Vegetation-Insect Dynamics in Earth System Models

Challenges and opportunities

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Oct 4, 2016

Photo: CD Allen *in* Breshears et al. 2009, *Frontiers in Ecol. & Env.*

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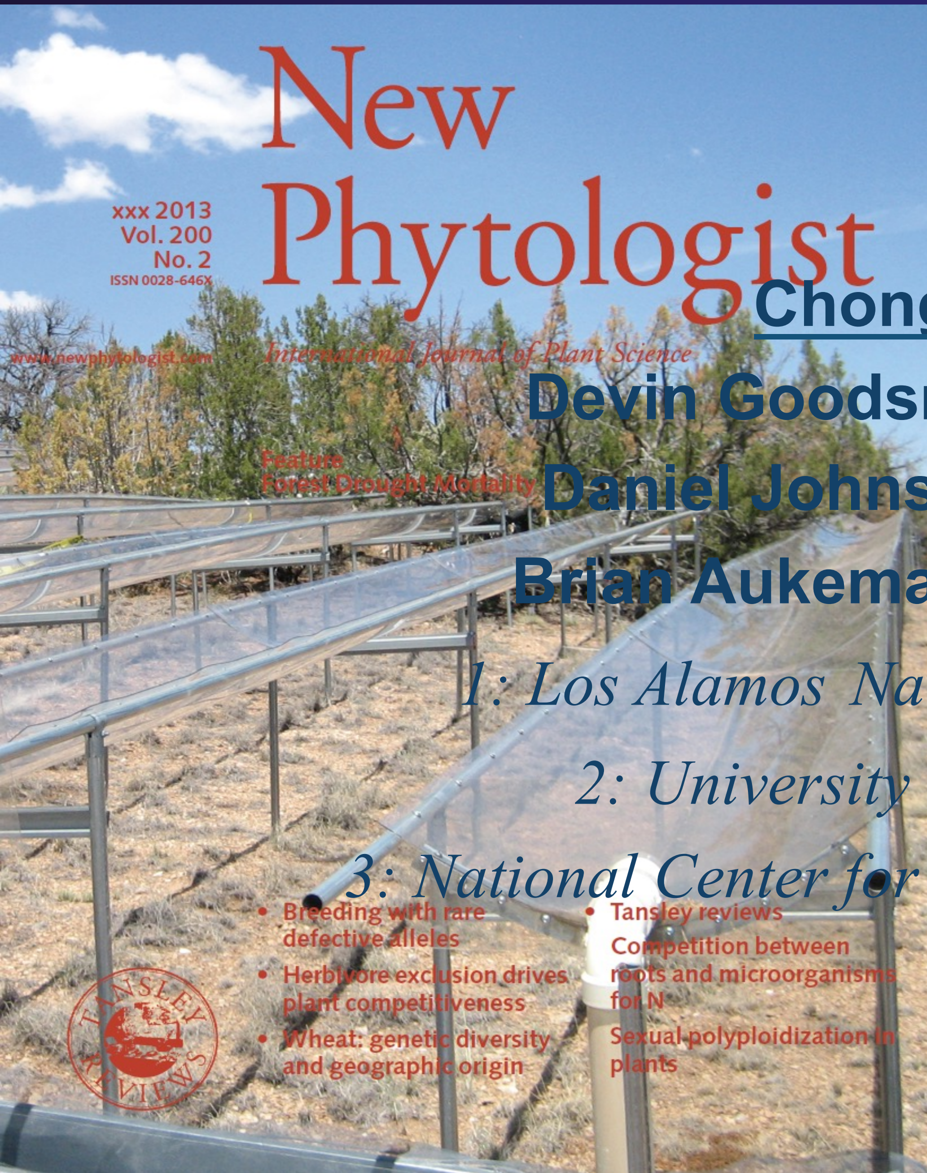
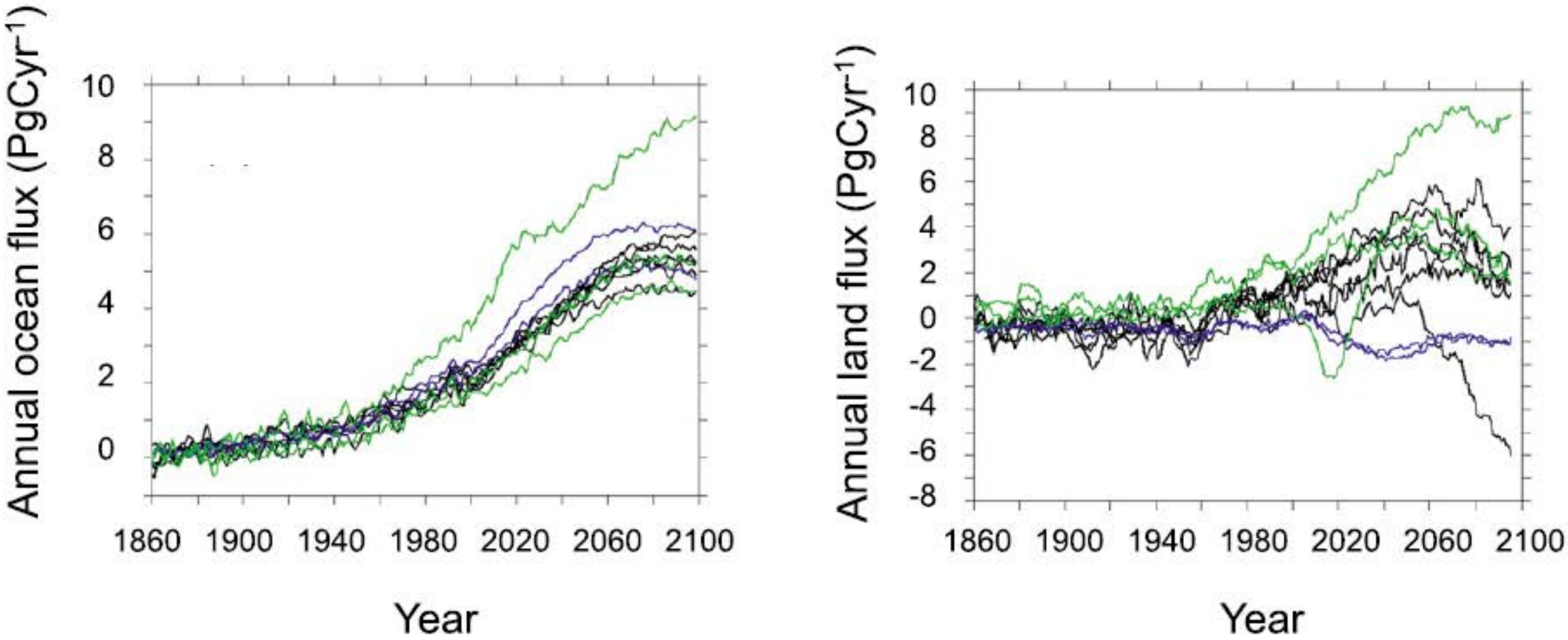
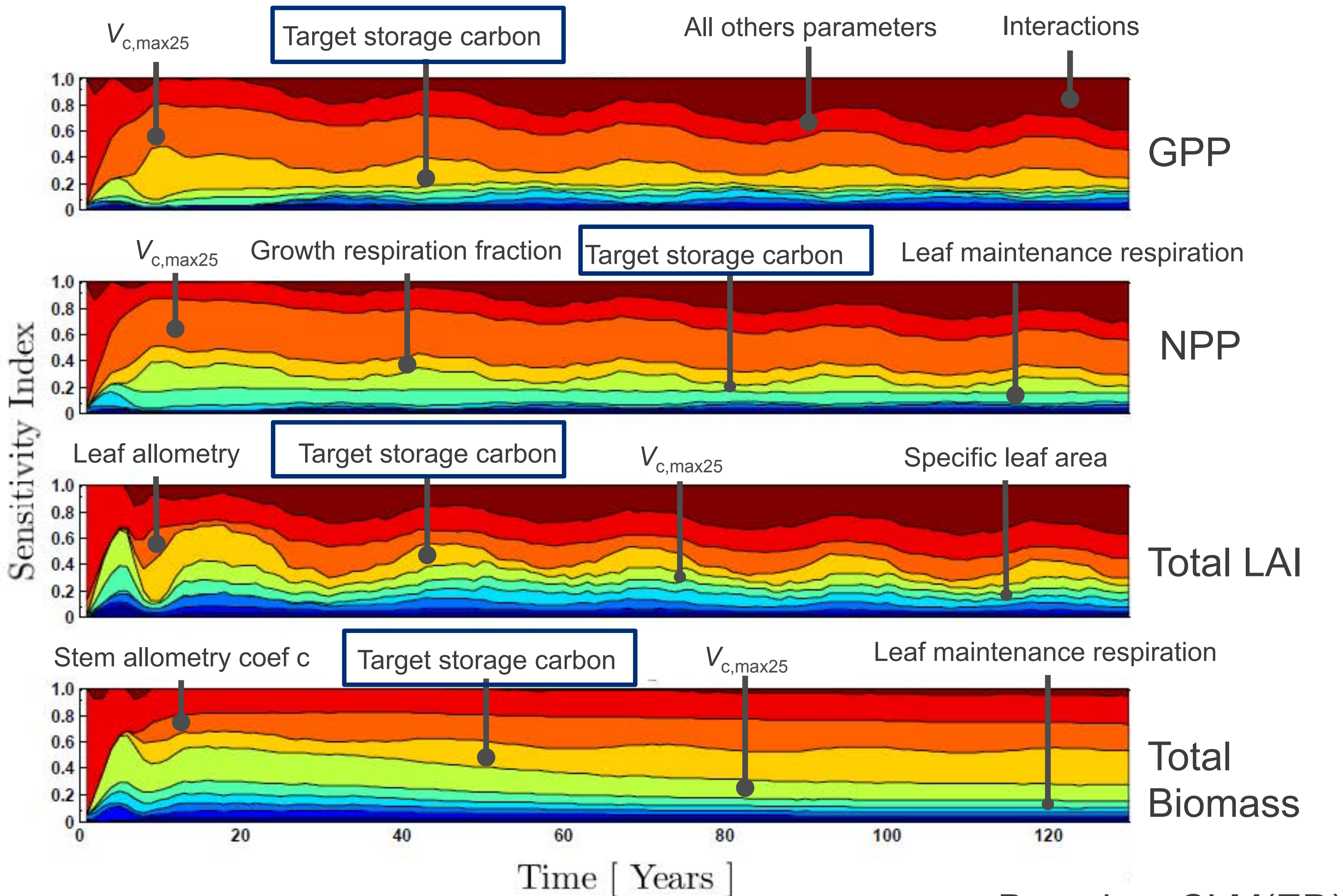


Uncertainty in the simulated terrestrial carbon sink



FRIEDLINGSTEIN et al. 2014.

Key components that control vegetation carbon and fluxes



Based on CLM(ED)

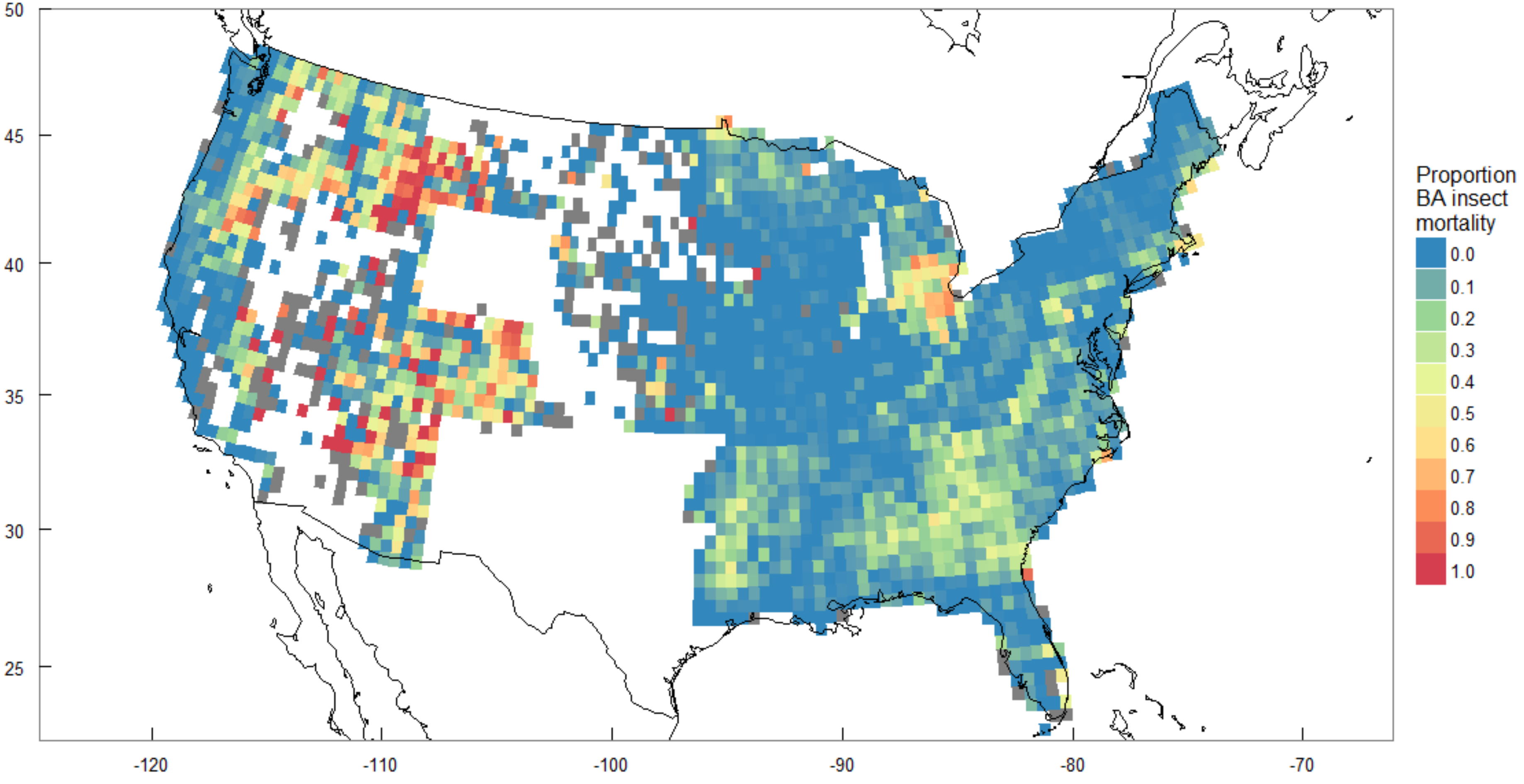
Elias and Xu et al. In Prep.

Mortality mechanisms in current Earth System Models

Mortality algorithms	Description
Productivity dependence	No explicit concept of mortality; plant biomass reduced via declining productivity [88]
Background rate	Mortality is set at a constant, invariant rate (approximately 1–2% yr^{-1}). This does not allow climate to drive variation in mortality [89–91]. In [12,92], background mortality increases as wood density decreases relative to the community maximum
Climate tolerance	Death occurs if the 20-year average climate exceeds predefined monthly climatic tolerances [93–96]
Size threshold	Death occurs if trunk diameter $>$ 1.0 m [96].
Age threshold	Death increases as stand age approaches the plant functional type-specific maximum [84]
Heat stress threshold	Mortality is a function of the number of days per year in which the average temperature exceeds a threshold temperature, and the number of degrees (°C) by which this threshold is exceeded [84,92–97]
Negative productivity	Death occurs if annual net productivity $<$ 0.0 g [93–96]
Shading/competition	Mortality increases as a function of canopy cover [12,92–97]
Growth efficiency threshold	Mortality occurs when biomass increment per unit leaf area falls below a quantitative threshold that varies between models [86,93–96,98]
Carbon starvation	Mortality is a function of carbohydrate storage per unit leaf biomass [12]

McDowell et al 2011.

Impact of insect-caused tree mortality in the past

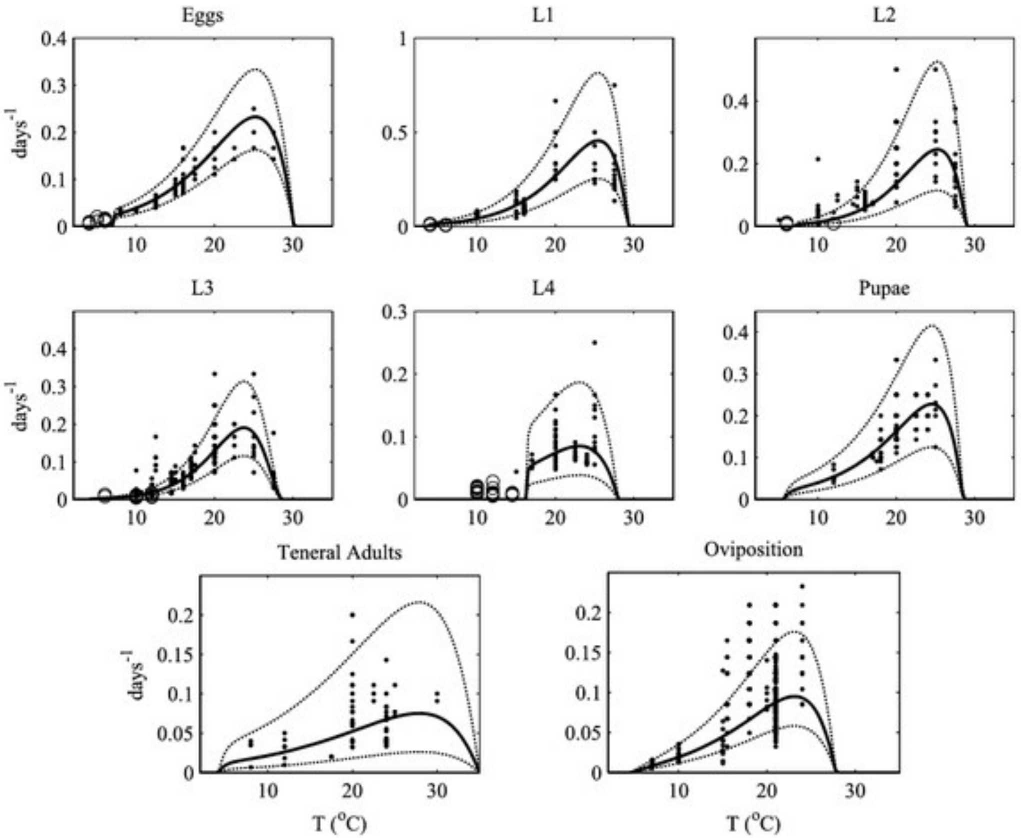


Proportion of insect-caused mortality in US from 2000-2015 based on FIA data

Xu and Johnson et al. In Prep

Impact of insect-caused tree mortality in the future

- **Higher temperatures in the future could facilitate the development of insects and lead to earlier adult emergence, or multiple attacks from multiple life cycles.**



From: Bentz & Powell (2014). Mountain Pine Beetle Seasonal Timing and Constraints to Bivoltinism. *American Naturalist* 184: 787-796

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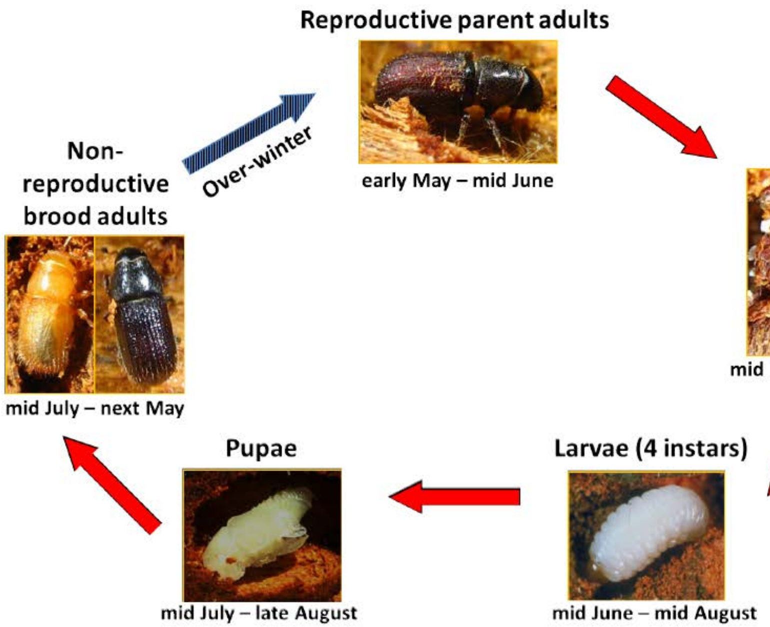
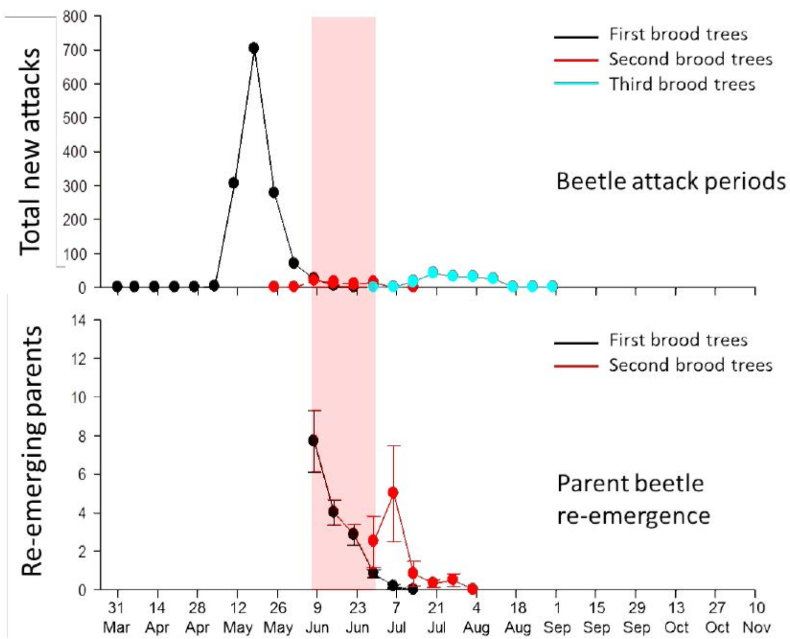
Eastern larch beetle life cycle





Simpson 1929, Baker 1972, Furniss Carolin 1977, Werner 1986, Langor & Raske 1987

McKee, Fraser R.; Aukema, Brian H. 2016 .

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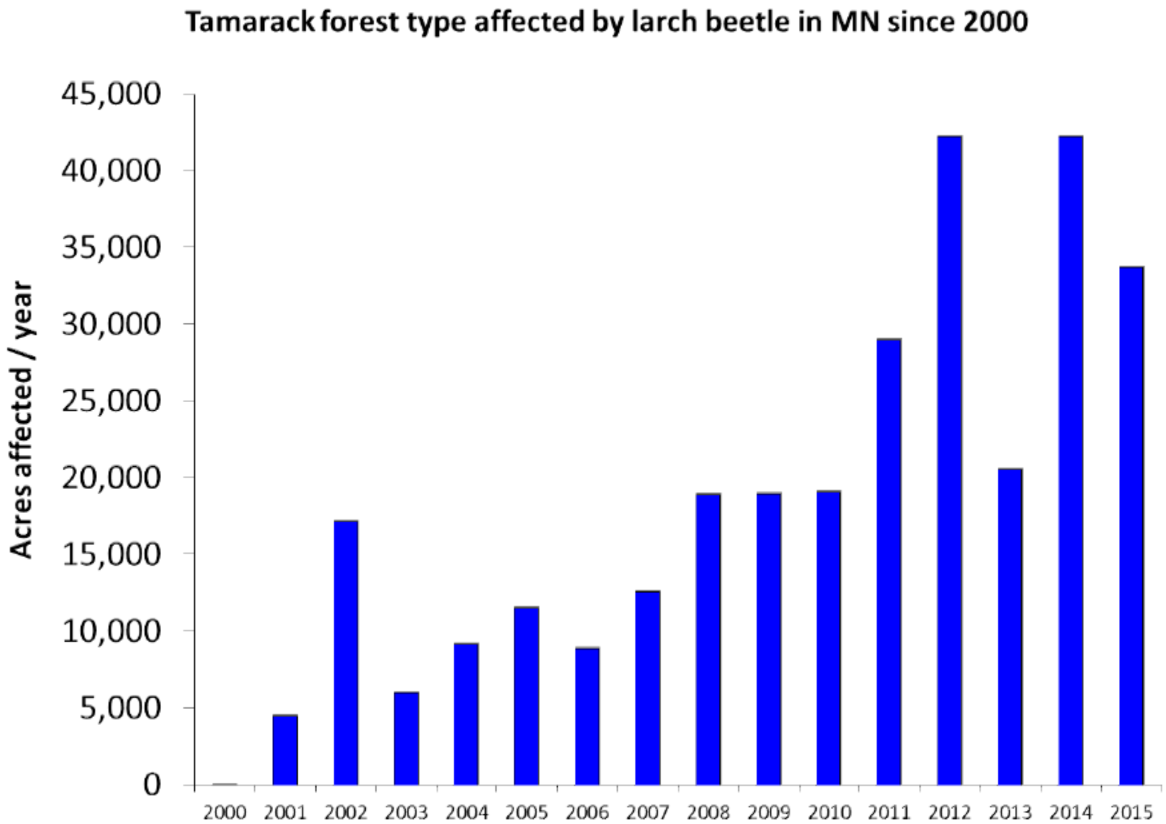
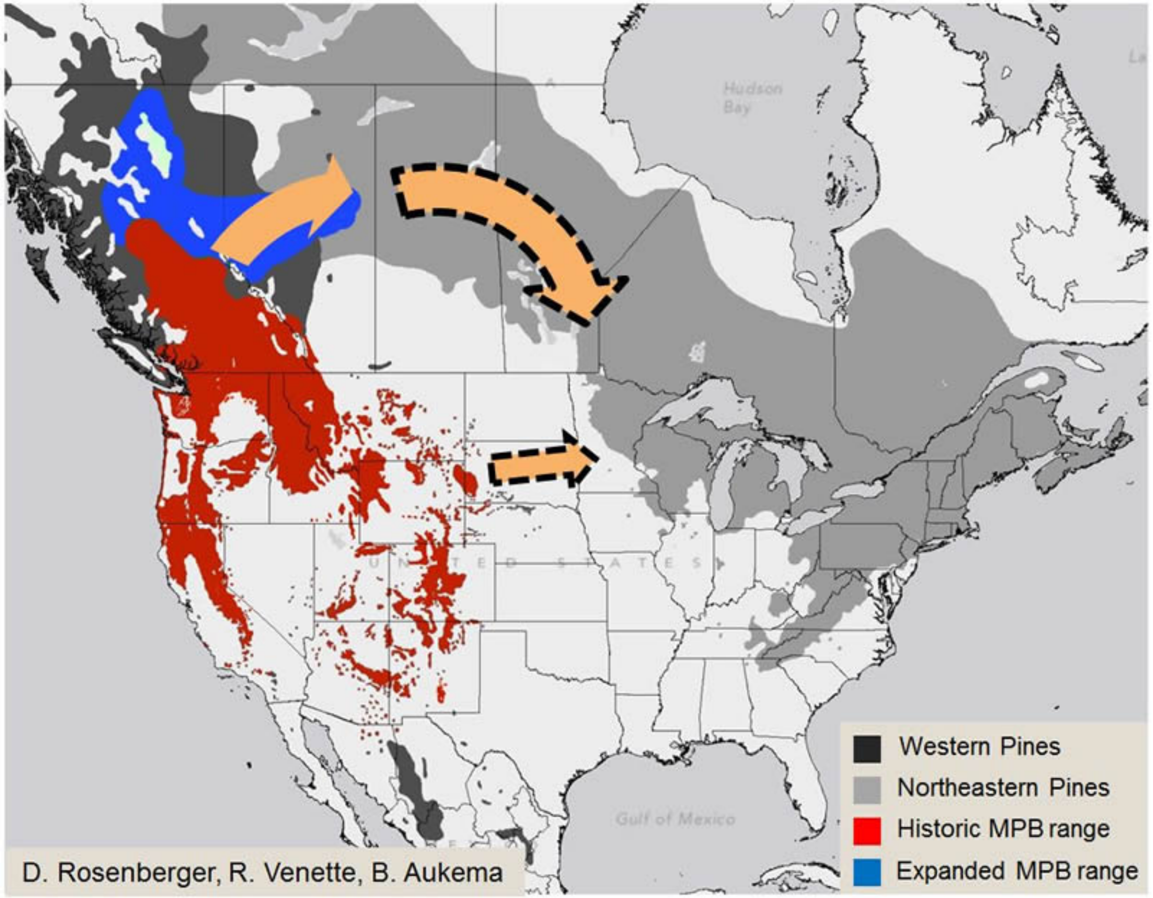


McKee, Fraser R.; Aukema, Brian H. 2016 .

Impact of insect-caused tree mortality in the future

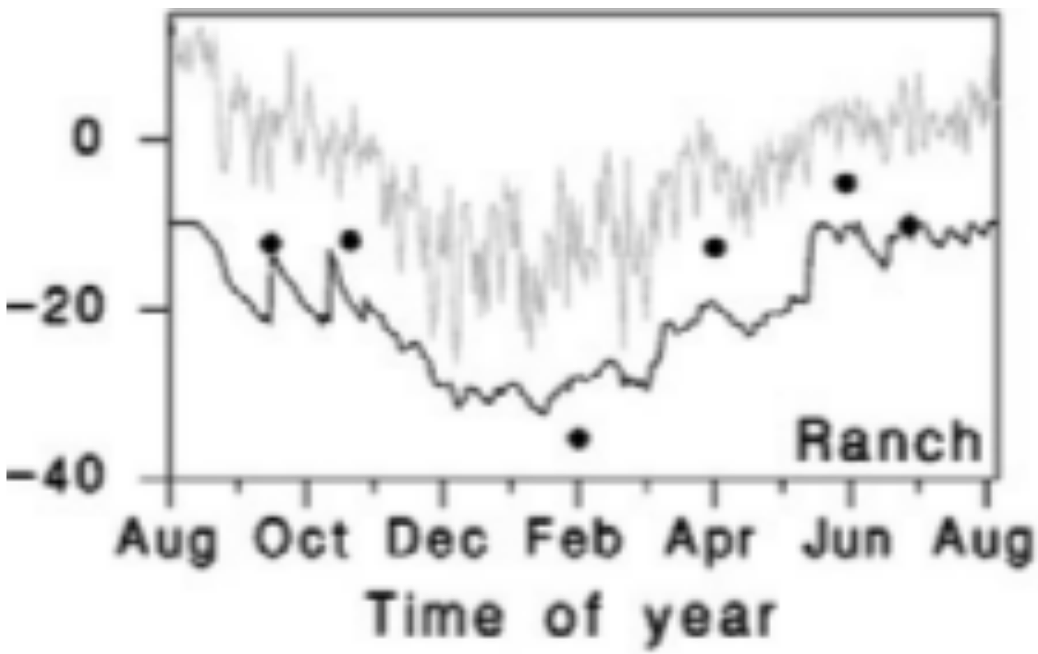
- **Winter insect survival will be increased by the overall winter warming in the future**



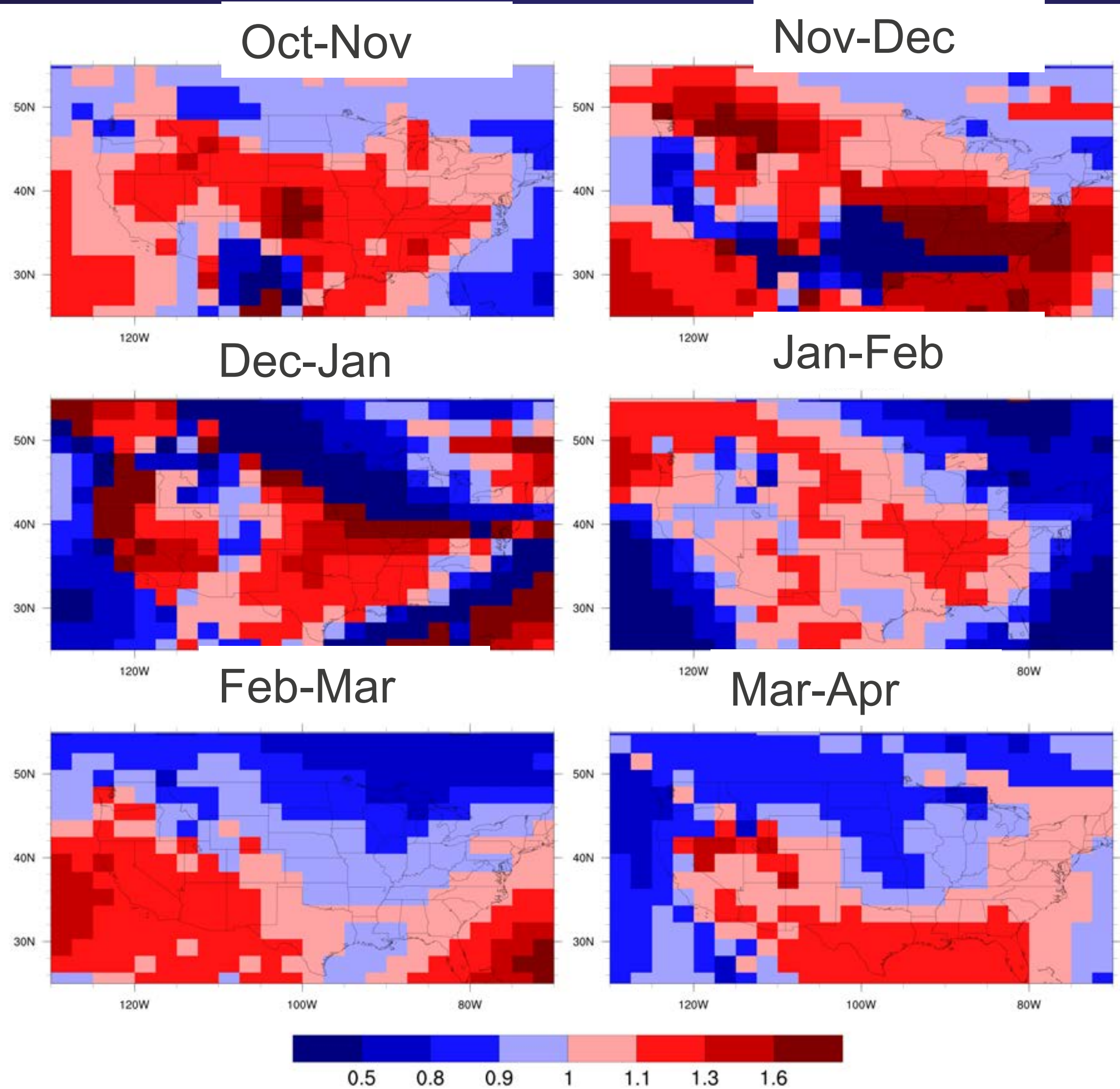
Impact of insect-caused tree mortality in the future

- **Heat waves and cold spells during winter and early spring that reduce insect cold hardening may augment mortality**

From: Régnière and Bentz (2007). Modeling cold tolerance in the mountain pine beetle, *Dendroctonus ponderosae*. *Journal of Insect Physiology* 53: 559-572



Impact of insect-caused tree mortality in the future



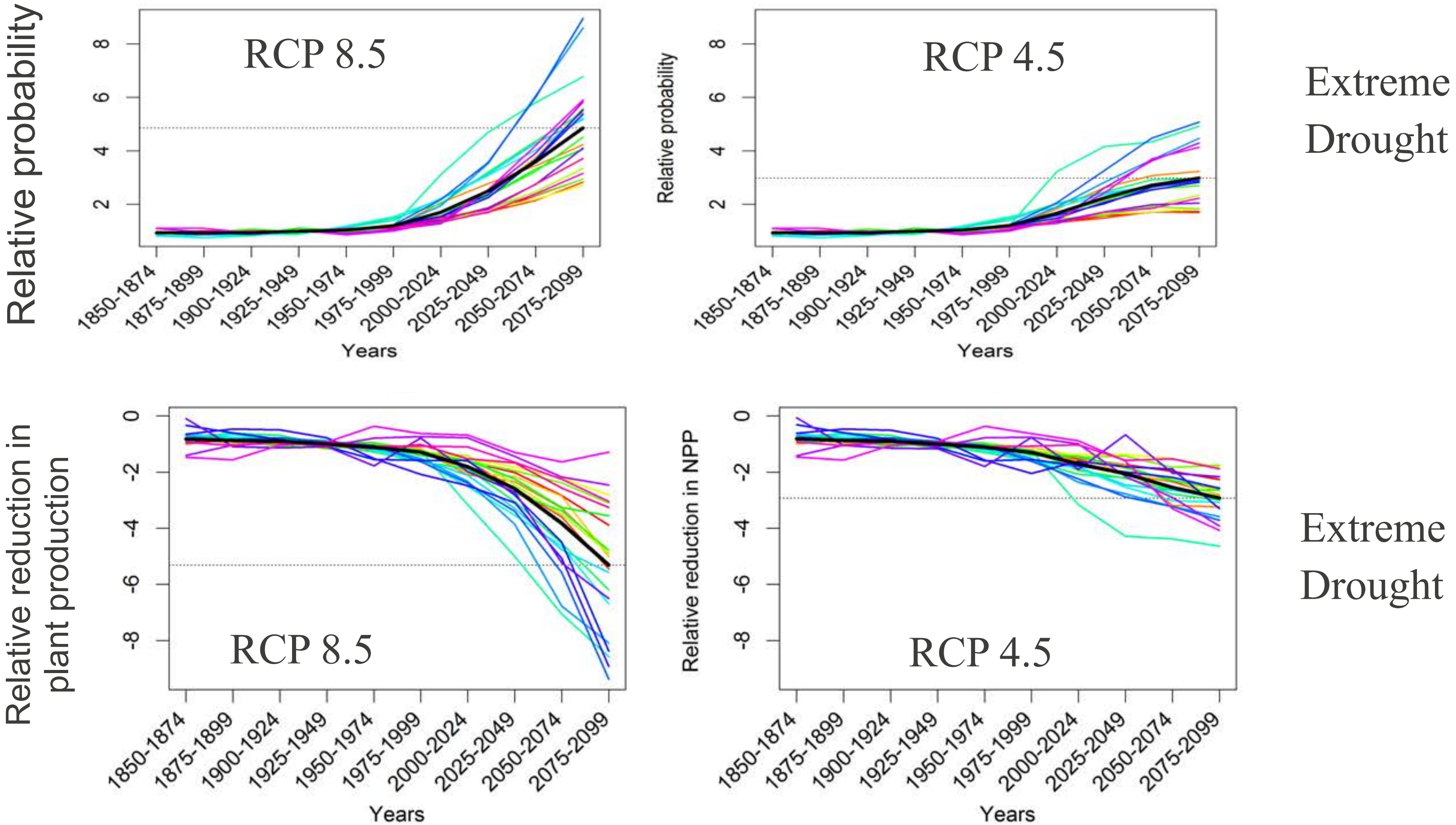
Risk of heave waves during 2075-2100 compared to 1850-2000

Risk of heave waves during year 2075-2100 compared to 1850-2100 predicted by GFDL-ESM2G model.

Xu et al . In Prep.

Impact of insect-caused tree mortality in the future

- **Extreme events of droughts and heat waves in the future could reduce the plant defense and thus lead to higher risks of insect outbreaks**



Xu et al. In Review

Impact of insect-caused tree mortality in the future

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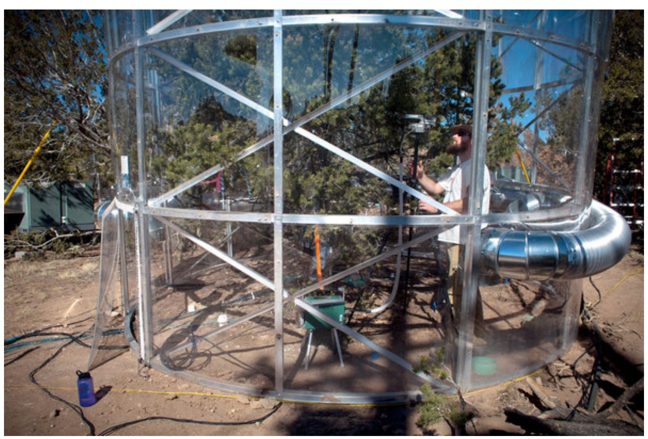
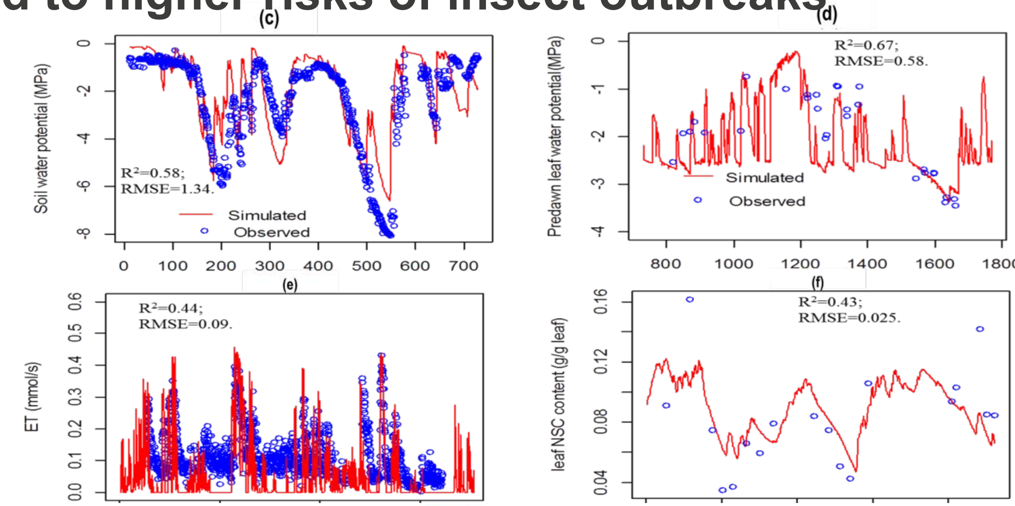
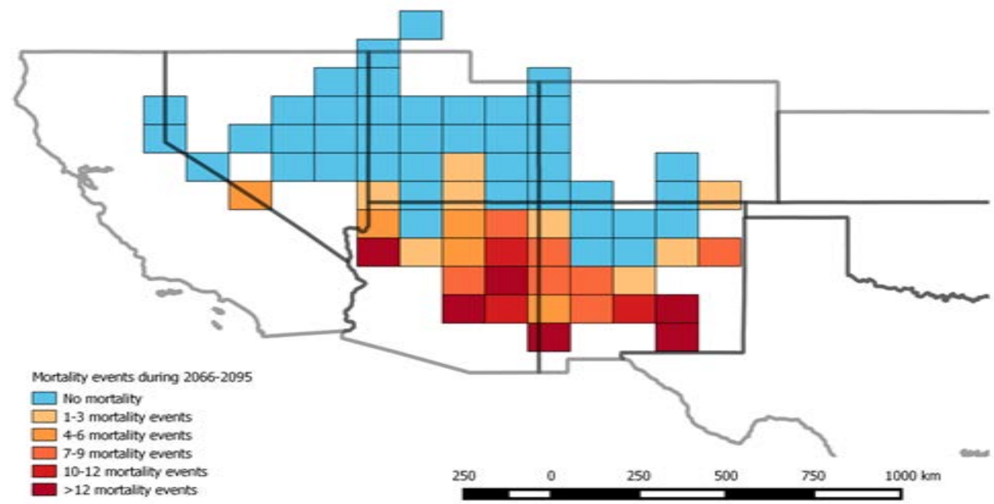
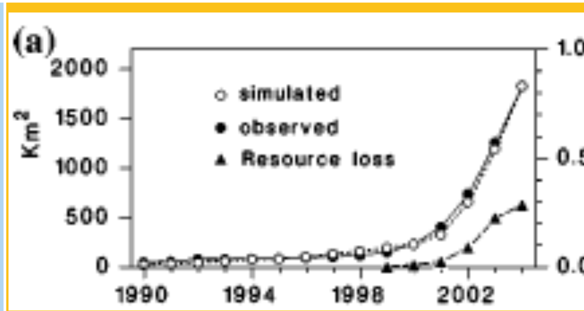
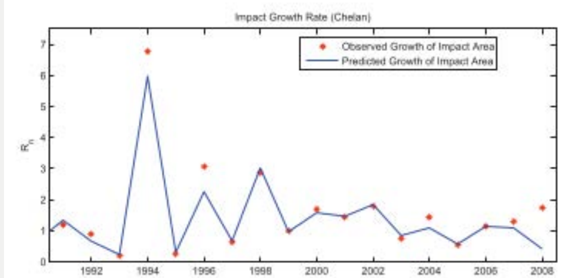
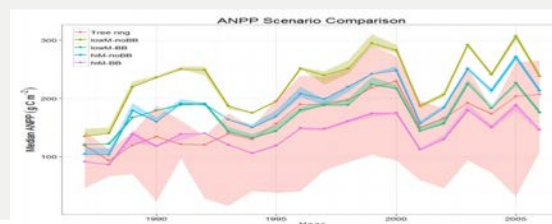






McDowell et al 2013; 2016 and Xu et al 2013.

Current climate-dependent forest insect outbreak models

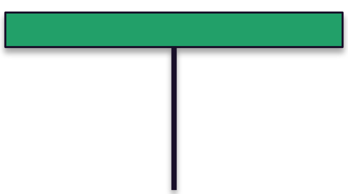
Framework	Components/Details	Predictions
Individual-based modeling Régnière et al (2015) Individual-based modeling: mountain pine beetle seasonal biology in relation to climate.	1. Temperature-dependent phenology 2. Temperature-dependent insect mortality 3. Spatially implicit 4. Tree-level attack threshold	
Partial differential equation modeling Powell & Bentz (2014) Phenology and density-dependent dispersal predict patterns of mountain pine beetle (*Dendroctonus ponderosae*) impact.	1. Temperature-dependent phenology 2. Host density-dependent insect dispersal 3. Spatially explicit 4. Tree-level attack threshold	 **Fig. 6.** Comparison of yearly predicted growth rates (solid) with observed growth rates (*) in the Chelan study area, using parameters estimated for the SNRA. The model had $r^2 = 0.9349$.
Vegetation susceptibility modeling LANDIS (Sturvant et al 2004)	1. No explicit insect population 2. Based on only host susceptibility	

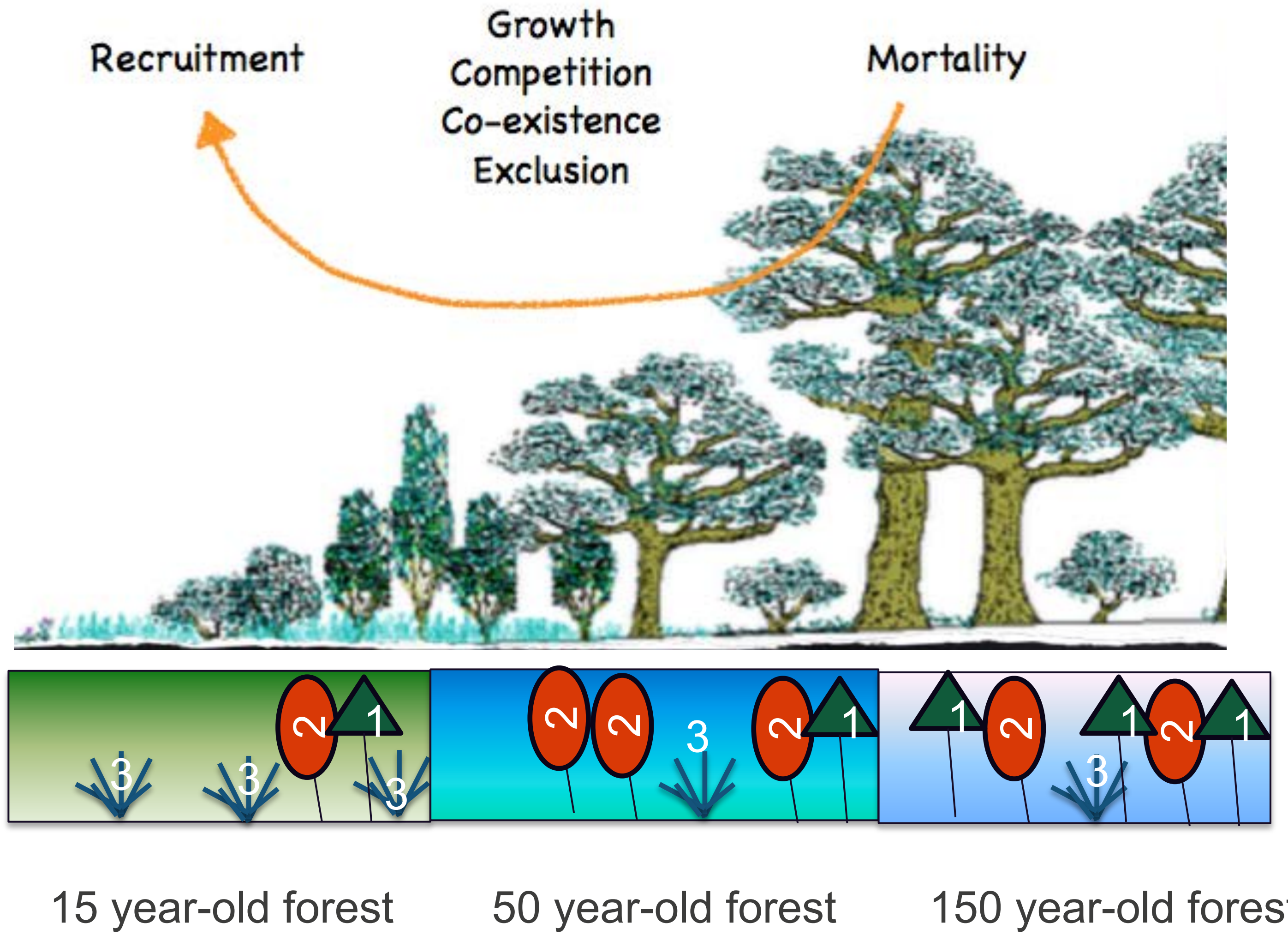
Challenges of incorporating insect population dynamics into ESMs

- Lack of consistent insect outbreak data (tree infestation vs insect population)
- Lack of appropriate vegetation models (size and plant functional types)
- Lack of appropriate vegetation defense models
- Representation of stochasticity
- Limited data on insect physiology
- Lack of data on dispersal and its difficulty in implementation for ESM

Solutions 1: Demographic vegetation model

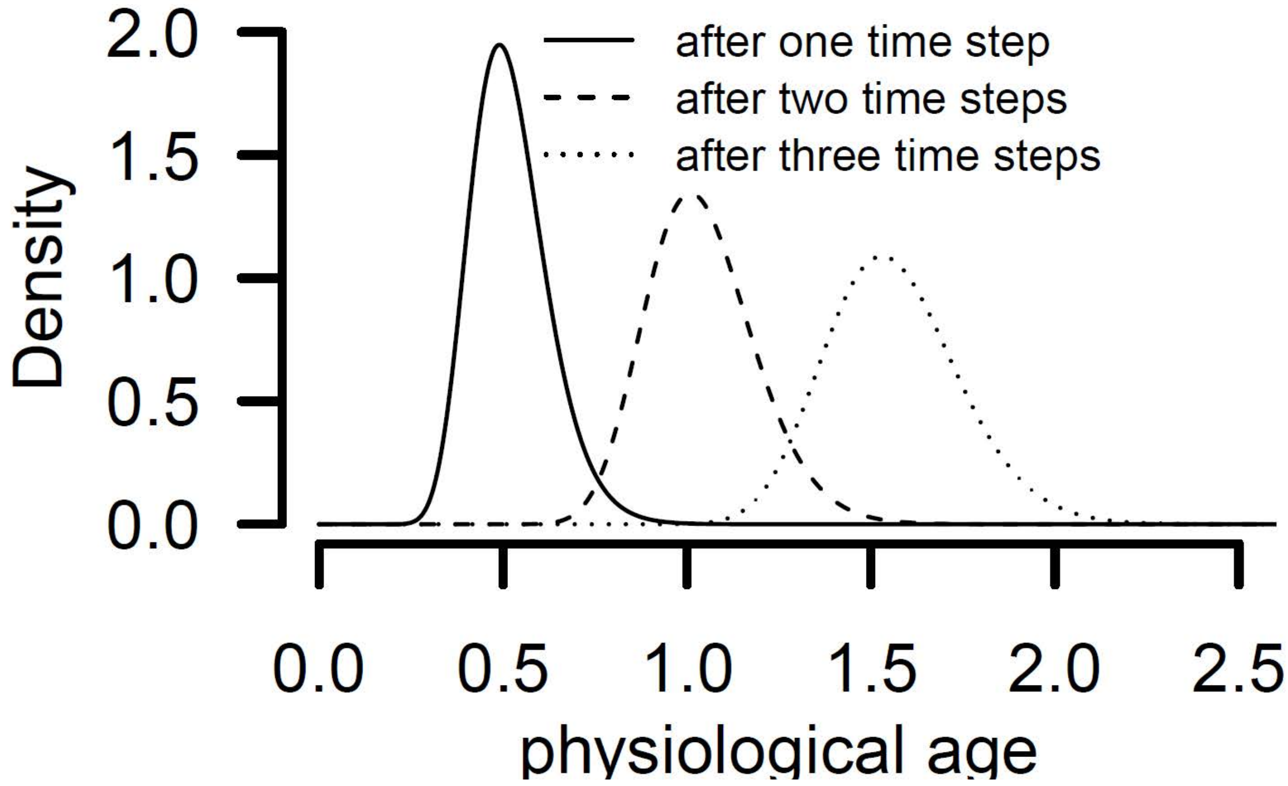
Big leaf model





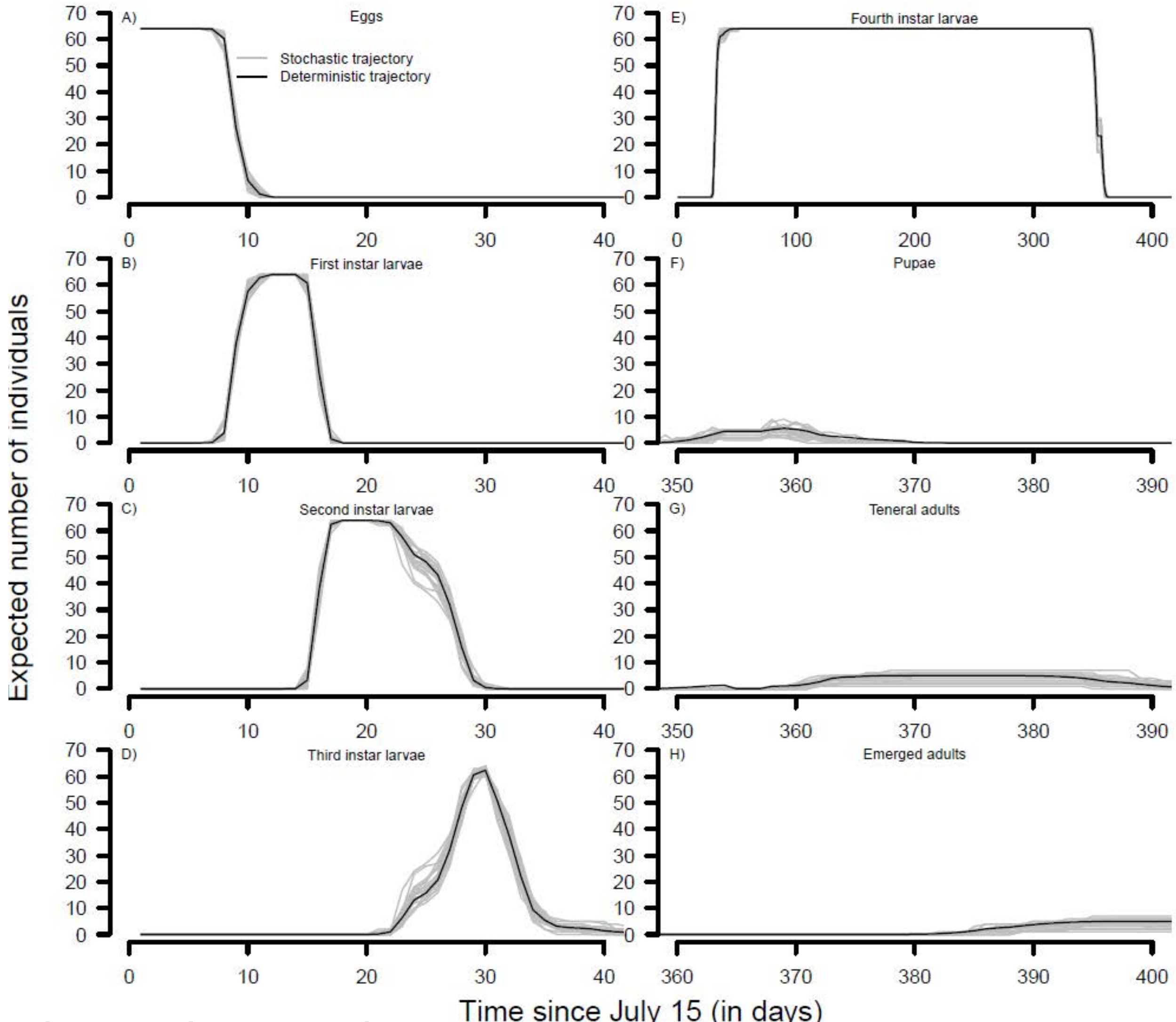
Moorcroft et al 2001; Fisher and McDowell et al 2010. Fisher et al. 2015.

Solutions 2: Stochasticity representation



Goodsman and ...Xu. In Prep.

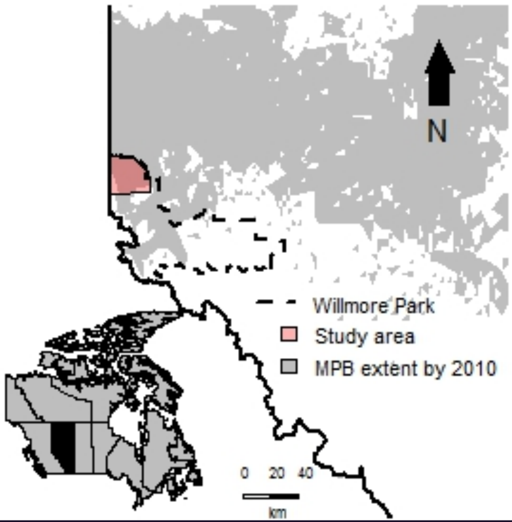
Solutions 2: Stochasticity representation

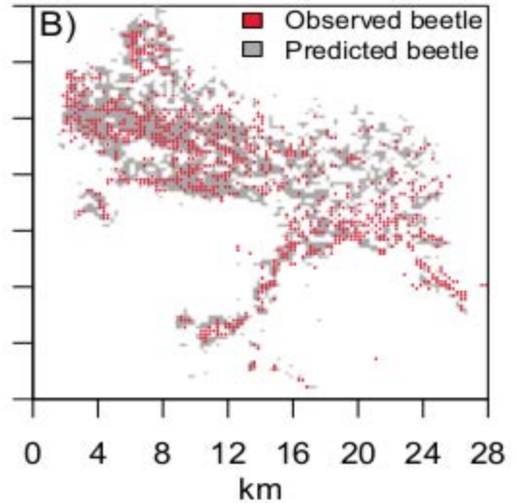


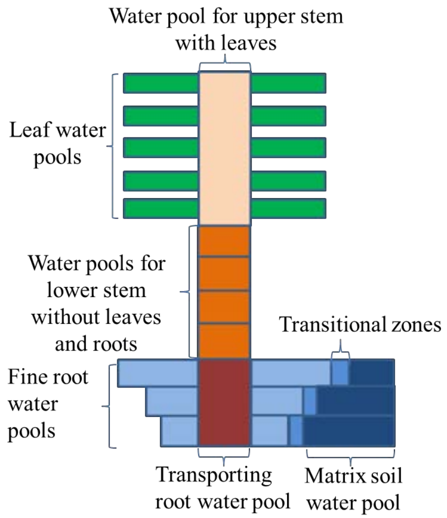
Convolution based analytical solution

Goodsman and ..Xu. In Prep.

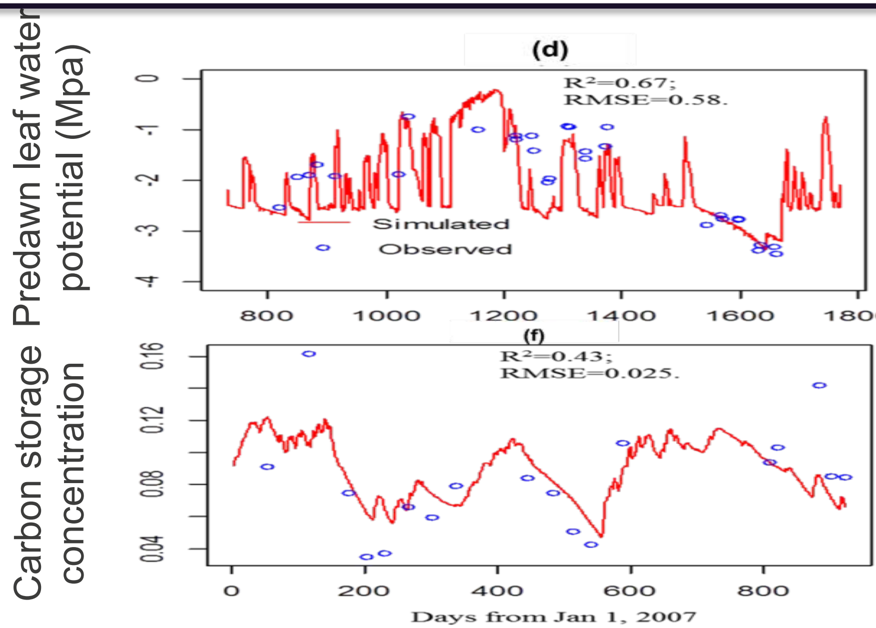
Solution 3: Insect attack and vegetation defense







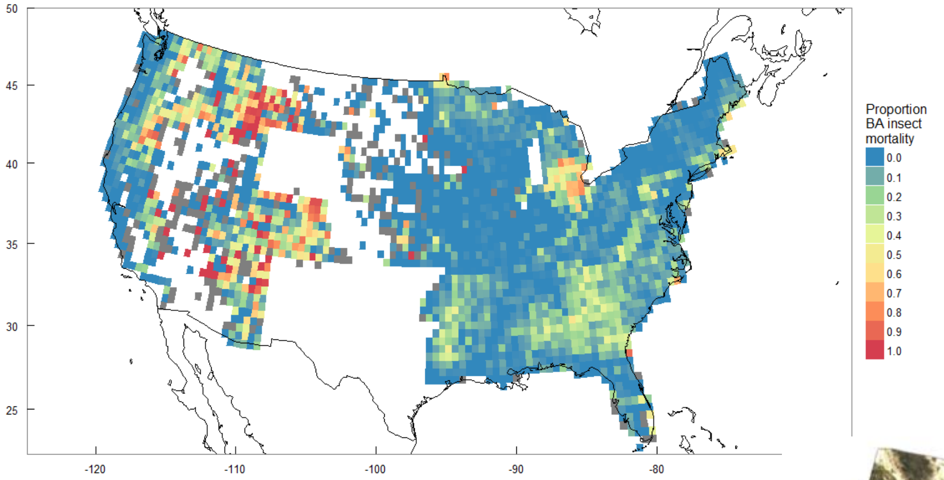
Framework of a general plant hydrodynamic module with explicit water pools from soil to leaves.



Goodsman et al 2016; Xu et al 2013; Sevanto and Xu et al 2016.

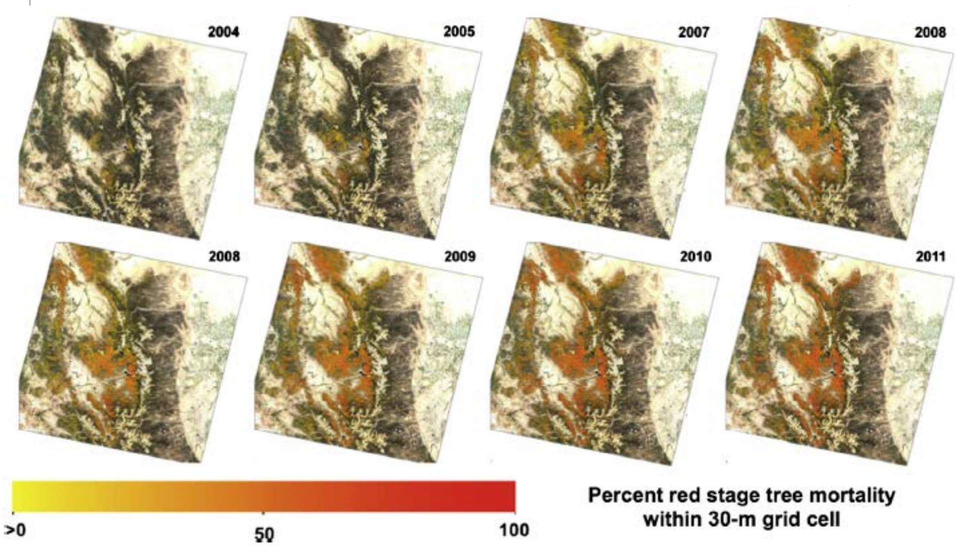
Solution 4: Benchmarking data

Forest inventory



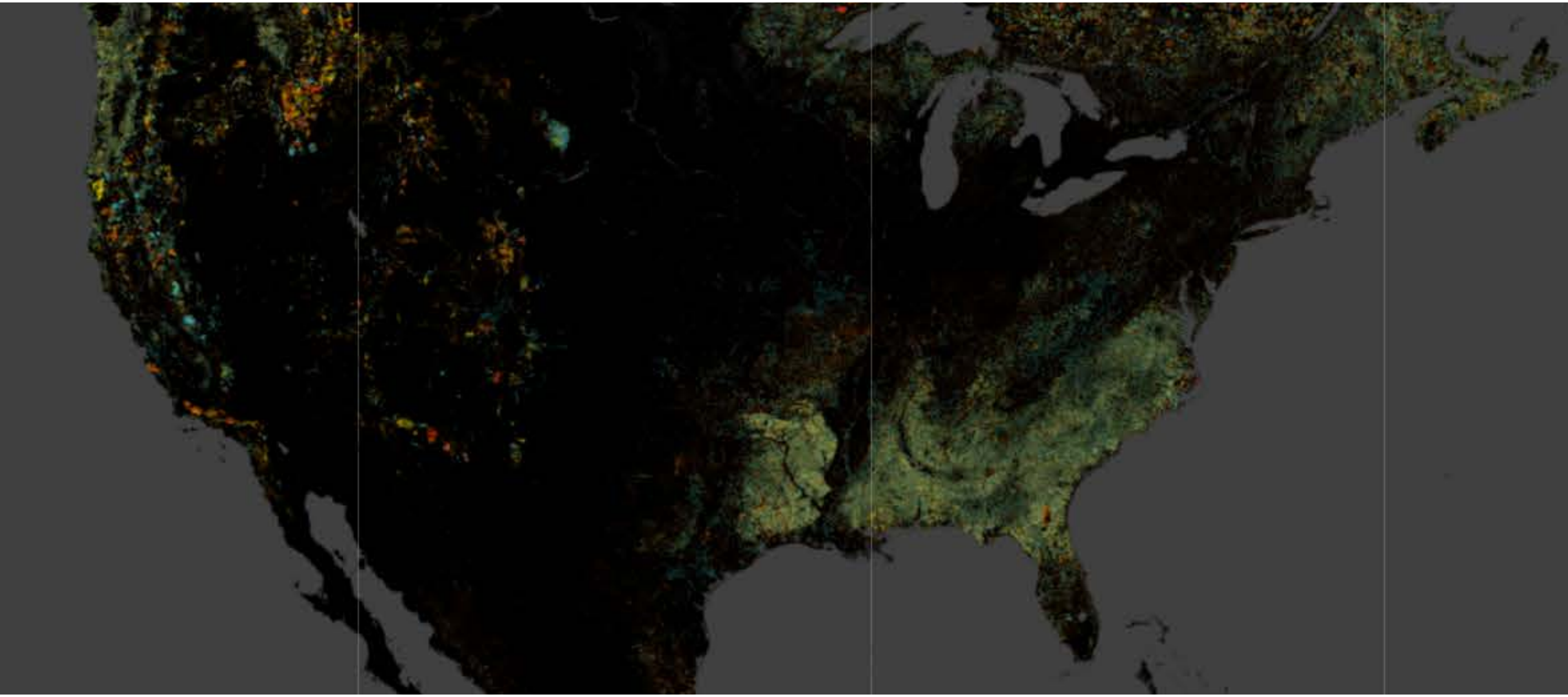
Johnson et al. In Prep.

Remote sensing



Meddens and Hicke et al 2014.

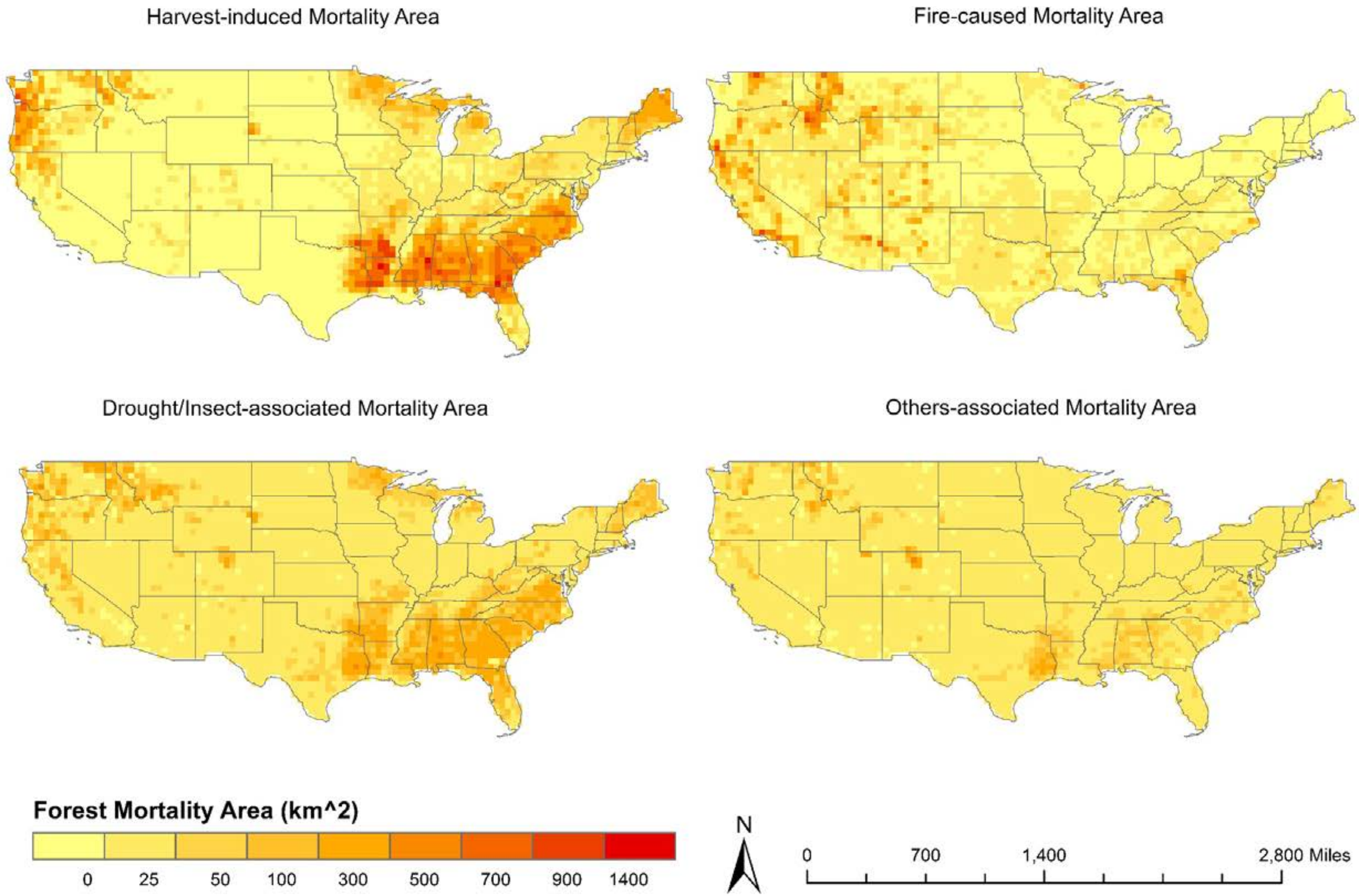
Disturbance attributions



Forest disturbance map from 2000-2014.

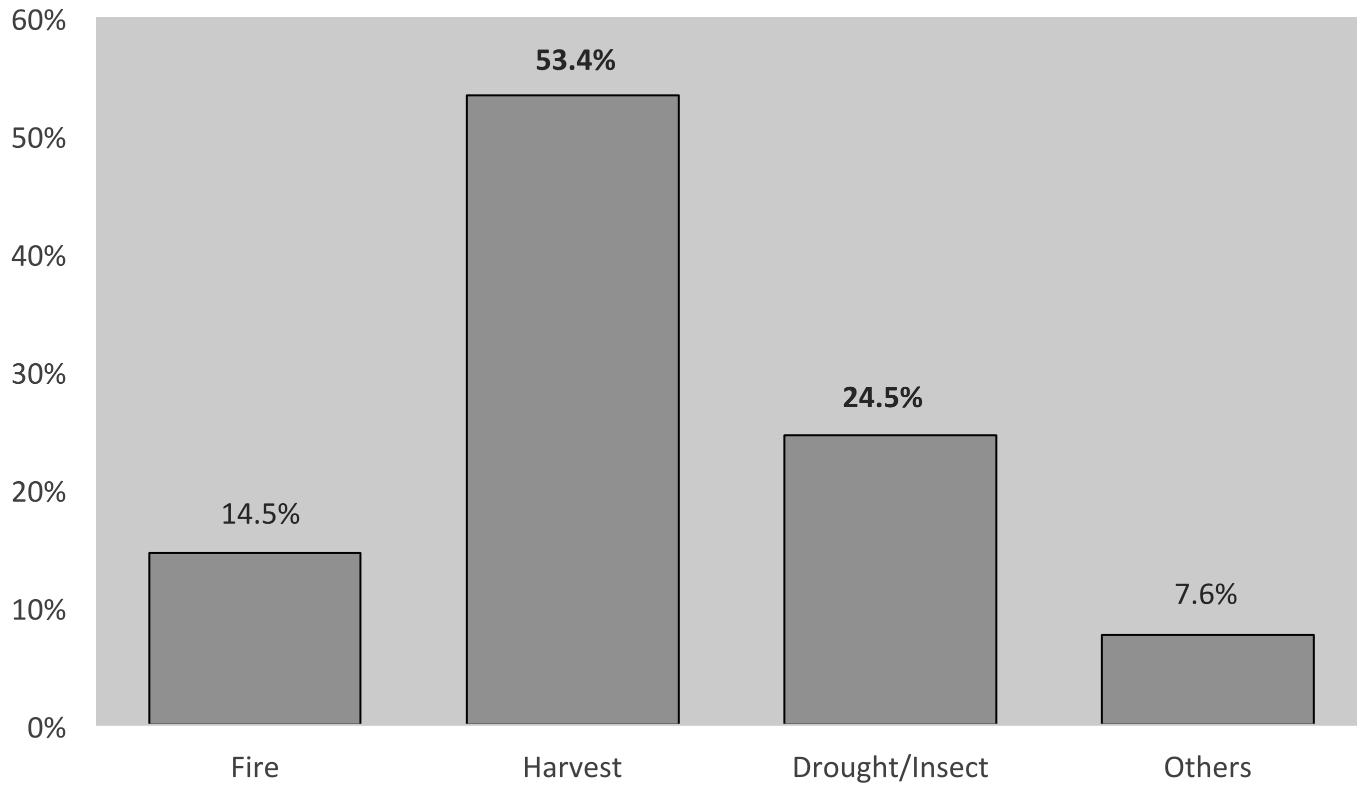
Hansen et al 2013 ; McDowell et al 2016

Areas affected by different disturbance types (2000-2014) in Continental US



Wang and Xu et al. In Prep.

Percent Carbon loss (2000-2014) by disturbance types in Continental US



Wang and Xu et al. In Prep.

Solution 5: Forest management

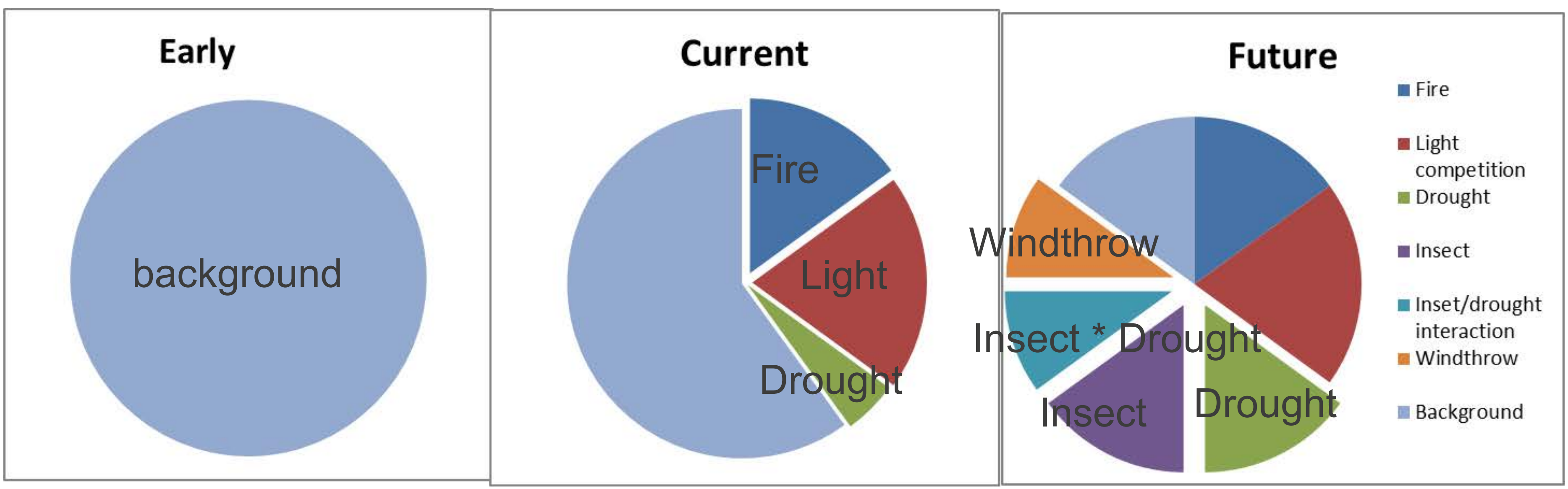
Thinning of small trees for fire suppression

Harvest of big trees to avoid the mountain beetle attack

http://bhfra.org/pine_beetles_images/experimental_forest_Years_1989_2013.jpg

Path forward

- Interactions of tree physiology community and entomology community
- Coordination and compiling of insect outbreak census across different countries
- Modex (Model experimental integrations)
- Improved understanding and predictions of interactions among different disturbance agencies (fire, insect and droughts)
- Identify key drivers for “background” mortality in ESMs



McDowell et al. In Prep.

Acknowledgments

- **Funding Sources:**
  - DOE Office of Science (SUMO, NGEE tropics)
  - LANL CSES program
  - LANL LDRD Early Career Research
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