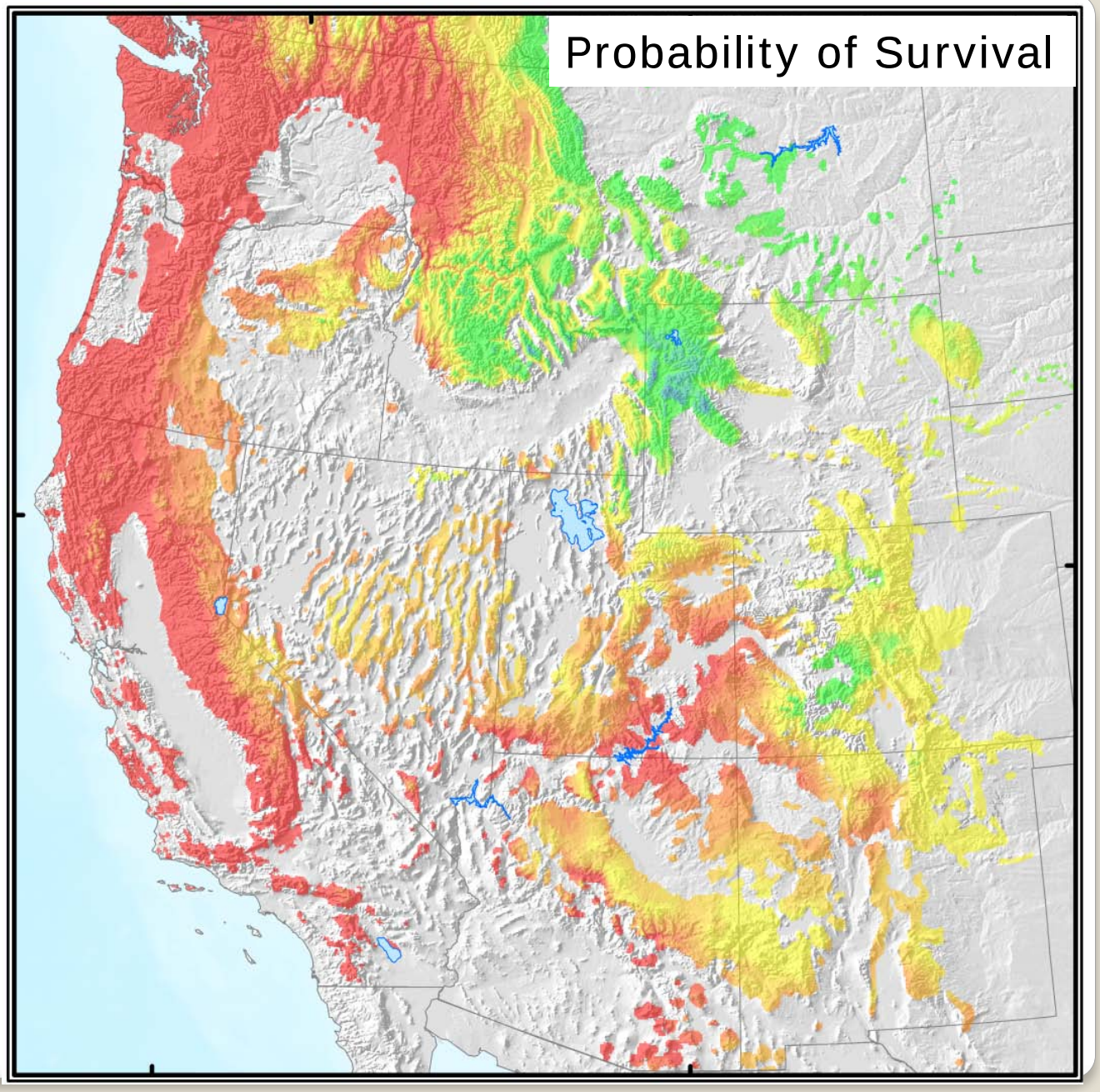
Mountain pine Beetle
Cold Tolerance

2001-2030



Mountain pine Beetle
Cold Tolerance

2071-2100



Relate mountain pine beetle development time to fitness (adaptive seasonality):

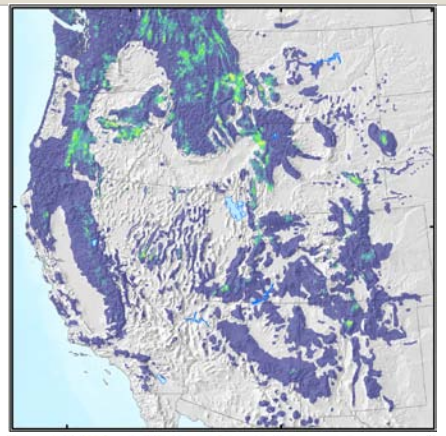
- Timing: Adult emergence occurs at appropriate time of year
- Synchrony: Peak adult emergence occurs during a relatively short period of time to facilitate mass attack
- Univoltine: 1 year lifecycle

Beetle wins

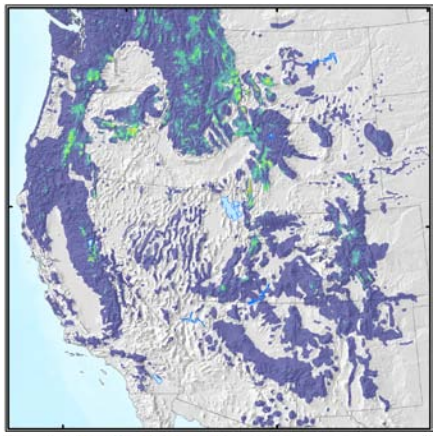
Beetle loses

Mountain pine Beetle ‘Adaptive Seasonality’

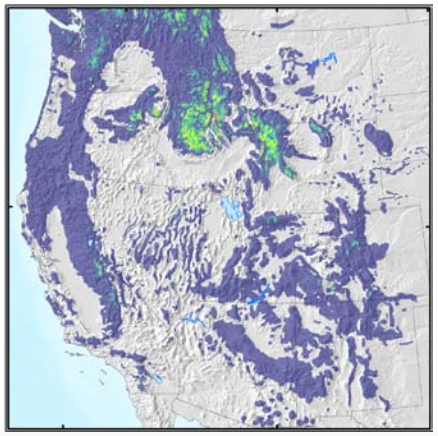
1961-1990



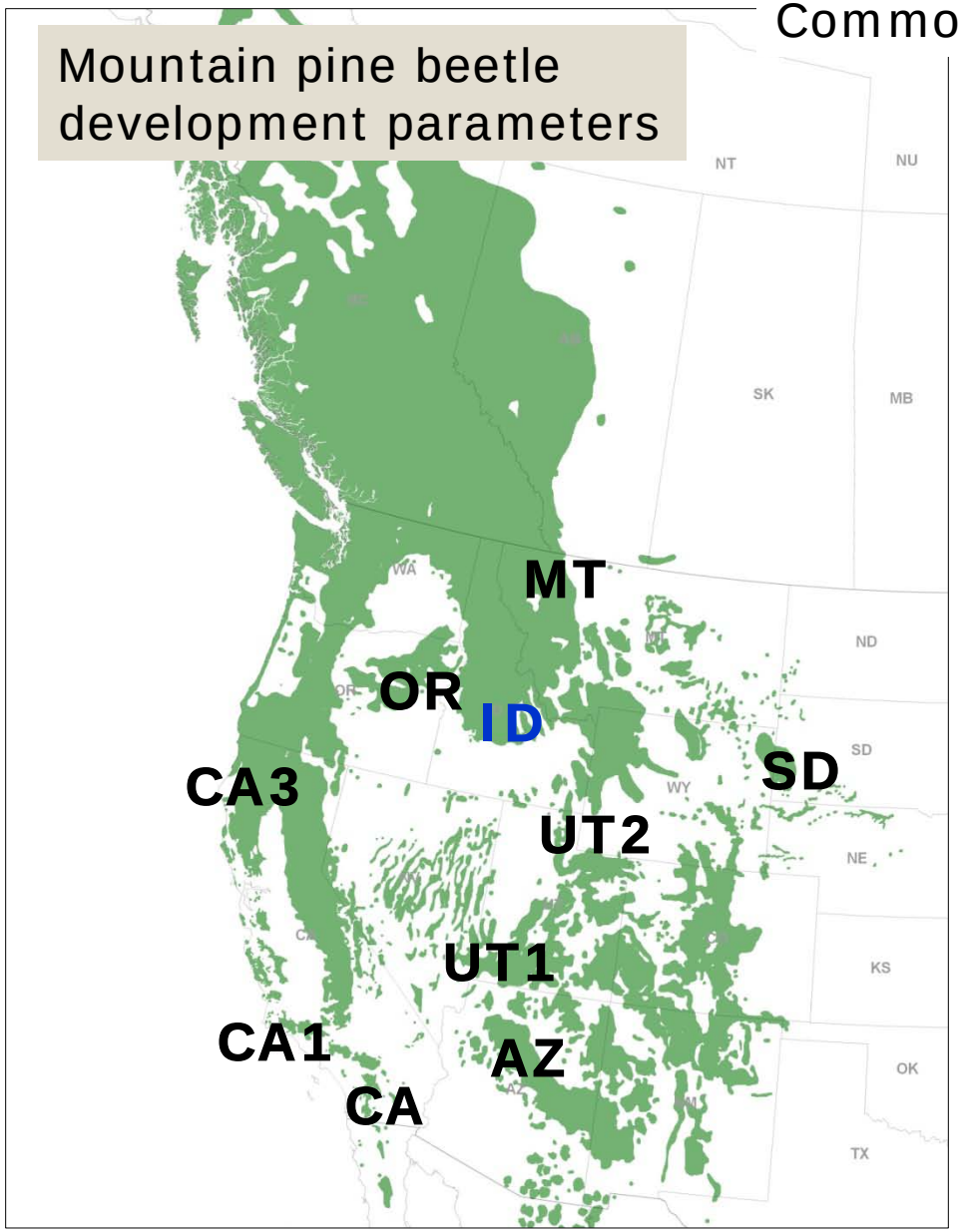
2001-2030



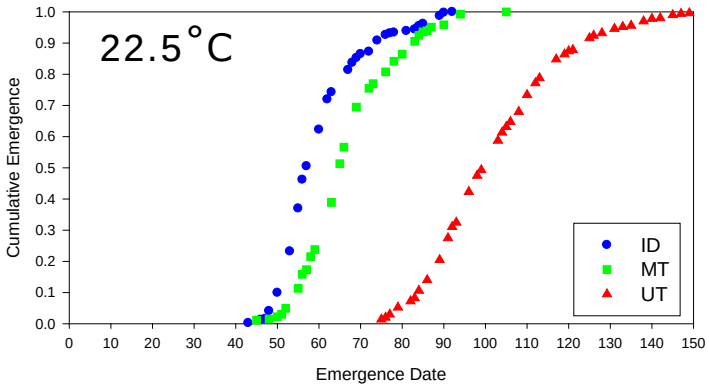
2071-2100

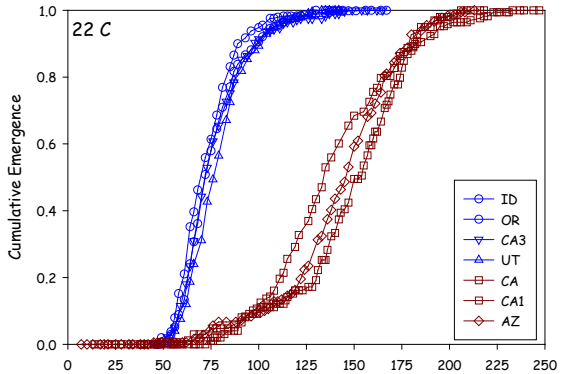


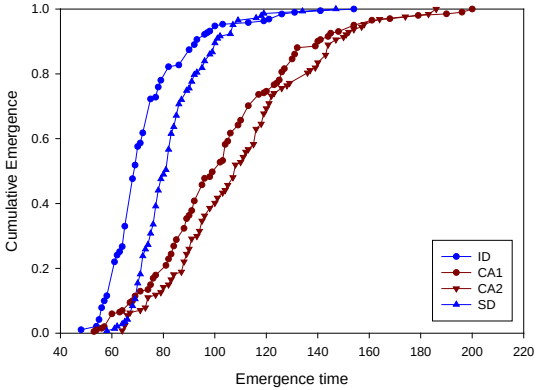
Mountain pine beetle development parameters



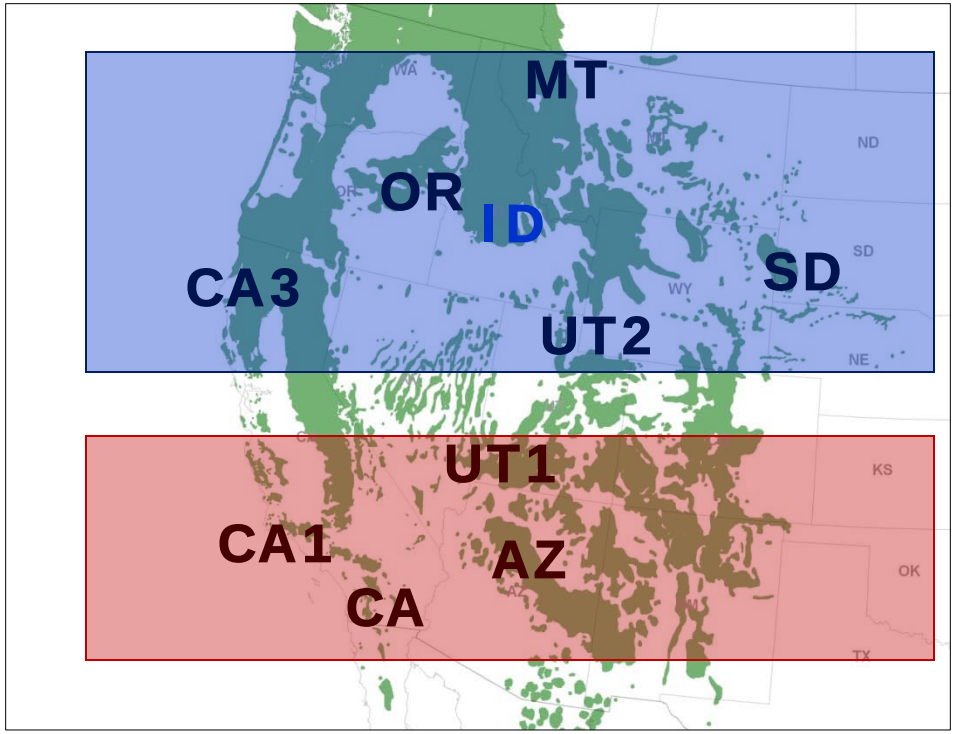
Common Garden Rearing Experiments

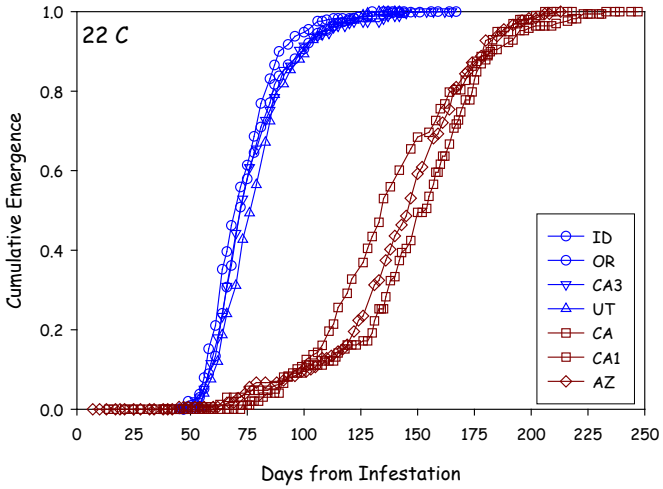






From: Bentz, Logan and Vandygriff 2001; Bracewell et al. 2009; Bentz et al. unpublished data.



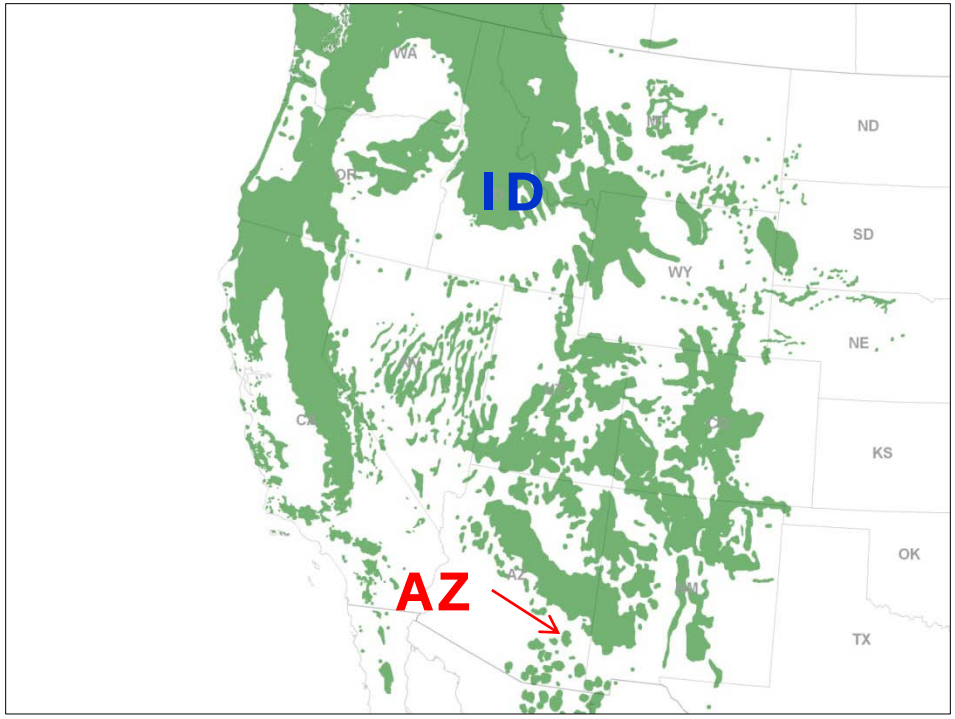


- Strong local selection for development time among geographically separated *D. ponderosae* populations, and the response varies with temperature.

- Slower total development at more southern latitudes (warmer environments) and faster development at more northern latitudes (colder environments) potentially facilitate the same strategy, univoltinism.

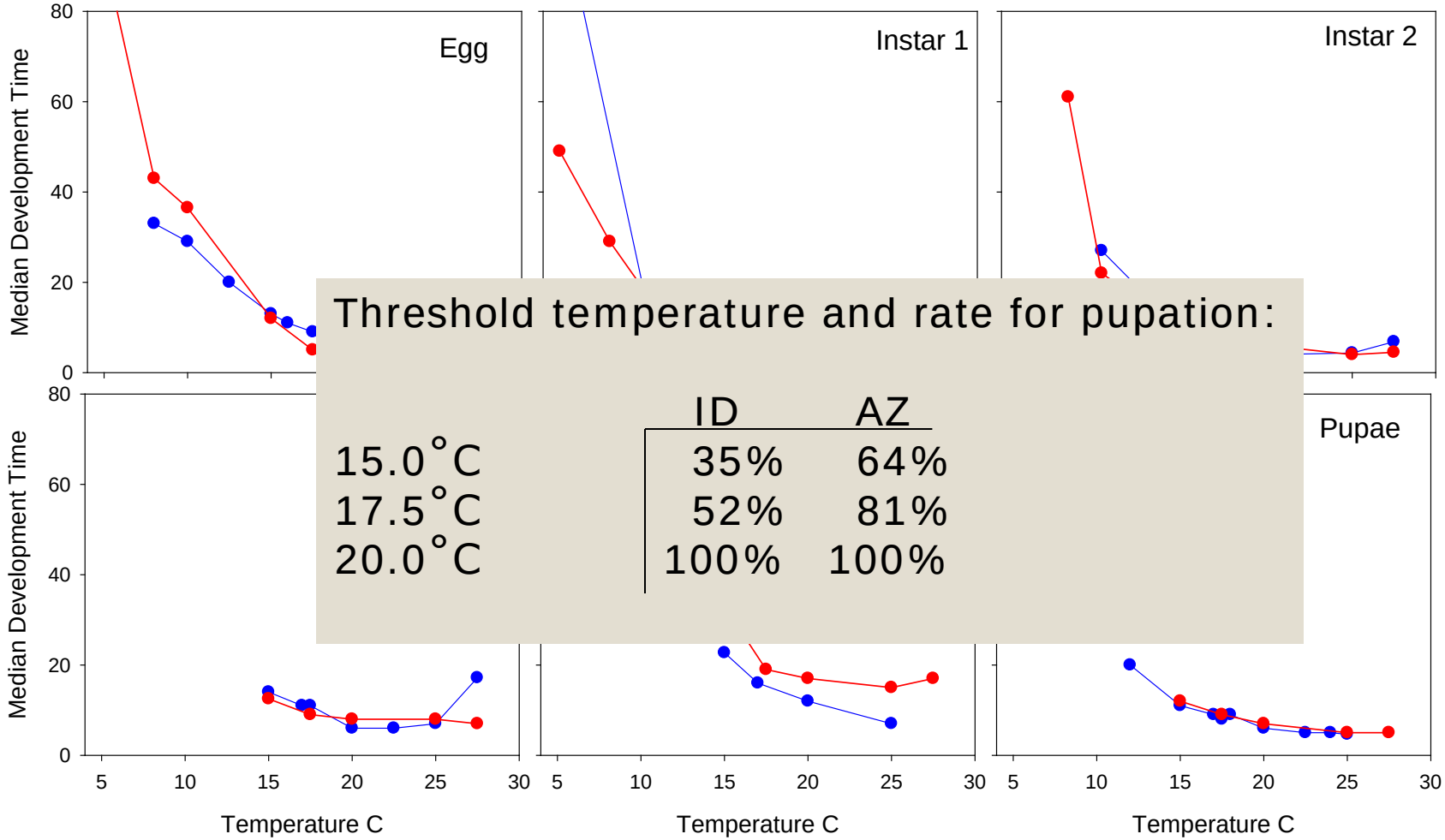
From: Bentz, Logan and Vandygriff 2001; Bracewell et al. 2009; Bentz et al. unpublished data.

What lifestage(s) are responsible for the significant phenotypic differences in total development time among populations?



Lifestage-specific development time using “phloem sandwiches”. Measure number of days required to complete each lifestage at several constant temperatures from 4.0 to 27.5°C.

Median development time (days)
ID (blue) & AZ (red) populations

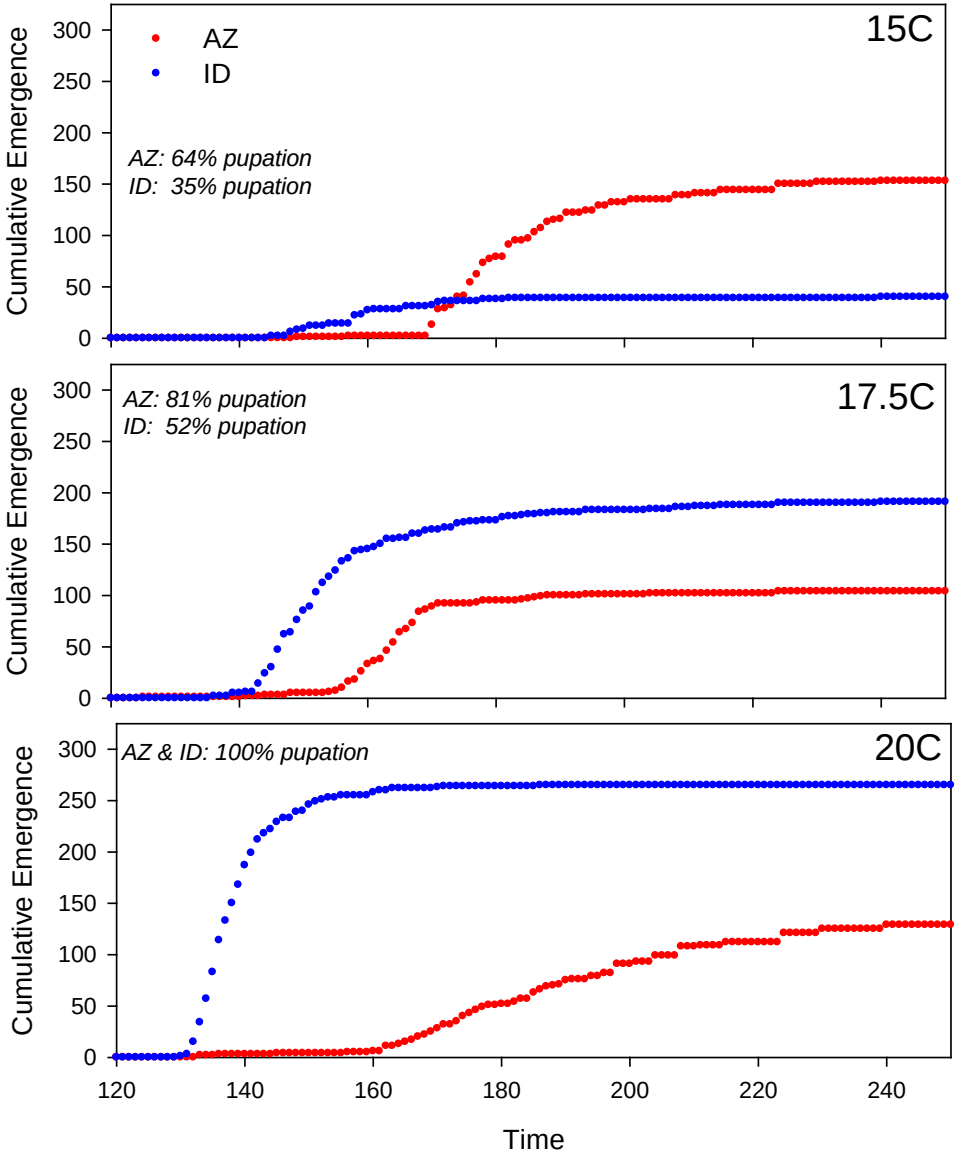


Threshold temperature and rate for pupation:

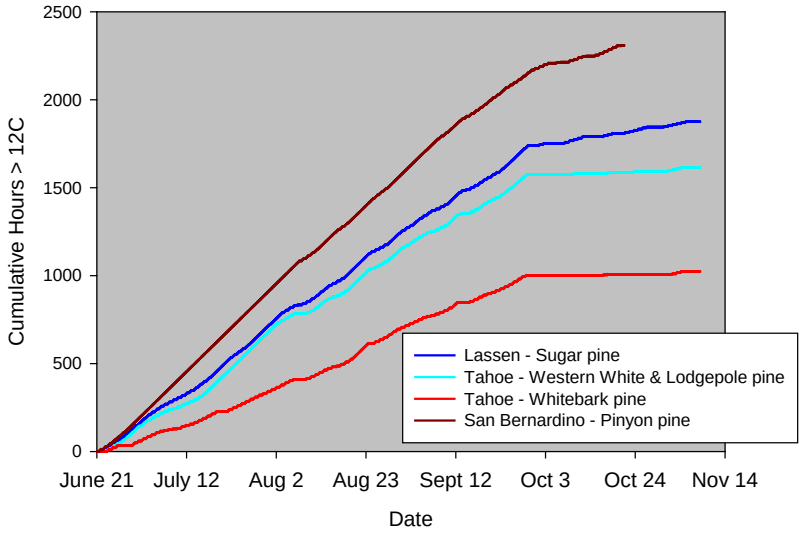
	ID	AZ
15.0°C	35%	64%
17.5°C	52%	81%
20.0°C	100%	100%

From: Bentz et al. 1991 & Bentz unpublished data

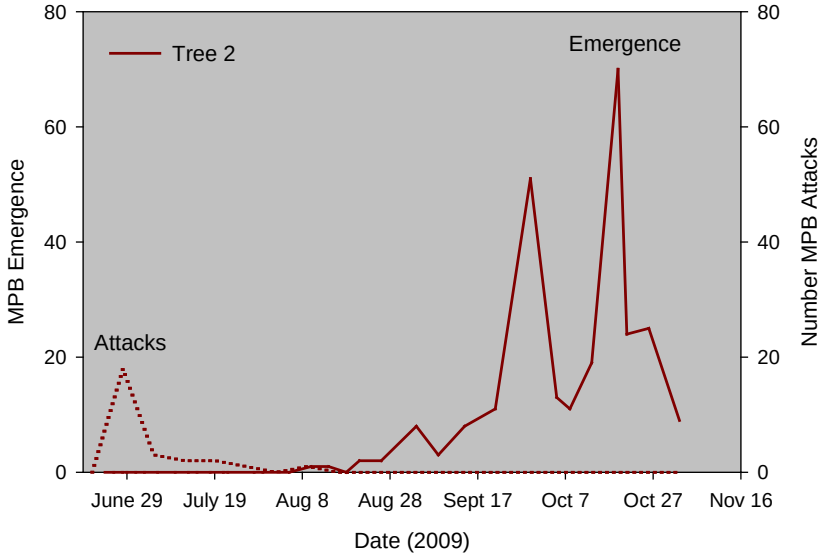
Teneral Adult Development



Mountain pine beetle in CA WC-EM-09-02



San Bernardino NF - Pinyon pine - 2079 m



Summary

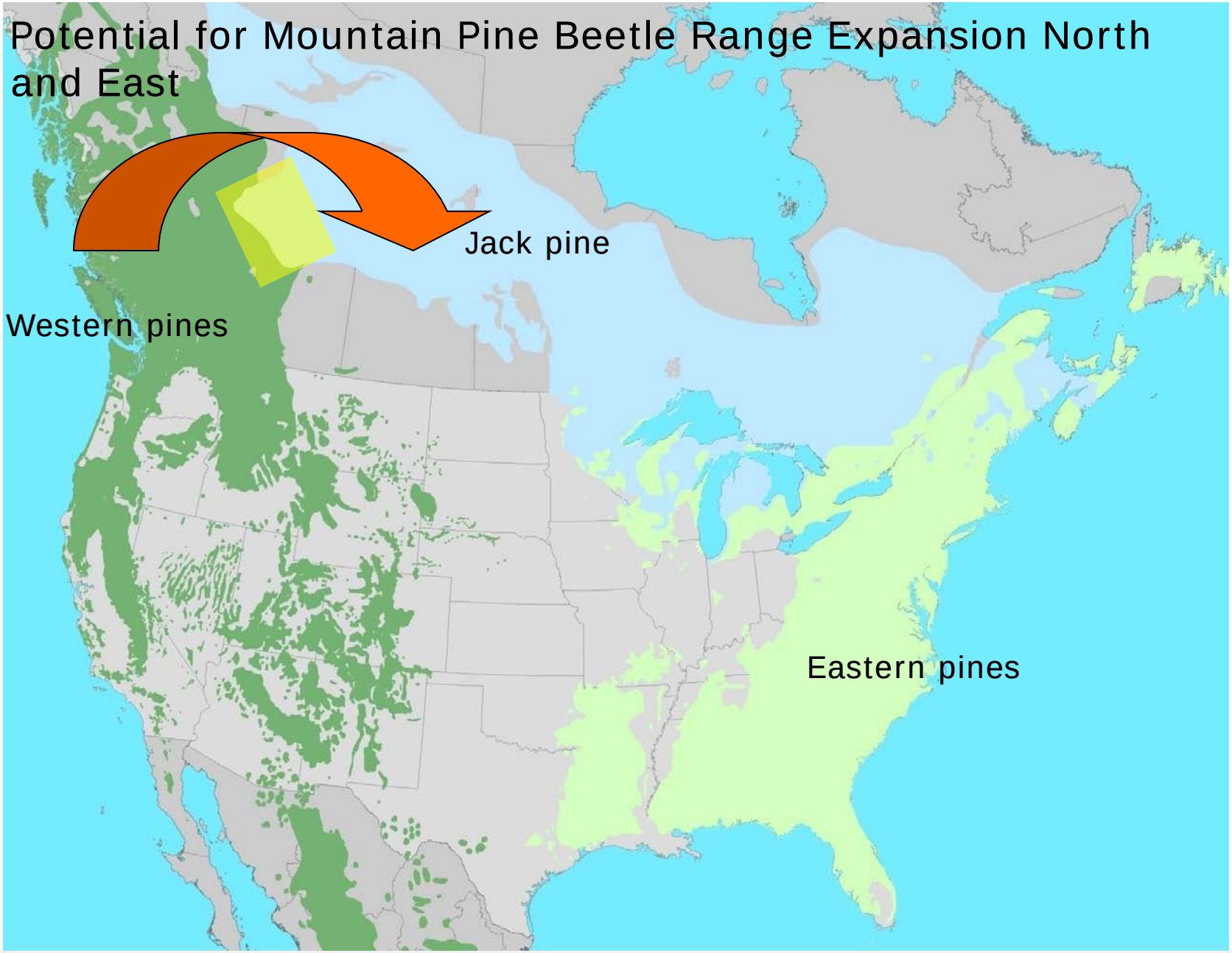
- Mountain pine beetle is adapted to local environments. This knowledge informs tools for predicting population trends. What about other species with large geographic ranges?

- A mechanistic understanding of bark beetle response to temperature is needed for development of adaptive forest management tools. We are working on a variant of our phenology model for mountain pine beetle in southern latitudes. Data is needed for other species.

- Can bark beetle species adapt to rapidly changing environmental conditions?

- Potential local expansions or extinctions?

Potential for Mountain Pine Beetle Range Expansion North and East

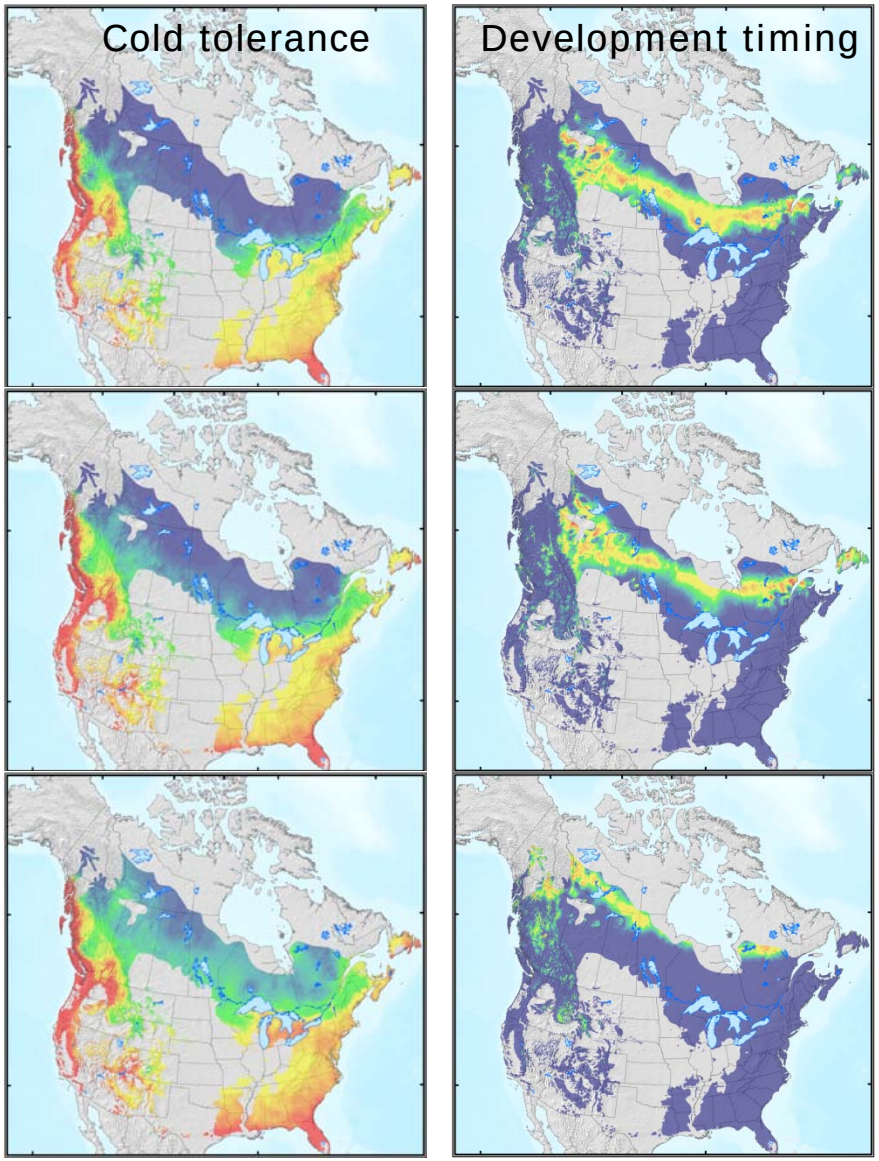


Potential for Mountain Pine Beetle Range Expansion North and East

1961-1990

2001-2030

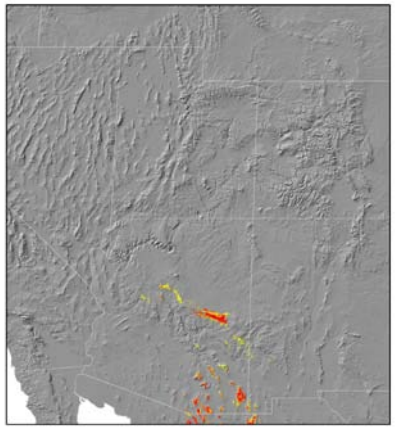
2071-2100



Summary *cont.*

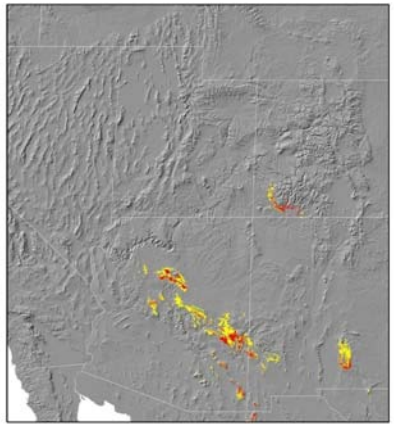
- Tree species will also adapt or migrate.

Current

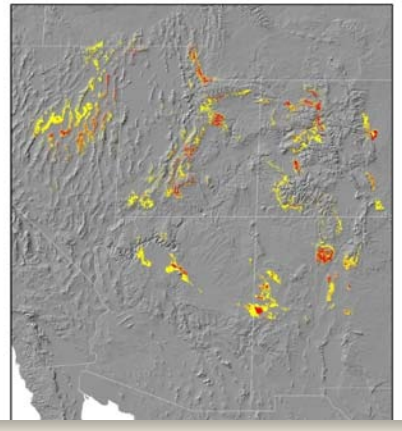


Chihuahua Pine
Projected Distribution

2030



2090



How will bark beetles adapted to this and other tree species in Mexico respond to climate change?

From: http://forest.moscowfsl.wsu.edu/climate/

Acknowledgements

Matt Hansen, Jim Vandygriff, Kim Huntzinger, Jim Powell, Ryan Bracewell, Ann Lynch

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Photo: Deems Burton