Western pine beetle voltinism in a changing California climate

USDA Forest Service Rocky Mountain Research Station

Voltinism is the number of generations within a year

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Areas with Tree Mortality from Bark Beetles

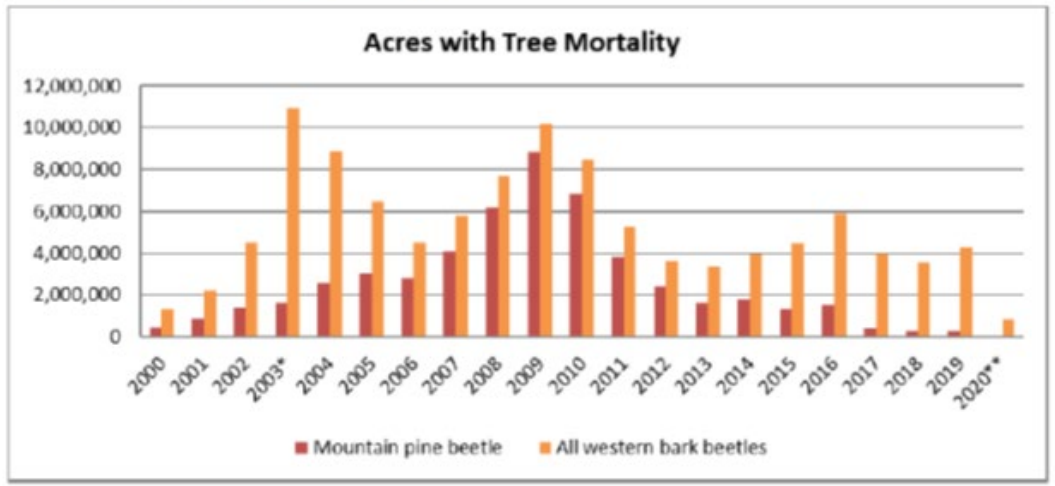
Summary for 2000 – 2020**

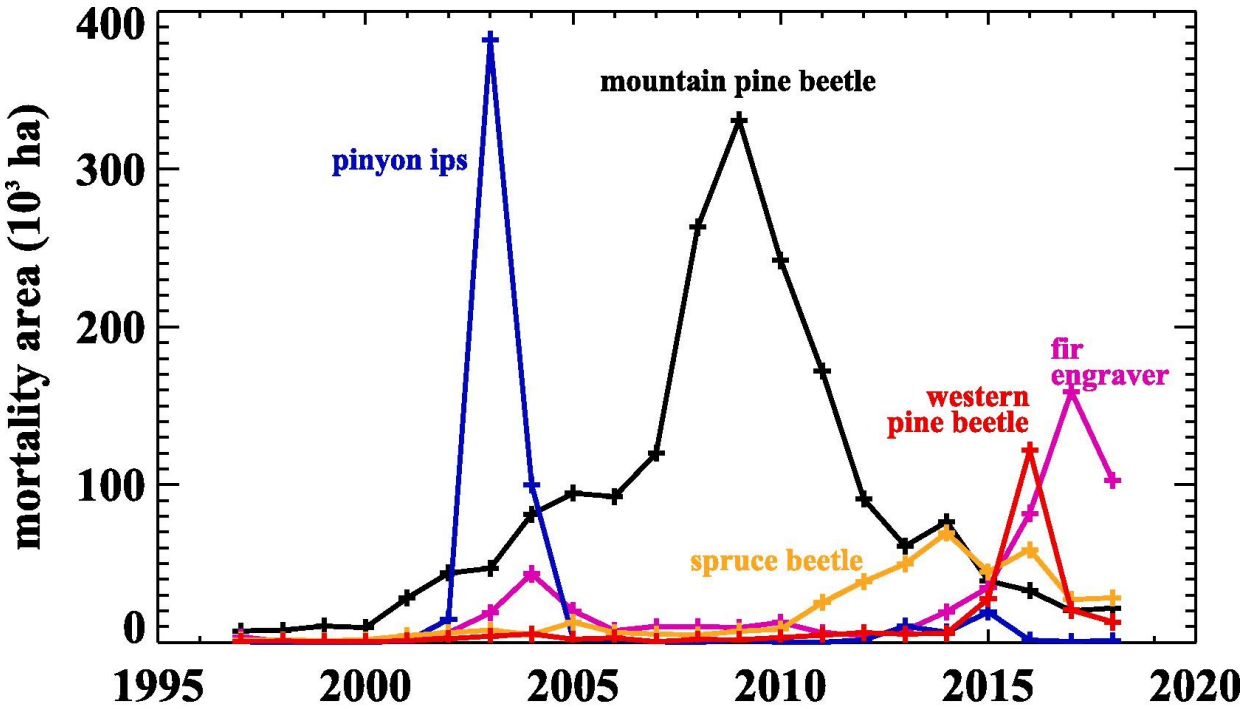
Western US

21 Year Footprint for Mountain Pine Beetle = 26.7M Acres

21 Year Footprint for All Western Bark Beetles = 59.2M Acres

Many areas of pest activity overlap from year to year. The footprint area is the cumulative area covered by pest activity with no double counting of acres between years.

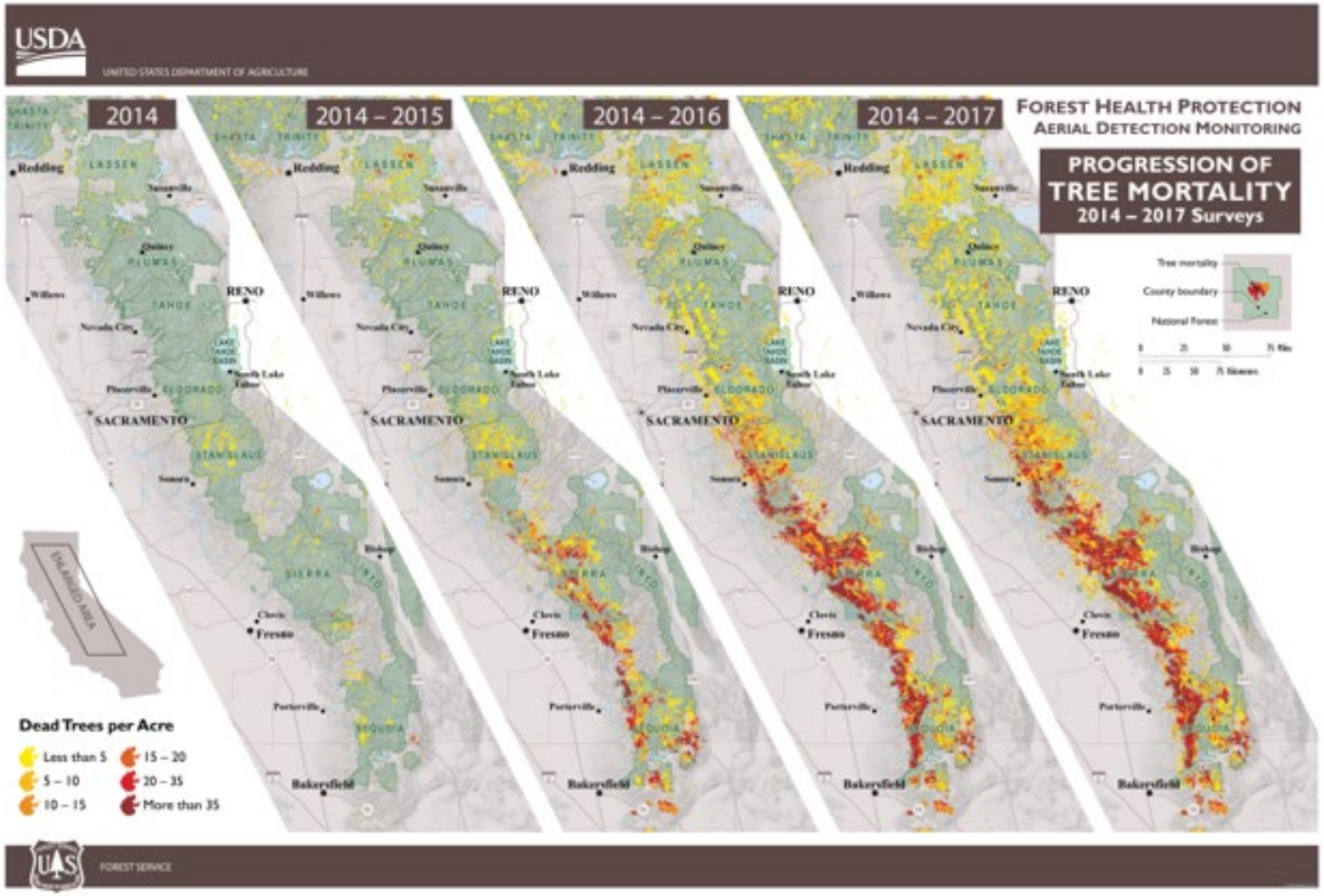


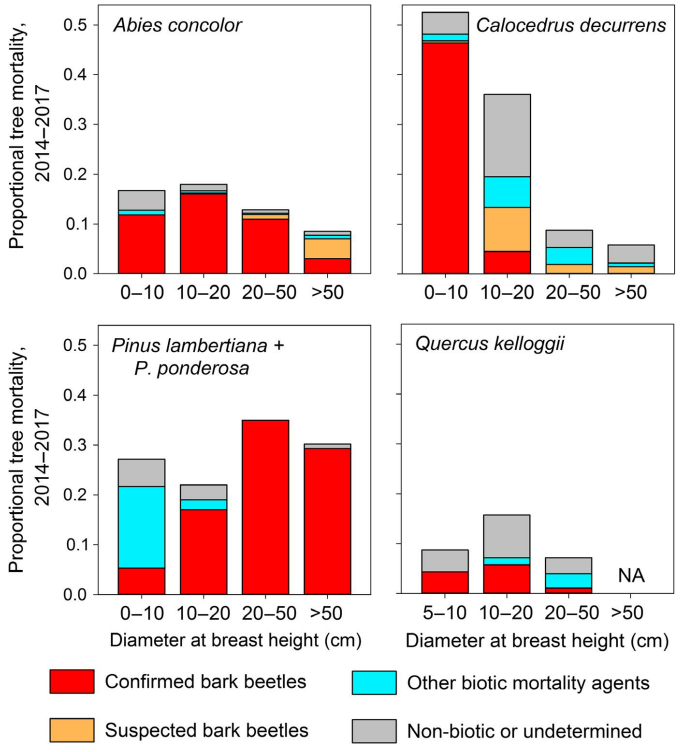


https://www.fs.fed.us/foresthealth/technology/pdfs/MpbWestbb_Summary.pdf

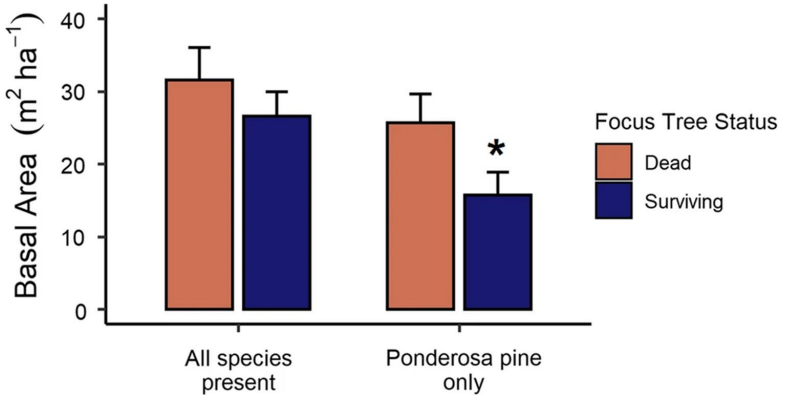
Hicke et al. 2020

USDA National Forests in California

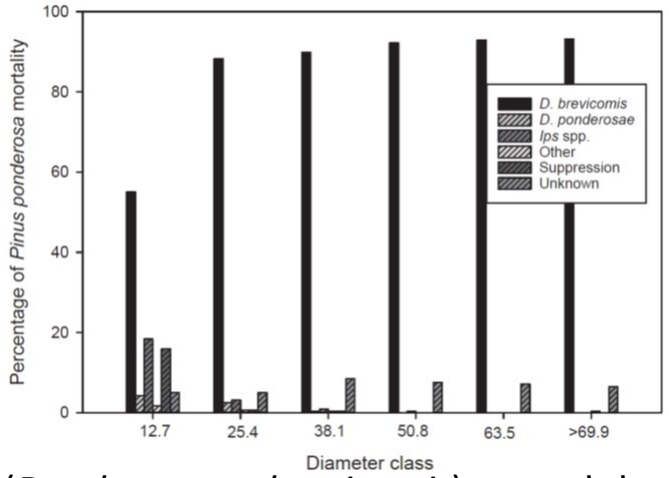




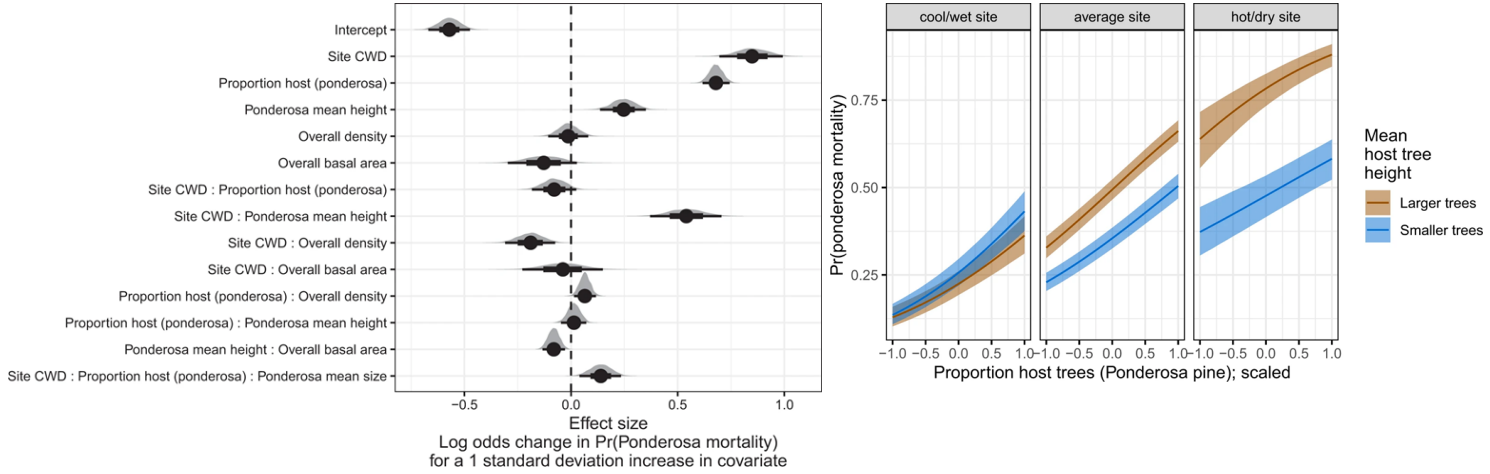
Bark beetles were the proximate cause of tree mortality during the 2012-2017 CA drought, but the size and vigor of trees differed by tree taxa (*Stephenson et al. 2019*).



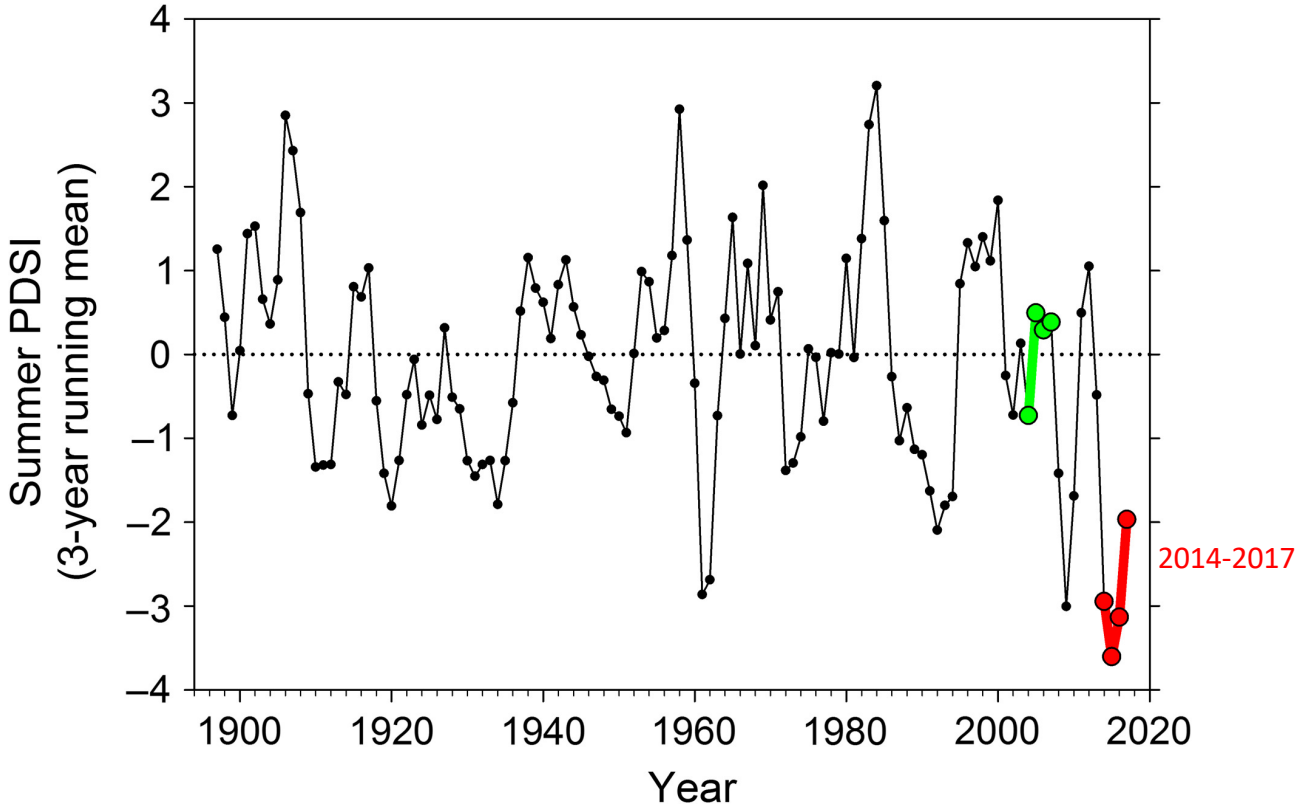
Ponderosa pine in stands with greater BA of ponderosa pine were more likely to be attacked and killed, but the fastest growing of the large trees could also be the most resilient (*Keen et al. 2020*).



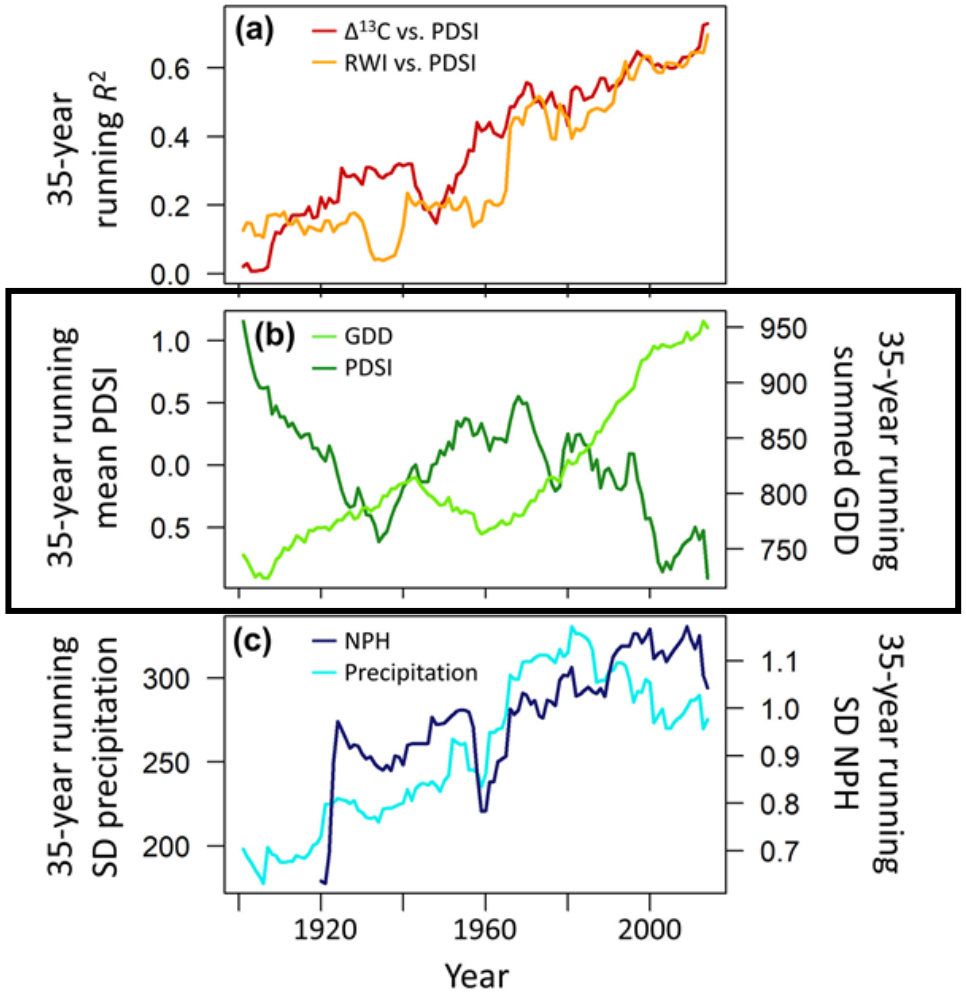
Western pine beetle (*Dendroctonus brevicomis*) caused the majority of ponderosa pine mortality, particularly in large trees (*Fettig et al. 2019*).



Ponderosa pine was more likely to be attacked and killed at low elevations and at sites with a high climatic water deficit (CWD) indicating high plant stress (*Koontz et al. 2021*).



Stephenson et al. 2019



Keen et al. 2021

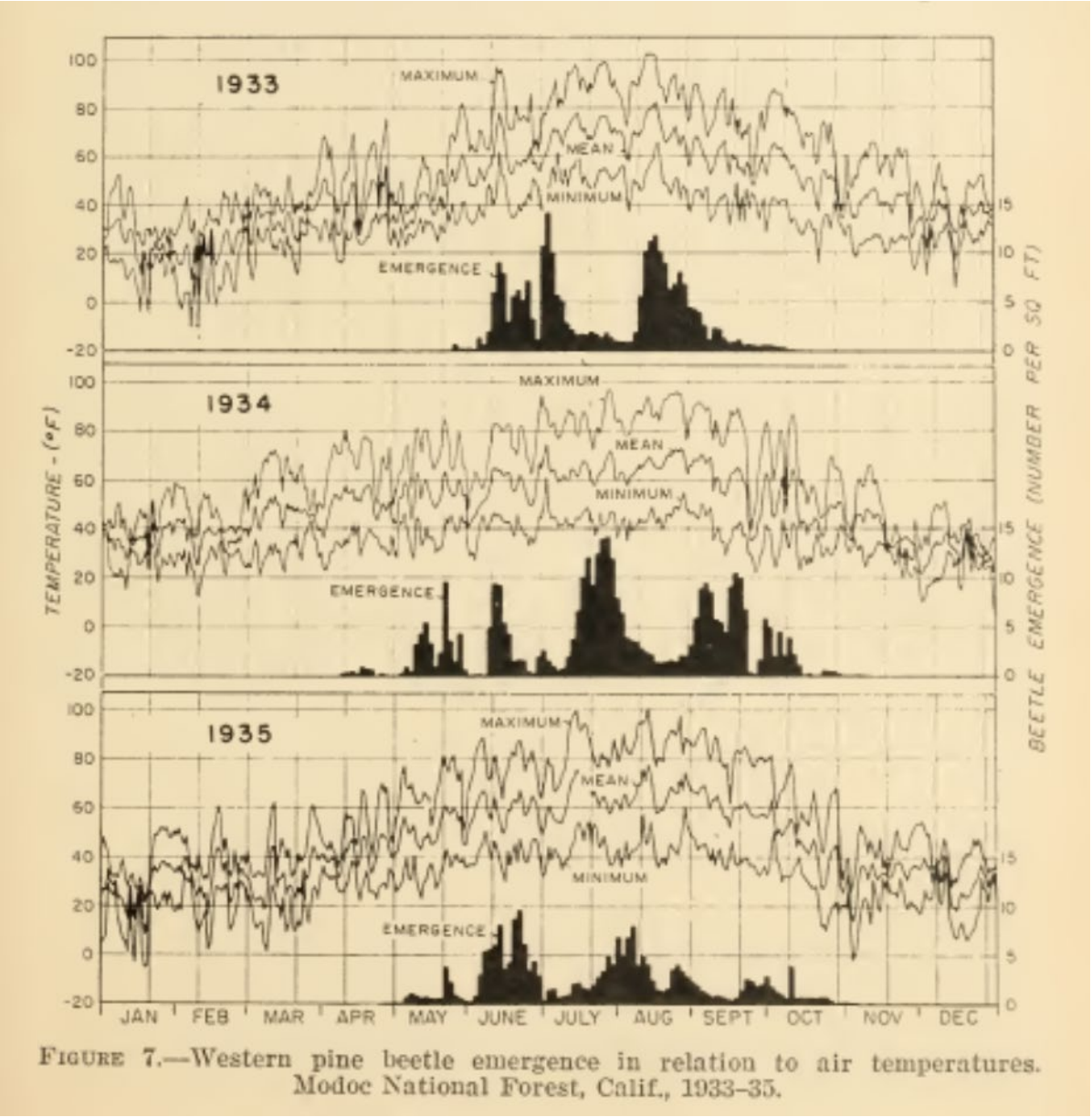
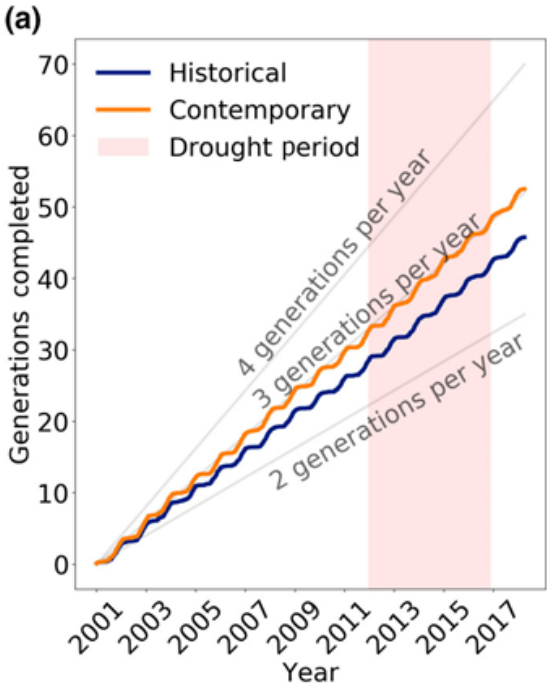


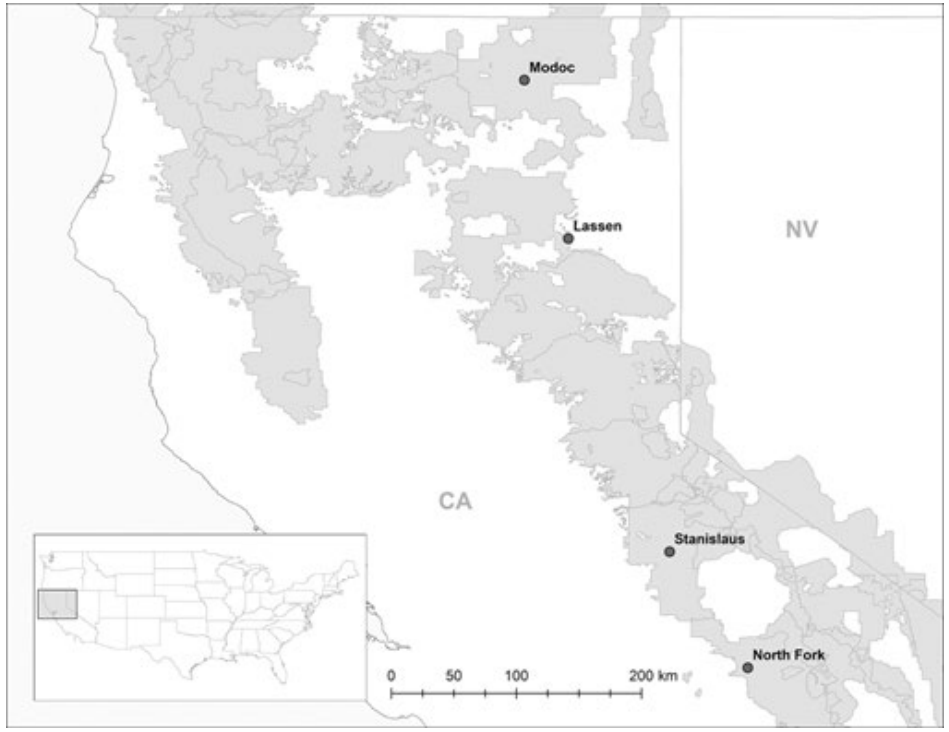
FIGURE 7.—Western pine beetle emergence in relation to air temperatures. Modoc National Forest, Calif., 1933–35.

Miller and Keen 1960
Biology and Control of the Western Pine Beetle



"During the drought period, voltinism increased an average of 1.46 generations per sub-region (~0.36 generations year−1) when comparing contemporary and historical temperatures" (*Robbins et al. 2021*).

Western pine beetle lifecycle timing study sites



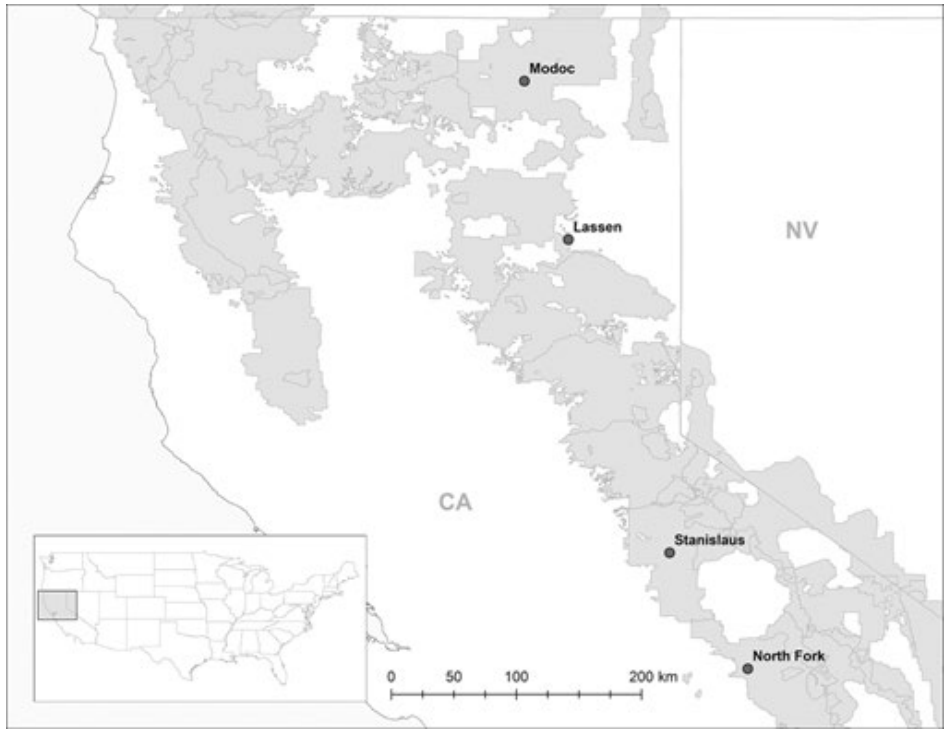
Attacks monitored weekly

Air temperature

Adult emergence monitored weekly

2017 - 2019

Western pine beetle lifecycle timing study sites

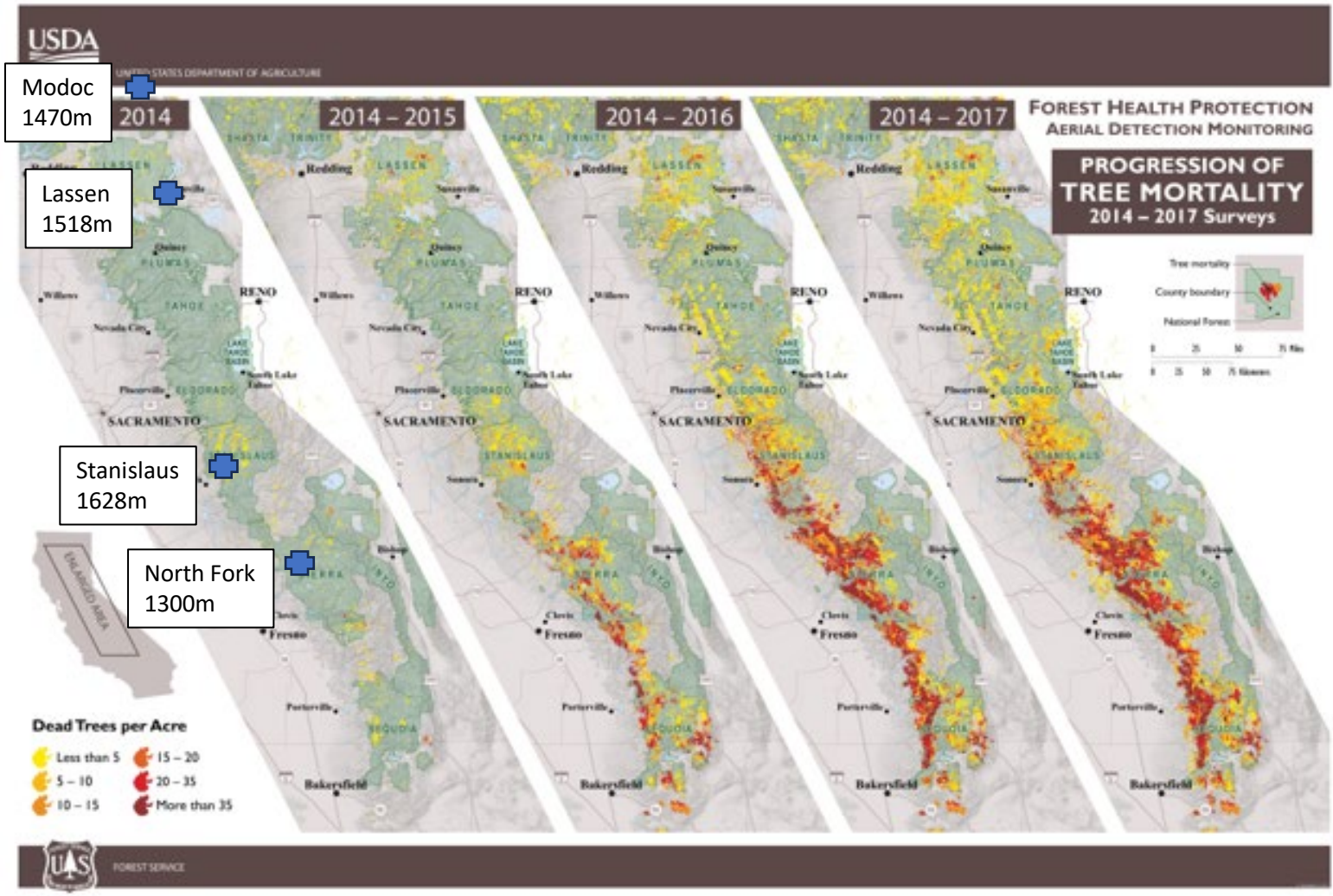


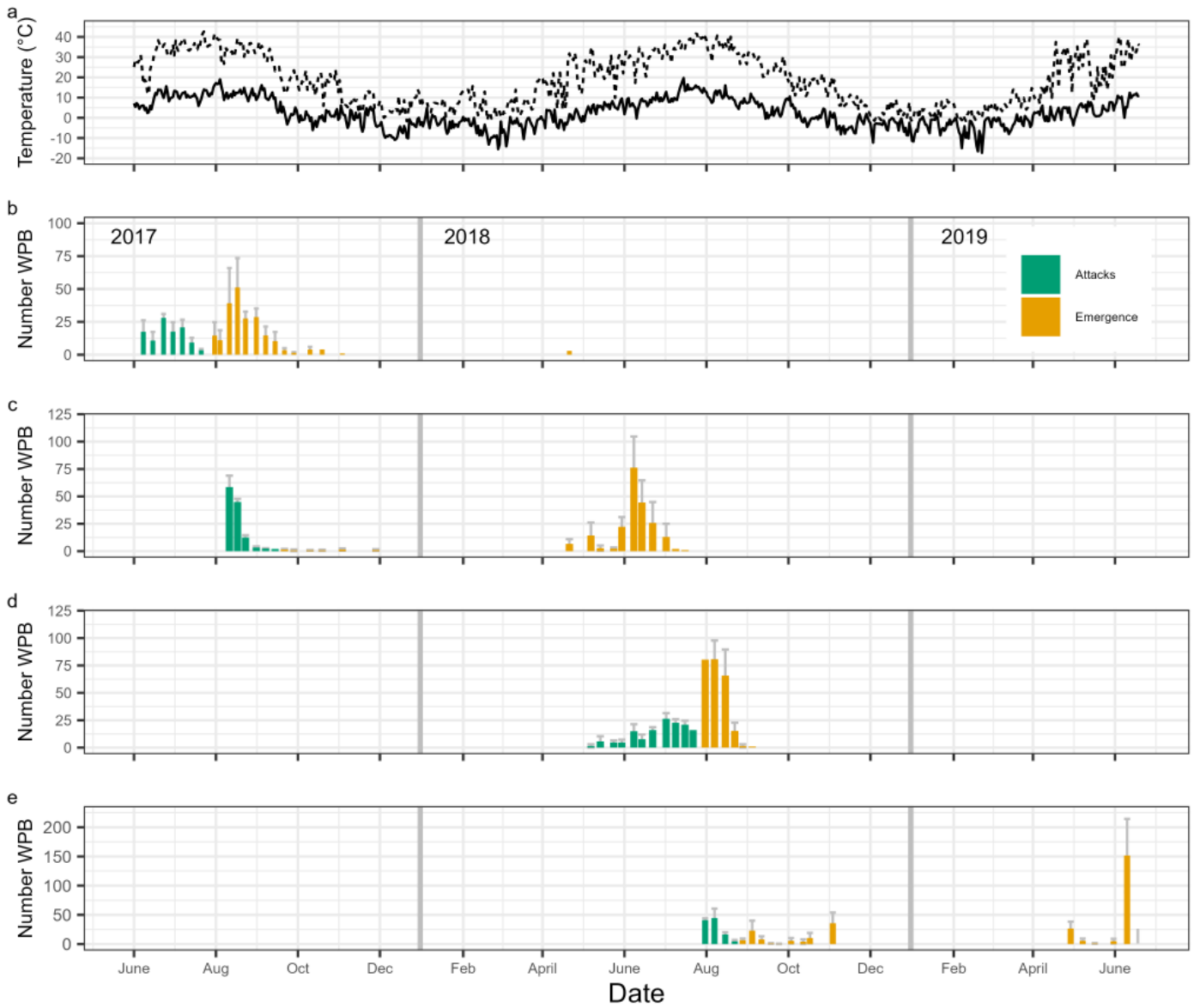
Modoc
1470m

Lassen
1518m

Stanislaus
1628m

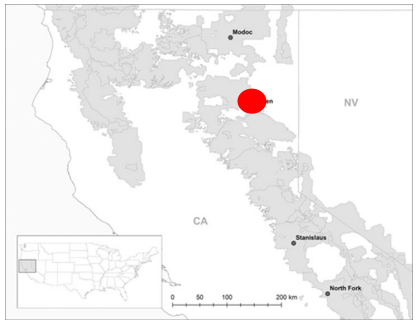
North Fork
1300m



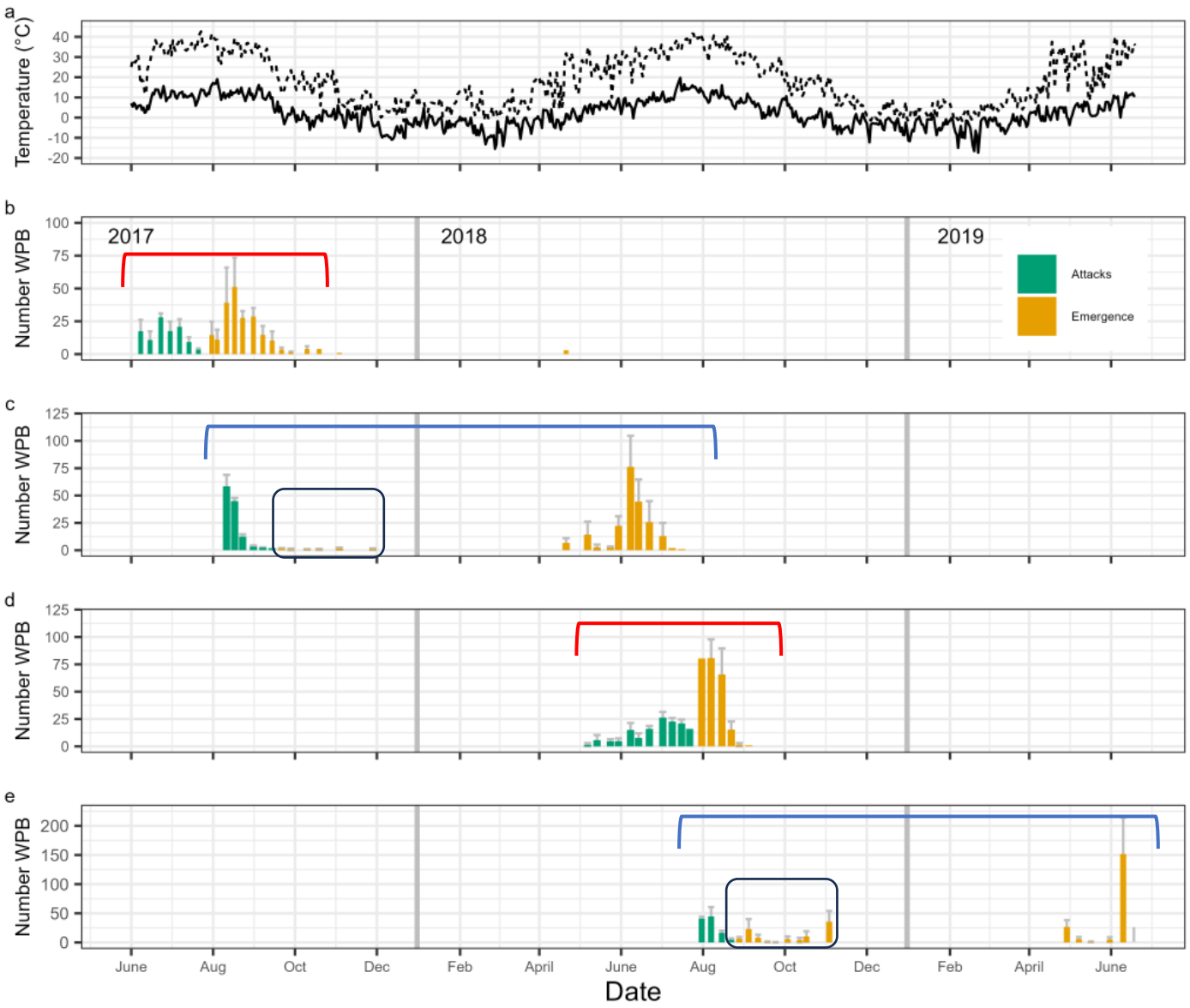


Western pine beetle
Life-cycle timing
Lassen National Forest
1500-1600 meters

2017 - 2019



Bentz et al. 2023



Western pine beetle
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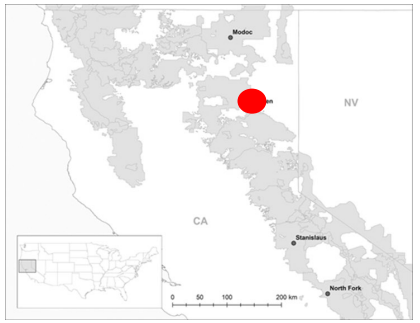
1500-1600 meters



1 full summer generation
1 overwinter generation
partial generation

Partial generation : < 100% adult emergence from a late summer/fall cohort

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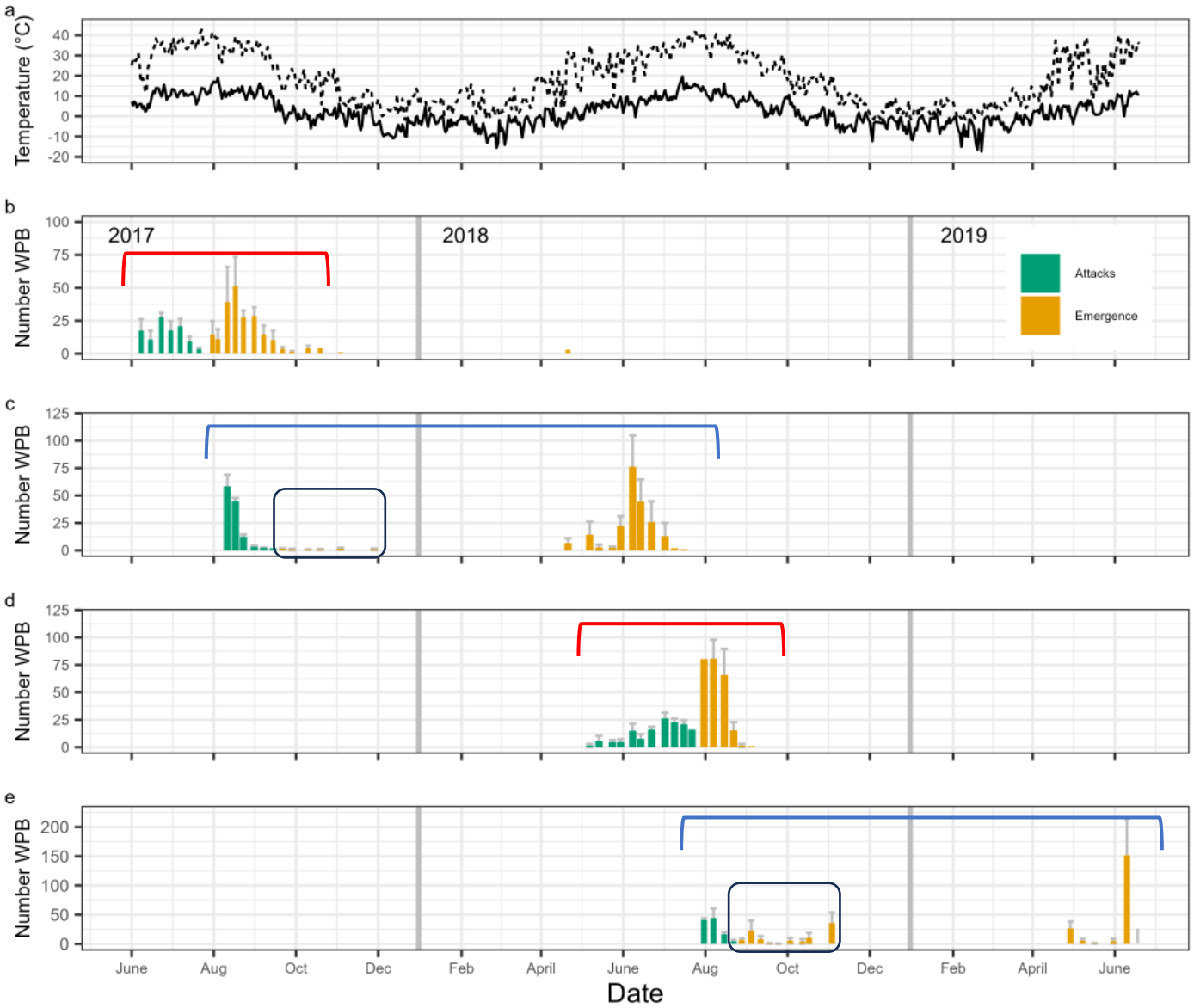

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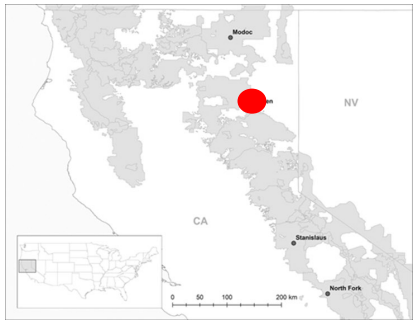
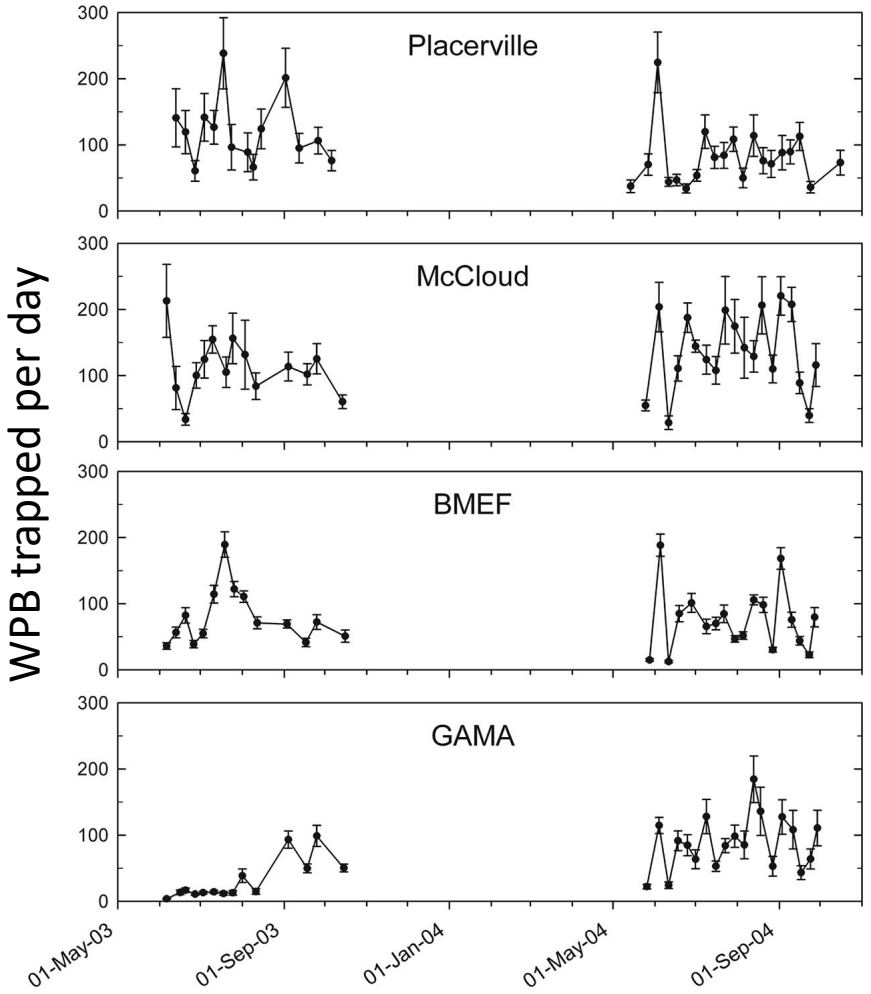
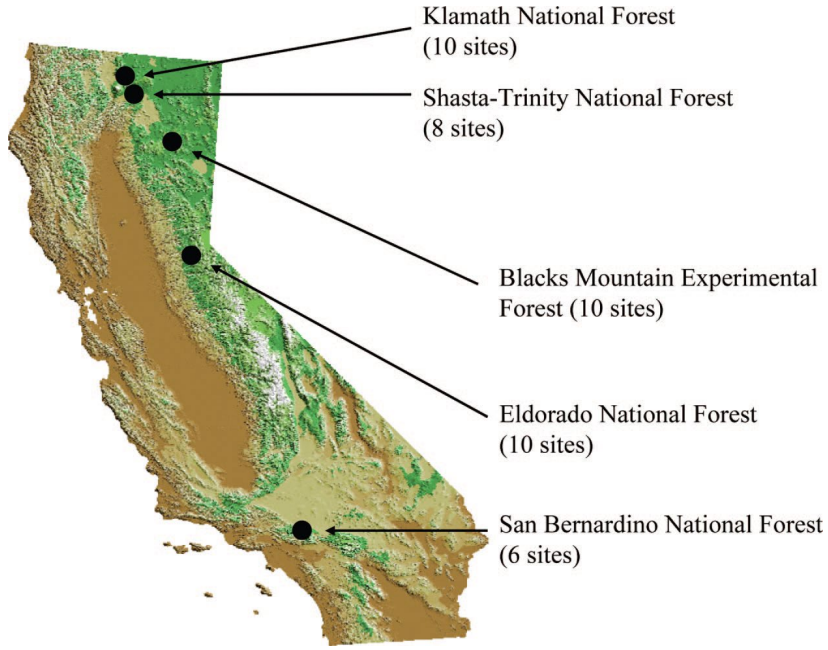


"Parent adult beetles re-emerged to the extent of 53.6% of attacking population. Parent adult emergence…reached its peak when the larvae were half grown…"
Miller and Keen 1960

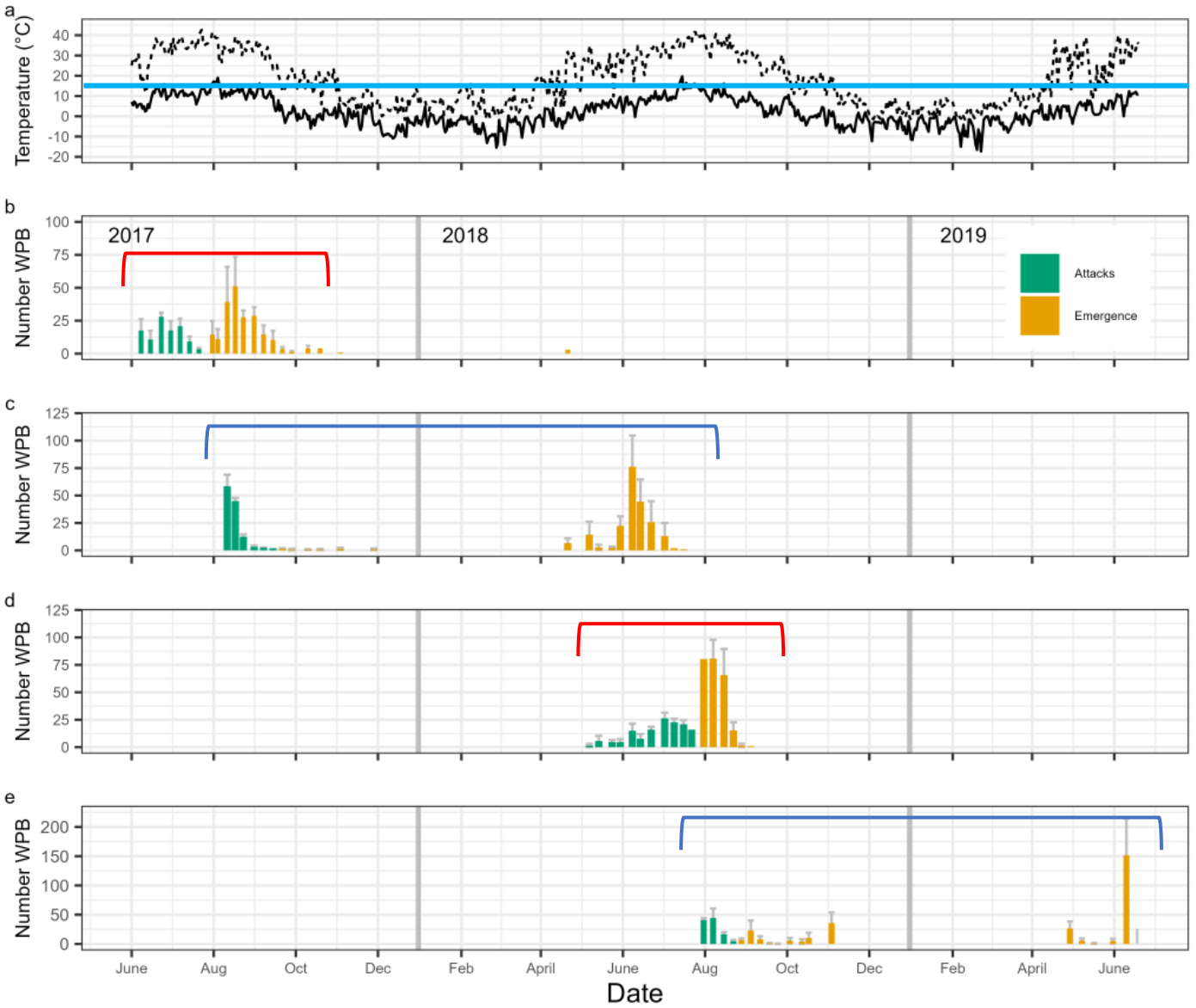
Bentz et al. 2023





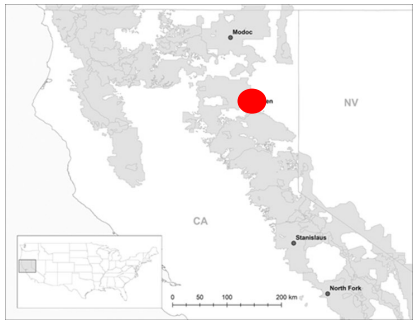
Western pine beetle pheromone traps tend to catch adults continuously - likely due to catches of both brood adults and re-emerged parents.

Hayes et al. 2009



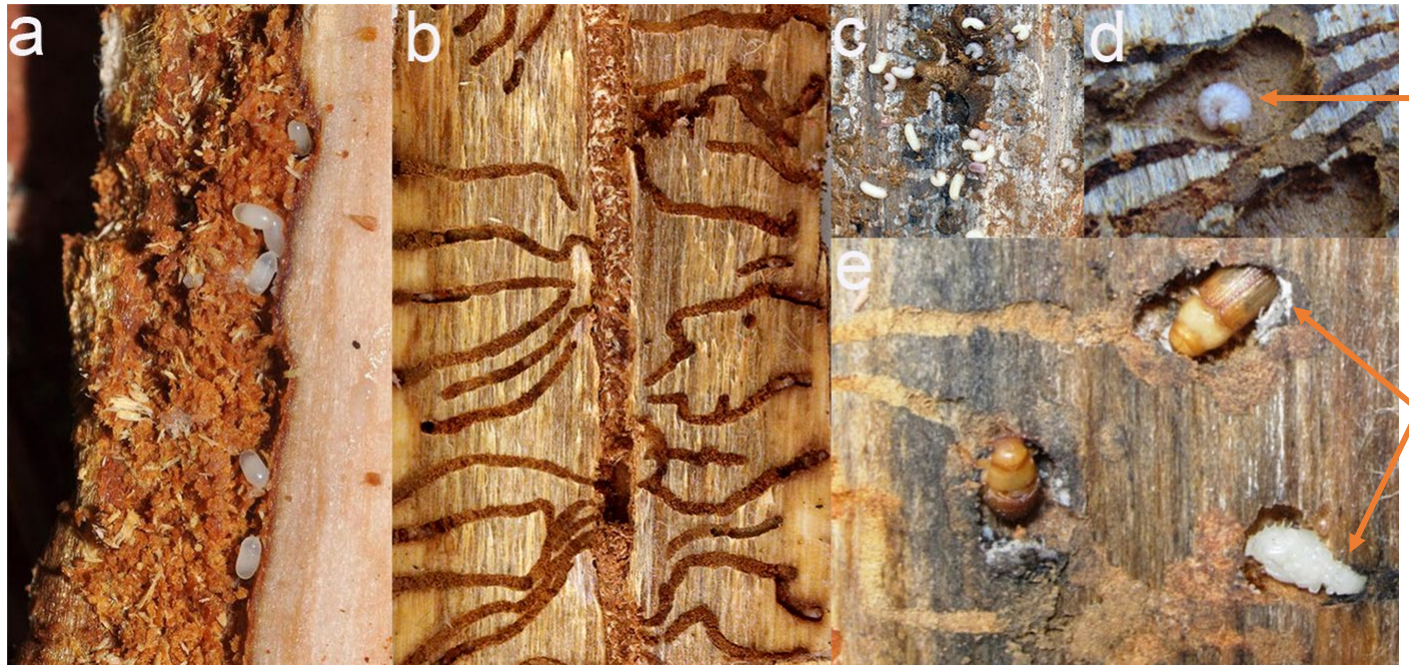
15°C

Western pine beetle
Life-cycle timing
Lassen National Forest
1500-1600 meters

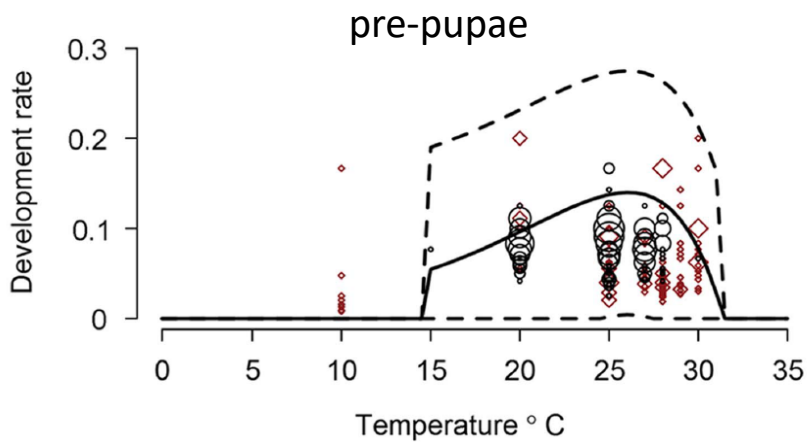


"Apparently prepupal larvae have a considerably higher temperature requirement for transformation than do the other stages of this insect."
Miller and Keen 1960

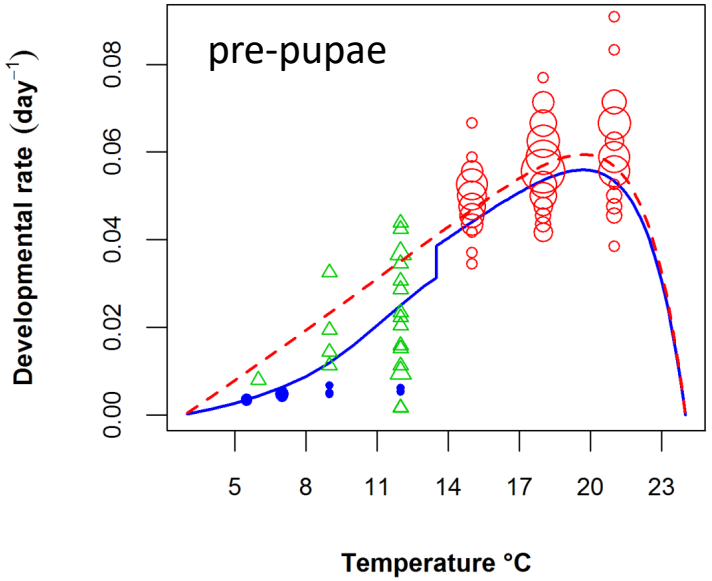
Bentz et al. 2023



A pre-pupal diapause has been described in 3 *Dendroctonus* species: *D. ponderosae*, *D. rufipennis*, and *D. micans*.



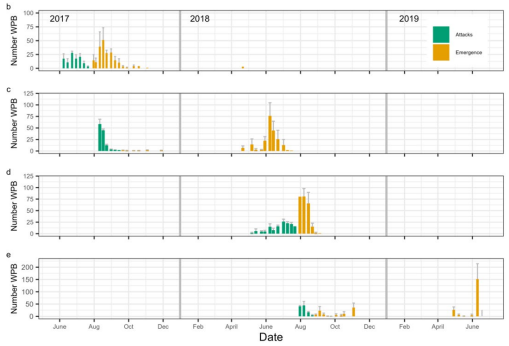
Mountain pine beetle (*Dendroctonus ponderosae*)

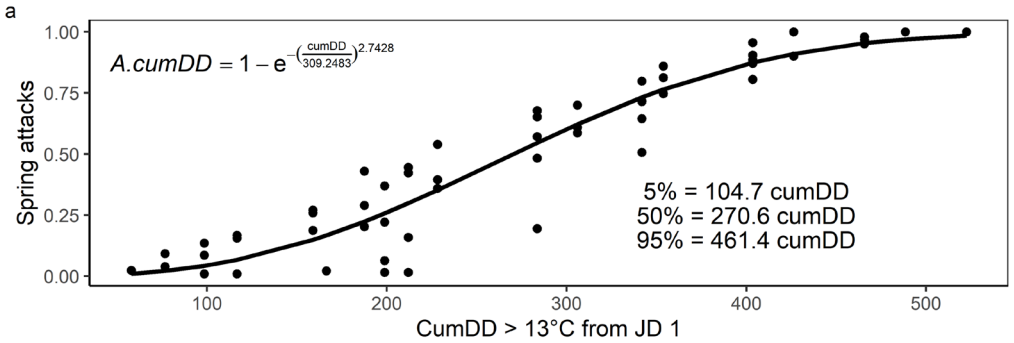


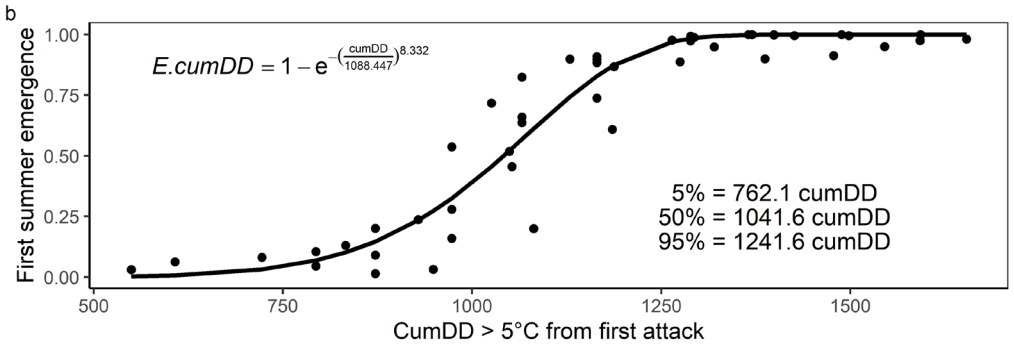
Spruce beetle (*Dendroctonus rufipennis*)

Dyer 1970
Hansen et al. 2011
Bentz and Powell 2014
Bentz and Hansen 2017
Gent et al. 2017
McManis et al. 2018
Bentz et al. 2021

Degree Day (DD) Model Development







1. Predict the distribution of attacks following an overwinter generation using DDs accumulated from 1 January fit to a Weibull distribution. Different low temperature thresholds were tested.

2. Accumulate DDs from the first attack to predict adult emergence of the first summer generation.

3. Accumulate remaining DDs for predicting adult emergence for a second summer generation.

4. Repeat step 3 to test for additional summer generations.

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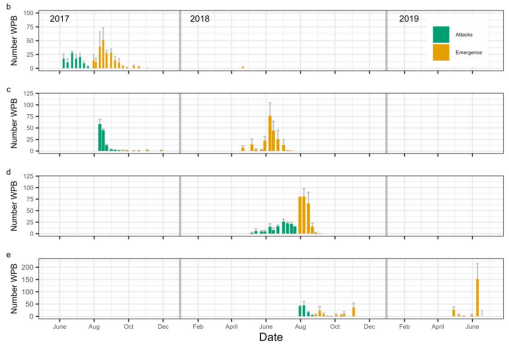
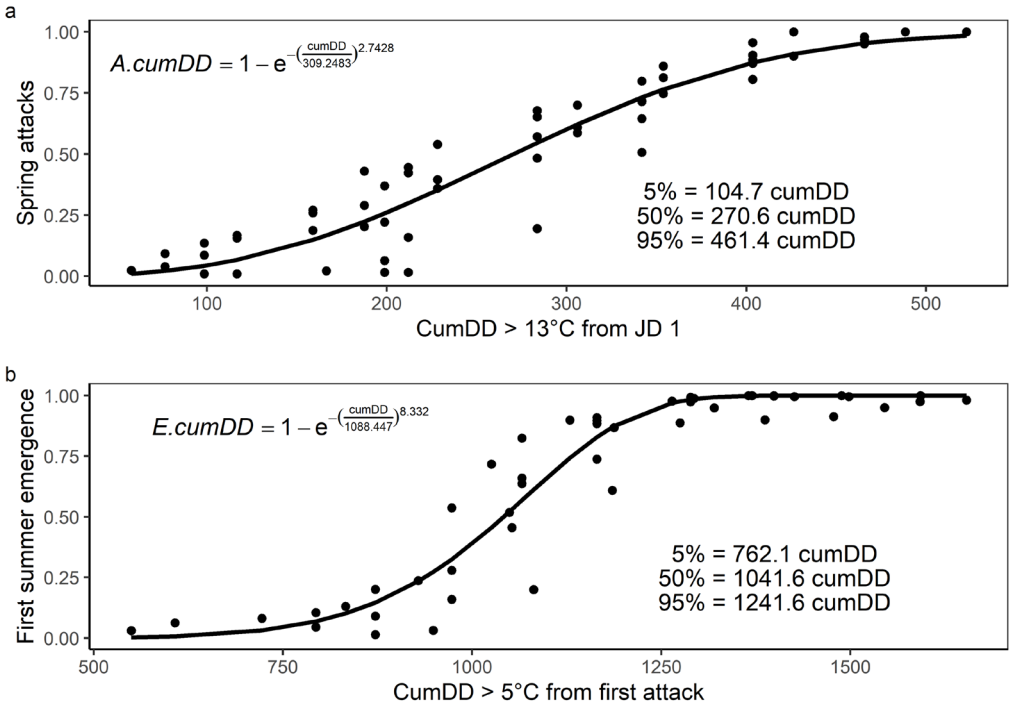
Degree Day (DD) Model Development





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Combined Model

Site Year	Adj. R^2	Prediction
Lassen 2017	0.72	1 summer generation + < 30% partial
Lassen 2018	0.74	1 summer generation + < 30% partial
Stanislaus 2017	0.82	1 summer generation + > 91% partial
Stanislaus 2018	0.70	1 summer generation + > 91% partial

Historical (1900 to 2022) and future temperatures for each site were estimated using BioSIM 11.0 (Régnière et al. 2017).

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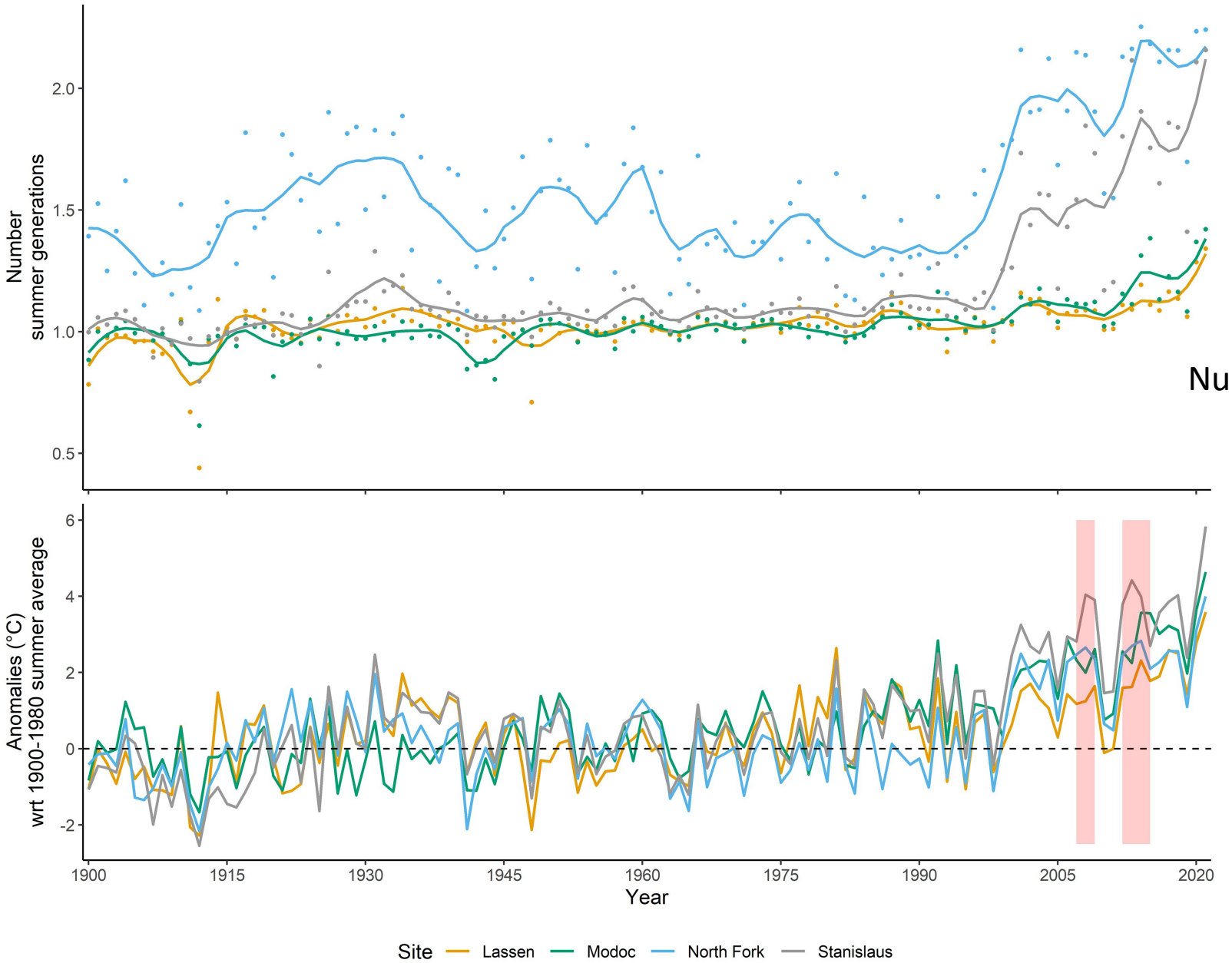
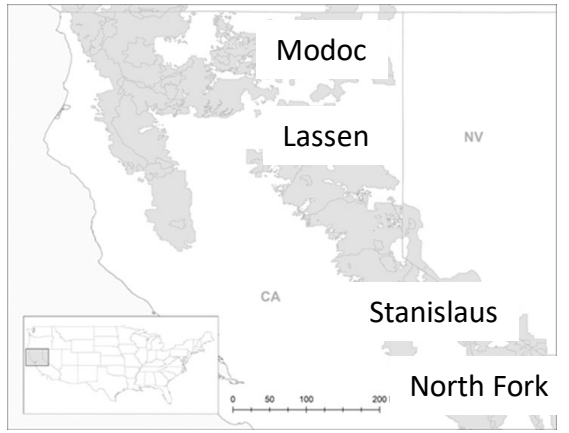
Model Predictions





Number of summer generations

Anomalies in temperature relative to 1900 – 1980 summer average

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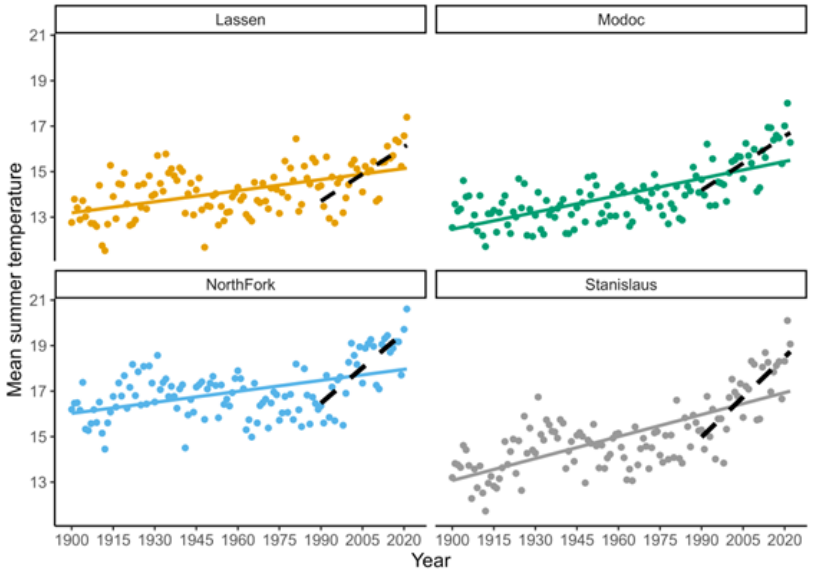
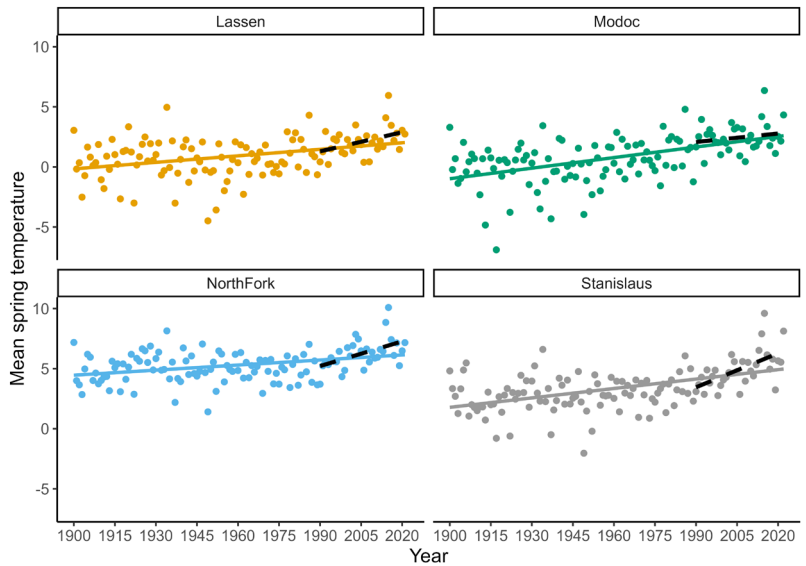
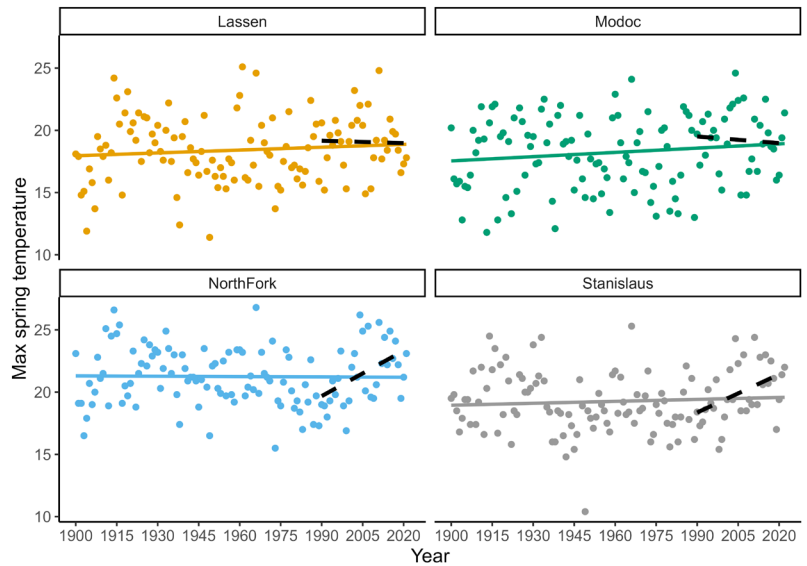
Mean summer T



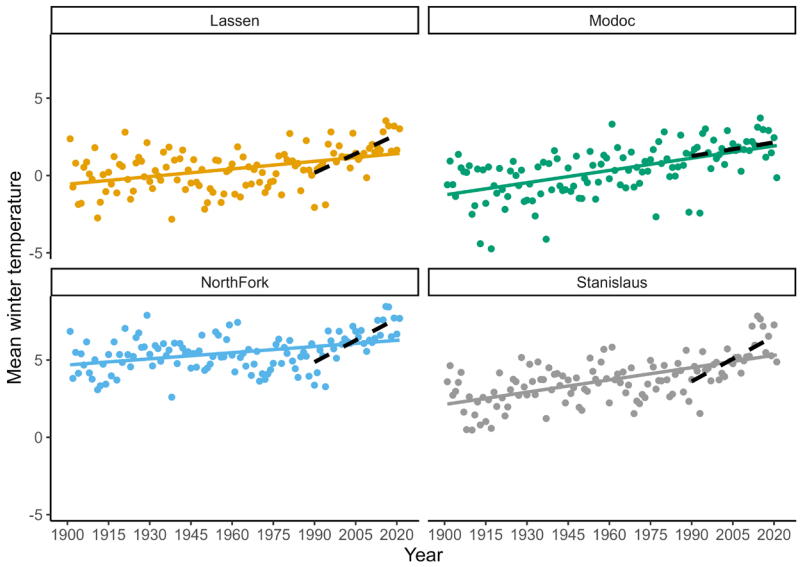
Mean spring T



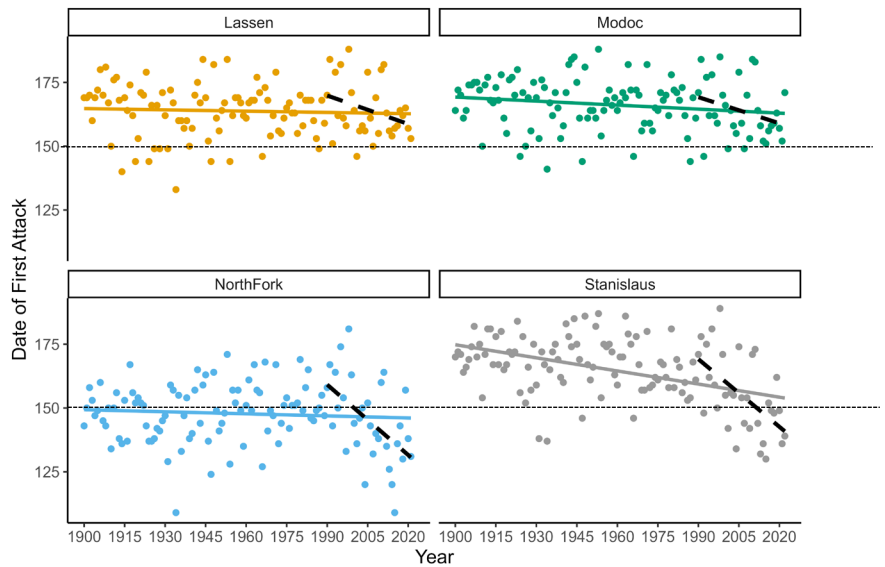
Max spring T



Mean winter T



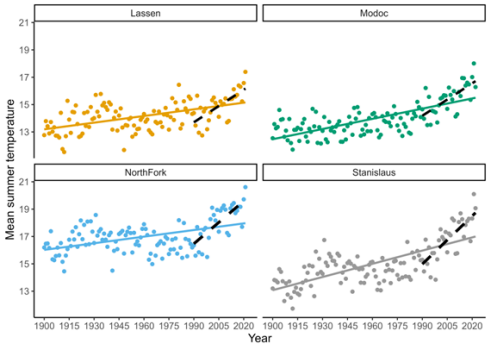
Predicted Date of first attack in spring/summer



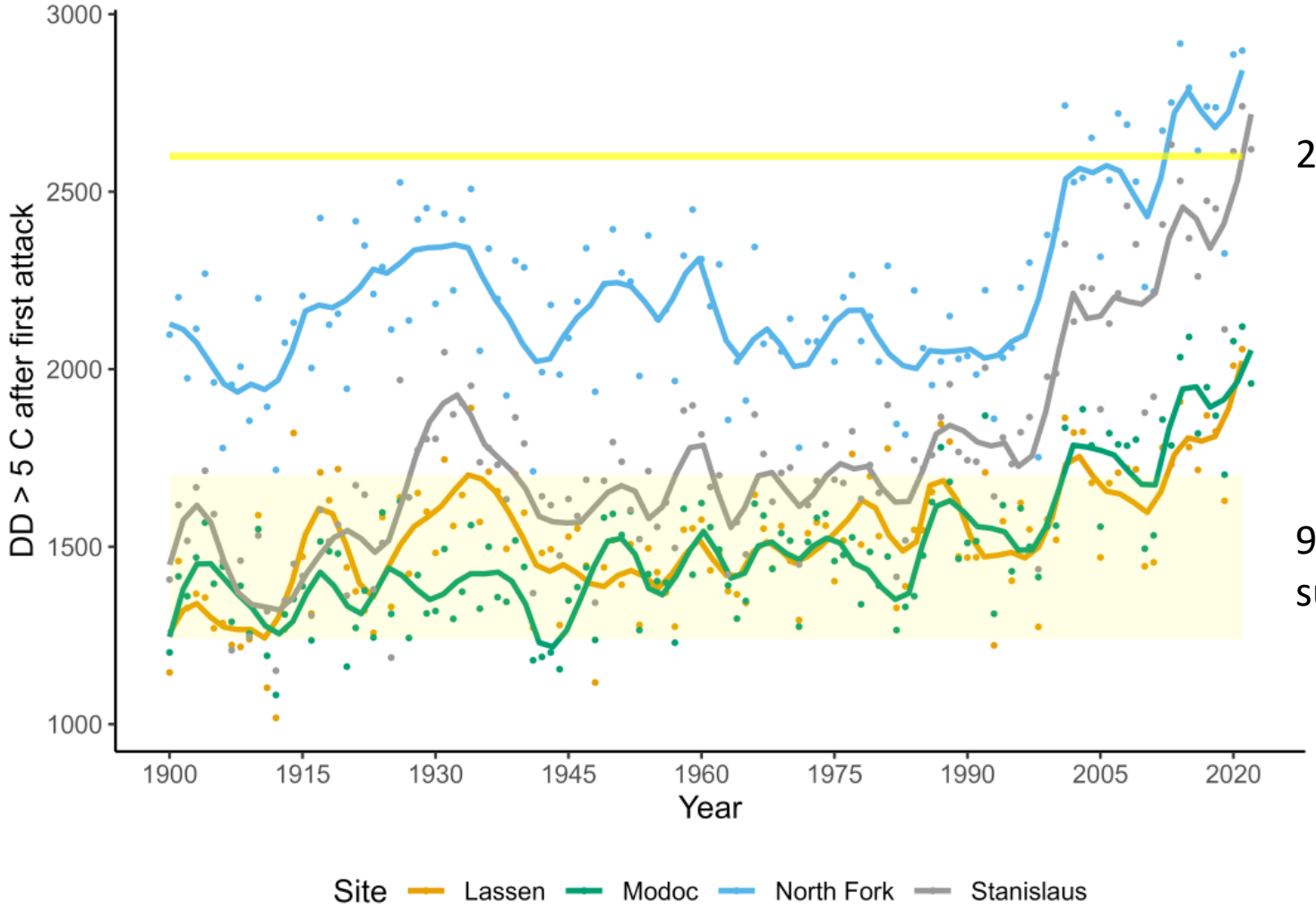
May 1

May 1

Change in mean summer temps



Summer DDs > 5°C



2 summer generations

95 to 100% probability of 1 summer generation

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Historical temperatures 1900 - 2021

Site	Mean annual temperature (°C) 1900-1980	cumDD > 5 1900-1980 mean annual	Summer generations 1900-1980	cumDD > 5 2021	cumDD > 5 change from 1900-1980 to 2021	Summer generations 2021
Lassen	7.9	1466.5	1.0	2056.4	590	1.3
Modoc	7.6	1403.9	1.0	2120.0	716	1.4
North Fork	11.7	2147.6	1.5	2897.4	750	2.2
Stanislaus	9.4	1618.7	1.1	2740.4	1122	2.1

Projected climate normals

Site	Mean annual temperature (°C) 2041-2070	cumDD > 5 2041-2070	Summer generations 2041-2070	Mean annual temperature (°C) 2071-2100	cumDD > 5 2071-2100	Summer generations 2071-2100
Lassen	12.0	2231.0	1.7	14.1	2726.2	2.2
Modoc	12.6	2344.3	1.8	14.3	2657.6	2.2
North Fork	16.4	3253.9	2.9	17.3	3544.7	3.2
Stanislaus	14.3	2701.7	2.2	16.3	3206.4	2.6

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Stanislaus	14.3	2701.7	2.2	16.3	3206.4	2.6

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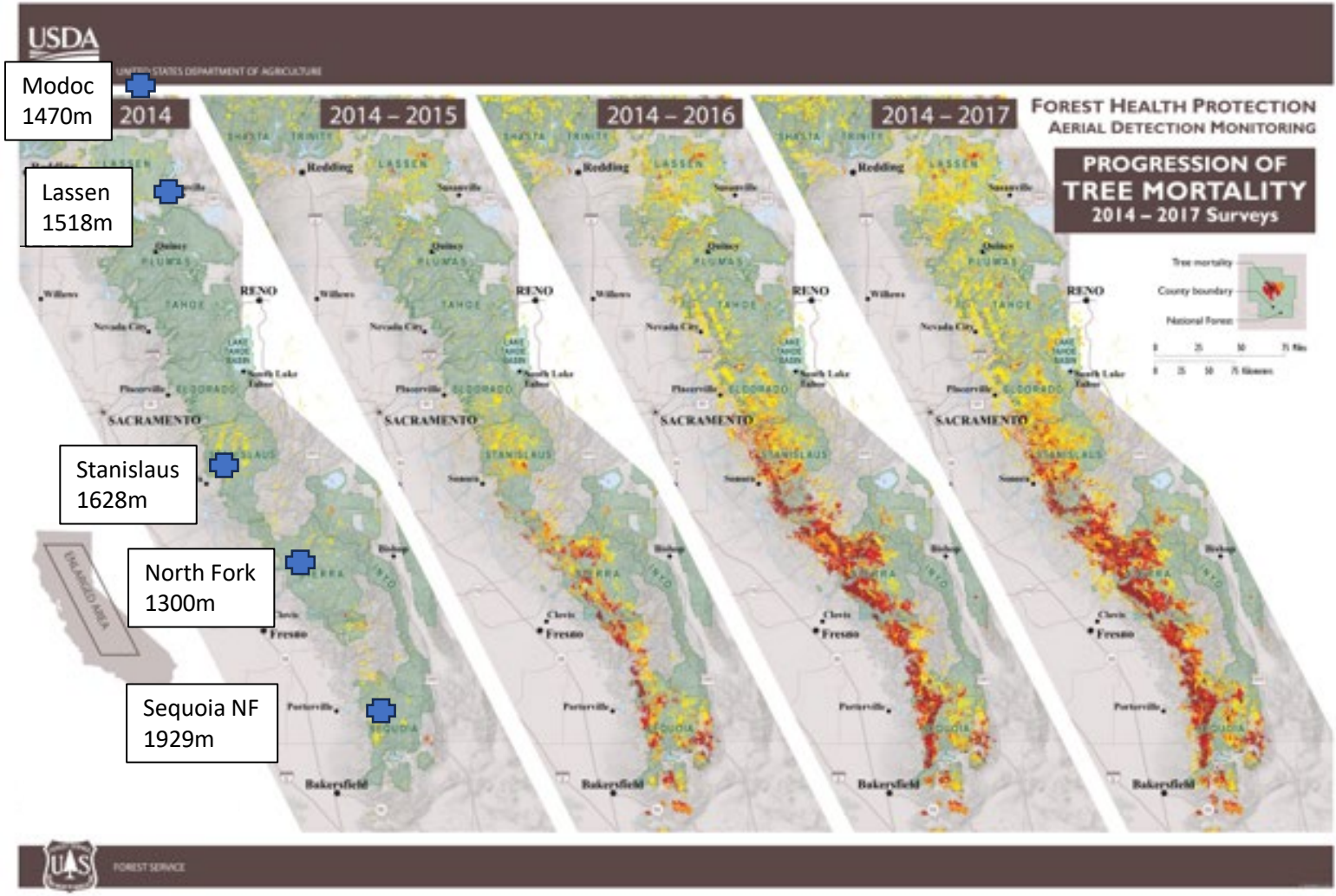
Predicted Summer Generations

1900-1980	2021	
~ 1.0	1.4	Modoc 1470m
~ 1.0	1.3	Lassen 1518m
~ 1.1	2.1	Stanislaus 1628m
~ 1.5	2.2	North Fork 1300m
~ 1.0	1.3	Sequoia NF 1929m



SUMMARY

Relative to historical temperatures, summer temperatures at our study sites have warmed, particularly in the last 2 decades. Degree Day model predictions suggest this warming has altered western pine beetle lifecycle timing.

The warmer the site the greater increase in emergence of a partial fall generation. In 2021 our two most southern sites were predicted to have two full summer generations; one summer and < 50% of partial generation were predicted at the two more northern sites. All sites had a single generation overwinter.

Temperatures were not sufficient for an additional generation overwinter and physiological adaptations (i.e., a potential pre-pupal diapause) will likely limit additional winter generations in a future climate.

By the middle of this century, based on climate change temperature projections, model predictions suggest ~2-3 summer generations may occur at our sites, depending on the elevation and latitude of the site.

Re-emerged parents and individuals in partial summer generations are likely important to population outbreaks, particularly in drought years, but causal factors are unclear, and research is needed.

Please contact me with questions: barbara.bentz@usda.gov