Modeling the Interactions Among Climate, Vegetation, and Western Pine Beetle in the Sierra Nevada

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Los Alamos NATIONAL LABORATORY EST. 1943

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NNSA National Nuclear Security Administration

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'LA-UR-23-32896'

CA drought 2012-2016

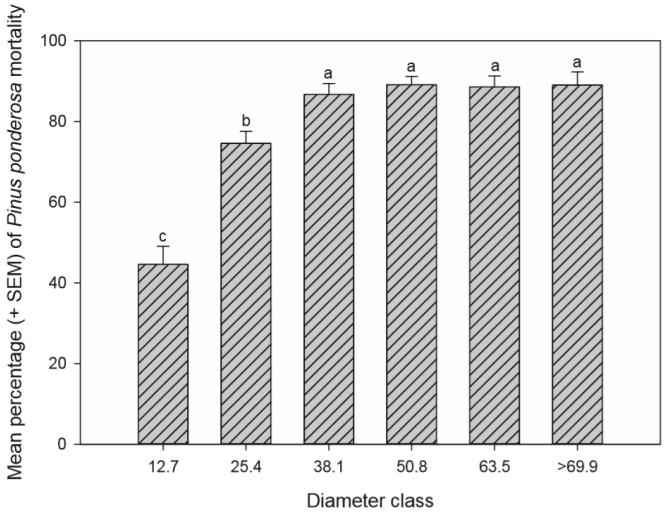
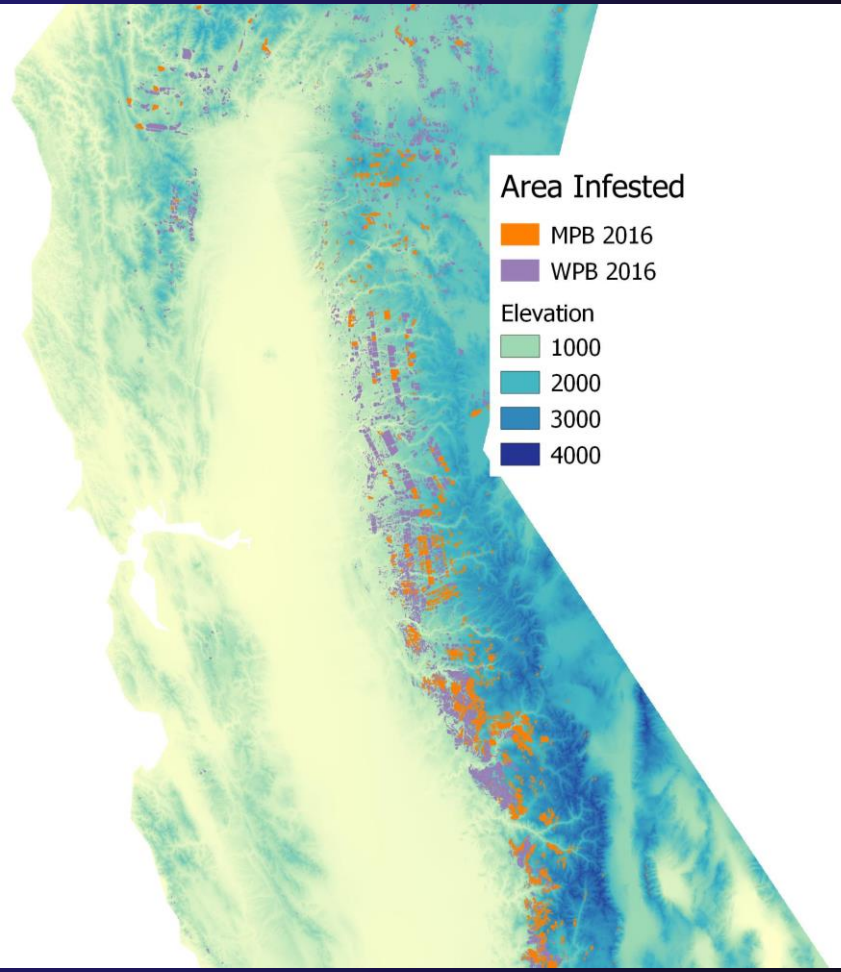


Fig. 4. Mortality of *Pinus ponderosa* by diameter class (mid-point of 12.7-cm diameter classes, except for largest) on the Eldorado, Stanislaus, Sierra and Sequoia National Forests, California, U.S. Means (+SEM) followed by the same letter are not significantly different ($P > 0.05$).

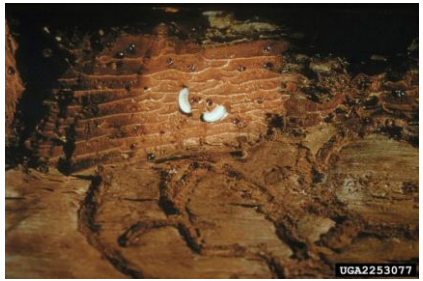


Fettig, C. J., Mortenson, L. A., Bulaon, B. M., & Foulk, P. B. (2019). Tree mortality following drought in the central and southern Sierra Nevada, California, US. *Forest Ecology and Management*, *432*, 164-178.

Non-linear response to climate.

Host stress

Climate



Population levels of insects

Host availability

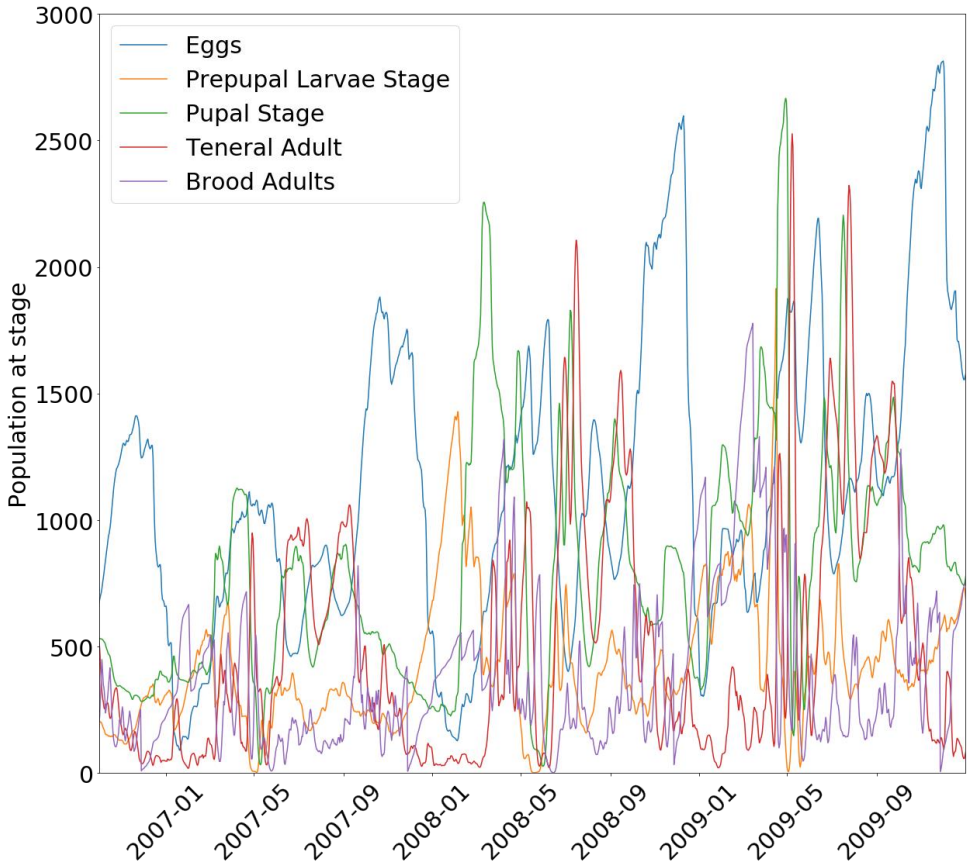
Insect mortality and phenology model (IMAP)

Simulates measured ectothermic response in insect growth.

Calculates mortality of insects from cold temperatures, competition.

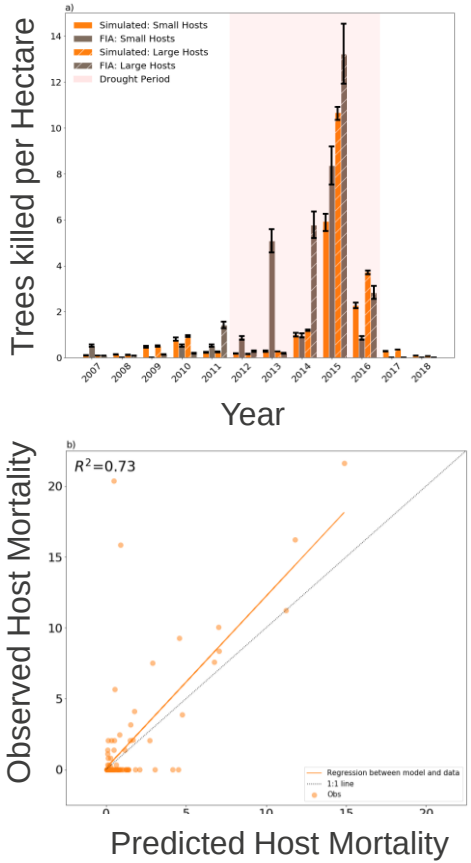
Simulates generations of beetles, growth, flight, and fecundity

In Sierra Nevada, correctly captures flight timing and generation rate.



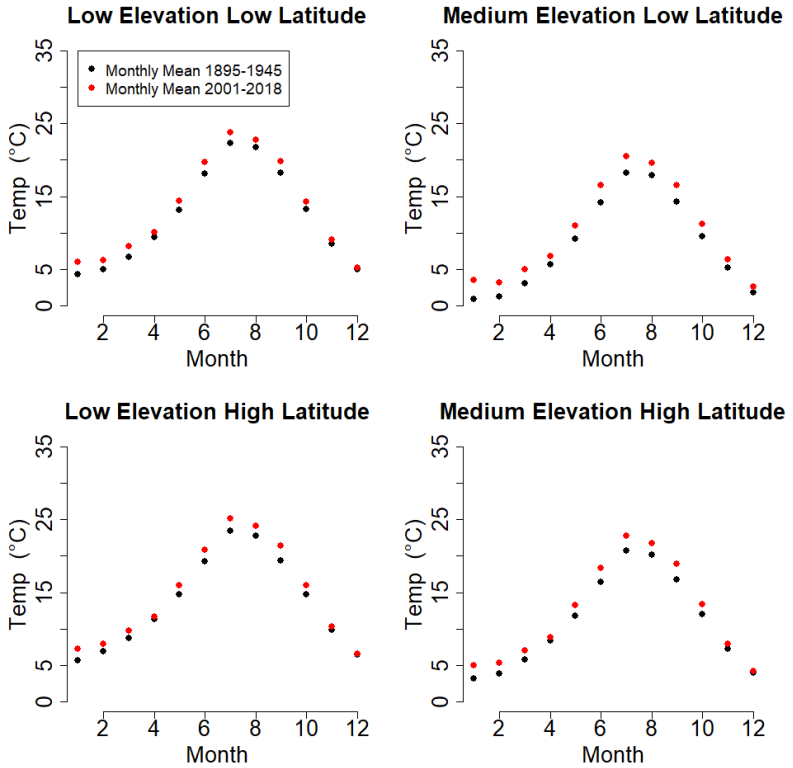
Tree defense and insect attack model (TDIA)

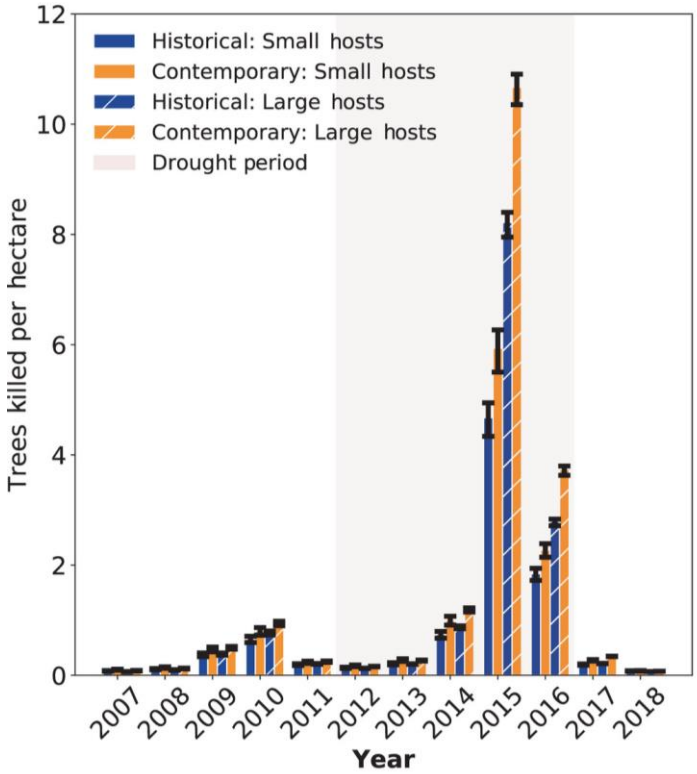
- Calculates the probability of mortality based on:
  - Insect population currently in flight (when beetles attack).
  - Insect flight behavior
  - The defense capability of the tree
    - Here modeled as 4-year SPI.

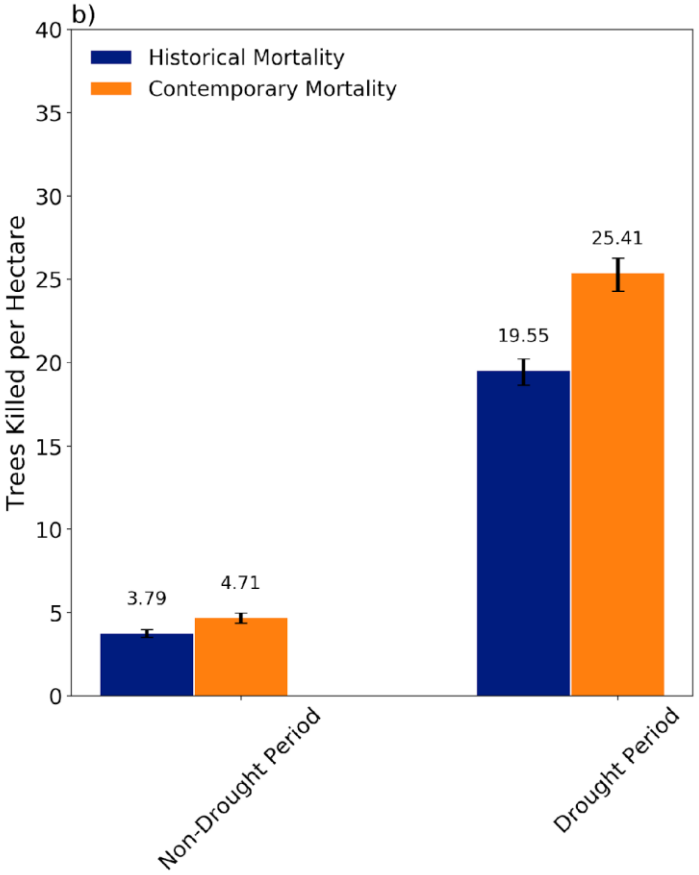


Study one: Effects of 20th century warming

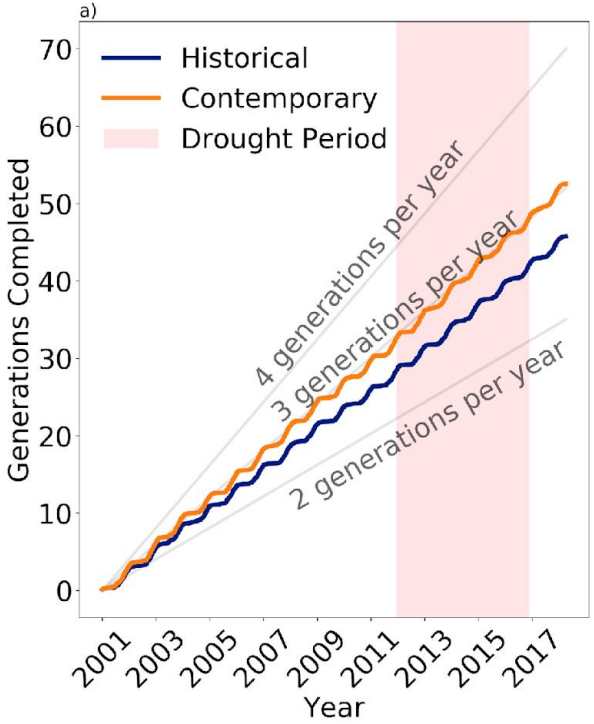
- Using IMAP-TDIA model understand the role warming temperatures play in ponderosa pine mortality.
- Re-run 2012-2016 drought with pre-industrial temperatures to understand the difference in mortality.

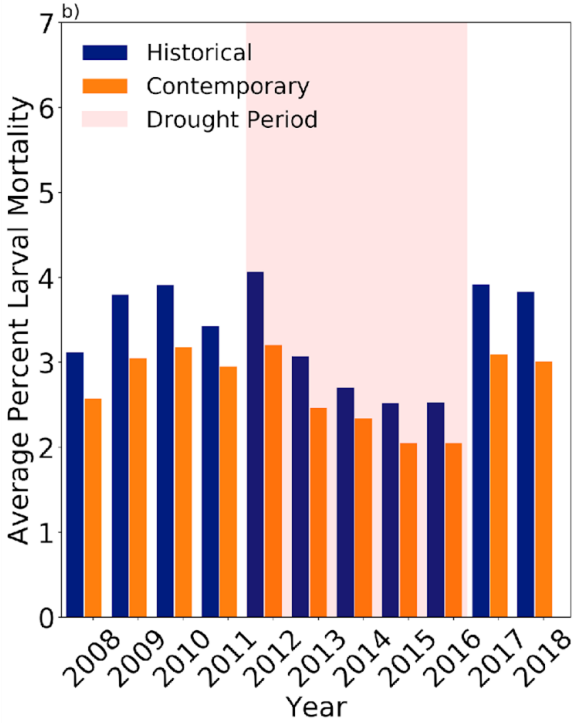



Historical: Small hosts
Contemporary: Small hosts
Historical: Large hosts
Contemporary: Large hosts
Drought period
Trees killed per hectare
0
2
4
6
8
10
12
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year


b)
Historical Mortality
Contemporary Mortality
Trees Killed per Hectare
0
5
10
15
20
25
30
35
40
3.79
4.71
19.55
25.41
Non-Drought Period
Drought Period

Mechanisms driving increased mortality



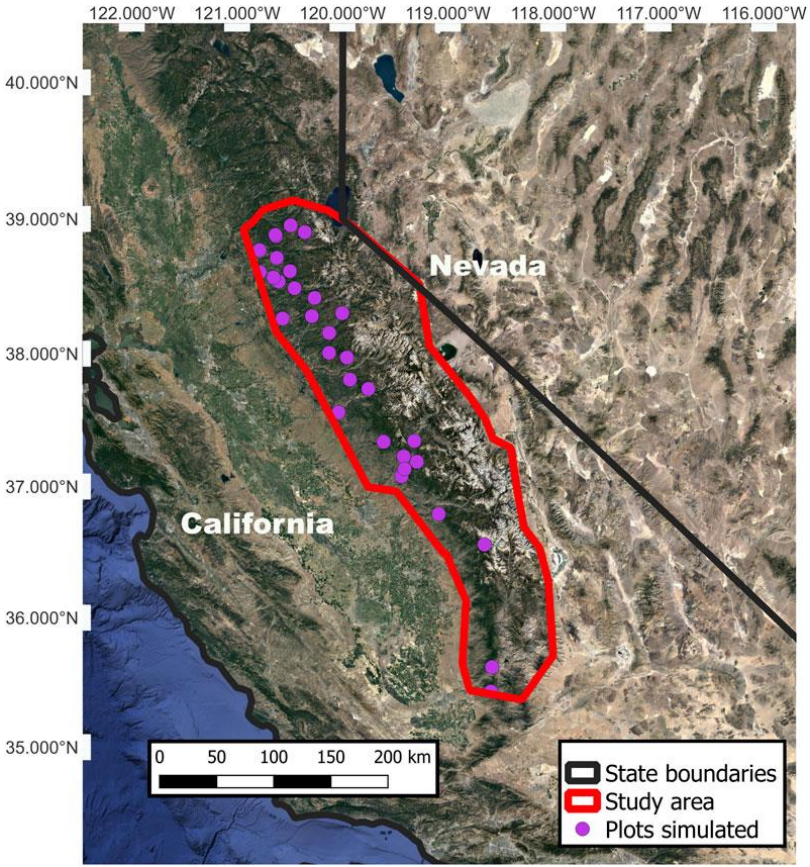


Take aways

- Warmer contemporary temperatures increased 2012-2016 mortality by 30 %
- This is primarily due to increased voltinism in western pine beetle, and to a lesser degree lower mortality.
- Warmer temperatures primarily result in more mortality under periods of drought stress.

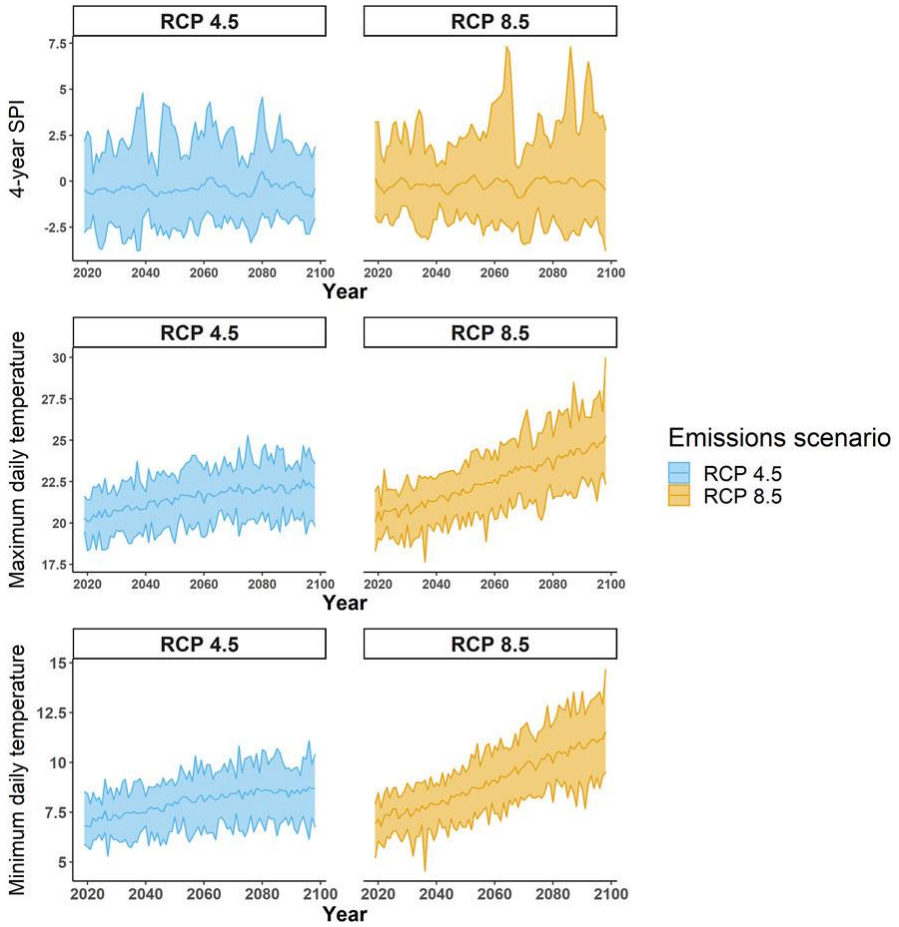
Study 2: WPB outbreak under climate change scenarios

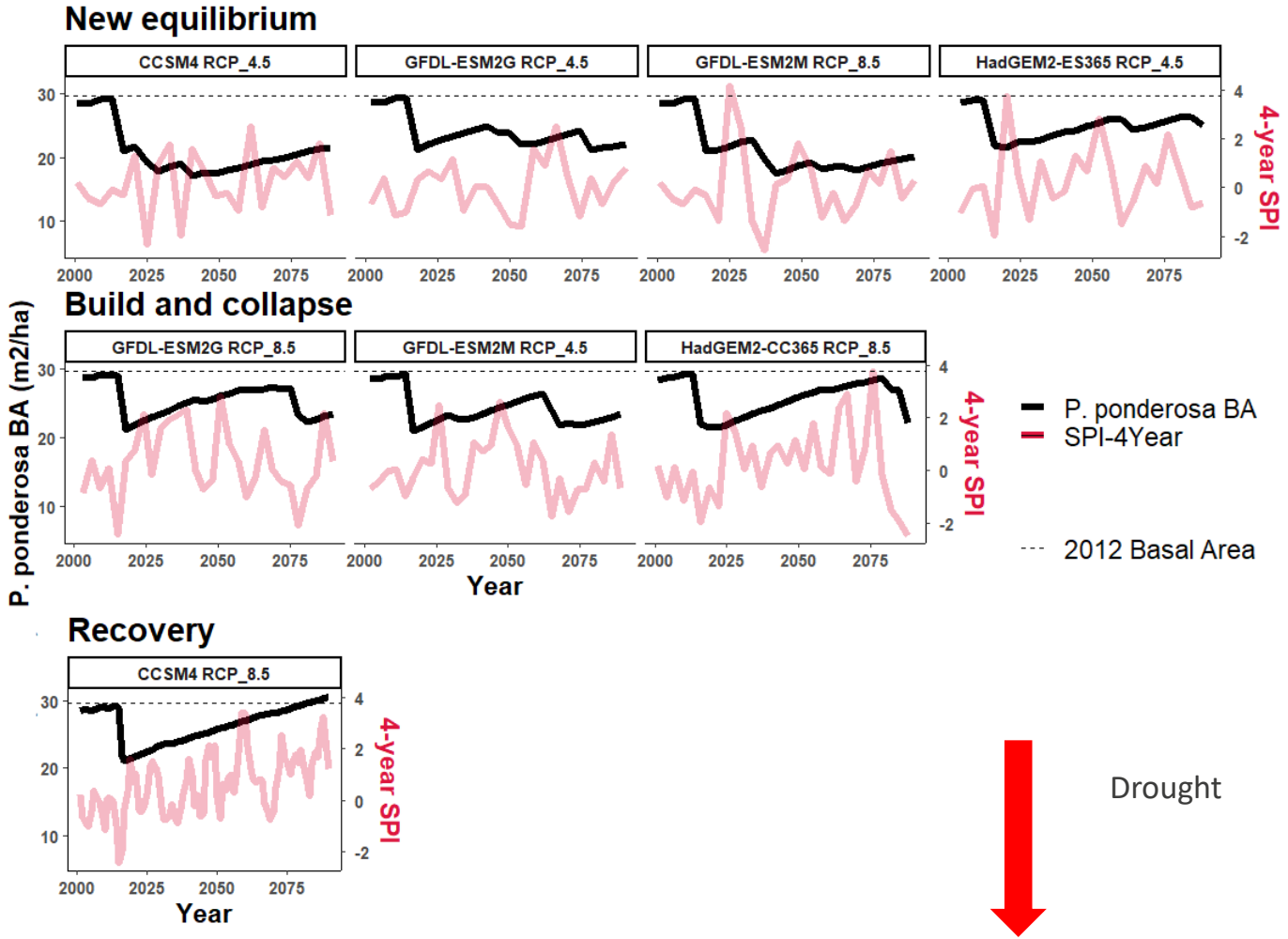
- Simulating recovery and future outbreak for 22 sites in the Sierra Nevada.
- Regeneration and growth determined by empirical equations based on density, tree size and species.
- Used 18 climate CMIP5 climate to determine the likelihood of outbreak.

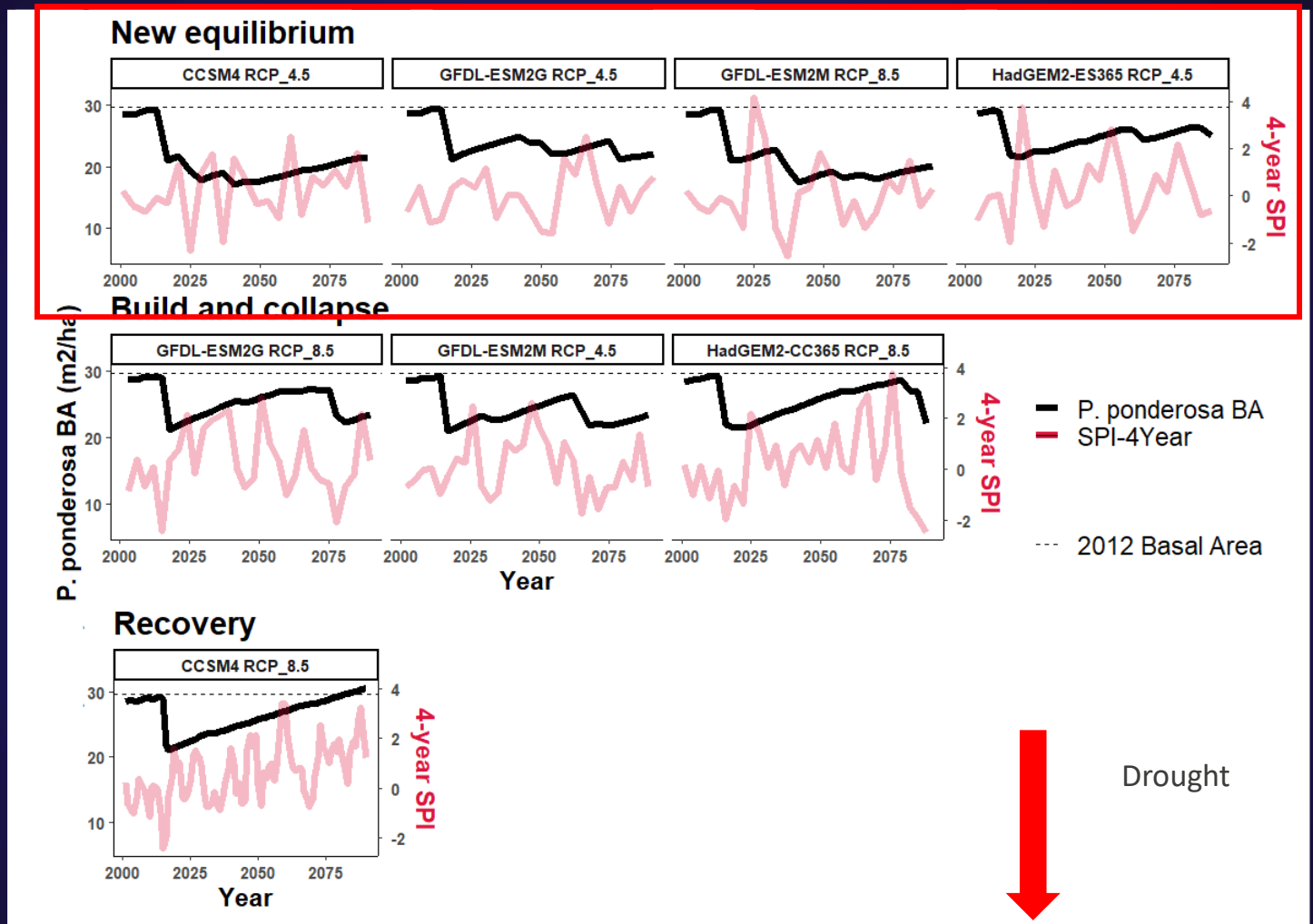


Future Climate in the Sierra Nevada

- A compilation of all available CMIP-5 climate models
- RCP 4.5 shows an increase of ~ 2.25 C by the end of the century
- RCP 8.5 shows an increase ~ 5.5 C by the end of the century.
- Drought occurrence varies greatly by model.




New equilibrium
CCSM4 RCP_4.5
GFDL-ESM2G RCP_4.5
GFDL-ESM2M RCP_8.5
HadGEM2-ES365 RCP_4.5
Build and collapse
GFDL-ESM2G RCP_8.5
GFDL-ESM2M RCP_4.5
HadGEM2-CC365 RCP_8.5
Recovery
CCSM4 RCP_8.5
P. ponderosa BA (m2/ha)
4-year SPI
Year
P. ponderosa BA
SPI-4Year
2012 Basal Area
Drought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Year
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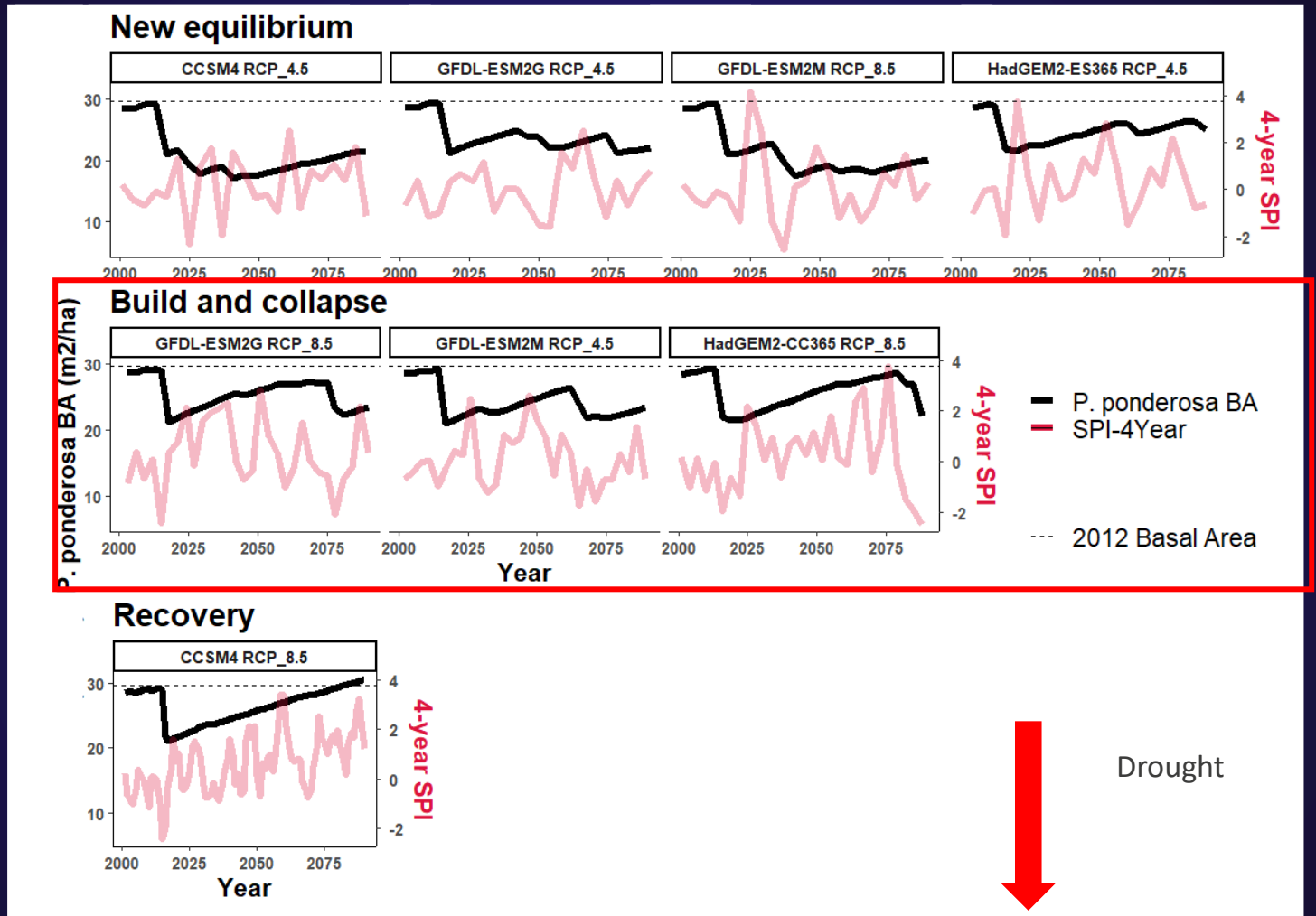
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Year
P. ponderosa BA
SPI-4Year
2012 Basal Area
Recovery
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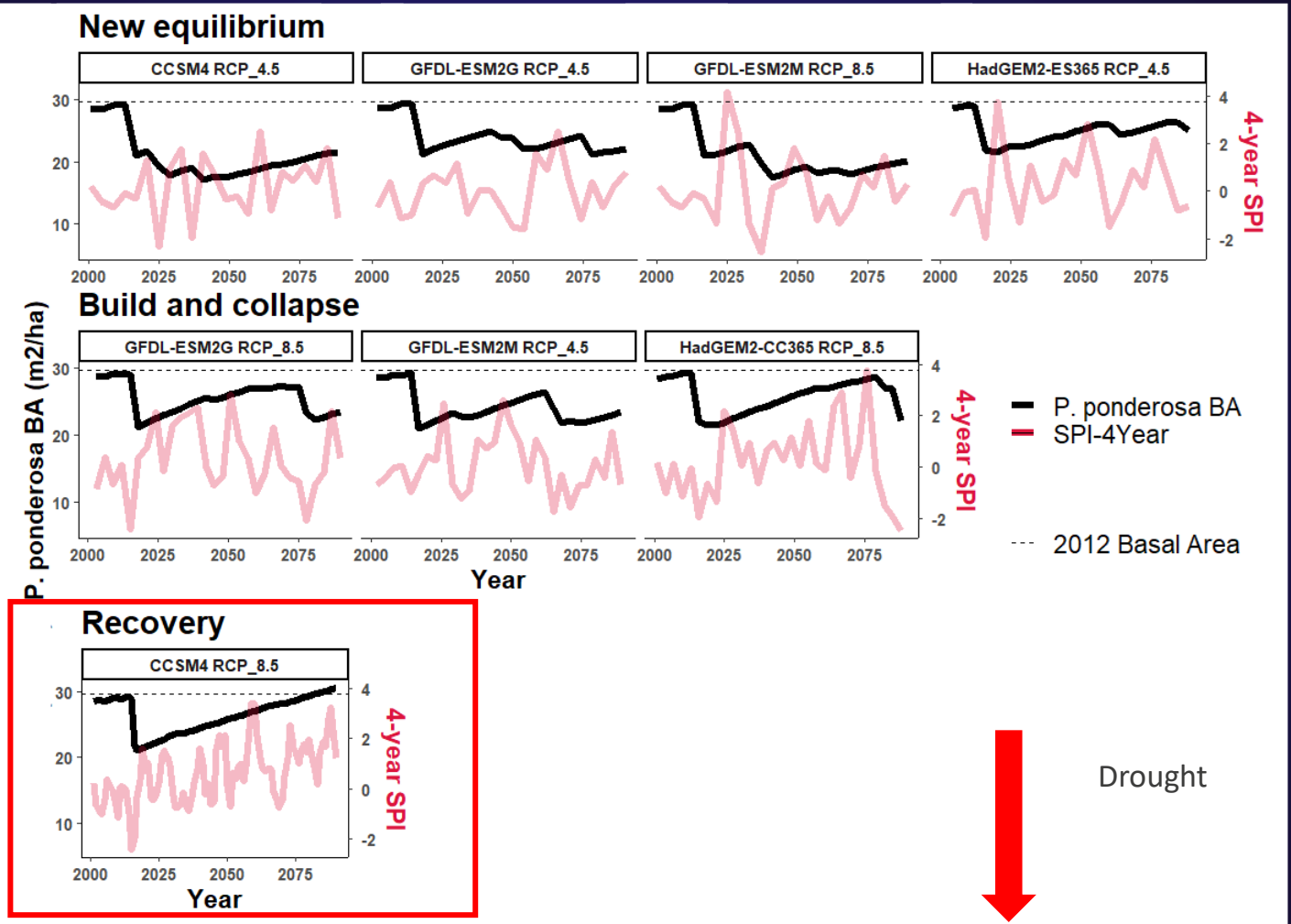
Drought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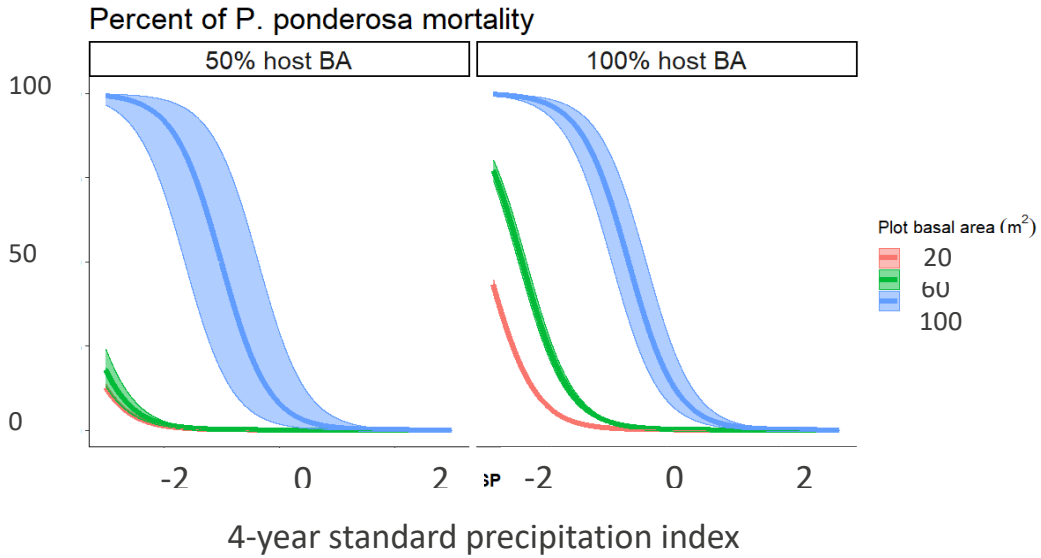
GFDL-ESM2G RCP_4.5
GFDL-ESM2M RCP_8.5
HadGEM2-ES365 RCP_4.5
Build and collapse
GFDL-ESM2G RCP_8.5
GFDL-ESM2M RCP_4.5
HadGEM2-CC365 RCP_8.5
Recovery
CCSM4 RCP_8.5
P. ponderosa BA (m2/ha)
4-year SPI
Year
P. ponderosa BA
SPI-4Year
2012 Basal Area
Drought

Relative contribution

- Under all scenarios, what is the relative contribution to probability of mortality.
- Even under extreme drought, lower total and hos basal area drastically reduces likelihood of mortality.
- Lower stocking density reduces risk of carbon loss over long time periods.

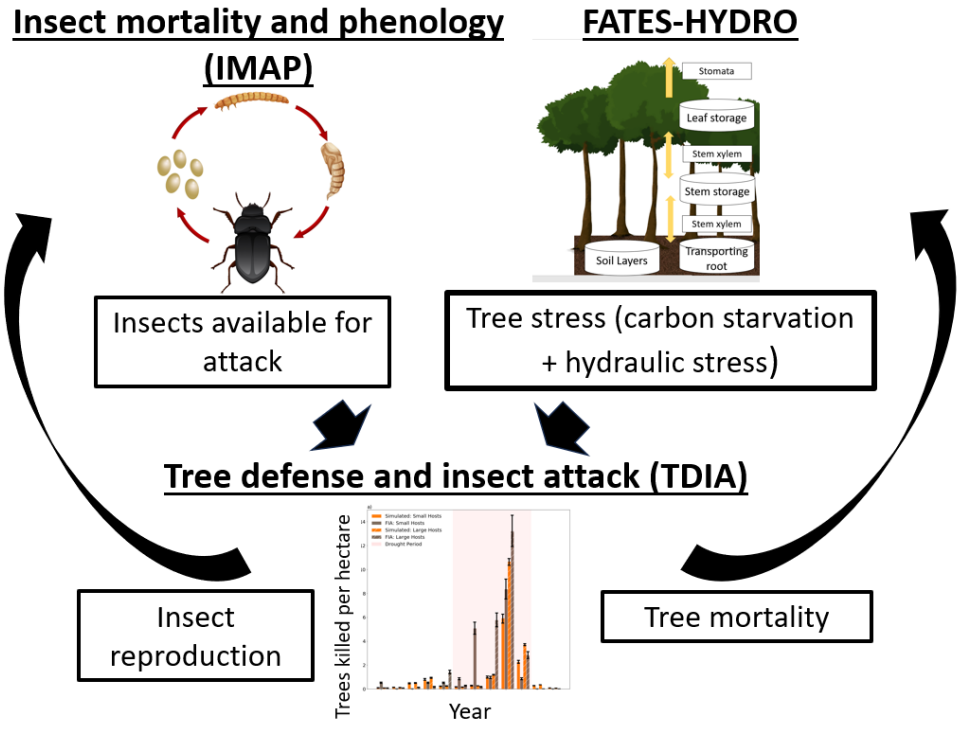


Takeaways

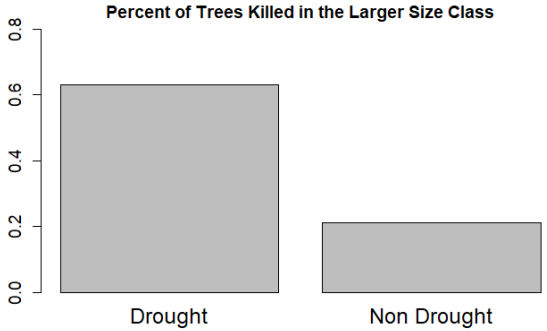
- Most climate models show new equilibrium with lower density of ponderosa pine.
- Western pine beetle outbreaks similar to that of 2012-2016 unlikely until ponderosa pine stocks return (~2080).
- Big divergence in precipitation in climate models projects varied trajectories for ponderosa pine.

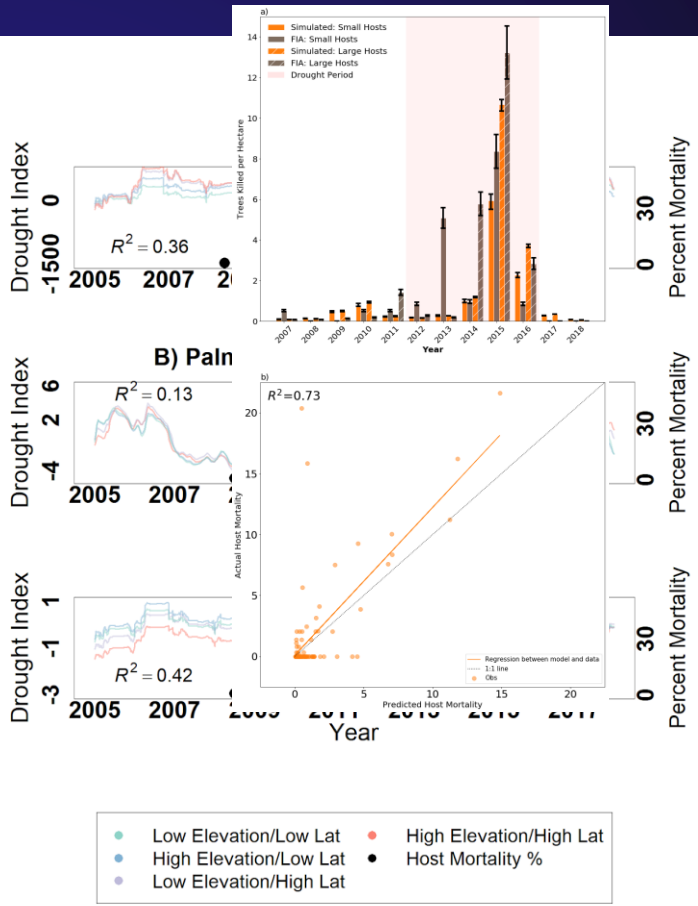
Future Work:

- Connecting IMAP-TDIA to measurements of hydraulic failure and carbon starvation.
- Expanding modeling to additional species.
- Connecting insect disturbance and fire risk feedbacks.

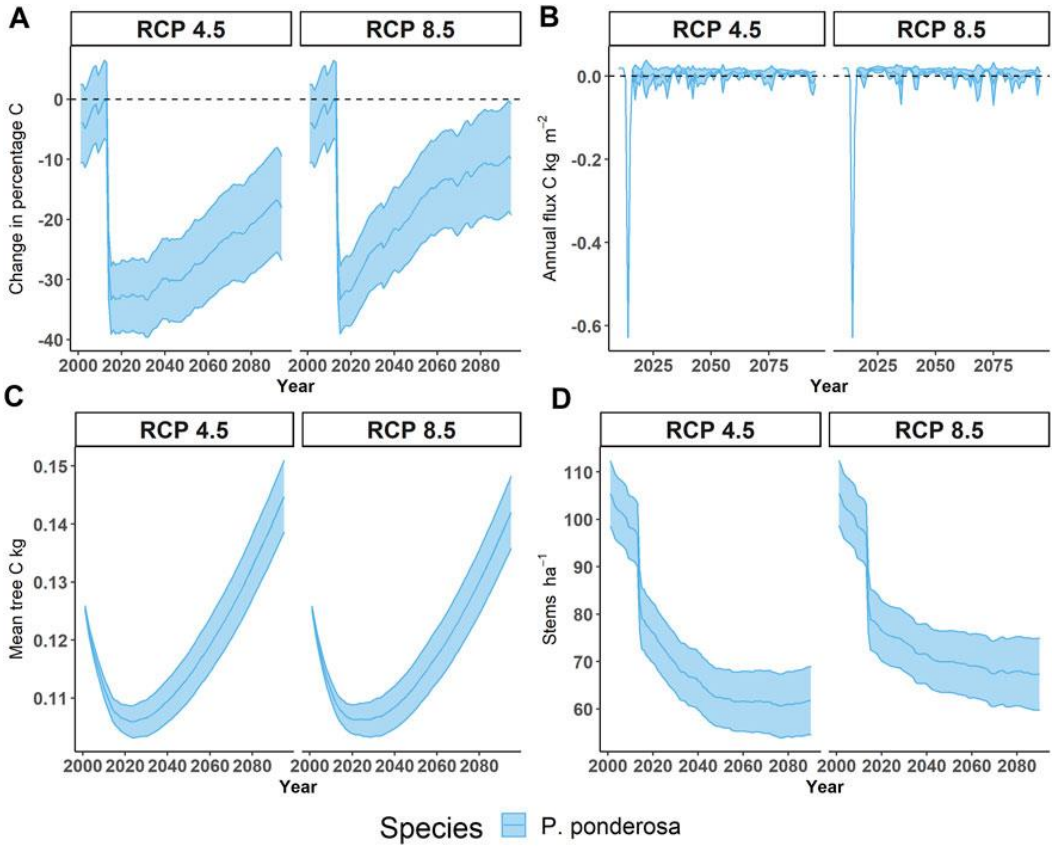


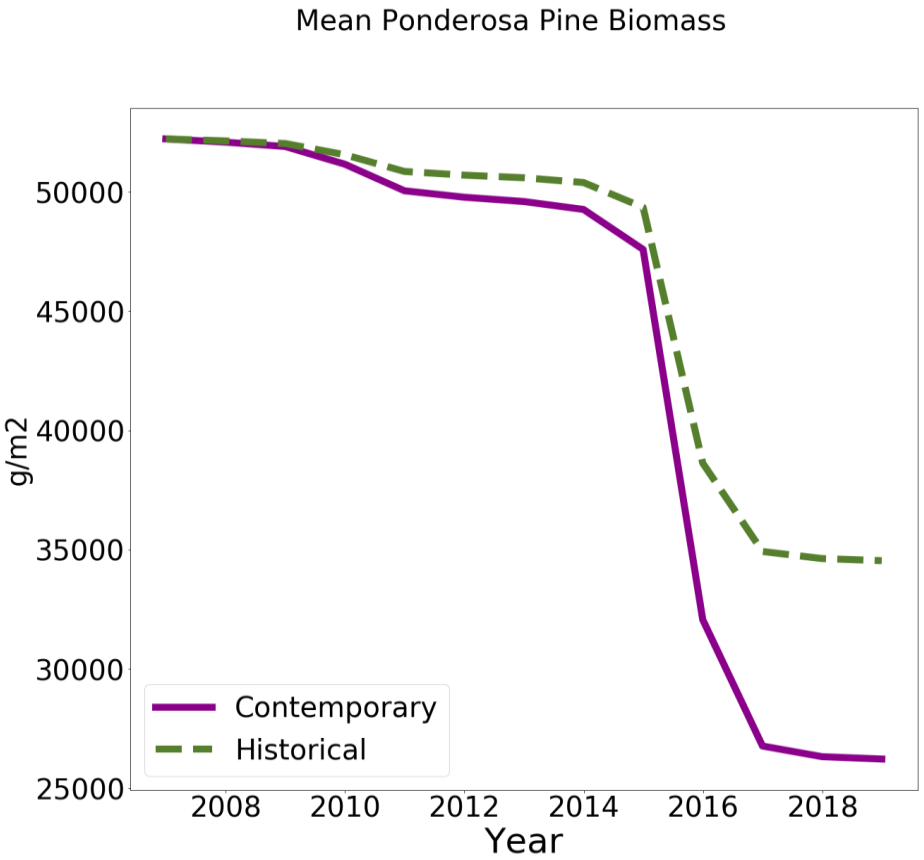
Thank you.


Percent of Trees Killed in the Larger Size Class
0.0
0.2
0.4
0.6
0.8
Drought
Non Drought


Drought Index
Percent Mortality
$R^2 = 0.36$
$R^2 = 0.13$
$R^2 = 0.42$
R^2=0.73
Simulated: Small Hosts
FIA: Small Hosts
Simulated: Large Hosts
FIA: Large Hosts
Drought Period
Trees Killed per Hectare
Year
Actual Host Mortality
Predicted Host Mortality
Regression between model and data
1:1 line
Obs
Low Elevation/Low Lat
High Elevation/Low Lat
Low Elevation/High Lat
High Elevation/High Lat
Host Mortality %

- S


A
RCP 4.5
RCP 8.5
Change in percentage C
0
-10
-20
-30
-40
2000 2020 2040 2060 2080
Year
B
RCP 4.5
RCP 8.5
Annual flux C kg m^{-2}
0.0
-0.2
-0.4
-0.6
2025 2050 2075
Year
C
RCP 4.5
RCP 8.5
Mean tree C kg
0.15
0.14
0.13
0.12
0.11
2000 2020 2040 2060 2080
Year
D
RCP 4.5
RCP 8.5
Stems ha^{-1}
110
100
90
80
70
60
2000 2020 2040 2060 2080
Year
Species
P. ponderosa


Mean Ponderosa Pine Biomass
50000
45000
40000
35000
30000
25000
g/m2
2008
2010
2012
2014
2016
2018
Year
Contemporary
Historical