Building Community Models of Disturbance and Vegetation Dynamics

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Vegetation change affects climate

- Carbon cycle and biogeophysical (energy balance) effects

(Friedlingstein et al. 2003, Arora et al. 2014, O’Halloran et al. 2012)
Vegetation change affects climate and watersheds

Bark beetle tree mortality can alter
- Snow accumulation
- Transmission of radiation

(Pugh & Small 2012; Bearup et al. 2014)
Disturbance and Vegetation Dynamics in Earth System Models Workshop

- March 15-16, 2018 Gaithersburg, MD
- Co-organized with Jim Clark, Duke U.
- Participants had expertise in
  - Earth system modeling, vegetation dynamics (demography), individual-based models, disturbance (fire, hurricane, insect outbreak, drought) impacts, ecophysiology, statistical methods, manipulative experiments, etc.
- Report in draft form
  - Expected end of May 2018
Terms

- **Vegetation dynamics** – birth, growth, death & competition/dispersal

- **Disturbance** – discrete events that disrupt the structure and function of an ecosystem

- Chronic **environmental change** can alter vegetation dynamics and disturbance regimes

- Crossing (unknown) thresholds into novel regimes \(\rightarrow\) probable large-scale **biome transitions**

- Major challenge for understanding and prediction
Disturbance intensity following Hurricane Maria, 2017

El Yunque National Forest

(Fang et al. 2018)
Forest damage and resilience

• Differential tree mortality and damage
  - Palms
  - Strategies for regrowth?
• Massive litterfall, rapid decomposition
  - Fate of C, nutrients?
• Damaging winds occur elsewhere (e.g., Amazon basin)

(Windthrows in Amazon)

(Negron-Juarez et al. in press)
Rising temperature alters dynamics

- Recruitment declines with warmer temperatures in subalpine forest
- Increasing mortality in many Western US forests
  - Temperature? Drought? Insects? Tree density?

Engelmann spruce recruitment in subalpine forest

Engelmann spruce population

(Kueppers et al. 2017; Conlisk et al. 2017)
Traits determine vulnerability, resistance and resilience

- Combinations of plant traits yield ecological strategies that reflect adaptations to disturbance regimes
  - Frequent fire $\rightarrow$ thick bark (3:1, savanna:forest)

(Pellegrini et al. 2017)
The complexity challenge: putting ecology back into ecosystems

(Bonan 2008)
‘Cohort-based’ models are intermediate solutions
e.g., Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

Individuals within cohort are same size, PFT, on same patch

(Koven, Fisher, Knox)
Cohorts coexist on each tile (patch)

Each *time-since-disturbance* tile contains *cohorts* of plants, defined by *PFT* and *size*.

Time-Since-Disturbance tiling

- 60 years
- 30 years
- 90 years
- 15 years
- 1 year
- 5 years

(Koven, Fisher, Knox)
Benefits for modeling vegetation dynamics and disturbance

- Heterogeneity in light availability
- Competition (for light), exclusion & coexistence
- Mechanistic Ecosystem Assembly
- Recovery after Disturbance (fire, land use, mortality)
- Arbitrary PFT definition
- PFT distribution emerges from trait filtering

(Koven, Fisher, Knox)
Are tropical forests resilient to drought?

- ED2-hydro cohort model
- Two axes of competition
  - **Light**: early- vs late-successional (wood density and photosynthesis traits)
  - **Water**: drought-tolerant vs -intolerant (hydraulic traits)
- Stable coexistence under historical hydroclimate variation at BCI, Panama

(Powell et al. accepted)
Functional types responded to hydroclimate change

Aboveground biomass [kg C m^{-2}]

Simulation year

0 100 200 300 400

BASELINE (observed)  ENSO  Variable dry season

No Variation  Wetter annual mean

Longer dry season  Drier wet season  Drier dry season

4 plant functional types:
- early drought-tolerant
- early drought-intolerant
- late drought-tolerant
- late drought-intolerant

(Powell et al. accepted)
Variable hydroclimates maintains functional diversity

Aboveground biomass [kg C m\(^{-2}\)]

- BASELINE (observed)
- ENSO
- Variable dry season

Variable climate

No Variation
- Wetter annual mean

Longer dry season
- Drier wet season
- Drier dry season

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(Powell et al. accepted)
Wetter hydroclimates favor drought-intolerant functional types

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(Powell et al. accepted)
Functional diversity provides resilience to hydroclimate change

How general is this result??

(Powell et al. accepted)
FATES as a community model: status

- Global parameterization & testing (Holm, Fisher)
FATES as a community model: status

• Global parameterization & testing (Holm, Fisher)
• Initial disturbance processes in FATES
  - Plant hydrodynamics for drought effects (Xu, Christoffersen)
  - Fire spread and effects on vegetation (Shuman, Fisher)
FATES as a community model: status

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  - Tree harvest (Huang, Xu)
- Site-scale tropical forest testbeds at BCI, Panama; Manaus, Brazil; Panama rainfall gradient (emerging)
Needs: Observational testbeds for FATES evaluation and development

- Site scale
  - Demographic measurements + flux data + meteorology + land use history
- Landscape-regional scale targeting disturbance-recovery dynamics
- Environmental gradients to test ecological strategies
Knowledge gaps

• What are the environmental sensitivities of key demographic and disturbance processes?
• What is the relationship between vegetation damage and mortality?
• How fast can ecosystem transitions occur?
• How does anthropogenic disturbance or its legacy alter ecosystem vulnerability to disturbance and recovery?
• How do nutrients constrain vegetation development & competitive dynamics?
• ...
Elements needed

Complex dataset integration and use
Community effort

Demographic, dynamic trait models
Disturbance processes & impacts
Benchmark models (IBMs, SDMs)

New observations

Data synthesis

Modeling advances

New sensing approaches
Distributed experiments
Novel benchmarks

Ameriflux BADM

ShrubHub
Thanks!