DISTURBANCE AT THE THRESHOLD: WHEN DOES TREE MORTALITY BREAK THE FOREST CARBON CYCLE?

CHRISTOPHER M. GOUGH* WITH BEN BOND-LAMBERTY (PNNL), PETER CURTIS (OSU), GIL BOHRER (OSU), & NUMEROUS STUDENT COLLABORATORS

*VIRGINIA COMMONWEALTH UNIVERSITY; CMGOUGH@VCU.EDU

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WHO AM I (AND WHERE AM I)?

- I'm an plant physiological and ecosystem ecologist, focusing on forest carbon cycling in the upper Great Lakes region.
- My home institution is Virginia Commonwealth University in Richmond, VA; I "summer" for research in northern MI.
- I have a long history working with the DOE, with ongoing DOE-affiliated projects as an Ameriflux Core Site co-PI (US-UMB, US-UMd), and with Ben Bond-Lamberty and Alexey Shiklomanov.

Source: Google Earth

The University of Michigan Biological Station (UMBS) is located in the heart of the Great Lakes watershed.

OUTLINE FOR TODAY'S WEBINAR

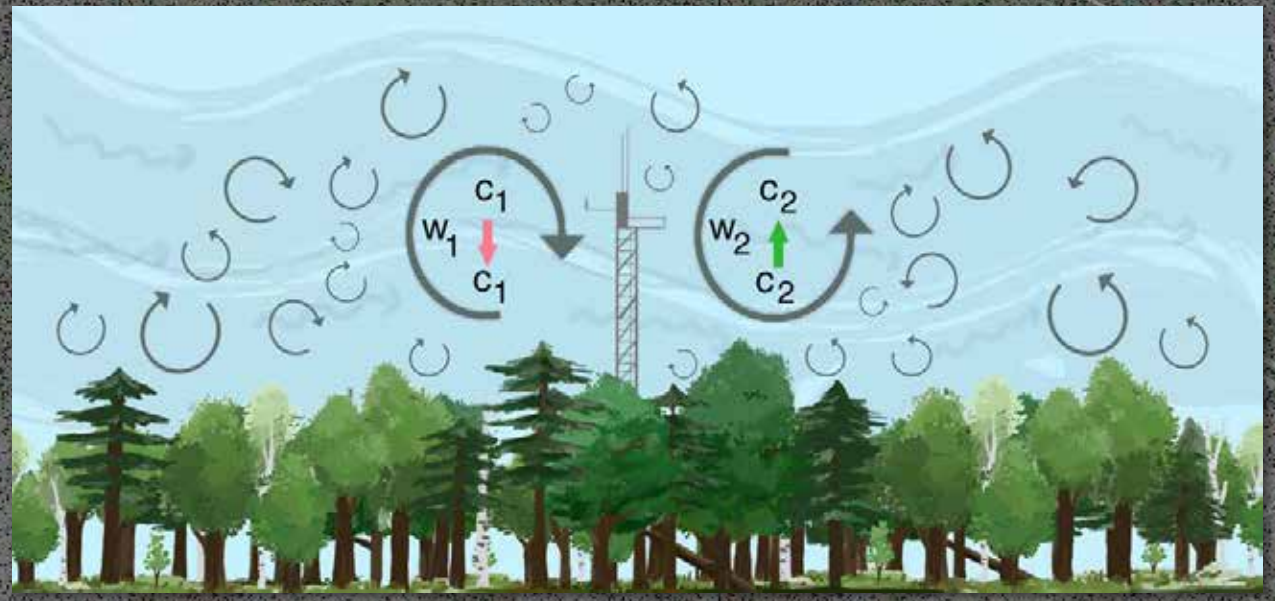
1. What is the extent, source, and severity of forest disturbance?
2. How have ecologists and biogeochemists traditionally viewed disturbance severity-C cycling interactions?
3. What do observations tell us about the reality of disturbance severity-C cycling interactions?
4. What are the knowledge gaps and how do we fill them?
5. Conclusions

These fine lab members do all the work.

A FEW TERMS AND CONCEPTS

- *Net primary production (NPP)*: the annual rate of plant biomass accumulation in an ecosystem, usually expressed in terms of carbon currency
- *Net ecosystem production (NEP)*: NPP minus carbon losses from heterotrophic respiration
- *Disturbance severity*: The (relative or absolute) amount of foliage or biomass lost to disturbance

NEP is often measured using "flux" towers. NPP is typically derived from ground inventory and, increasingly, remotely sensed data.



Artist: Catherine McGuigan (VCU)

ALL FORESTS ARE RECIPIENTS OF DISTURBANCE.

Mill Creek Sawmill, Cheboygan County,

First Sawmill in Northwest Territory

1. What is the extent, source, and severity of forest disturbance?

State Archives of Michigan

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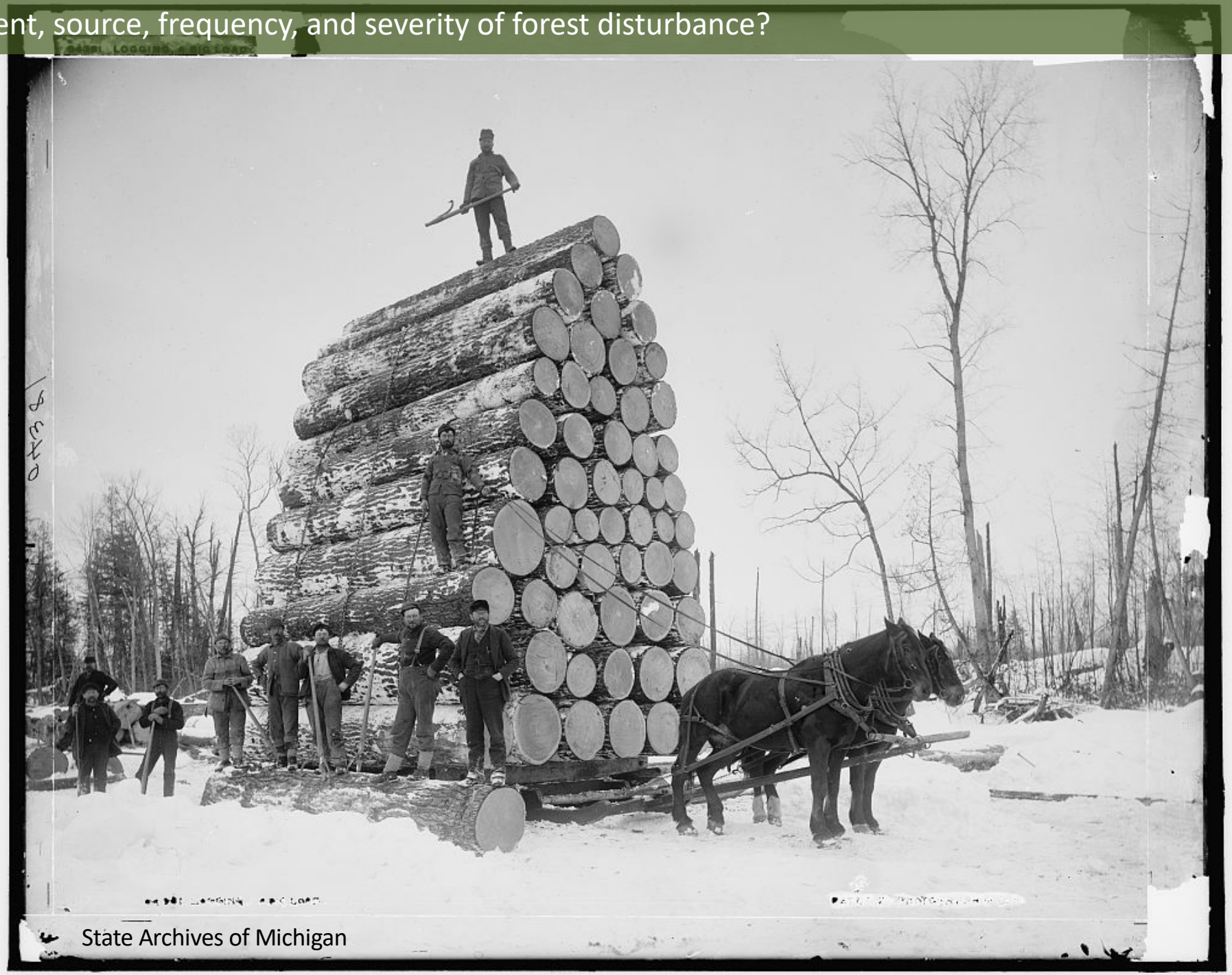

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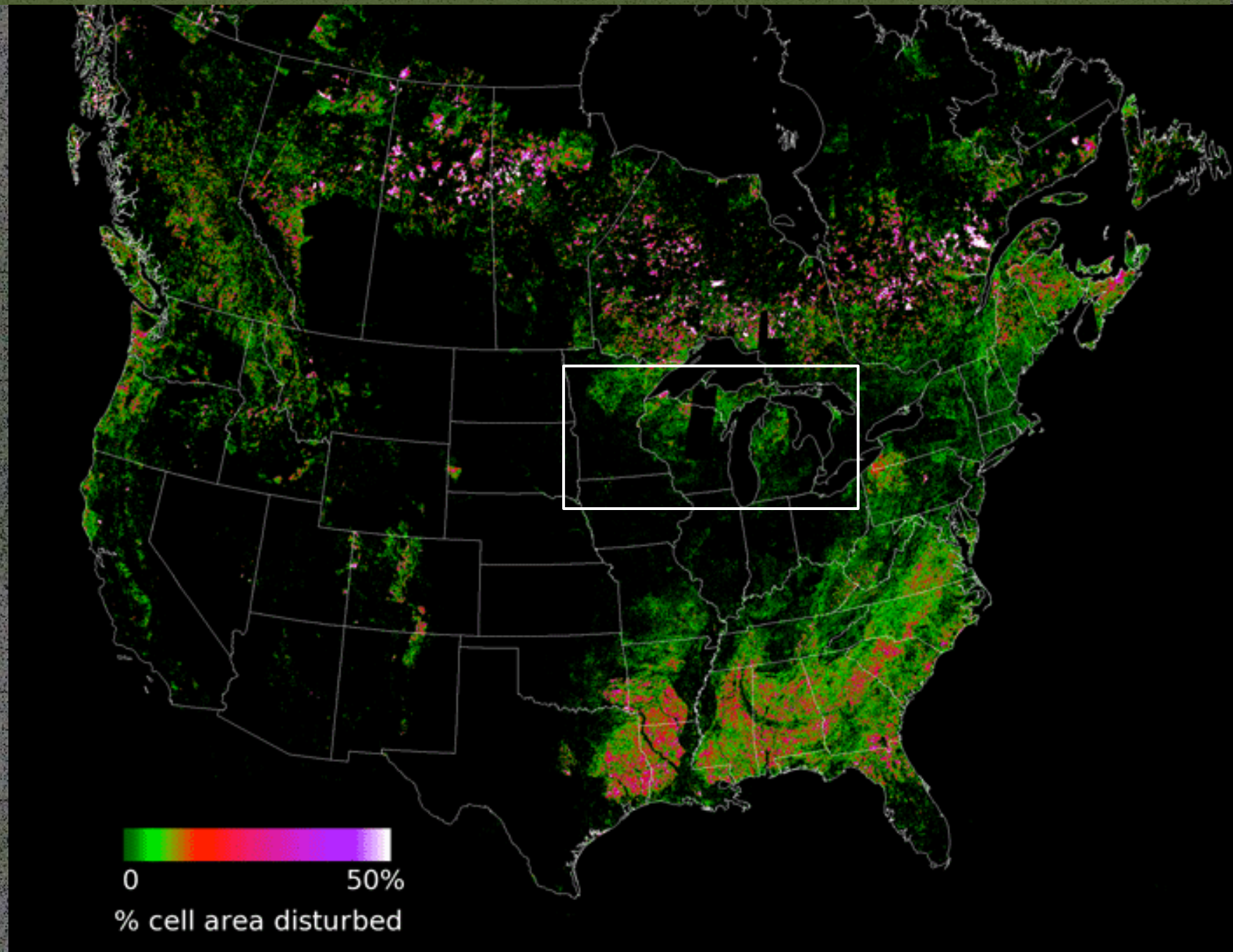
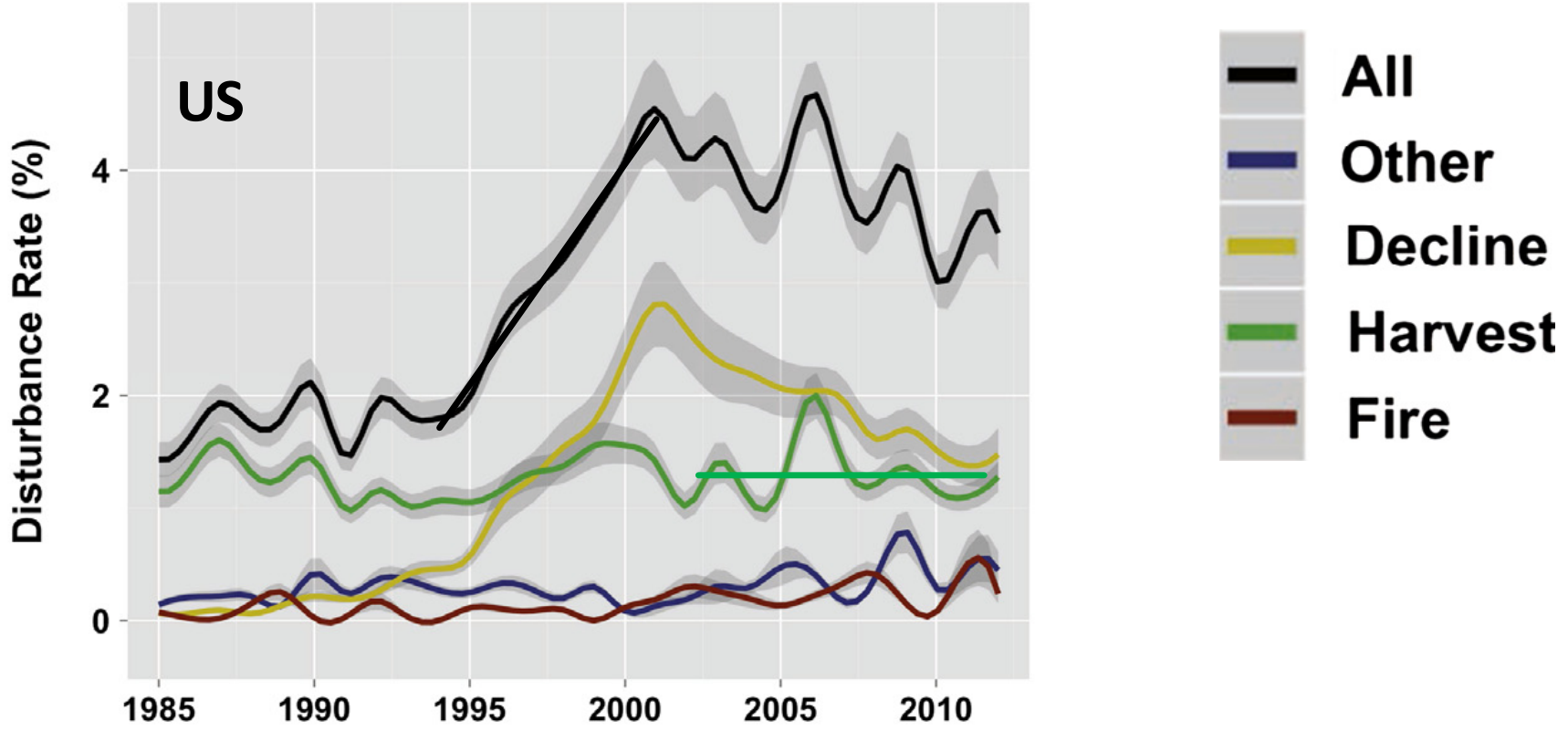
GOWARD, S.N., C. HUANG, J.G. MASEK, W.B. COHEN, G.G. MOISEN AND K. SCHLEEWEIS. 2012. NACP NORTH AMERICAN FOREST DYNAMICS PROJECT: FOREST DISTURBANCE AND REGROWTH DATA. AVAILABLE ON-LINE [HTTP://DAAC.ORNL.GOV] FROM ORNL DAAC, OAK RIDGE, TENNESSEE, U.S.A.HTTP://DX.DOI.ORG/10.3334/ORNLDAAC/1077



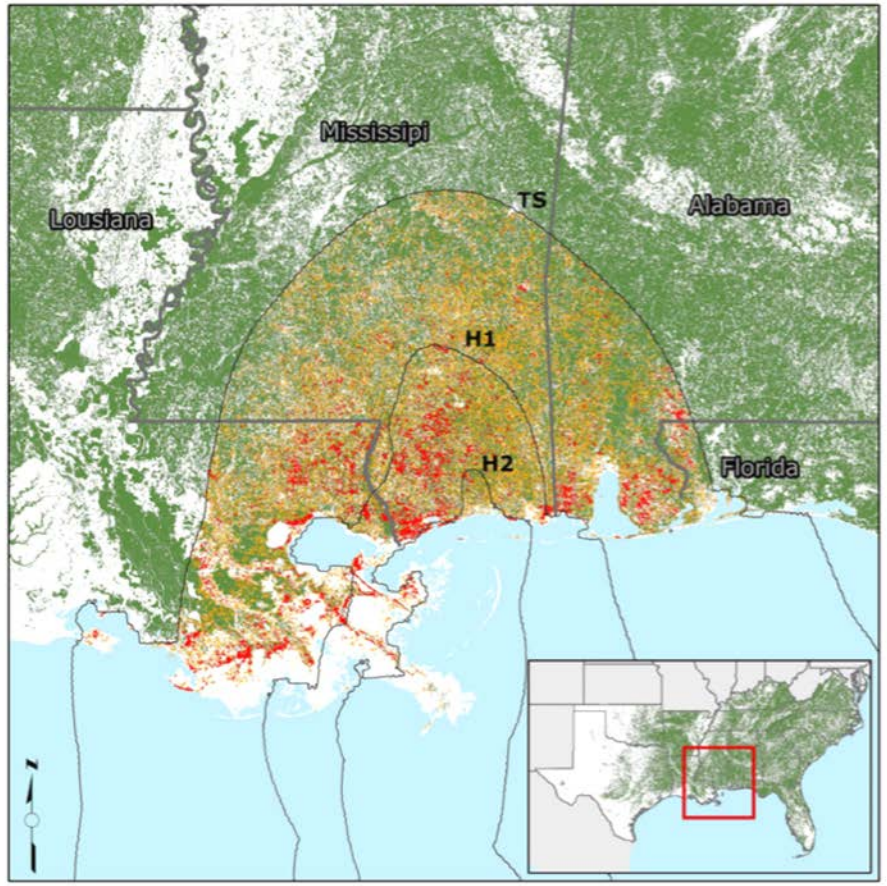
IN THE US, COHEN *ET AL.* REPORT ANNUAL FOREST DISTURBANCE RATES OF 1.5 TO 4.5 %.

W.B. Cohen et al./Forest Ecology and Management 360 (2016) 242–252



DISTURBANCE OCCURS ALONG A CONTINUUM OF SEVERITY

Tree Mortality in Southern Costal Forests after Katrina.



Tree mortality degree*

High

Low

Forest cover

Non-forest

Forest

Equal wind speed (isotachs)**

State boundary

0 25 50 100 150 Miles

** Change in the non-photosynthetic vegetation fraction from 2003-2006, derived from a MODIS satellite imagery.*

*** Isotachs represent tropical storm (TS), category 1 (H1), and category 2 (H2) wind fields. More information in: M. D. Powell, S. H. Houston, L. R. Amat, N. Morisseau-Leroy, J. 1998. Wind Eng. Ind. Aerodyn. 53: 77-78.*

WORLD RESOURCES INSTITUTE

Data sources:

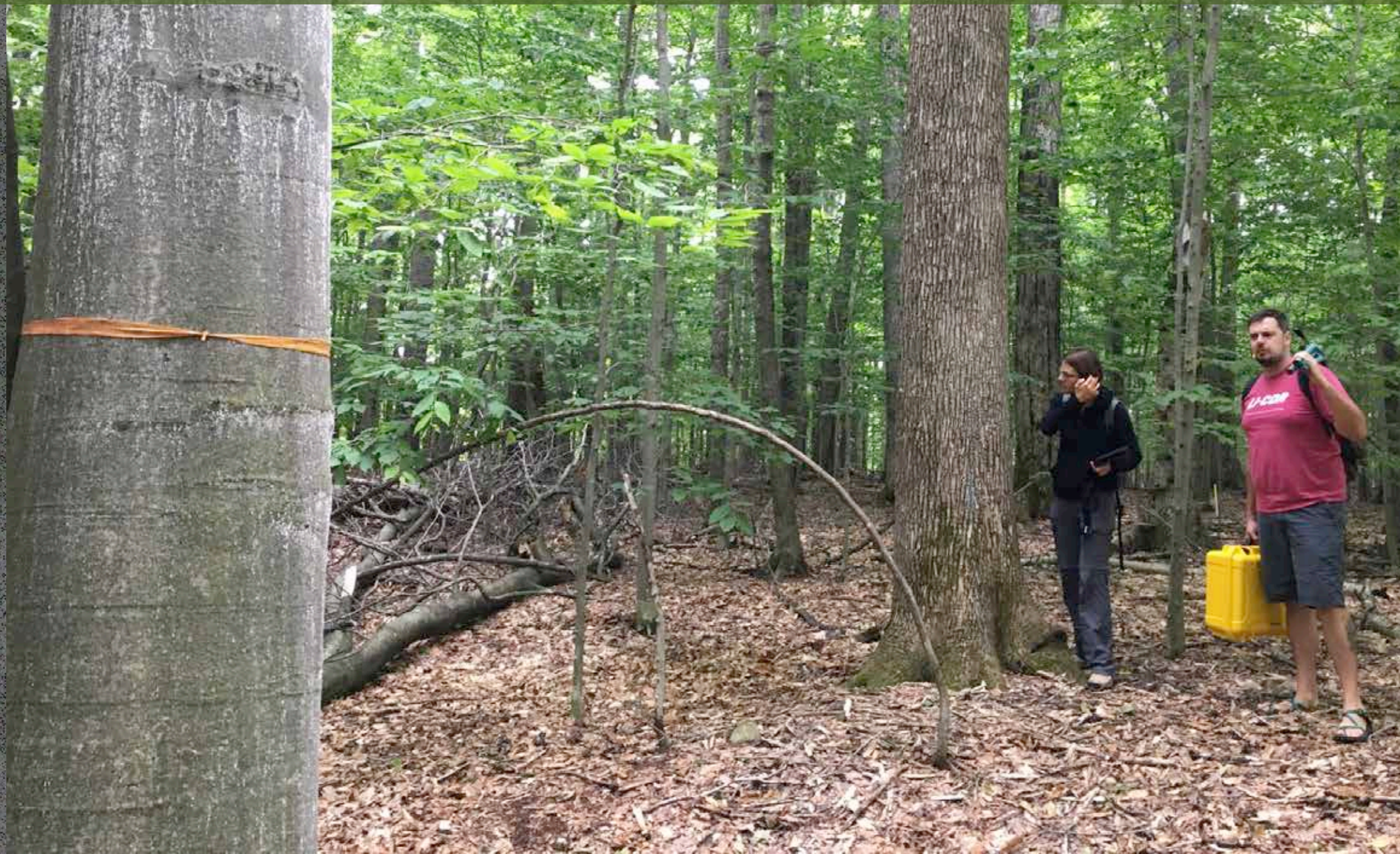
Tree mortality degree and isotachs (Tulane University, 2007), state boundaries (2009 Data and Maps, ESRI, 2009), forest cover (NLCD 2001, USGS, 2007), base map (Microsoft Corporation and its data suppliers, 2009).

1. What is the extent, source, frequency, and severity of forest disturbance?

Emerald Ash Borer

1. What is the extent, source, frequency, and severity of forest disturbance?

Beech Bark Disease



1. What is the extent, source, frequency, and severity of forest disturbance?

Wind Throw

1. What is the extent, source, frequency, and severity of forest disturbance?

Fire

Wooly Adelgid

Physical structure sometimes predicts primary production thresholds to disturbance, but why the inconsistency?

PART 1, SUMMARY

- Disturbance is increasing in extent.
- Severe disturbance from harvesting is relatively constant (and in some regions decreasing); moderate severity disturbances have increased.
- Substantial variation exists in disturbance severity.

DIS·TUR·BANCE (ACCORDING TO GOOGLE):

The disruption of healthy functioning.

Disturbance-carbon cycling theory

The Strategy of Ecosystem Development

An understanding of ecological succession provides a basis for resolving man's conflict with nature.

Eugene P. Odum

The principles of ecological succession bear importantly on the relationships between man and nature. The framework of successional theory needs to be examined as a basis for resolving man's present environmental crisis. Most ideas pertaining to the development of ecological systems are based on descriptive data obtained by observing changes in biotic communities over long periods, or on highly theoretical assumptions; very few of the generally accepted hypotheses have been tested experimentally. Some of the confusion, vagueness, and lack of experimental work in this area stems from the tendency of ecologists to regard "succession" as a single straightforward idea; in actual fact, it entails an interacting complex of processes, some of which counteract one another.

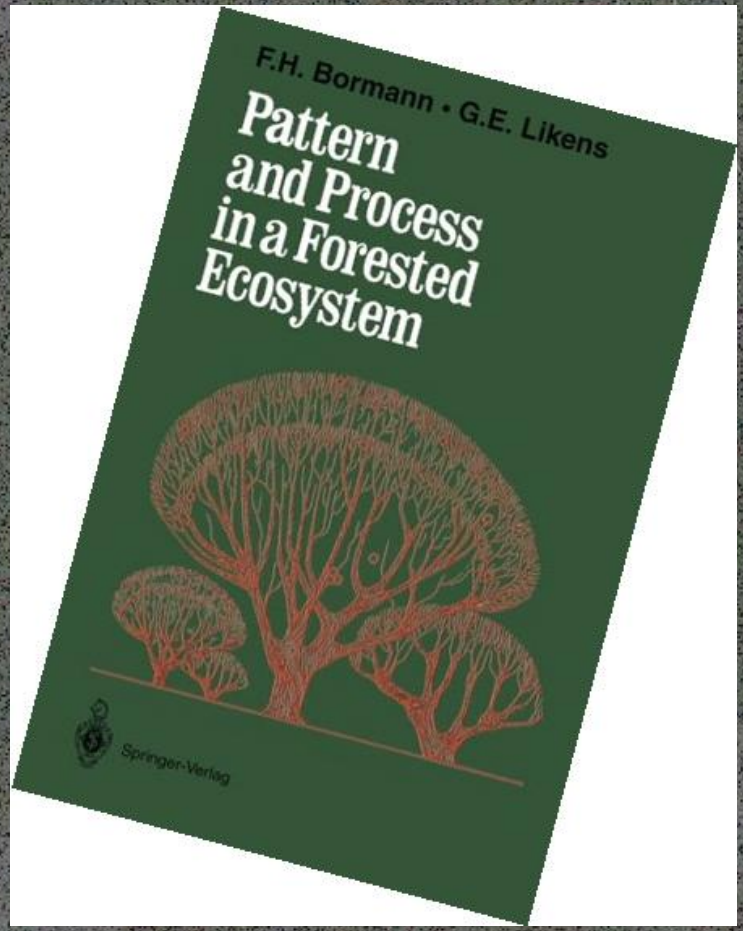
As viewed here, ecological succession involves the development of ecosystems; it has many parallels in the developmental biology of organisms, and also in the development of human society. The ecosystem, or ecological system, is considered to be a unit of biological organization made up of all of the organisms in a given area (that is, "community") interacting with the physical environment so that a flow of energy leads to characteristic trophic structure and material cycles within the system. It is the purpose of this article to summarize, in the form of a tabular model, components and stages of development at the ecosystem level as a means of emphasizing those aspects of ecological succession that can be accepted on the basis of present knowledge, those that require more study, and those that have special relevance to human ecology.

The author is director of the Institute of Ecology, and Alumni Foundation Professor, at the University of Georgia, Athens. This article is based on a presidential address presented before the annual meeting of the Ecological Society of America at the University of Maryland, August 1966.

Definition of Succession

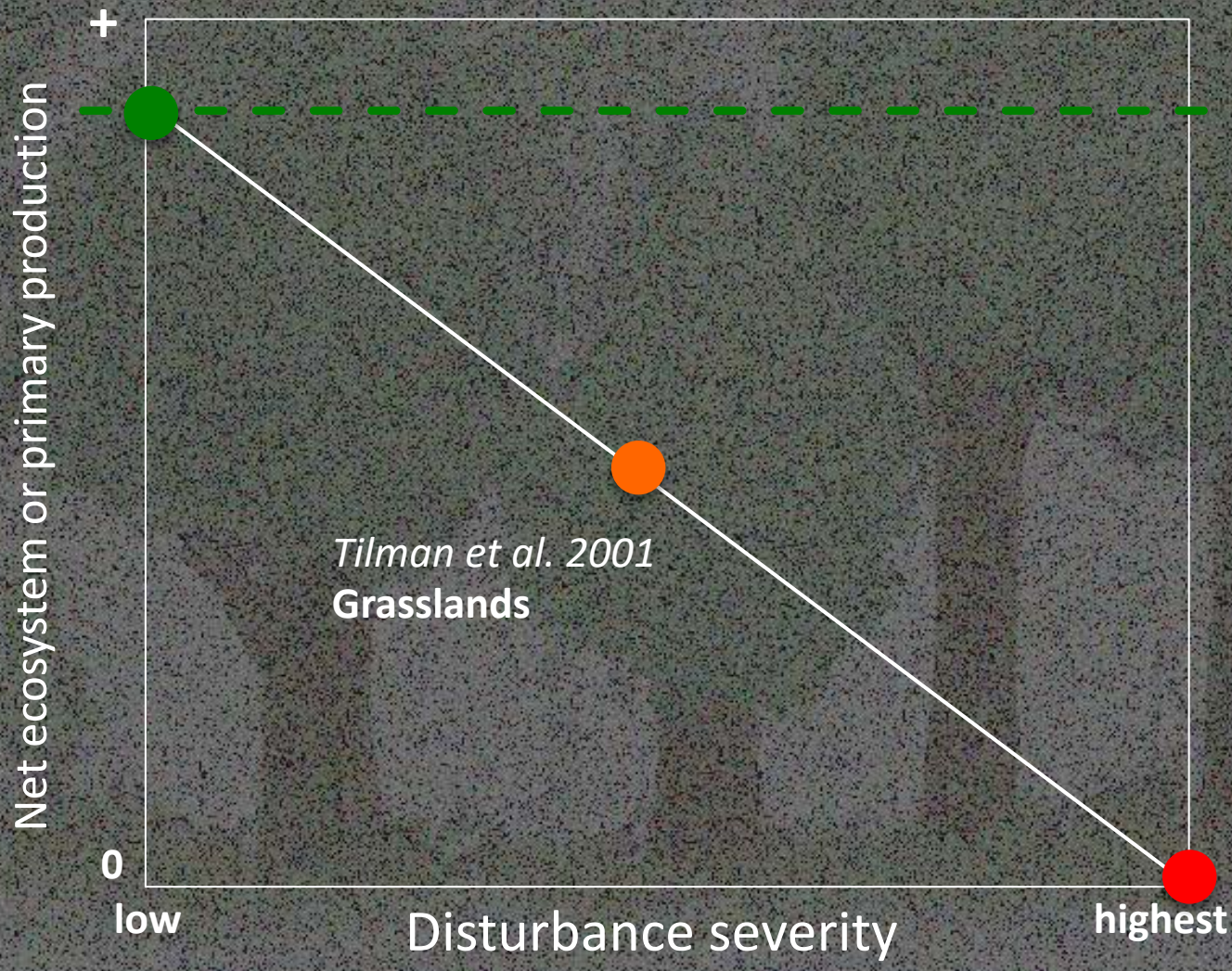
Ecological succession may be defined in terms of the following three parameters (*1*). (i) It is an orderly process of community development that is reasonably directional and, therefore, predictable. (ii) It results from modification of the physical environment by the community; that is, succession is community-controlled even though the physical environment determines the pattern, the rate of change, and often sets limits as to how far development can go. (iii) It culminates in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function between organisms are maintained per unit of available energy flow. In a word, the "strategy" of succession as a short-term process is basically the same as the "strategy" of long-term evolutionary development of the biosphere—namely, increased control of, or homeostasis with, the physical environment in the sense of achieving maximum protection from its perturbations. As I illustrate below, the strategy of "maximum protection" (that is, trying to achieve maximum support of complex biomass structure) often conflicts with man's goal of "maximum

1969



1979

THE THEORY: THREE POTENTIAL SHORT-TERM RESPONSES OF FOREST PRODUCTION TO RISING DISTURBANCE SEVERITY:



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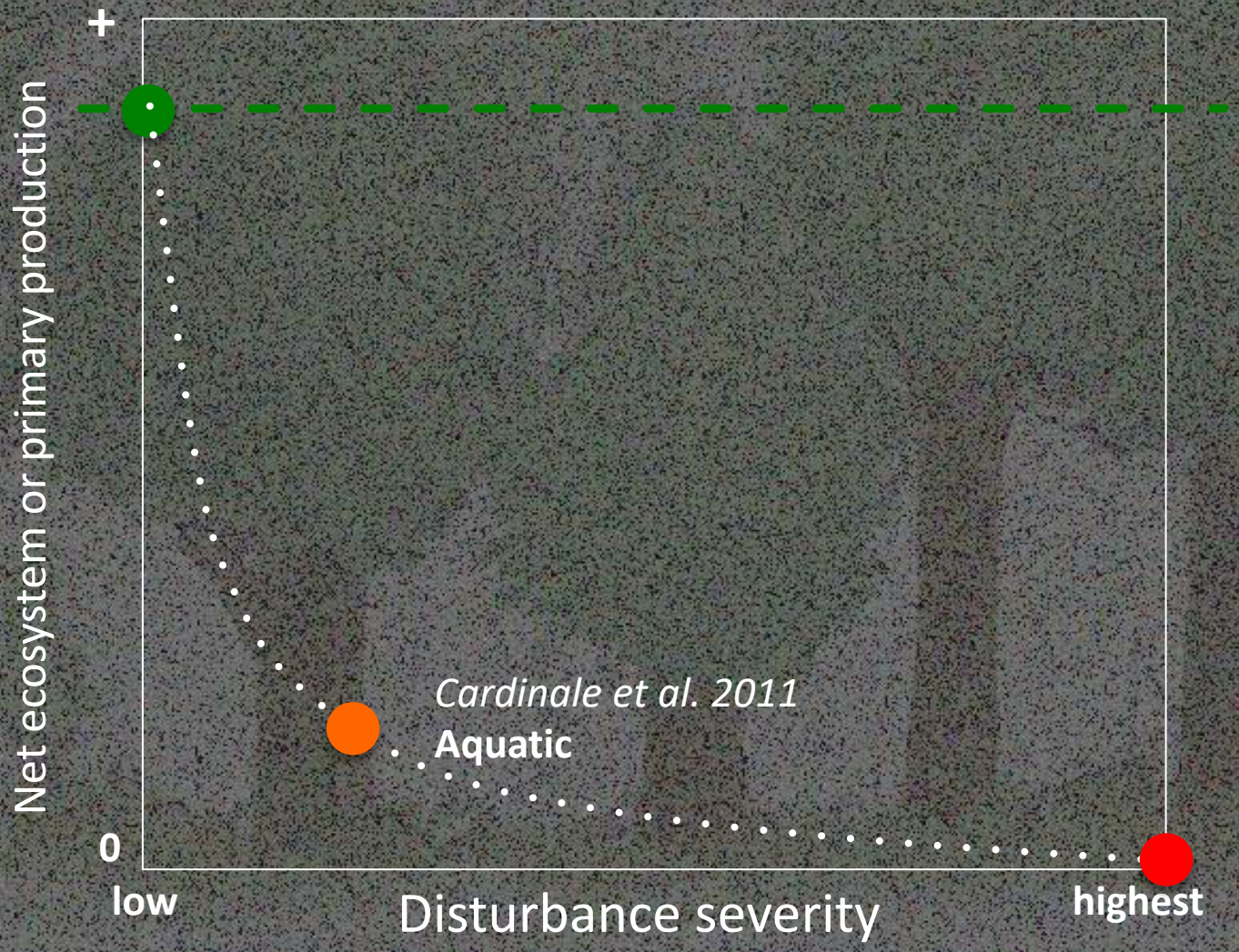

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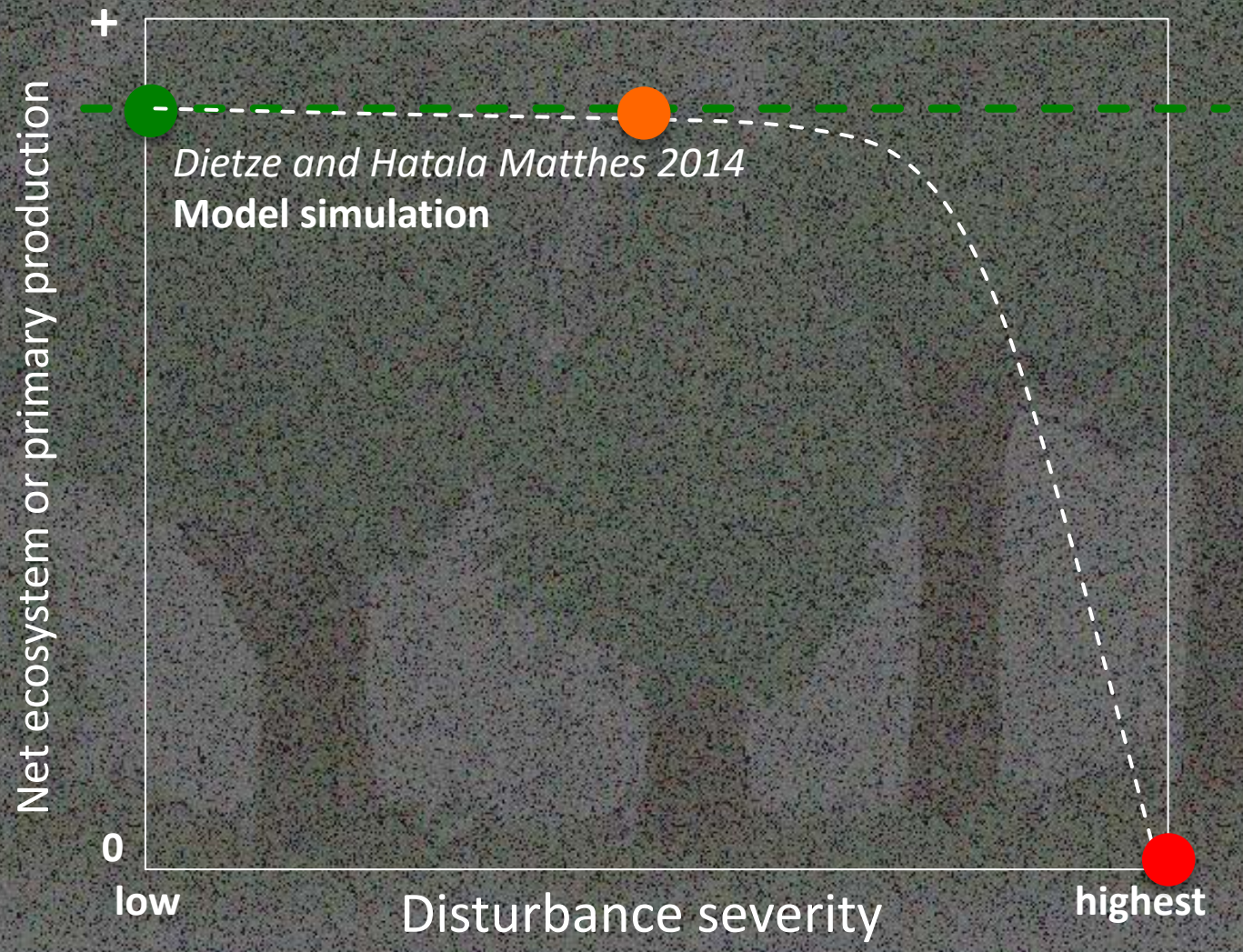
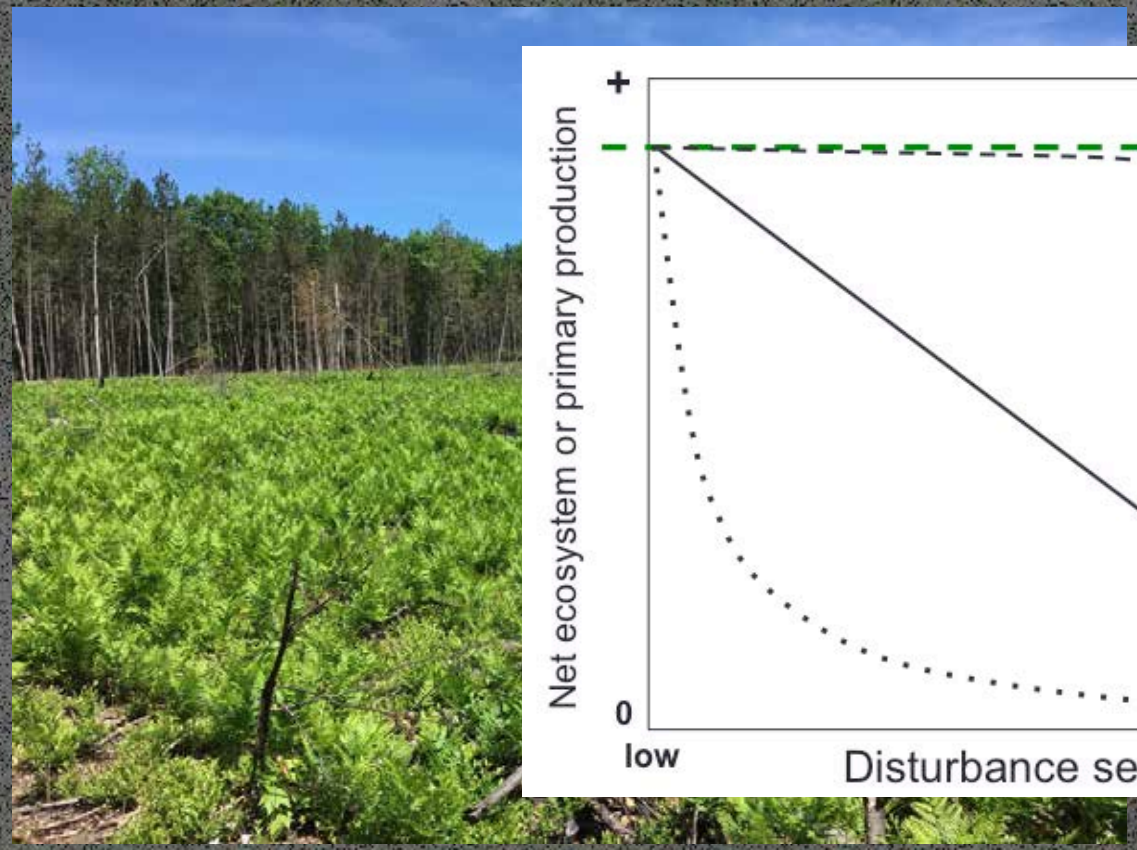
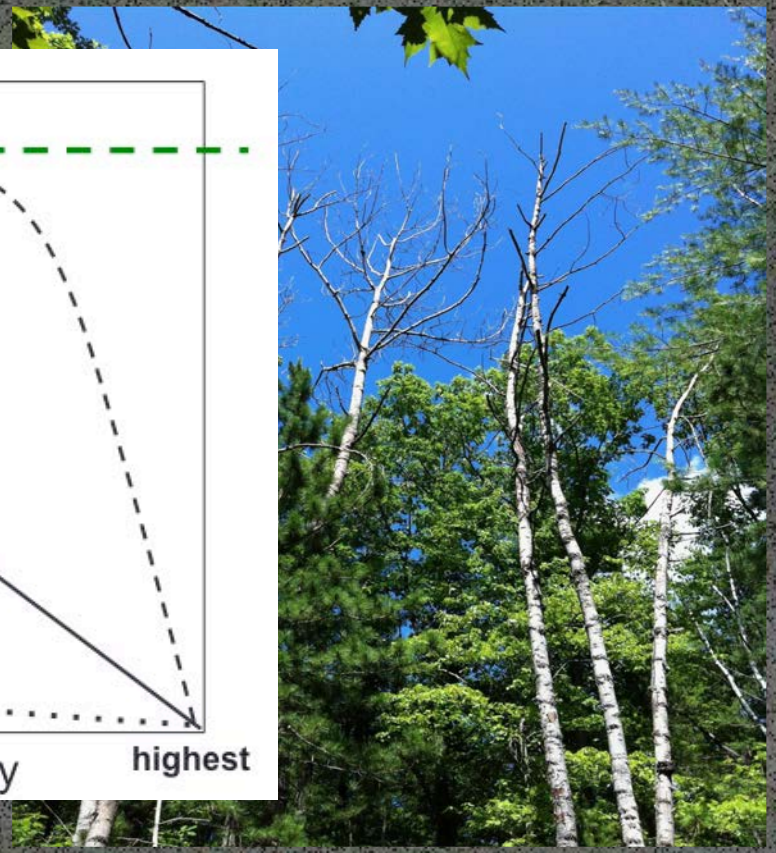


PART 2, SUMMARY

- Ecologists have generally assumed a 1:1 linear relationship between tree mortality and net primary and ecosystem production decline.
- Some modeling and observational data from other ecosystems suggest other production-disturbance severity relationships are possible in forests.

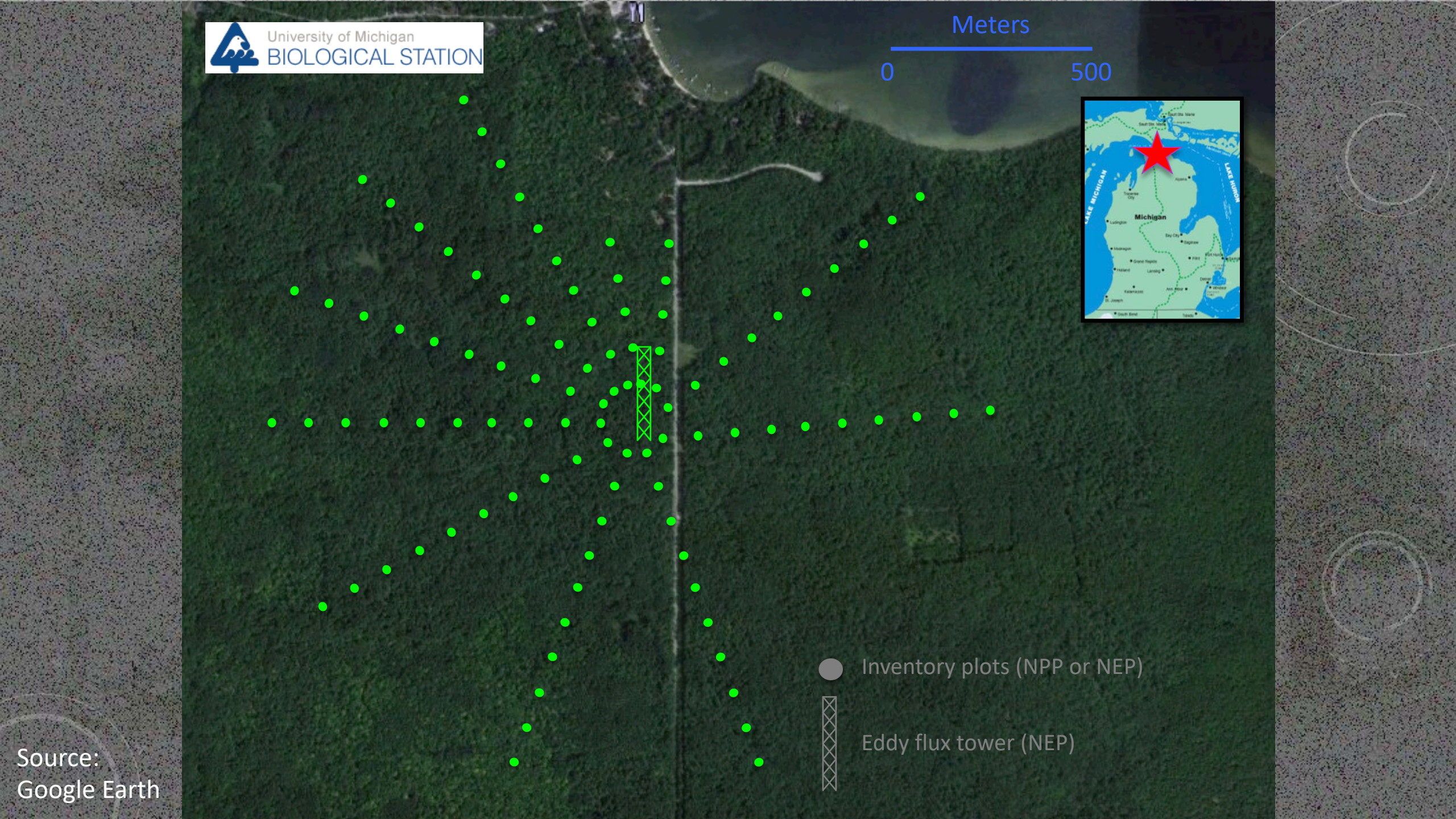
WE USE EXPERIMENTS TO STUDY DISTURBANCE SEVERITY AT THE ECOSYSTEM SCALE



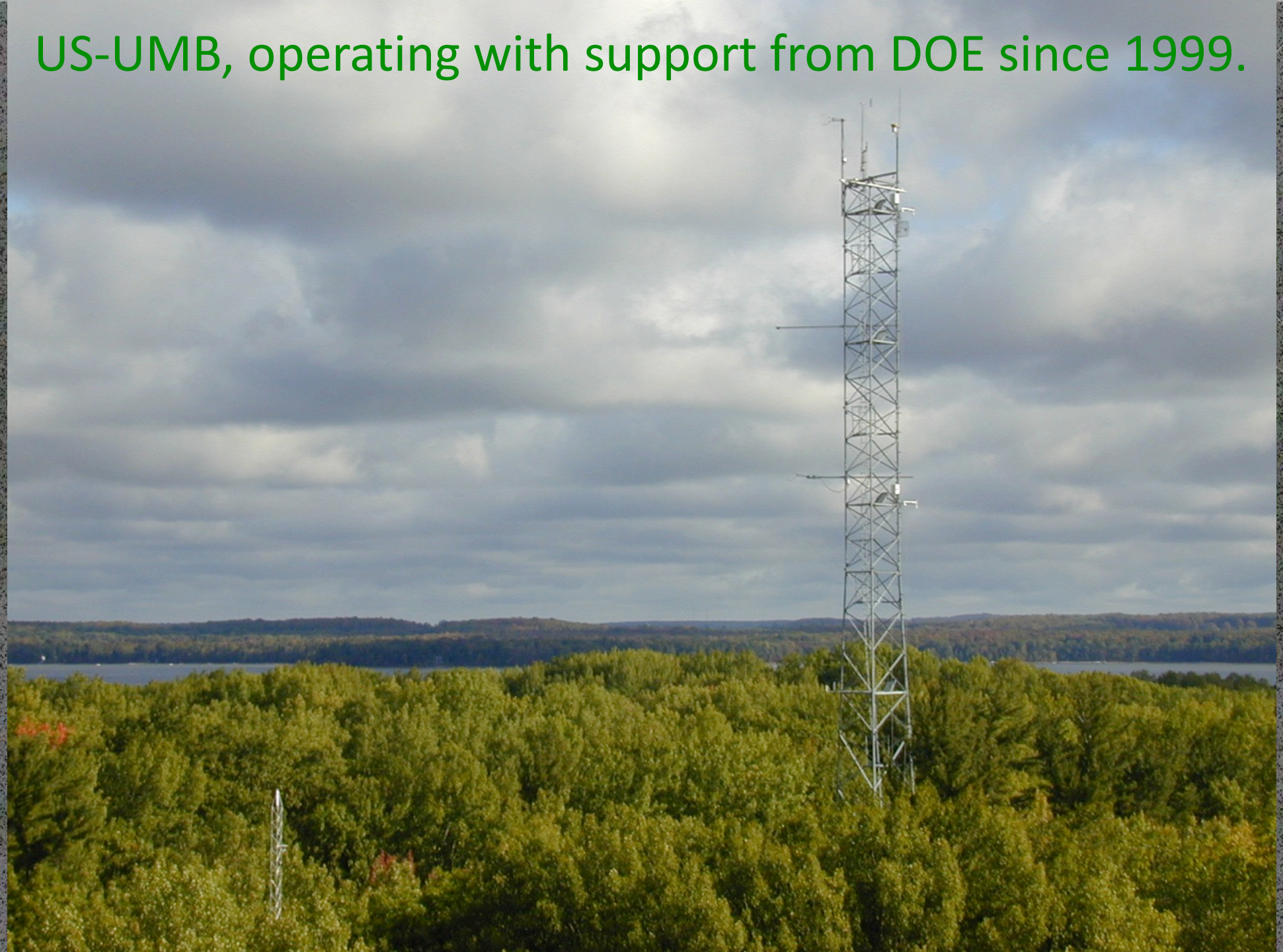


Experimental clear-cut

Experimental partial defoliation


University of Michigan
BIOLOGICAL STATION
Meters
0
500
Michigan
LAKE MICHIGAN
LAKE HURON
Inventory plots (NPP or NEP)
Eddy flux tower (NEP)
Source:
Google Earth

US-UMB, operating with support from DOE since 1999.



Source:
Google Earth

Snapshots in time: Using fire and logging to recreate a century of forest history at the U-M Biological Station

Most trees larger than 5 inches in diameter were removed from the plots in April. Dead branches and other logging debris were left on the ground. Then the plots were burned in October. Image credit: Roger Hart, Michigan Photography

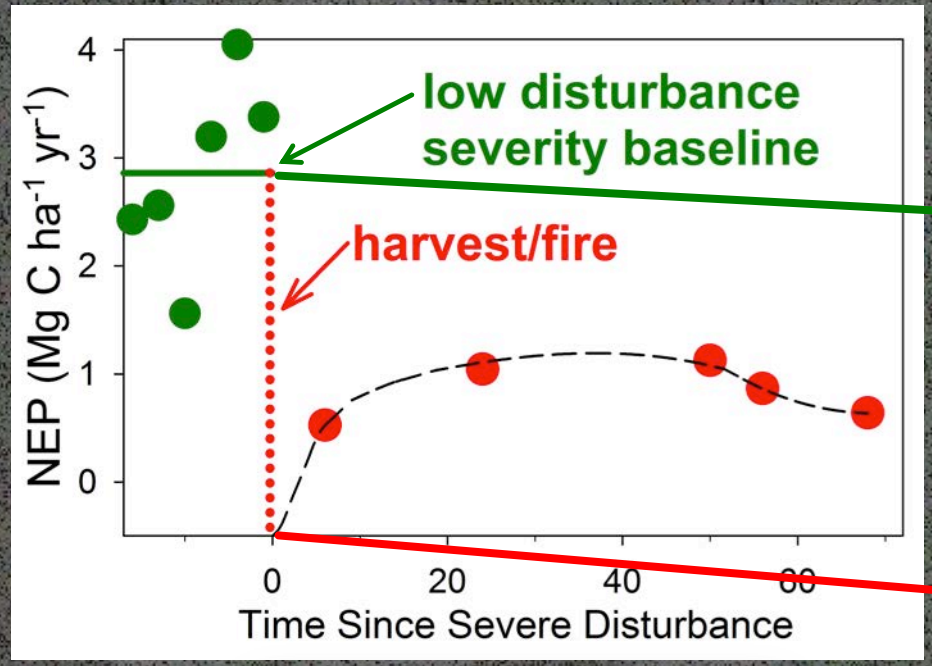
November 20, 2017

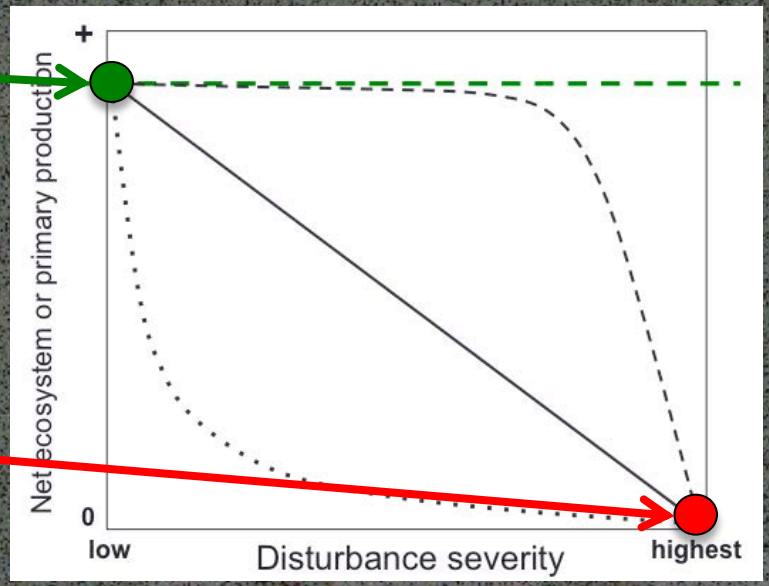
Contact: Jim Erickson
ericksn@umich.edu

Share on:

https://news.umich.edu/snapshots-in-time-using-fire-and-logging-to-recreate-a-century-of-forest-history-at-the-u-m-biological-station/

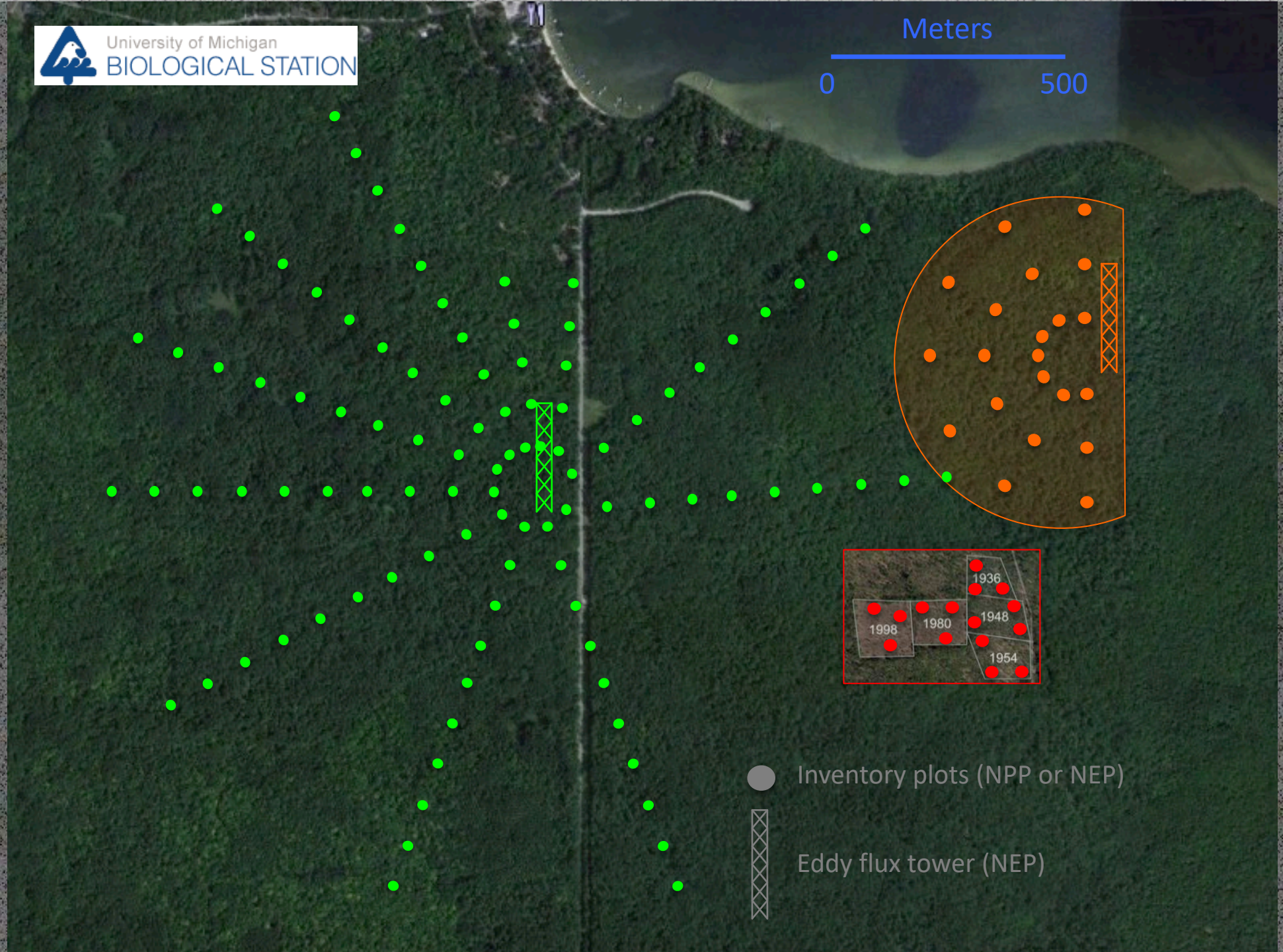
LIKE OTHER SITES, SEVERE STAND-REPLACING DISTURBANCE AT UMBS SIGNIFICANTLY REDUCED NEP.





6 years following severe, stand-replacing disturbance

Gough et al. 2007, ***Global Change Biology***

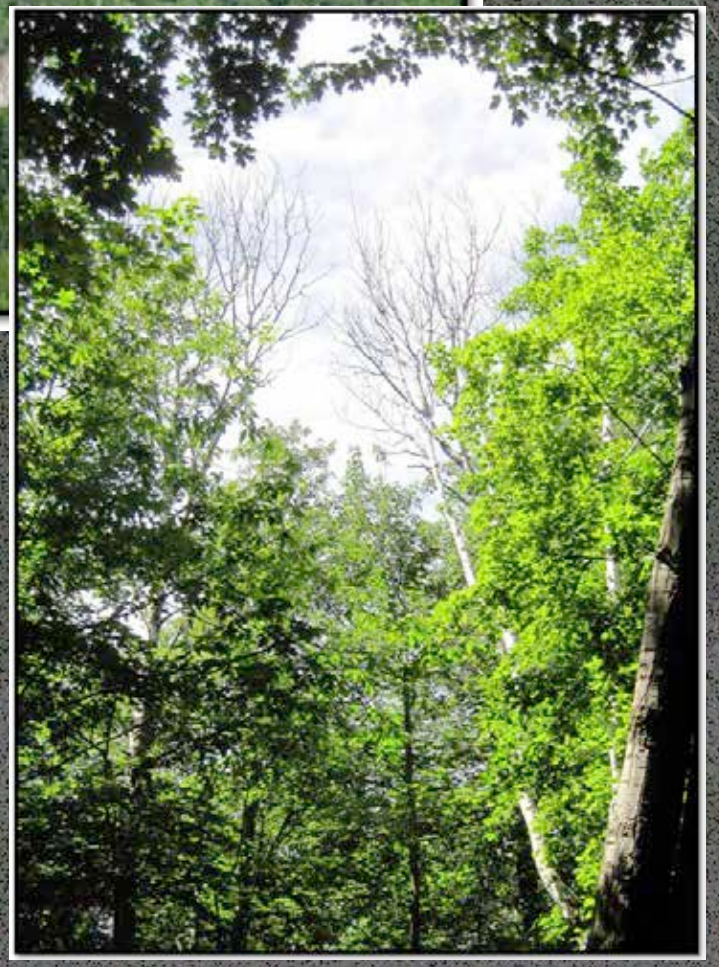


Source:
Google Earth

THE FOREST ACCELERATED SUCCESSION EXPERIMENT (FASET) INITIATED MAY, 2008

- 7,000 aspen and birch girdled
- 39 ha (~100 acres)

3. What do observations tell us about the reality of disturbance severity-C cycling interactions?

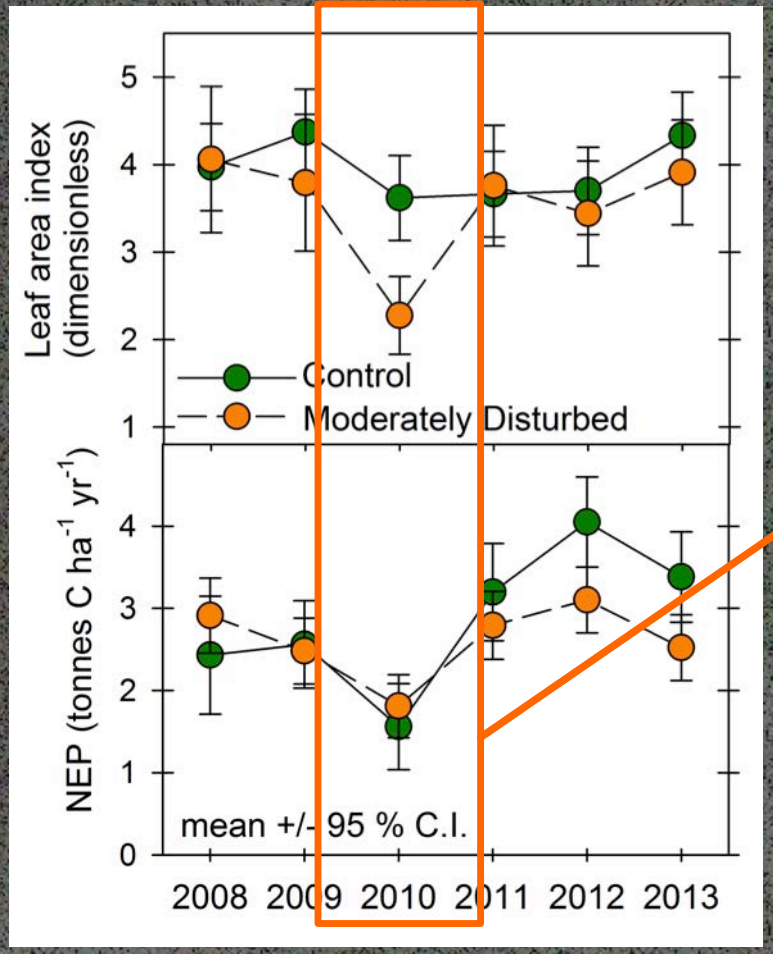


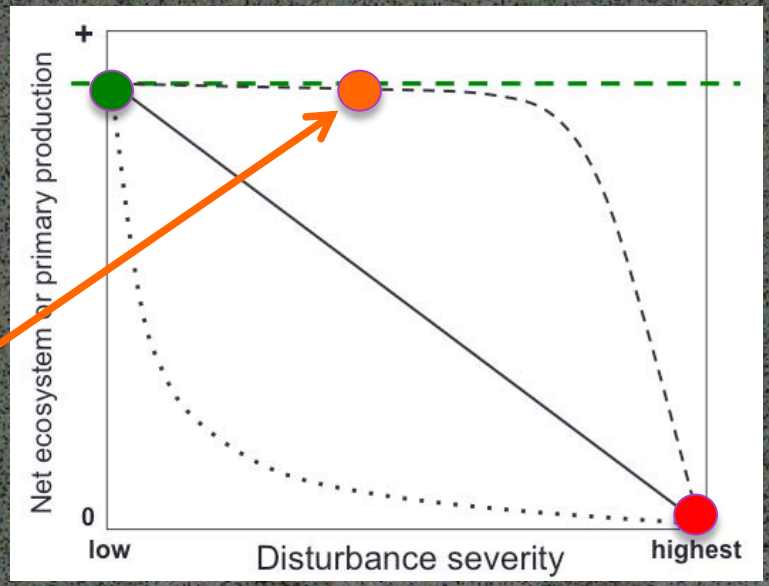
Four years following girdling (2012) *all* aspen and birch were dead, with mortality distributed heterogeneously.

3. What do observations tell us about the reality of disturbance severity-C cycling interactions?

Credit:
Peter Curtis

NEP IN THE CONTROL AND MODERATELY DISTURBED FORESTS WAS COMPARABLE DESPITE A ~40 % LAI REDUCTION.





Gough et al. 2013, ***Ecological Applications***

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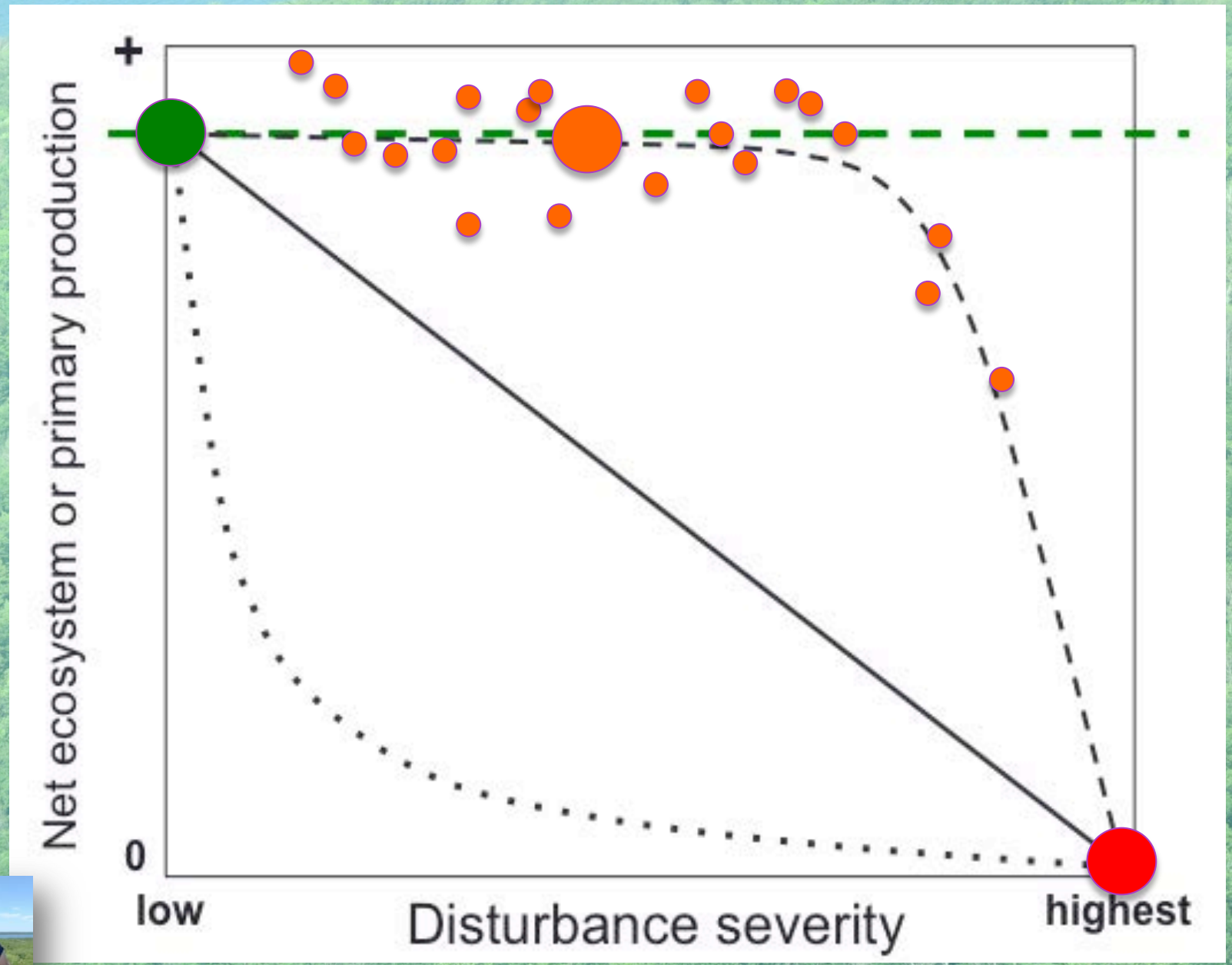
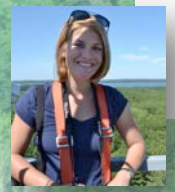
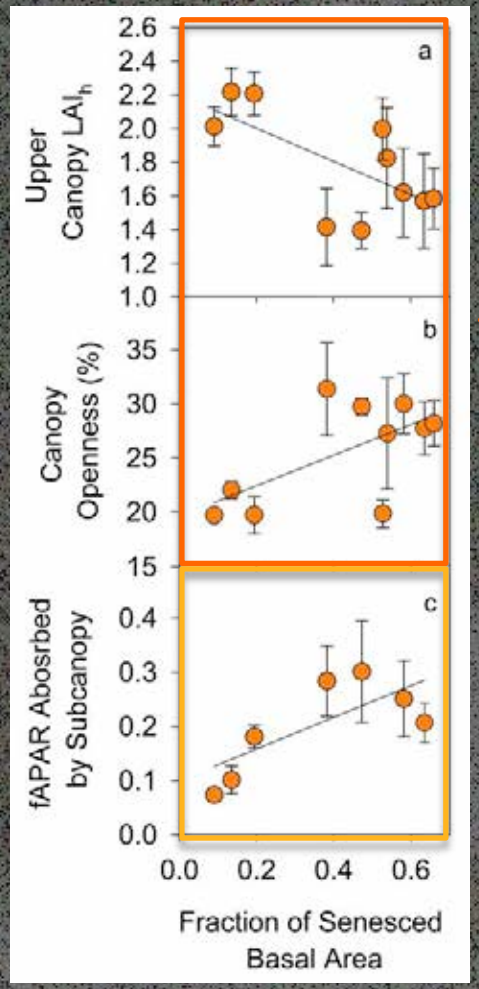




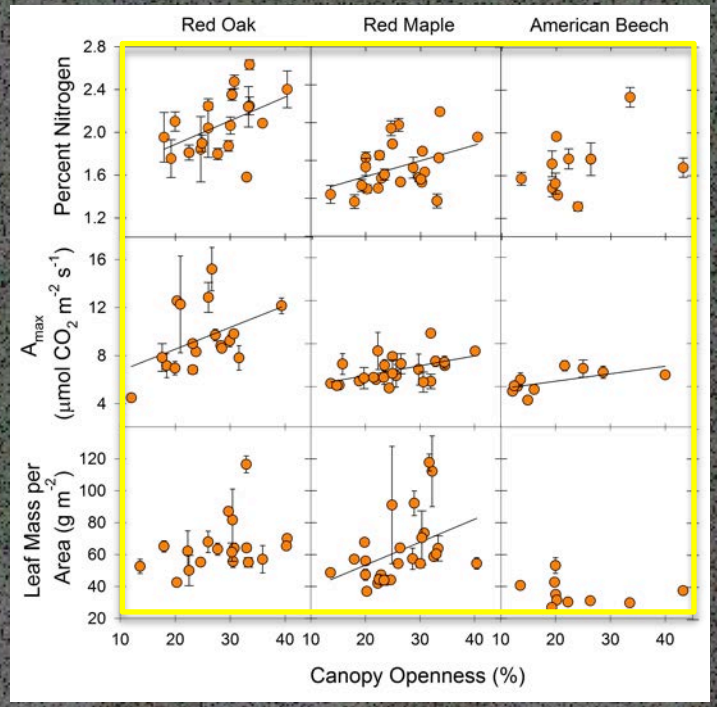
Orange data points from Stuart-Haëntjens et al. 2015, ***Ecology***

AS CANOPY STRUCTURE CHANGED, RESOURCE REDISTRIBUTION QUICKLY INCREASED SUBCANOPY PHYSIOLOGICAL COMPETENCY.



Structural change

Change in light distribution

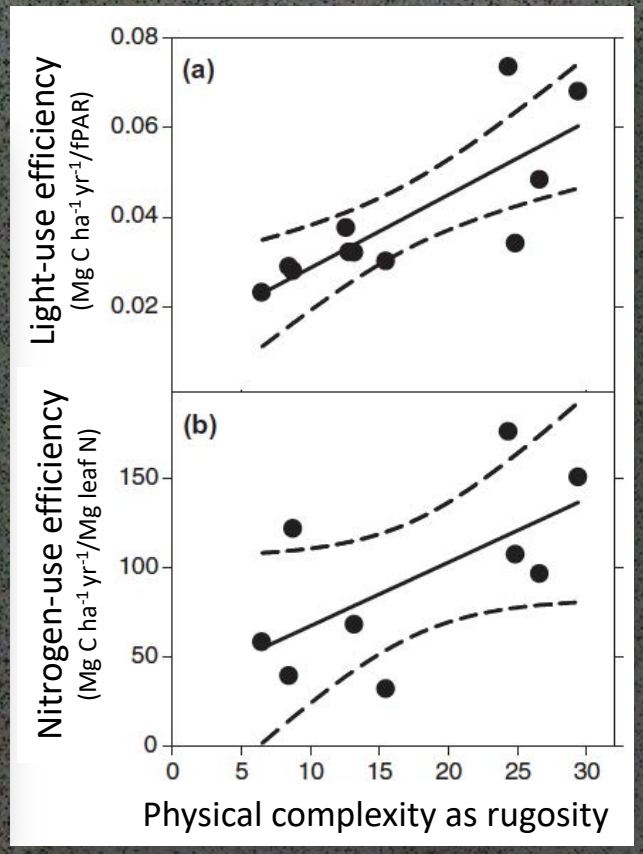


Subcanopy leaves become more sun-acclimated

Stuart-Haëntjens et al. 2015, ***Ecology***

MODERATE DISTURBANCE MAY COUNTERINTUITIVELY INCREASE HOW EFFICIENTLY RESOURCES ARE USED TO DRIVE NPP.

Severe



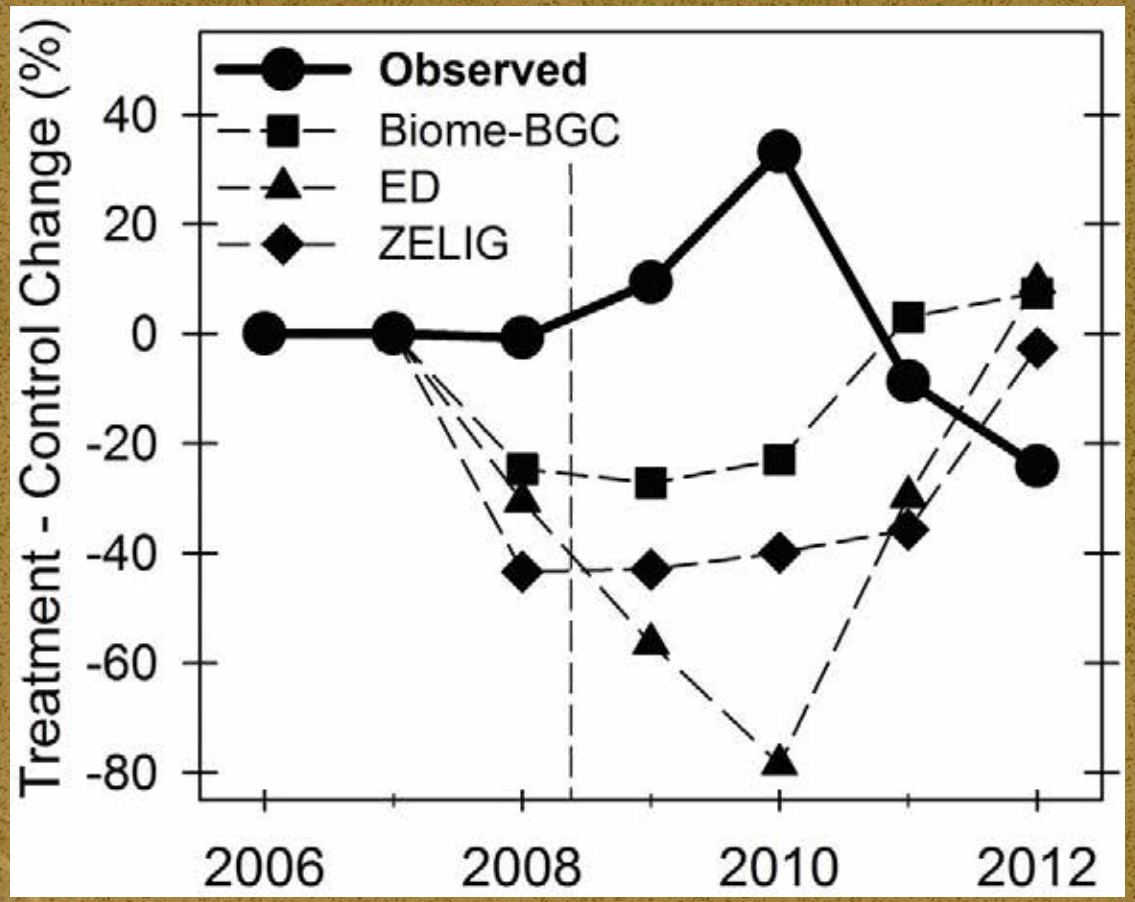
Hardiman et al. 2013, Forest Ecology and Management

Moderate

Biologically simple
Structurally simple
Even-aged

Biologically complex
Structurally complex
Multi-aged

MODELS FAIL TO SIMULATE OBSERVED RESISTANCE TO DISTURBANCE.



Moderate forest disturbance as a stringent test for gap and big-leaf models

B. Bond-Lamberty[1], J. P. Fisk[2], J. A. Holm[3], V. Bailey[4], G. Bohrer[5], and C. M. Gough[6]

[1]Pacific Northwest National Laboratory, Joint Global Change Research Institute at the University of Maryland–College Park, 5825 University Research Court, Suite 3500, College Park, Maryland, MA 20740, USA
[2]Department of Geographical Sciences, 1150 LeFrak, University of Maryland, College Park, Maryland, MA 20742, USA
[3]Climate Sciences Department, Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., MS 74-0171, Berkeley, CA 94720, USA
[4]Pacific Northwest National Laboratory, 902 Battelle Boulevard, Richland, WA 99352, USA
[5]Department of Civil, Environmental and Geodetic Engineering, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, Ohio, OH 43210, USA
[6]Virginia Commonwealth University, Department of Biology, P.O. Box 842012, 1000 West Cary Street, Richmond, VA 23284-2012, USA

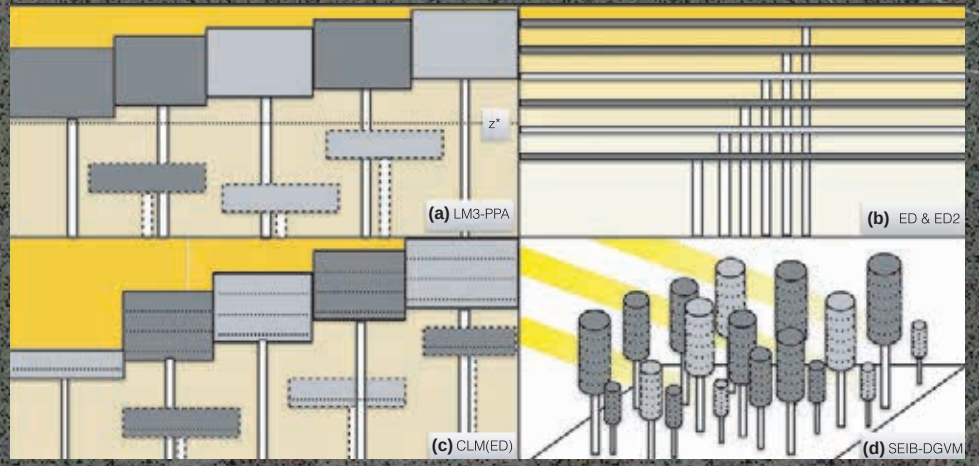
PART 3, SUMMARY

- Net primary and ecosystem production may resist moderate severity disturbance.
- Compensatory mechanisms offset declining growth up to a threshold or tipping point.
- Models fail to simulate observed resistance to disturbance.

"THERE ARE KNOWN UNKNOWNS AND THERE ARE UNKNOWN UNKNOWNS" –A FORMER POLITICIAN

- Many of the modeling unknowns are also ecological unknowns.
- Data and models need each other.

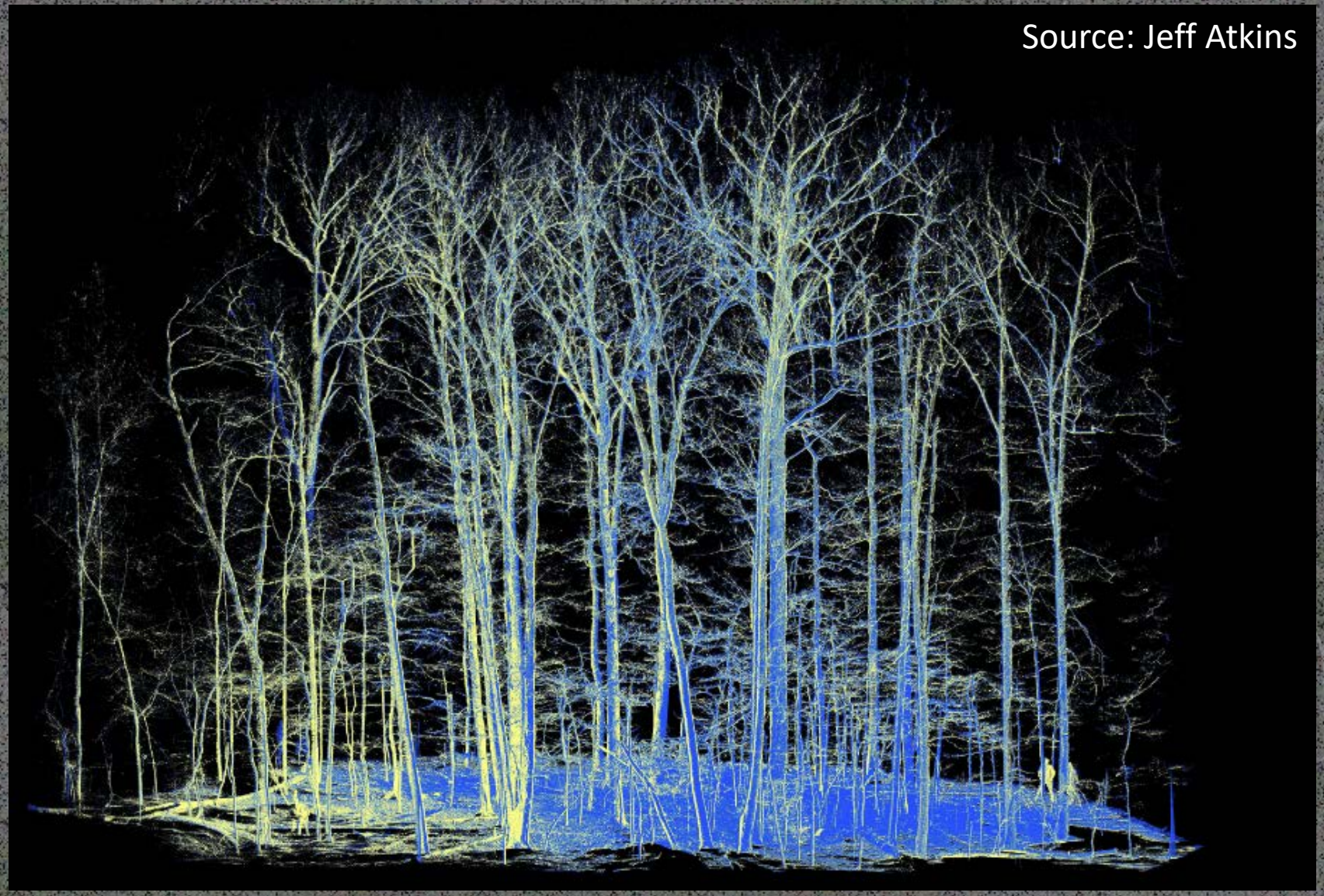
KNOWLEDGE GAP 1: WHAT PRE-DISTURBANCE CANOPY STRUCTURES CONFER CARBON CYCLING STABILITY AND HOW SHOULD THIS BE REPRESENTED IN MODELS?



Fisher et al. 2018, *Global Change Biology*

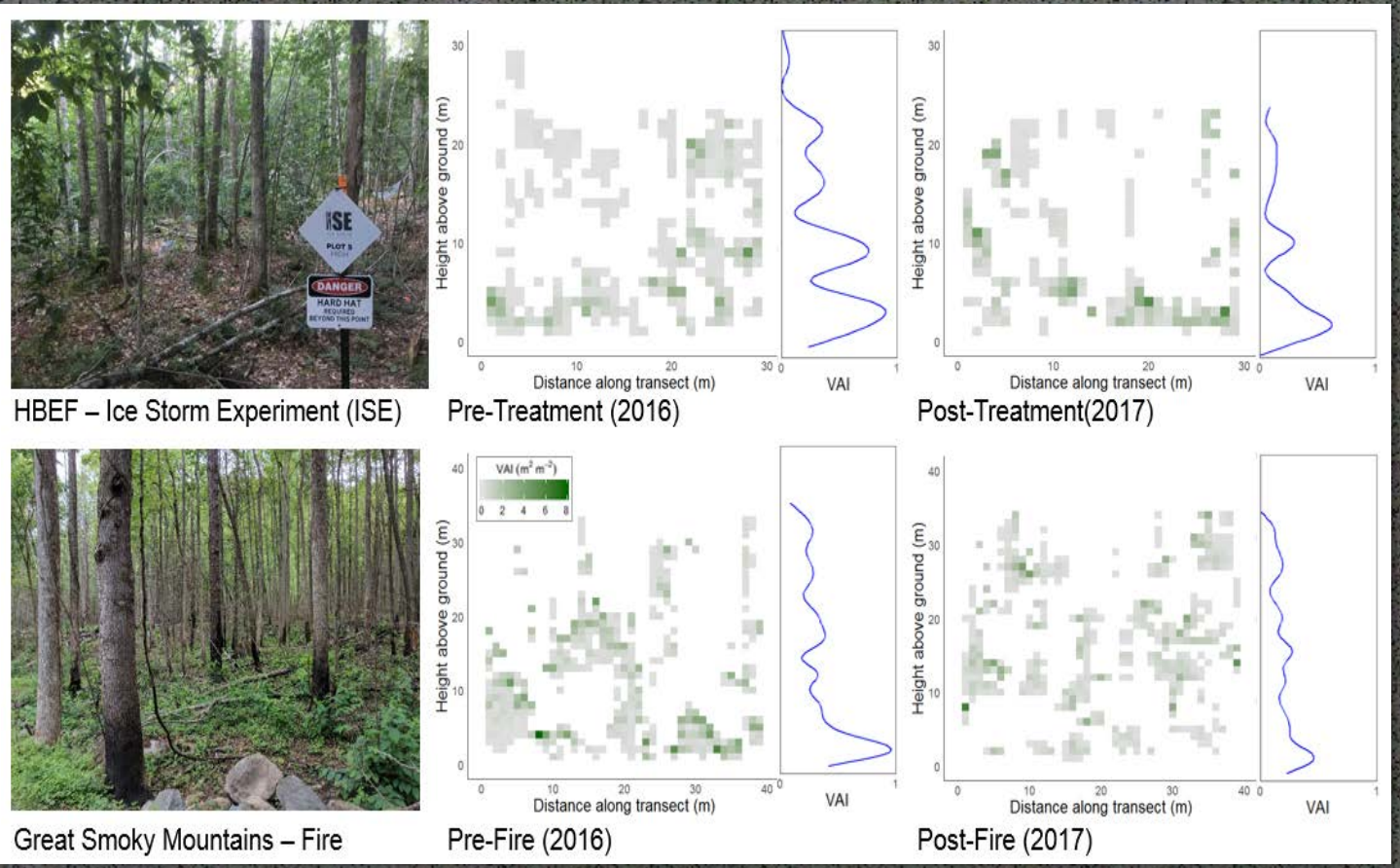
4. What are the knowledge gaps and how do we fill them?

Atticus Stovall, NASA
Jeff Atkins, postdoc, VCU



Source: Jeff Atkins

KNOWLEDGE GAP 2: WITHIN THE REALM OF "MODERATE DISTURBANCE", DOES SOURCE MATTER TO THE CARBON CYCLE?



Atkins et al., in prep

Ice damage shifted vegetation distribution downward.

Fire more evenly reduced vegetation quantity across canopy strata.

KNOWLEDGE GAP 2: WITHIN THE REALM OF "MODERATE DISTURBANCE", DOES SOURCE MATTER TO THE CARBON CYCLE?

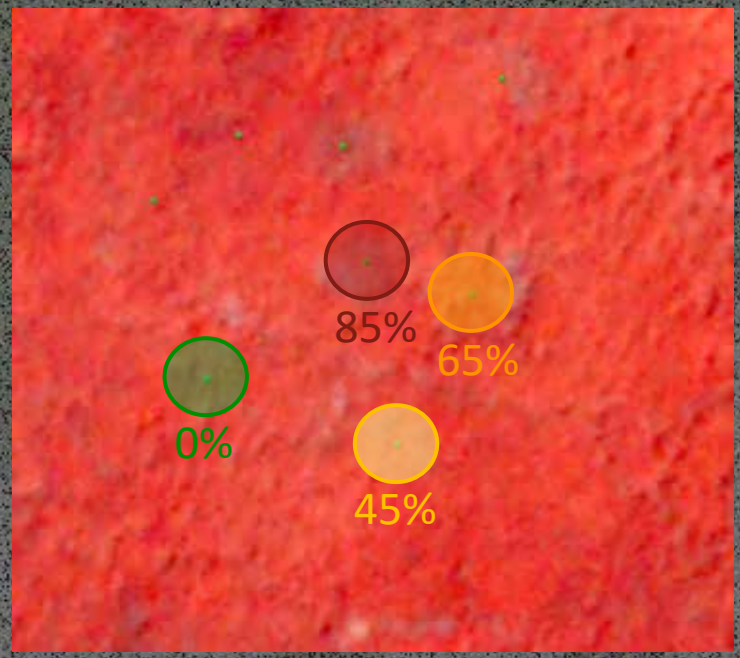
Bob Fahey and Danielle Tanzer (Uconn)

Photo credit: Bob Fahey

KNOWLEDGE GAP 3: WHAT CONTROLS CARBON CYCLING TIPPING POINTS?

July 2018

July 2019

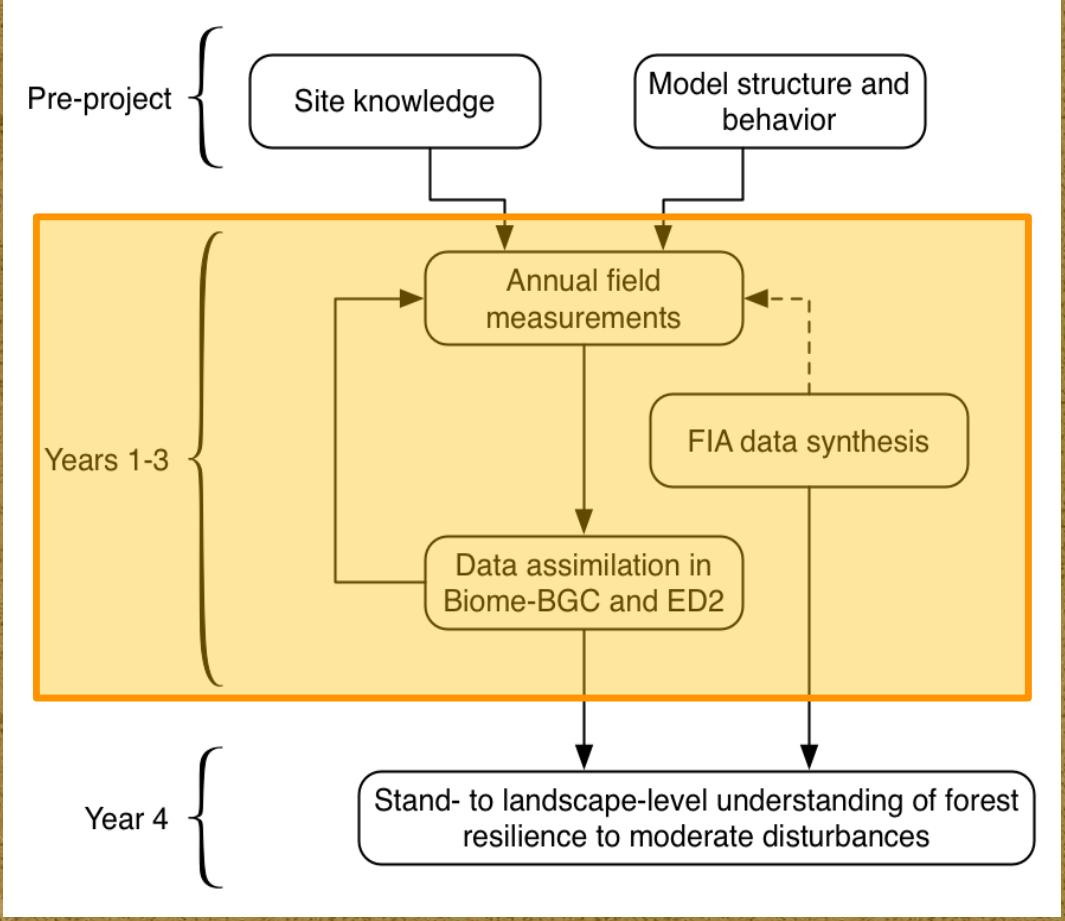


False-color IR Imagery retrieved by Jason Tallant. Planet Team (2017). Planet Application Program Interface: In Space for Life on Earth. San Francisco, CA. https://api.planet.com.

The Forest Resilience Threshold Experiment FoRTE


UNIVERSITY OF MICHIGAN
BIOLOGICAL STATION

KNOWLEDGE GAP 4: WHY DO MODELS FAIL AND WHAT DATA ARE NEEDED TO IMPROVE THEM?



Ben Bond-Lamberty,
Co-lead PI

Shiklomanov, Alexey
PNNL postdoc

TO ADVANCE DISTURBANCE-CARBON CYCLING KNOWLEDGE AND PREDICTION, WE NEED TO:

- Acknowledge that moderate levels of disturbance are increasingly prevalent and thus relevant to the carbon cycle;
- Understand why some forests resist the effects of disturbance and when this resistance breaks down;
- Resolve which mechanisms must be incorporated in models to simulate observed responses to disturbance.

QUESTIONS? CMGOUGH@VCU.EDU

References:

Gough et al. 2007. https://doi.org/10.1111/j.1365-2486.2007.01406.x

Gough et al. 2013. https://doi.org/10.1890/12-1554.1

Stuart-Haëntjens et al. 2015. https://doi.org/10.1890/14-1810.1

Hardiman et al. 2013. https://doi.org/10.1016/j.foreco.2013.02.031

Bond-Lamberty et al. 2015. https://doi.org/10.5194/bg-12-513-2015