Resilience of Great Lakes Forest Carbon Stocks to Disturbance and Succession

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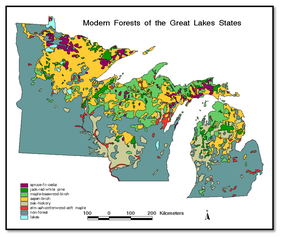
Abstract & Background

Forests of the upper Great Lakes are a diverse assemblage of ecosystems but many share a common land use and disturbance history that has an important bearing on their future composition and function in the face of a changing climate.



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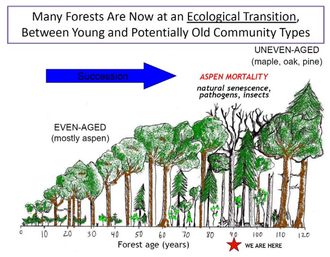
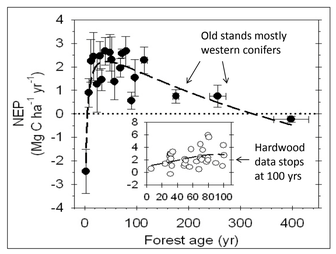
After regrowth following harvesting in the late 19th century many Great Lakes forests are poised to transition to structurally and biotically more complex ecosystems with significant implications for their functional resilience to future disturbance and for their carbon stocks.



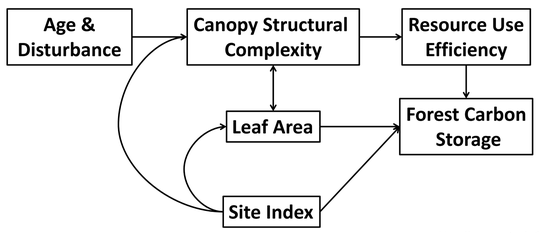
Ecosystem theory predicts that as forests age their capacity to store carbon declines, while ecosystems with greater biological diversity are more resilient to disturbance than those with less diversity.

Both theories are relevant to resource managers and ecosystem modelers yet have been impossible to directly test in forests until recently.



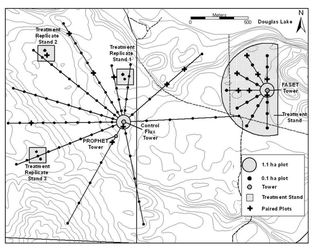
Gough et al. 2008

Our research challenges the idea that carbon storage declines through ecological succession in all forests and suggests a new mechanism for forest functional resilience to disturbance.



Hardiman et al. 2013

Our work takes place at the University of Michigan Biological Station, in northern lower Michigan, USA. Long-term flux and ecological measurements take place in an unmanipulated control forest typical of 70-90 yr old transitional forests of the region.



The Forest Accelerated Succession Experiment (FASET) was begun in 2008 when all aspen and birch within a 39 ha treatment forest were killed by stem girdling. This represented ~35% of the canopy leaf area. Parallel flux and ecological measurements are made in both treatment and control forests.

References

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Succession & Carbon Dynamics

❑ We found that canopy structural complexity increases with stand age, resulting in higher canopy light and nitrogen use efficiencies and an increase in net primary production and carbon storage in forests up to 200 years old.

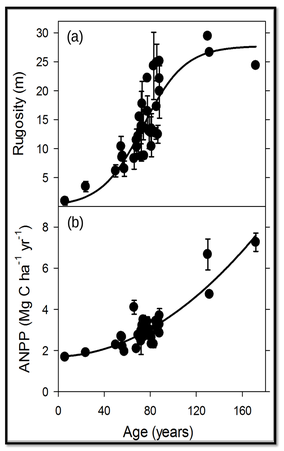


Figure 1.

Figure 1. Relationships of canopy rugosity (a) and ANPP (b) with stand age (R^2 =0.73 and R^2 =0.80, respectively). Rugosity is mean (±S.E.) among years. ANPP is the yearly production of leaf and aboveground wood biomass averaged over ≥2 years of data collections to reduce climate-associated interannual variability.

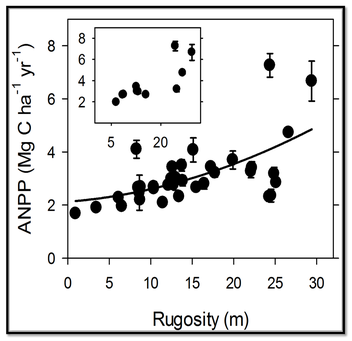


Figure 2.

Figure 2. ANPP and canopy structural complexity (rugosity) in forest plots ranging across >160 years of development and encompassing disturbance histories varying widely in severity (R^2 = 0.34). Inset illustrates the representative subset of research plots in which fAPAR and foliar N mass was quantified (R^2 = 0.65).

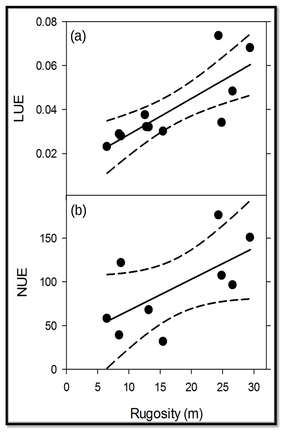
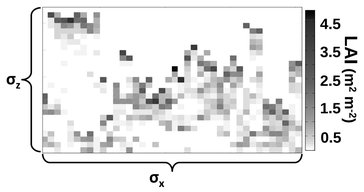


Figure 3. Hardiman et al. 2013

Figure 3. Relationships between Light Use Efficiency (LUE, a), Nitrogen Use Efficiency (NUE, b), and canopy rugosity. R^2 =0.6 and 0.3 for LUE and NUE, respectively. Areas bounded by dotted lines are 95% confidence intervals.

Complexity of canopy structure was quantified as rugosity (*R*), or the spatial heterogeneity of foliage distribution, using a Portable Canopy LiDAR system.

$$R = \sigma[\sigma(\mathrm{LAD})_z]_x$$



We established transects passing through the center of each plot and with length (x) equal to approximately two times canopy height (z).

Rugosity is a stand-level expression of canopy structural complexity, summarizing the 3-D heterogeneity of foliage distribution.

Acknowledgements

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Disturbance & Carbon Dynamics

❑In stands subjected to moderate experimental disturbance, similar to that of age-related or climatically induced tree mortality, we found that the treatment forest resisted C storage declines by retaining nitrogen and sustaining canopy light use efficiency and light absorption during and following peak tree mortality.

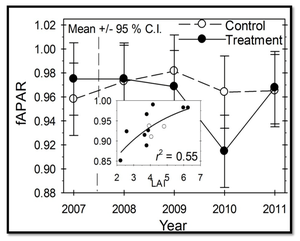


Figure 4.

Figure 4. The fraction of absorbed photosynthetic active radiation (fAPAR) by control and treatment forest canopies. fAPAR was measured directly in 2011 and inferred all other years from the inset relationship between fAPAR and leaf area index (LAI). Vertical dashed line indicates time of girdling in the treatment forest.

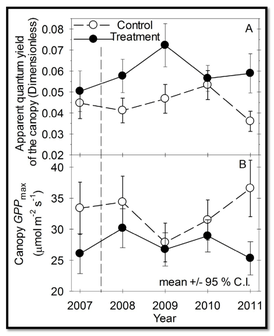


Figure 5.

Figure 5. Apparent quantum yield of the canopy (A) and potential canopy maximum gross primary production (GPPmax) (B) for control and treatment forests.

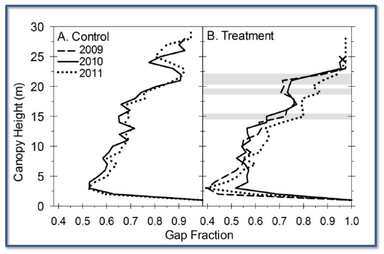


Figure 7.

Figure 7. Sustained canopy physiological competency and light absorption following moderate disturbance coincided with upper canopy gap formation and a rise in structural complexity as the canopy became more multi-layered.

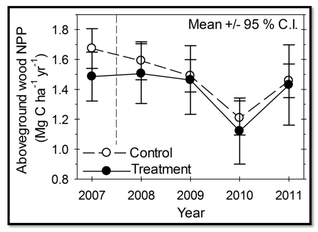


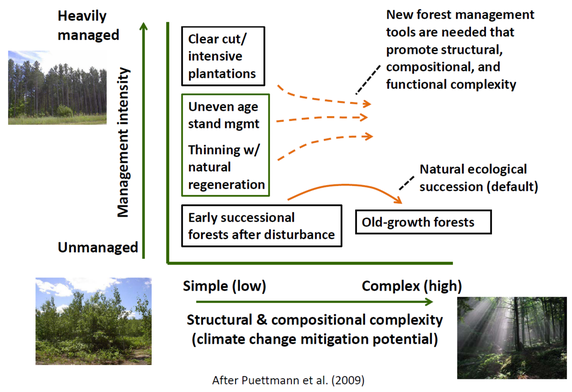
Figure 6. Gough et al. 2013

Figure 6. Aboveground wood net primary production (NPP) of control and treatment forests, 2007-2011. Vertical dashed line indicates time of girdling in the treatment forest.

❑Stability of canopy processes central to sustaining C storage during moderate disturbance suggests a rapid shift in structure-function occurred in which the photosynthetic contribution of subcanopy vegetation increased to compensate for defoliation of canopy dominant trees.

Managing for Climate Change Mitigation

❑We suggest a focus on forest management that increases structural and biotic complexity at the stand-level will facilitate carbon sequestration and biodiversity conservation, critical features of sound climate change mitigation policy.



After Puettmann et al. (2009)