

The role of unmanaged forests in climate mitigation and adaptation: the benefits of proforestation

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Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good

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Climate change and loss of biodiversity are widely recognized as the foremost environmental challenges of our time. Forests annually sequester large quantities of atmospheric carbon dioxide (CO₂), and store carbon above and below ground for long periods of time. Intact forests—largely free from human intervention except primarily for trails and hazard removals—are the most carbon-dense and biodiverse terrestrial ecosystems, with additional benefits to society and the economy. Internationally, focus has been on preventing loss of tropical forests, yet U.S. temperate and boreal forests remove sufficient atmospheric CO₂ to reduce national annual net emissions by 11%. U.S. forests have the potential for much more rapid atmospheric CO₂ removal rates and biological carbon sequestration by intact and/or older forests. The recent *1.5 Degree Warming Report* by the Intergovernmental Panel on Climate Change identifies *reforestation* and *afforestation* as important strategies to increase negative emissions, but they face significant challenges: afforestation requires an enormous amount of additional land, and neither strategy can remove sufficient carbon by growing young trees during the critical next decade(s). In contrast, growing existing forests intact to their ecological potential—termed *proforestation*—is a more effective, immediate, and low-cost approach that could be mobilized across suitable forests of all types. Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low impact recreation, and scenic beauty.

Keywords: biodiversity crisis, Pinchot, afforestation, reforestation, forest ecosystem, biological carbon sequestration, old-growth forest, second-growth forest

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Terms

- **Climate Mitigation in forests**– enhancing carbon storage/sequestration in forest ecosystems to alleviate potential adverse effects of climate change

Carbon **Sequestration** – the rate at which carbon is taken up by plants from the atmosphere

Carbon **storage** – the accumulated carbon stored in the forest as a result of sequestration

- **Climate Adaptation in forests** – maintaining high levels of compositional, functional, and/or structural complexity to enhance the ability of an ecosystem to respond or adapt to new or changing conditions associated with a changing climate

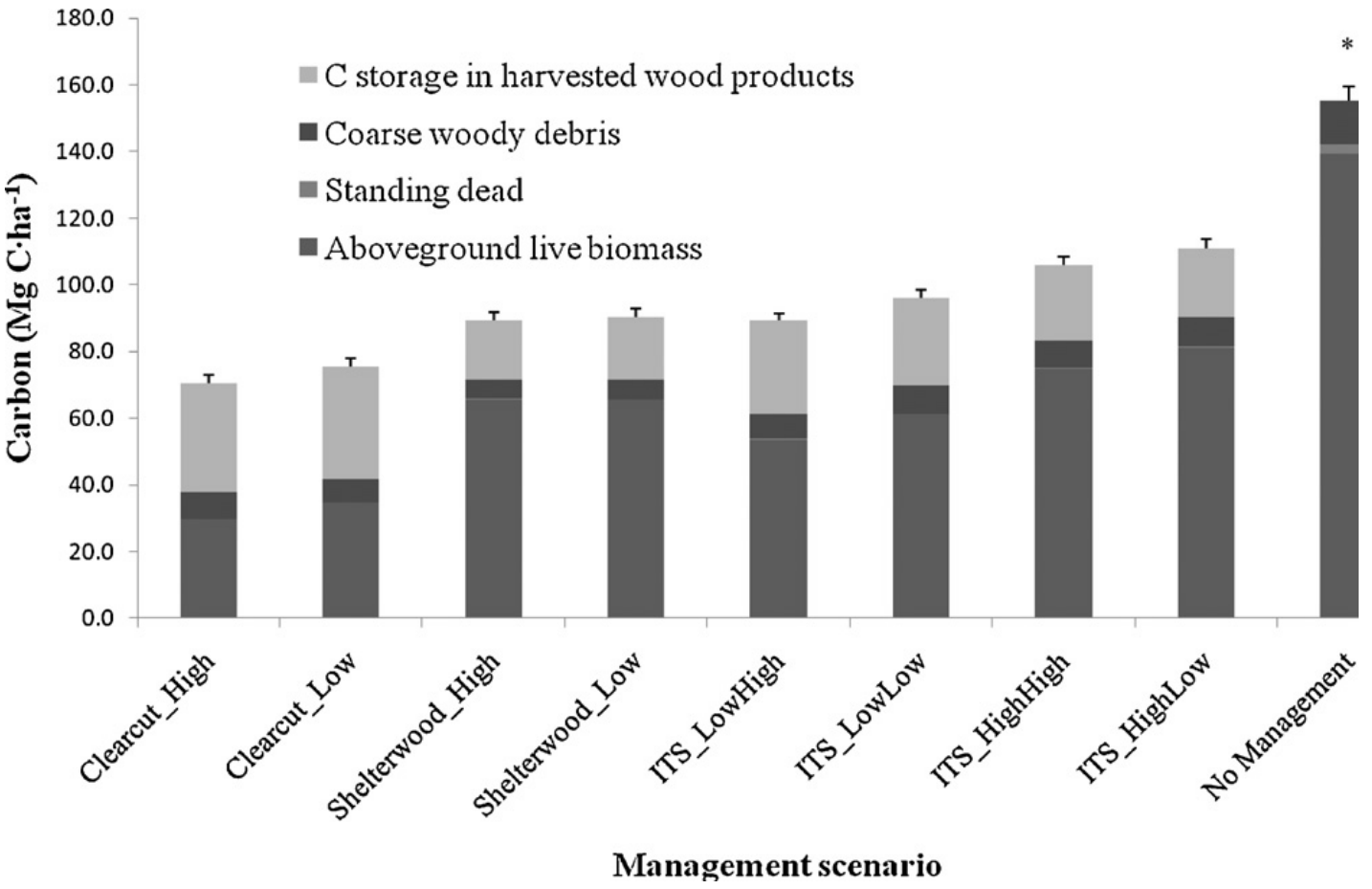
Resilience – ability of a system to recover quickly from a disturbance and return to a previous state

Resistance - the capacity of a system to absorb disturbance or stress and remain relatively unchanged

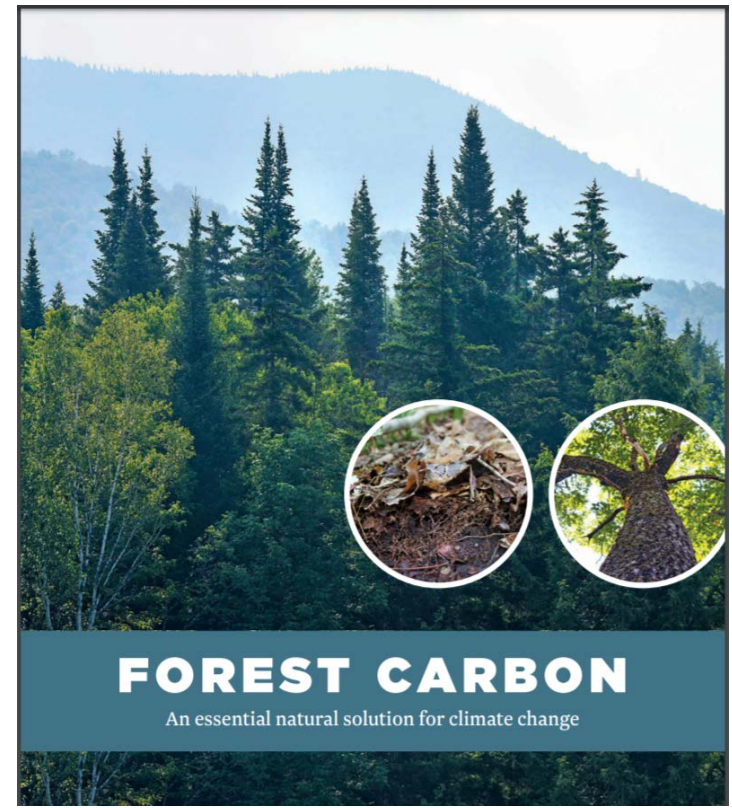
Unmanaged forests store more carbon than do managed forests

Mitigation

'No management' forests stored 39-118% more carbon than managed forests



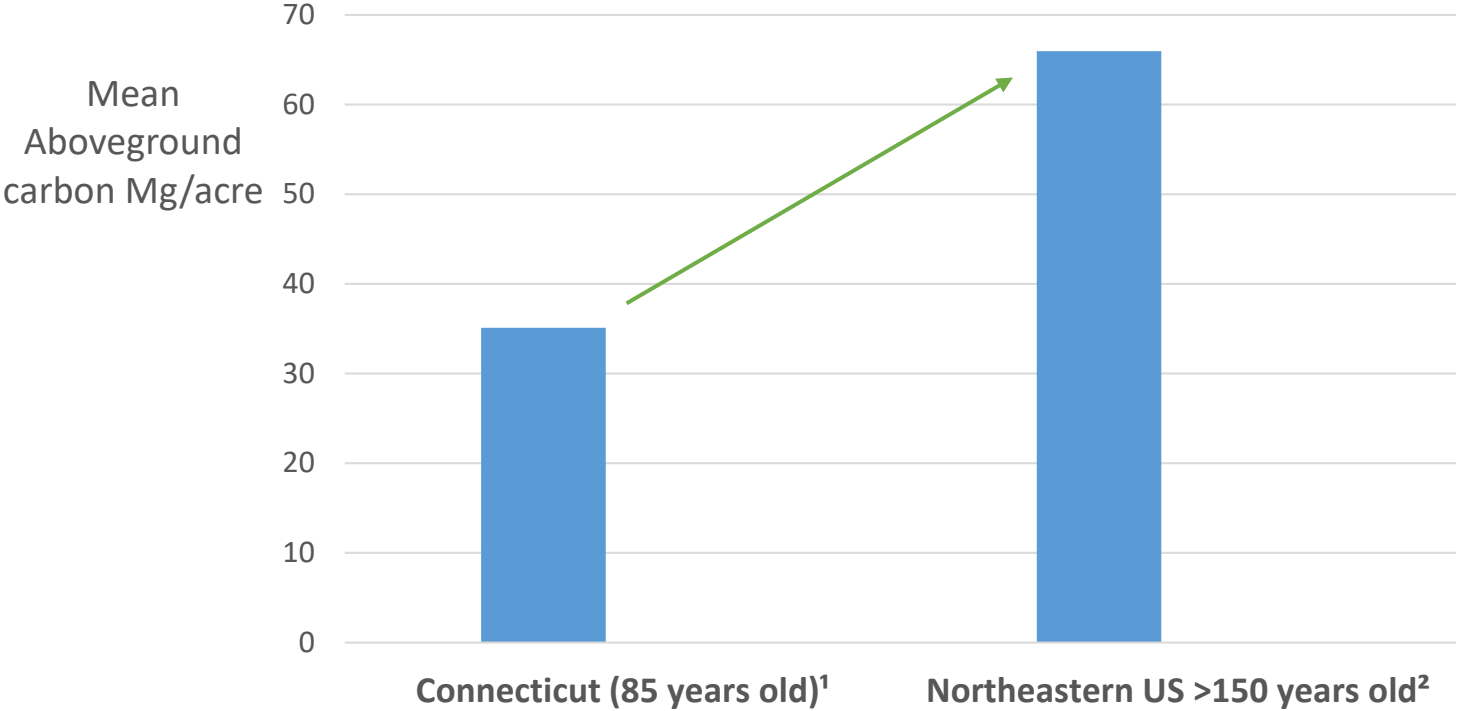
“All harvesting reduces carbon storage of a forest below the maximum potential for the site.”
(D’Amato and Catanzaro 2019)



Nunery, J. S., & Keeton, W. S. (2010). Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. *Forest Ecology and Management*, 259(8), 1363-1375.

Connecticut's forests have the potential to almost double aboveground carbon storage

Mitigation



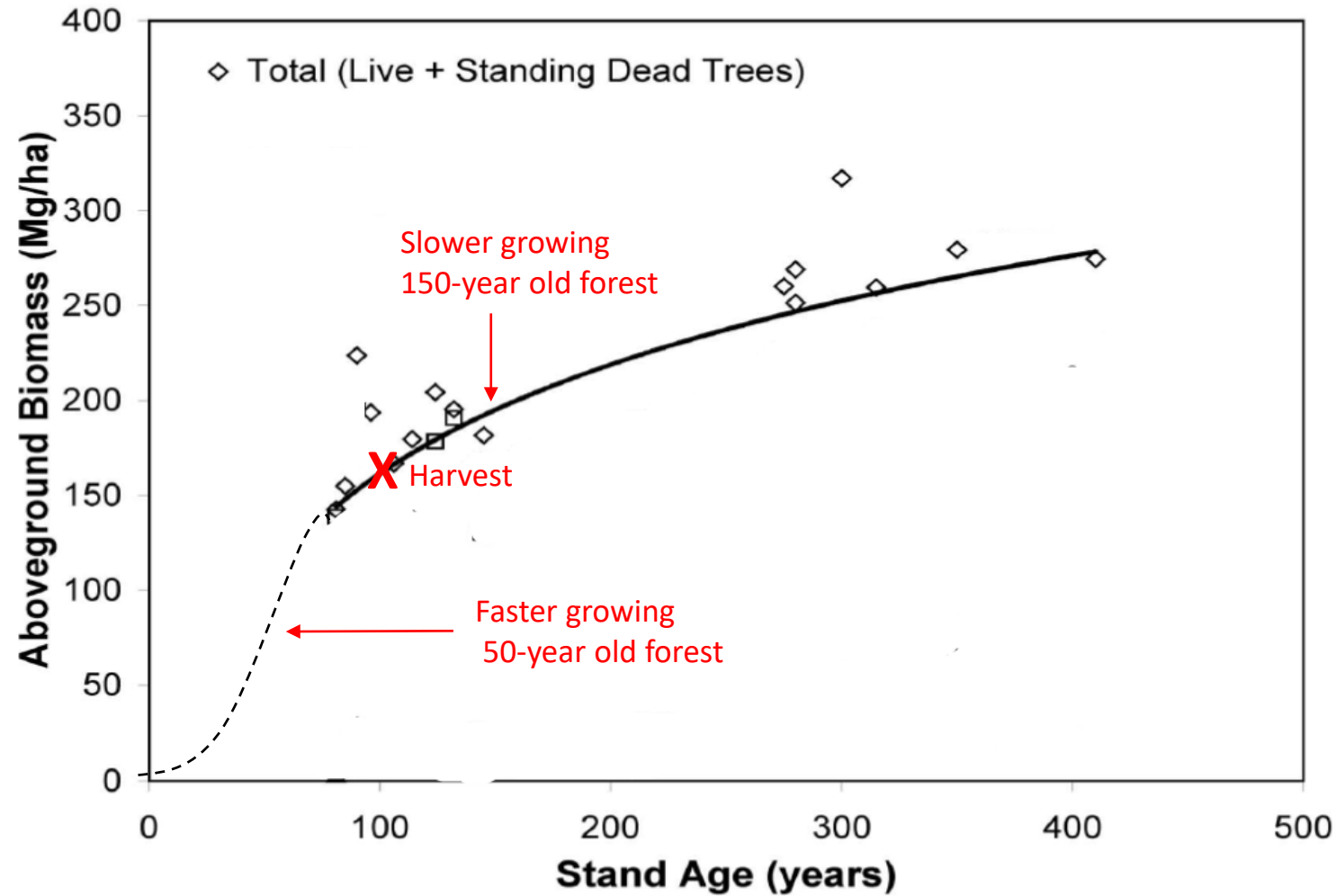
“Stand age was the strongest predictor of [carbon] biomass” (Keeton et al. 2011)

¹Data from USDA FIA

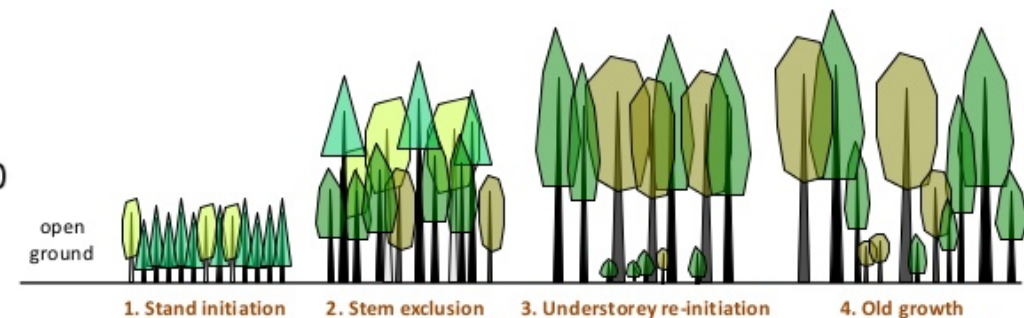
²Data from Keeton, W. S., Whitman, A. A., McGee, G. C., & Goodale, C. L. (2011). Late-successional biomass development in northern hardwood-conifer forests of the northeastern United States. *Forest Science*, 57(6), 489-505. (Maine, New Hampshire, Adirondacks, NY); **and** McGarvey, J. C., Thompson, J. R., Epstein, H. E., & Shugart Jr, H. H. (2015). Carbon storage in old-growth forests of the Mid-Atlantic: toward better understanding the eastern forest carbon sink. *Ecology*, 96(2), 311-317 (Pennsylvania, New Jersey, Maryland, Virginia, and West Virginia)

Creating younger forests from older forests does not help climate mitigation

Mitigation



“The mitigation value of forests lies not in their present net uptake of CO₂, but in the longevity of their accumulated carbon stocks” (Mackey et al. 2013. *Nature Climate Change*)



Adapted from Keeton, W. S., Whitman, A. A., McGee, G. C., & Goodale, C. L. (2011). Late-successional biomass development in northern hardwood-conifer forests of the northeastern United States. *Forest Science*, 57(6), 489-505.

<https://www.slideshare.net/ERWilson1/teaching-forest-stand-dynamics>



Unmanaged lands at early successional stages: leveraging the power of afforestation

Mitigation

- Afforestation sequesters about 2 metric tons of carbon per acre/year – that’s about ~10-20 times the annual carbon sequestration rate in grasslands¹

¹Bachelet et al. 2018. <https://carbon2018.globalchange.gov/chapter/10/>; Potter et al. 2007. Satellite-derived estimates of potential carbon sequestration through afforestation of agricultural lands in the United States



Forest structural complexity is greater in unmanaged forests than in managed forests

Adaptation



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Seven decades of change in forest structure and composition in *Pinus resinosa* forests in northern Minnesota, USA: Comparing managed and unmanaged conditions

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ABSTRACT

An understanding of long-term patterns of forest structural and compositional development is critical for anticipating management outcomes and developing appropriate silvicultural strategies for restoring complex forest conditions. In most cases, this information comes from stand-level assessments; however, the impacts and outcomes of management and other disturbances on forest development occur over multiple spatial scales across a landscape. We compared historical (1941) and contemporary (2012–2014) forest structure and composition on 300 plots distributed across managed and unmanaged, late-seral red pine (*Pinus resinosa*)-dominated forests in a 1230-ha landscape in north-central Minnesota, USA. Discriminant factor analysis was used to determine which compositional and structural attributes best described the forest conditions between two sampling periods (1941, 2012–2014) and management histories (managed and unmanaged). Plot basal area, average diameter of live trees, richness of tree size classes, and the basal area of standing deadwood were the four most important variables in discriminating between the managed and unmanaged plots in 1941 and 2013. In some cases, structural conditions between managed and unmanaged plots converged, including contemporary BA, trees per hectare, size inequality, and structural complexity indices. In contrast, several attributes, including standing deadwood basal area and percent hardwood basal area, were significantly greater in unmanaged plots after 72 years and highlight the lasting influence of land use on these structural and compositional conditions. The broad ranges of structural and compositional conditions observed across the landscape highlight the importance of having spatially varying desired future conditions across managed stands to approximate this range in live and dead-tree attributes in unmanaged forests. In addition, the lower basal area of standing dead trees documented in this and other comparisons of unmanaged and managed *P. resinosa*

esa ECOSPHERE

SPECIAL FEATURE: SCIENCE FOR OUR NATIONAL PARKS' SECOND CENTURY

National parks in the eastern United States harbor important older forest structure compared with matrix forests

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Abstract. We analyzed land-cover and forest vegetation data from nearly 25,000 permanent plots distributed across 50 national parks in the eastern United States, along with the matrix around each park, to examine structural characteristics of park forests in relation to their surrounding landscape. Over 2000 of these plots are part of the National Park Service (NPS) Inventory and Monitoring Program (IM&M), and the remaining 22,520 plots are part of the US Forest Service (USFS) Forest Inventory and Analysis (FIA) Program. This is the first study to compare forest structure in protected lands with the surrounding forest matrix over such a large area of the United States and is only possible because of the 10-year cycle of data that are now publicly available from USFS-FIA and NPS IM&M. Results of this study indicate that park forests, where logging is largely prohibited, preserve more of regionally significant older forest habitat. Park forests consistently had greater proportions of late-successional forest, greater live tree basal area, greater densities of live and dead large trees, and considerably larger volume of coarse woody debris. Park forests also had lower tree growth and mortality rates than matrix forests, suggesting different forest dynamics between park and matrix forests. The divergent patterns we observed between matrix and park forests were similar to those reported in studies that compared managed and old-growth forests, although the differences in our study were less pronounced. With the majority of park forests in second growth, eastern parks may be a more realistic landscape to compare with the more intensively managed matrix forests.

Reports

High rates of primary production in structurally complex forests

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Abstract. Structure-function relationships are central to many ecological paradigms. Chief among these is the linkage of net primary production (NPP) with species diversity and canopy structure. Using the National Ecological Observatory Network (NEON) as a subcontinental-scale research platform, we examined how temperate-forest NPP relates to several measures of site-level canopy structure and tree species diversity. Novel multidimensional canopy traits describing structural complexity, most notably canopy rugosity, were more strongly related to site NPP than were species diversity measures and other commonly characterized canopy structural features. The amount of variation in site-level NPP explained by canopy rugosity alone was 83%, which was substantially greater than that explained individually by vegetation area index (31%) or Shannon's index of species diversity (36%). Forests that were more structurally complex, had higher vegetation-area indices, or were more diverse absorbed more light and used light more efficiently to power biomass production, but these relationships were most strongly tied to structural complexity. Implications for ecosystem modeling and management are wide ranging, suggesting structural complexity traits are broad, mechanistically robust indicators of NPP that, in application, could improve the prediction and management of temperate forest carbon sequestration.

Key words: carbon cycling, complexity, forests, FPAR, leaf area index, light, National Ecological Observatory Network, net primary production, species diversity, structure-function.

“Based on the findings of previous work conducted at the stand-level, we expect more complex forest structure across the landscape will develop over time to a greater degree in unmanaged than managed [forests]” Young et al. 2017

“[we] found [forests in national] parks to have consistently greater structural complexity than surrounding forests...and [thus] potentially be more resilient to climate change” Miller et al. (2018)

Unmanaged forests have greater tree species diversity than do managed forests

Adaptation



Eastern national parks protect greater tree species diversity than unprotected matrix forests

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ABSTRACT

Decline in tree species diversity is a widespread trend in eastern US forests, with implications for ecosystem functions and services, biodiversity and vulnerability to climate change and other stressors. While some impacts on diversity are widespread such as forest pests, forest management practices vary across the landscape. For example, forests in US national parks are managed to promote ecological integrity, diversity under natural disturbance regimes, and are largely protected from timber harvesting. In this study we compared forests in 39 eastern US national parks with surrounding matrix forests to assess whether forest protection has led to differences in tree diversity patterns in parks. We calculated multiple alpha and beta diversity metrics using tree stem data. We examined alpha diversity metrics at the scale of the 7.31 m radius subplot and for an equal number of individuals, and examined beta diversity at multiple scales. This is the first study to compare tree diversity in protected lands with the surrounding forest matrix over such a large area of the US, and is only possible because of the 10+ years of data that are publicly available from US Forest Service (USFS) Forest Inventory and Analysis (FIA) and the National Park Service (NPS) Inventory and Monitoring (IM) programs. Overall, results indicated that park forests have consistently greater alpha diversity. Park forests have higher tree species richness, particularly after the influence of the number of individuals was removed. Park forests also consistently had higher Shannon Evenness, lower McNaughton Dominance, and higher percentage of rare species. Beta diversity analysis also suggest that parks were less homogeneous across sites, although results are exploratory due to differences in scale and small sample size. While a number of studies have documented higher diversity in protected areas, few studies have examined multiple diversity metrics or covered the large area of

“higher species richness was observed in 77% of parks compared to matrix forests” Miller et al. 2018



Regional patterns of local diversity of trees: associations with anthropogenic disturbance

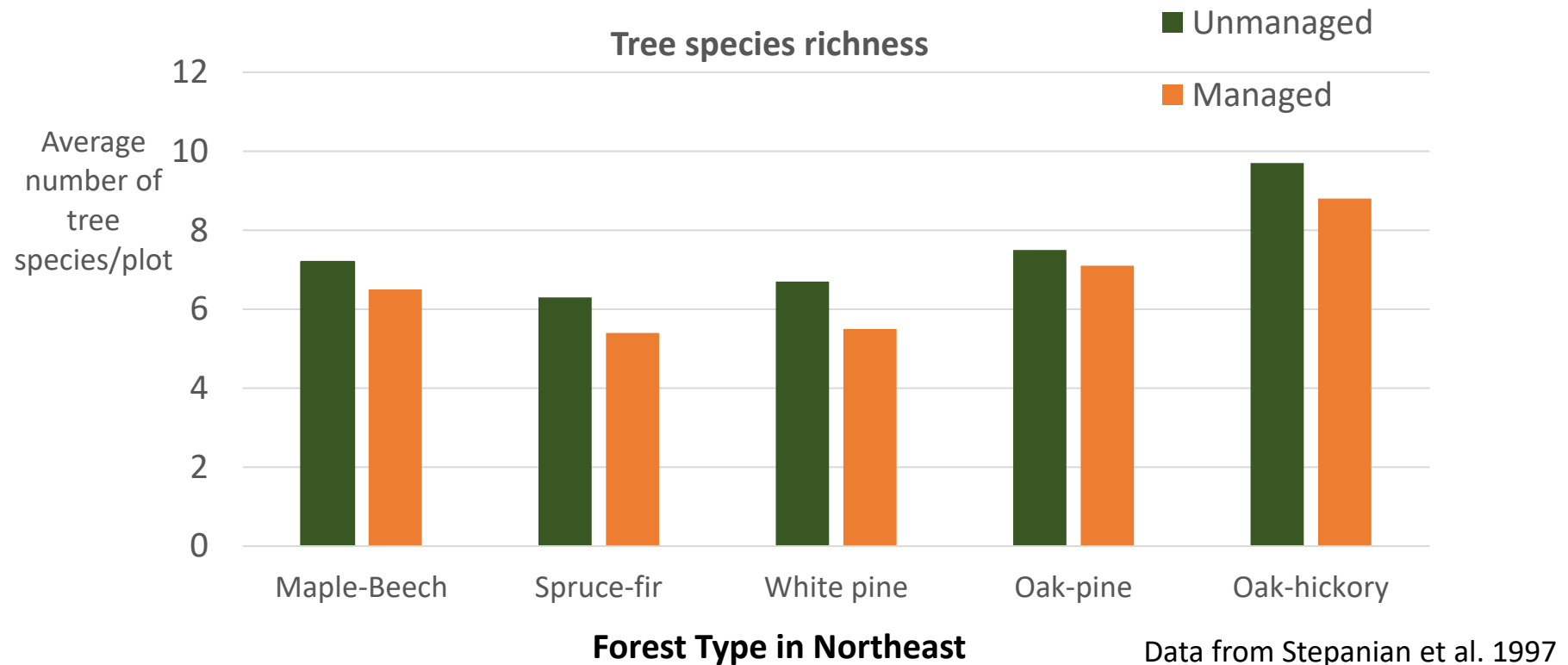
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Abstract

We used a probability-based sampling scheme to survey the forested lands of 14 states in five regions in the US (California, Colorado, and parts of the Southeast, Mid-Atlantic, and Northeast) from 1990 to 1993. Using a nationally consistent plot design, we evaluated the local diversity of trees over 2.5 cm in diameter at breast height (dbh) at 700 1.75 ha plots nationwide by measuring the plot-level species richness (R). Visually evident anthropogenic disturbances (e.g. artificial regeneration, logging, grazing by livestock, and prescribed burning), if any, were recorded on each plot. We classified plots with visually evident anthropogenic disturbance as ‘disturbed’ and the remaining plots as ‘undisturbed’. In each of the five geographical regions, we quantified the difference in mean R between disturbed and undisturbed plots. With the exception of Colorado (56%), between 34 and 55% of forested lands in each region had recorded anthropogenic disturbances. Mean R was significantly higher for undisturbed areas than for disturbed areas in the Northeast and Southeast, with the largest differences occurring in the Southeast. Mean R was greater in undisturbed areas than in disturbed areas in most forest cover types for all regions. These differences were greatest in the loblolly pine (*Pinus taeda*), oak (*Quercus spp.*) hickory (*Carya spp.*), and oak-pine forest types of the Southeast. The only group for which mean R was significantly greater in disturbed areas was the mixed western hardwoods in California. As expected from previous studies, significant differences between regions in mean R were observed, in both disturbed and undisturbed areas. This study bridges an important gap between site-specific forest studies and remote-sensing studies of the forests of a

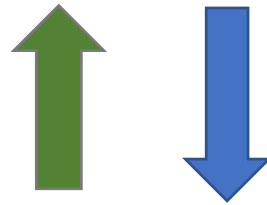


A greater density and diversity of forest birds often occurs in unmanaged than in managed forests

Adaptation

- Total density of birds
- Total number of bird species
- Abundance of individual species

Wildland forest Managed forest



“the richness of early-successional forest species did not vary between wilderness and managed forest...likely because of the presence of natural openings [in the wilderness sites]...that provided appropriate open, shrubby habitat (Zlonis and Niemi 2014)”

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Avian communities of managed and wilderness hemiboreal forests

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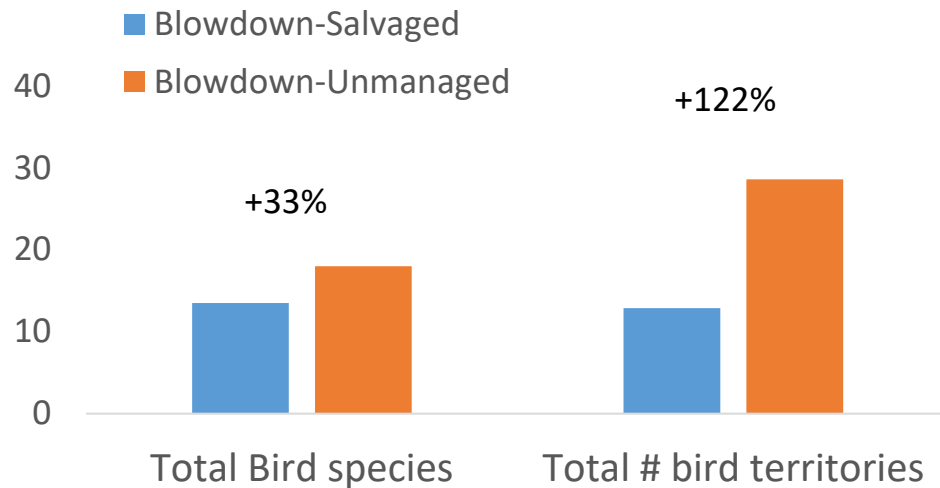
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Hemiboreal forest
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ABSTRACT

We compared breeding bird communities of hemiboreal forests in multiple-use managed forests and relatively unmanaged wilderness forests in northern Minnesota. A total of 240 point-count locations, 120 in each of the managed and wilderness areas, were sampled three times across five paired transects in 2010 and 2011. Transects were paired near lotic systems that cross each management type, with half of the points adjacent to (100 m) or distant (400 m) from the riparian corridor. Total number of individuals and species richness detected per count were higher within the unmanaged forest ($F_{1,2} = 9.76, p < 0.01$; $F_{1,2} = 11.17, p < 0.01$) and forest adjacent to the riparian corridor ($F_{1,2} = 28.30, p < 0.001$; $F_{1,2} = 42.12, p < 0.001$). These results were generally consistent with increased area of regenerating forests (mainly from logging) within the managed forest and positively correlated with tree species richness and evenness height of forest stands within the wilderness forest. Of 35 species analyzed individually, Black-capped Chickadee (*Parus atricapillus*), Brown Creeper (*Certhia americana*), Canada Warbler (*Gendolus canadensis*), Golden-crowned Kinglet (*Troglodytes aedon*), Least Flycatcher (*Empidonax minimus*), Red-breasted Nuthatch (*Sitta canadensis*), Winter Wren (*Troglodytes hiemalis*), and Yellow-bellied Flycatcher (*Empidonax flaviventris*) were more common in the wilderness forest. Only the Mourning Warbler (*Geothlypis philadelphia*) and Chipping Sparrow (*Spizella passerina*) were more common in the managed forest. Species associated with mature or mixed forests tended to be found in the wilderness area at higher densities, but most species associated with early-successional habitats did not differ between the managed and wilderness landscapes. Results suggest that forests with natural disturbance and succession regimes provide habitat for a higher density and richness of bird species. Responses by breeding birds were similar in both management types regarding distance from riparian areas. To adequately provide for effective conservation of the avian community, forested regions should include wilderness forests.

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Data from: Lain, E. J., Haney, A., Burris, J. M., & Burton, J. (2008). Response of vegetation and birds to severe wind disturbance and salvage logging in a southern boreal forest. *Forest Ecology and Management*, 256(5), 863-871.

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Response of vegetation and birds to severe wind disturbance and salvage logging in a southern boreal forest

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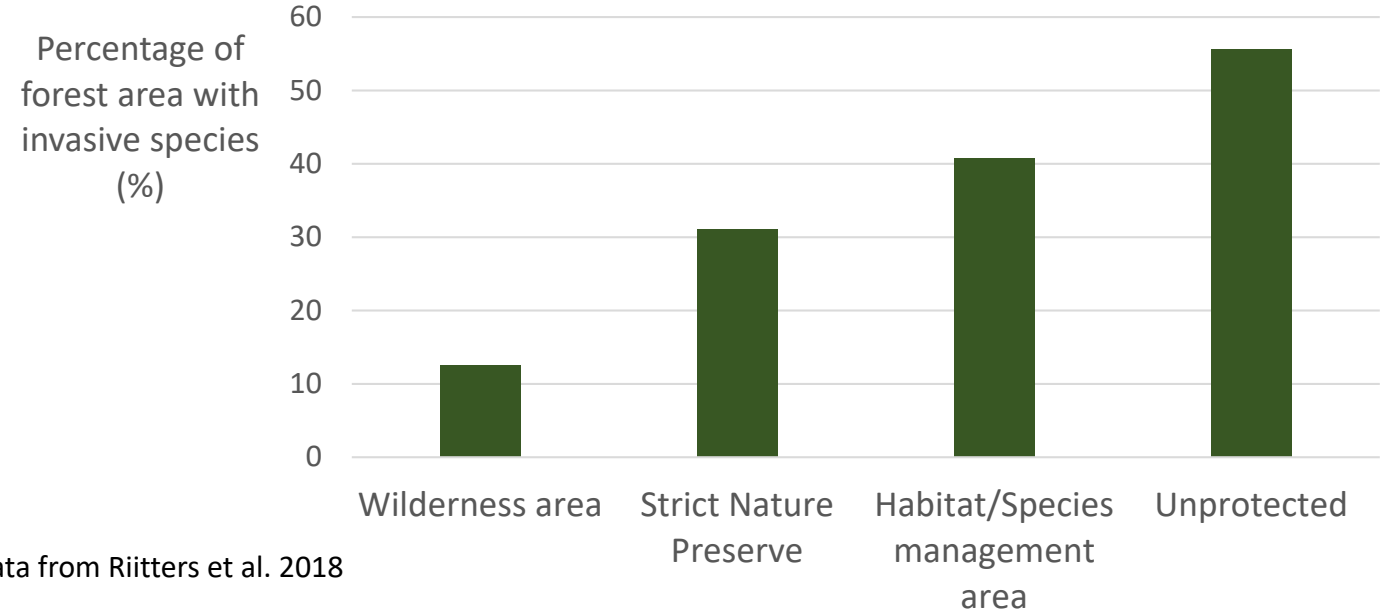
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ABSTRACT

Vegetation and birds were inventoried on the same plot before and after a severe windstorm in 1999 disturbed a mature black spruce (*Picea mariana*)-jack pine (*Pinus banksiana*) forest in northern Minnesota. Following the storm, another plot was established in an adjacent portion of the forest that was salvage-logged. Birds were inventoried on both plots through 2002. The original unsalvaged plot was prescribed-burned in 2004, but vegetation was surveyed through 2003, and through 2005 on the salvaged plot. We examined the effects of wind disturbance by comparing the pre-storm bird and vegetation communities with those developed afterwards through 2002 and 2003, respectively, and the effects of salvage logging by comparing vegetation and the bird community on the unsalvaged plot with those in the salvaged area. Wind reduced the canopy of the forest by over 50% with a temporary increase in the shrub layer, mostly resulting from tip-ups. Several plant species, including jack pine and beaked hazel (*Corylus americana*), appeared temporarily in the ground layer (<1 m height), but did not persist through 2003. Quaking aspen (*Populus tremuloides*) root sprouts were abundant in 2001, but decreased dramatically by 2003. Delayed mortality of tipped trees resulted in reduction of the shrub layer to pre-storm levels, and release of advanced regeneration black spruce and balsam fir (*Abies balsamea*). Bird species using the forest changed from dominance by canopy-foraging species to ground-bush foraging species, with an overall increase in bird diversity. Salvage logging resulted in significant reduction in coarse woody debris, and successful recruitment of aspen seedlings. Quaking aspen sprouts were nearly 30 times more abundant in the salvage-logged area compared to the unsalvaged control. Ruderal species, especially red raspberry (*Rubus idaeus*), fringed bindweed (*Polygonum*

Less management results in fewer invasive plant species



Data from Riitters et al. 2018

“[In Pennsylvania] the most significant *Ailanthus* invasions closely followed large scale clearcuts in the aftermath of oak roller defoliation as well as subsequent salvage logging following statewide gypsy moth defoliations...” (Kasson et al. 2013)

“[In Massachusetts] more intensive harvests were more likely to have *Berberis thunbergii* and *Rosa multiflora*” McDonald et al. 2008

forests MDPI

Article
Exposure of Protected and Unprotected Forest to Plant Invasions in the Eastern United States

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Abstract: *Research Highlights:* We demonstrate a macroscale framework combining an invasibility model with forest inventory data, and evaluate regional forest exposure to harmful invasive plants under different types of forest protection. *Background and Objectives:* Protected areas are a fundamental component of natural resource conservation. The exposure of protected forests to invasive plants can impede achievement of conservation goals, and the effectiveness of protection for limiting forest invasions is uncertain. We conducted a macroscale assessment of the exposure of protected and unprotected forests to harmful invasive plants in the eastern United States. *Materials and Methods:* Invasibility (the probability that a forest site has been invaded) was estimated for 82,506 inventory plots from site- and landscape attributes. The invaded forest area was estimated by using the inventory sample design to scale up plot invasibility estimates to all forest area. We compared the invasibility and the invaded forest area of seven categories of protection with that of de facto protected (publicly owned) forest and unprotected forest in 13 ecological provinces. *Results:* We estimate approximately 51% of the total forest area has been exposed to harmful invasive plants, including

2013 *NORTHEASTERN NATURALIST* 20(Monograph 10):1–60

The Invasive *Ailanthus altissima* in Pennsylvania: A Case Study Elucidating Species Introduction, Migration, Invasion, and Growth Patterns in the Northeastern US

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Abstract - *Ailanthus altissima* (Tree of Heaven), an invasive tree species native to China and East Asia, was first introduced into the US ca. 1784 by William Hamilton at his Philadelphia, PA estate. However, the means and temporal progression of spread from this and other early points of introduction are not clear. This species now occurs in >40 US states, primarily as an urban and roadside weed. The Northeast supports the highest densities of *Ailanthus* within the US, mainly in transportation corridors and urban areas, where it has become the dominant tree species. A recent, widespread increase in *Ailanthus* incidence in eastern hardwood forests, not unlike prior invasions along railways and roadsides, suggests that current conditions favor invasion in natural environments. To help elucidate the life history of *Ailanthus* in Pennsylvania and the northeastern US, as well as answer fundamental biological questions concerning this species, we conducted dendrochronological (tree-ring) studies and floristic surveys beginning in 2010. Although we studied population dynamics, age structure, and tree-ring characteristics of *Ailanthus* primarily in Pennsylvania, we supplemented our studies using trees from adjacent north-

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Assessing the influence of historical factors, contemporary processes, and environmental conditions on the distribution of invasive species*

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McDONALD, R. I. (Graduate School of Design, Harvard University, Cambridge, MA 02138), G. MOTZKIN and D. R. FOSTER (Harvard Forest, Harvard University, Petersham, MA 01366). Assessing the influence of historical factors, contemporary processes, and environmental conditions on the distribution of invasive species. *J. Torrey Bot. Soc.* 135: 260–271, 2008. —Despite concerns over potential detrimental effects of non-native invasive species on human and natural systems, the factors controlling regional distributions of invasive species remain unresolved. Few studies have evaluated the influence of both environmental factors and disturbance history on invasive species distributions, or assessed synthetically the importance of landscape-level disturbances like historical land-use, forest harvesting, and contemporary forest fragmentation. We analyzed vegetation, soils, and recent and historical land-use and landscape context for forests across central and western Massachusetts to identify controls on invasive species distributions. Almost half (49.3%) of 148 randomly selected sites had at least one non-native invasive plant present, and invasive species occurred more frequently on former agricultural sites than in continuous woodlands. We used logistic regression to model the probability of finding the four most common species: Japanese barberry (*Berberis thunbergii* DC), glossy buckthorn (*Rhamnus frangula* L.), multiflora rose (*Rosa multiflora* Thunb. ex Muell.), and oriental bittersweet (*Celastrus orbiculatus* Thunb.). Soil richness was the most important predictor of invasive presence, with rich soils (i.e., lower C:N) being more likely to have these species. The structure of the current forested landscape (i.e., the amount of forest within a 10 km buffer around a site) is also important, with sites not surrounded by more forest being less likely to have these species. After accounting for variation in C:N ratio and the structure of the current forested landscape, historical land-use was not a significant predictor of non-native species occurrence; however, C:N ratios may be influenced by historical land-use and by current vegetation, thus complicating interpretations of this edaphic variable. Recent forest harvesting increased the likelihood of invasive occurrence for some but not all species. Overall, our results suggest that regional patterns of invasive plant distributions result from a complex function of edaphic conditions, and present and historical land-uses.



Unmanaged forests are generally far more resilient than we realize: tree regeneration and deer

Adaptation



“As trees mature and die, or topple over during storms, gaps in the canopy become larger and more numerous. There are no young trees to fill the gaps.”

Rawinski, TJ 2008. *Impacts of White-Tailed Deer Overabundance in Forest Ecosystems: An Overview*



2003

2018

Uttertown Forest,
New Jersey



(photos by Neil Pederson)

Forest stressors result in a host of benefits: dense regeneration, diversity of structures, abundant dead wood, and habitat for shrubland species

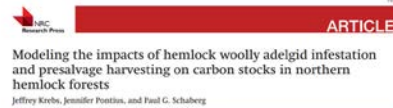
Adaptation



<https://today.uconn.edu/2019/06/uconn-collaborates-gypsy-moth-cleanup/>
T. Worthley photo



Photo by Santoro and Laflower 2018



Abstract: To better understand the potential impact of the invasive hemlock woolly adelgid (HWA), Adige Inger Anandani and presalvage harvesting on carbon (C) storage in northern forest stands dominated by hemlock (P. sitchensis) L. var. we used the Forest Vegetation Simulator and Forest Inventory and Analysis data to model C storage and ecosystem productivity under three scenarios: presalvage harvesting, HWA-induced mortality, presalvage harvesting plus HWA-induced mortality and no disturbance (control). Our simulation showed that all treatments differed in total C storage in the short term, with HWA-induced mortality providing the highest total C storage due to replacement and expansion of replacement species combined with retention of standing and downed deadwood. At the end of the 100-year simulation, all disturbance scenarios had significantly lower total C than the control. The simulation was C sink for the first 20 years, indicating that allowing HWA to progress naturally through a stand may result in the best impact to long-term C sequestration and net C storage. While differences were not significant on the hemlock forest stands, impacts on the watershed net HWA by a disturbance scenario where hemlock is dominated could result in conversion to red maple (Q. rubra) L. and a net loss of very wetlands. Net C storage of potential replacement C over the next 100 years.

Key words: Adige Inger Anandani, carbon sequestration, Forest Vegetation Simulator, HWA, Picea canadensis.

Resumé: Pour mieux comprendre l'impact potentiel de la chenille laineuse de l'épicéa (CE) dans les forêts boréales dominées par l'épicéa, nous avons utilisé le Forest Vegetation Simulator et les données de l'Inventaire et de l'Analyse des forêts pour modéliser le stockage de C et les écosystèmes successoraux en fonction de quatre scénarios: coupe de présauvage, mortalité induite par l'CE, coupe de présauvage plus mortalité induite par l'CE et contrôle sans perturbation. Nos simulations ont montré que tous les traitements différaient de façon significative en ce qui concerne le stockage de C à court terme et que la mortalité induite par l'CE fournissait le plus grand stockage de C à court terme. À la fin de la simulation, toutes les perturbations ont entraîné une diminution significative du stockage de C par rapport au contrôle. Les simulations ont montré que permettre à l'CE de progresser naturellement à travers un stand peut avoir le meilleur impact sur le stockage de C à long terme et le stockage net de C. Bien que les différences ne soient pas significatives pour les forêts à épicéa, les impacts sur le bassin versant net de l'CE par un scénario où l'épicéa est dominé pourraient entraîner la conversion de l'épicéa à l'érable rouge (Q. rubra) L. et entraîner une perte nette de très humides. Le stockage de C potentiel des espèces de remplacement C au cours des 100 prochaines années.

“...our results suggest that allowing the insect [HWA] to progress naturally may have lower impacts on long-term net Carbon flux than conducting presalvage harvests over the next 50 years” (Krebs et al. 2017)



Structural, compositional, and functional responses to tornado and salvage logging disturbance in southern New England hemlock-hardwood forests

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Natural disturbance
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ABSTRACT

The frequency and severity of wind storms, such as hurricanes and tornadoes, are expected to increase in northeastern North America under climate change. As such, salvage logging is likely to become a more frequently used post-disturbance management strategy; however, there is concern that the compositional disturbance of wind followed by salvage logging could generate negative impacts on species composition, forest structure, and ecological resilience. These impacts are variable and uncertain, posing an opportunity for further research that considers differences in forest recovery following stand-replacing wind alone versus stand-replacing wind and salvage logging. We evaluated the short-term impacts of these singular (tornado) and interactive disturbance events (tornado + salvage logging) on the structure, composition, and function of a mature hemlock-hardwood forest in south-central Massachusetts. Specifically, we were interested in quantifying the impacts of salvage logging practices on forest recovery and resilience. Our analyses consider salvage logging impacts on forest recovery in addition to the regeneration layer (defined here as tree seedlings and saplings that reside on the forest understorey). We found that (i) delayed overstorey mortality was highest on tornado-damaged sites, contributing additional mortality to dead wood pools, while salvaged sites lacked much of this mortality and associated structural legacies; (ii) tree regeneration layer diversity, as measured by Shannon's Index, was higher in the tornado-damaged sites than salvaged sites, but levels of sapling (2.1–4.1 m in height and < 13.7 cm in dbh) density and richness were the same; and (iii) regeneration present in tornado-damaged sites was more functionally similar to that present on undisturbed control sites than to that on salvaged sites. Our results indicate that the compositional disturbance created by salvage logging may have initially homogenized regeneration composition and pushed these areas toward disturbance-adapted species (e.g., Acer rubrum and Betula lenta) and traits (e.g., transient) vs site reproductive strategies). This shift in composition may have also been influenced

“tree regeneration layer diversity...was higher in the tornado-damaged sites than salvaged sites, but levels of sapling density and richness were the same” (Santoro and D’Amato 2019)



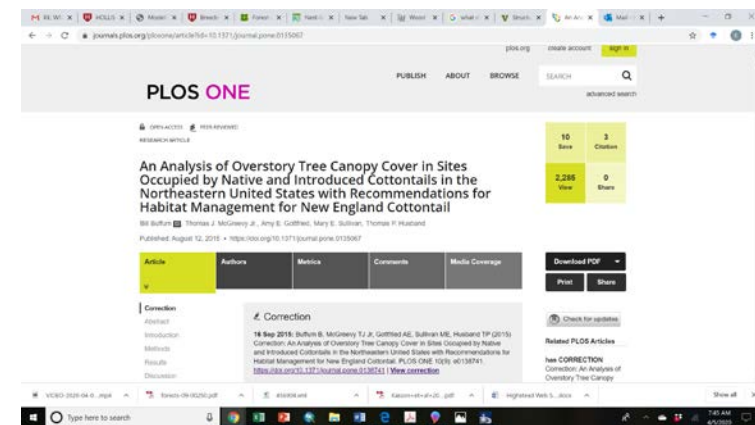
Forest stressors also benefit rare species



New England Cottontail
IUCN red list “vulnerable”

“...the New England cottontail is not limited to...young forests as other authors have suggested, but also occupies sites in maturing forests with overstory canopy cover of up to 80%”

“more New England cottontail [were detected]in the 61%-80% tree canopy class than any other canopy class” Buffum et al. 2015



Insect outbreaks often do not increase fire risk and may reduce it

“Interestingly, many...studies have found that insect outbreaks **reduce** the risk of fire (e.g., Flower et al. 2014, Meigs et al. 2016) or **do not affect it** at all (e.g., Hart et al. 2015). Similarly, a...study in the eastern spruce budworm system also found no evidence for an effect of defoliation on area burned (James et al. 2011).” (James et al. 2017. *Ecological Applications*)

“to date most available evidence indicates that bark beetle outbreaks do not substantially increase the risk of active crown fire in...forests under most conditions” (Black et al. 2013. *Natural Areas Journal*)

Ecological Applications, 27(2), 2017, pp. 332–344
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Lagged cumulative spruce budworm defoliation affects the risk of fire ignition in Ontario, Canada

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Abstract: Detailed understanding of forest disturbance interactions is needed for effective forecasting, modeling, and management. Insect outbreaks are a significant forest disturbance that alters forest structure as well as the distribution and connectivity of combustible fuels at broad spatial scales. The effect of insect outbreaks on fire activity is an important but contentious issue with significant policy consequences. The eastern spruce budworm (*Choristoneura fumiferana*) is a native defoliating insect in eastern North America whose periodic outbreaks create large patches of dead fir and spruce trees. Of particular concern to fire and forest managers is whether these patches represent an increased fire risk, if so, for how long, and how the relationship between defoliation and fire risk varies through space and time. Previous work suggests a temporary increase in flammability in budworm-killed forests, but regional and seasonal variability in these relationships has not been examined. Using an extensive database on historical lightning-caused fire ignitions and spruce budworm defoliation between 1963 and 2000, we assess the relative importance of cumulative defoliation and fire weather on the probability of ignition in Ontario, Canada. We modeled fire ignitions using a generalized additive logistic regression model that accounts for temporal autocorrelation in fire weather. We compared two ecoregions in eastern Ontario (Abitibi Plains) and western Ontario (Lake of the Woods) that differ in terms of climate, geomorphology, and forest composition. We found that defoliation has the potential to both increase and decrease the probability of ignition depending on the time scale, ecoregion, and season examined. Most importantly, we found that lagged spruce budworm defoliation (8–10 yr) increases the risk of fire ignition whereas recent defoliation (1 yr) can decrease this risk. We also found that historical defoliation has a greater influence on ignition risk during the spring than during the summer fire season. Given predicted increases in forest insect activity due to global change, these results represent important information for fire management agencies that can be used to refine existing models of fire risk.

Key words: boreal forest, disturbance interaction, forest fire, forest management, general additive model.



CONSERVATION ISSUES

Do Bark Beetle Outbreaks Increase Wildfire Risks in the Central U.S. Rocky Mountains? Implications from Recent Research

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ABSTRACT: Insect outbreaks in forest, widespread bark beetle (*Dendroctonus* spp.) outbreaks in the western United States has been the subject of much debate in scientific and policy circles. Among the proposed responses have been reducing forest structural heterogeneity to prevent the further spread of outbreaks and to reduce the fire risk that is believed to be associated with insect-killed trees. We review the literature on the efficacy of structural practices to control outbreaks and on the role of structural heterogeneity in forest fire risk. While research is ongoing, and separate questions remain unanswered, our most available evidence indicates that bark beetle outbreaks do not substantially increase the risk of active crown fire in temperate pine (*Pinus contorta*) and spruce (*Picea engelmannii*)-fir (*Abies concolor*) forest under most conditions. Instead, where crown fires in these forest types are generally contingent on dry conditions rather than variation in stand structure, such as those brought about by outbreaks, structure may increase the risk of ignition. In such conditions, it is unlikely to reduce susceptibility to large, landscape-scale ignitions. Once beetle populations reach widespread outbreak levels, structural complexity should be reduced to reduce the risk of ignition. Performance, such as structural measures could have substantial, unintended direct and long-term ecological costs associated with such action and an overall dependence of insect control.

Introduction

Forests in the western United States are being affected by the largest outbreak of bark beetles in at least a century, which has caused concern about forest health and wildfire risk and led to proposals for its removal in natural areas such as roadless forests. Such proposals stem in part from the rationale that bark beetle outbreaks increase wildfire risks due to increased dead fuel and that widespread treatment in beetle-infested forests is needed to lower such risks. Here, we review multi-decade peer-reviewed literature on detection of (1) that beetle outbreaks are associated with a higher incidence of wildfire in fire-prone types in the central Rockies and (2) if structural treatments are effective at lowering beetle-associated fire mortality before, during, and after outbreaks. We briefly review the impacts that additional logging may have on the ecology of insect-outbreak areas. Our results have broader policy implications as reviewed for

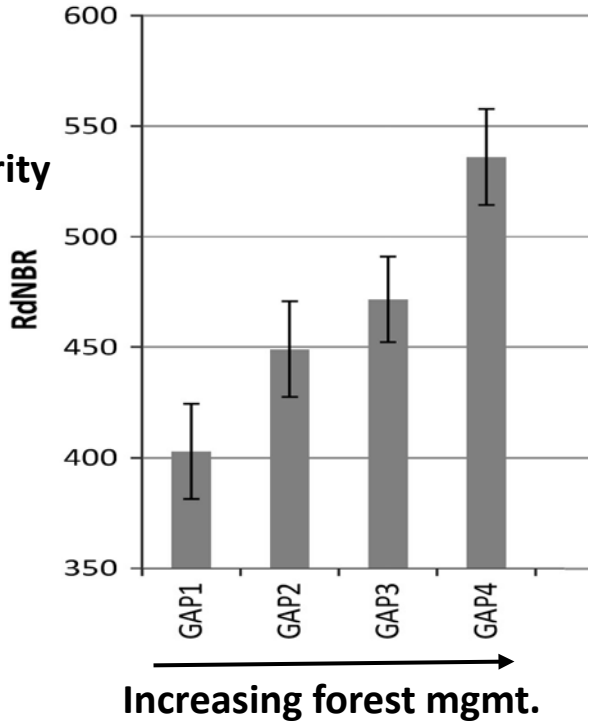
some of large, severe fires in subalpine, lodgepole pine (*Pinus contorta*) and spruce (*Picea engelmannii*)-fir (*Abies concolor*) forests in strongly contiguous or discrete conditions, especially drought (e.g., Kipphutler and Baker 2000; Reusser et al. 2000; Schell and Baker 2000; Schwenker et al. 2002; Kolden et al. 2008; Seward et al. 2008, 2011).

The debate on how outbreaks affect the risk and hazard of logging, but recent work emphasizes that the effect of outbreaks on subsequent fire risk is complex and is contingent on how insect fire outbreaks and on biological setting. To date, the majority of studies have failed to measure the fire occurrence, extent, or severity following outbreaks of spruce beetle (*Dendroctonus rufipennis*) and mountain pine beetle (*Dendroctonus ponderosae*) in Colorado (Whitney and Amthor 2003; Kolden et al. 2005; Righter et al. 2005; Kolden and Baker 2007; Isakov et al. 2008; Seward et al. 2008, 2011).

Thematically, the effect of outbreaks on subsequent fire may vary with the time since the outbreak occurred (Isakov et al. 2008). For example, it is reasonable to expect that foliar residues in trees killed by beetles will decompose and canopy density will be reduced during and immediately after an outbreak. In subsequent years, canopy density may be further reduced as dead needles and small branches fall from killed trees, and tree canopy health...

Less management often reduces the risk of fire severity

Burn severity index



Adapted from Bradley et al. 2016

“Areas that were salvage-logged and planted after the initial fire burned more severely than comparable unmanaged areas” Thompson et al. 2006 PNAS

esa ECOSPHERE

Does increased forest protection correspond to higher fire severity in frequent-fire forests of the western United States?

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Citation: Bradley, C.M., C. T. Hanson, and D. A. DellaSala. 2016. Does increased forest protection correspond to higher fire severity in frequent-fire forests of the western United States? *Ecosphere* 7(10):e1492. 10.1002/ec2.1492

Abstract. There is a widespread view, among land managers and others that the protected status of many forests in the western United States corresponds with higher fire severity levels due to historical restrictions on logging that contribute to greater amounts of biomass and fuel loading in less intensively managed areas, particularly after decades of fire suppression. This view has led to recent proposals—both administrative and legislative—to reduce or eliminate forest protections and increase some forms of logging based on the belief that restrictions on active management have increased fire severity. We investigated the relationship between protected status and fire severity using the Random Forests algorithm applied to 1500 fires affecting 9.5 million hectares between 1984 and 2014 in pure (*Pinus ponderosa*, *Pinus jeffreyi*) and mixed-conifer forests of western United States, accounting for key topographic and climate variables. We found forests with higher levels of protection had lower severity values even though they are generally identified as having the highest overall levels of biomass and fuel loading. Our results suggest a need to reconsider current overly simplistic assumptions about the relationship between forest protection and fire severity in fire management and policy.

Key words: biodiversity, climate, fire frequency, fire severity, fire suppression, Gap Analysis Program levels, logging, protected areas.

Received 4 May 2016; revised 28 June 2016; accepted 5 July 2016. Corresponding Editor: Debra F. C. Peters. Copyright © 2016 Bradley et al. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited. † E-mail: cbradley@biologicaldiversity.org

PNAS

Reburn severity in managed and unmanaged vegetation in a large wildfire

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Edited by Ruth S. DeFries, University of Maryland, College Park, MD, and approved April 26, 2007 (in final form January 10, 2009)

Debate over the influence of postwildfire management on future fire severity is occurring in the absence of empirical studies. We used satellite data, government agency records, and aerial photography to examine a forest landscape in southwest Oregon that burned in 1987 and then was subject, in part, to salvage-logging and conifer planting before it reburned during the 2002 Biscuit Fire. Areas that burned severely in 1987 tended to reburn at high severity in 2002, after controlling for the influence of several topographical and biophysical covariates. Areas unaffected by the initial fire tended to burn at the lowest severities in 2002. Areas that were salvage-logged and planted after the initial fire burned more severely than comparable unmanaged areas, suggesting that fuel conditions in conifer plantations can increase fire severity despite removal of large woody fuels.

public land management | salvage-logging | Biscuit Fire | landscape | landscape ecology

Large wildfires are increasingly common in western North America (1). Changing climate patterns and the legacy of fire suppression within fire-prone forests suggest that this trend will continue. Proactive management is, therefore, a growing concern for public land managers. Although it has been customary to salvage-log fire-killed trees and plant seedlings after large wildfires, there is a mounting debate regarding the practice (2–4). There are several reasons one might choose this management system, including recouping economic losses through timber sales and ensuring the reestablishment of desirable tree species.

is variably sized patches. In the 3 years following the Silver Fire, >800 hectares were salvage-logged and planted with conifers. The arrangement of these disturbances presented a unique opportunity to address two important research questions: First, was severity in the Biscuit Fire associated with severity in the Silver Fire in unmanaged areas? Second, did areas that were salvage-logged and planted with conifers after the Silver Fire burn more or less severely in the Biscuit Fire than comparable unmanaged areas?

With regard to the first question, hereafter referred to as “the reburn question,” a negative correlation between Biscuit and Silver Fire severity is plausible if the forests that burned severely in 1987 had less remaining fuel to support the Biscuit Fire in 2002, or if regenerating young forests did not effectively carry fire. This relationship has been observed in lodgepole pine ecosystems (9–11). An alternate hypothesis is that Biscuit Fire severity would be positively correlated with Silver Fire severity. This would occur if areas of higher Silver Fire severity had greater accumulations of fire-killed trees and vegetative growth available as fuel to the Biscuit Fire. This scenario is assumed to have influenced forest dynamics in more mesic forests of the Pacific Northwest (12). Finally, there may be no discernible association between the severity patterns of the two fires. Many independent factors influence fire severity, including weather, topography, fuel, landscape structure, and fire suppression. Any of these could overwhelm the signal from the legacy of the Silver Fire.

The second question, hereafter referred to as “the salvage-

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Preemptive management for resilience: uncertain success and the ‘cure’ may be worse than the stressor

Adaptation

“Evidence of successful use of silviculture to minimize damage from invasive species remains limited...Despite decades of research and extensive implementation, there remains uncertainty about how successful these established approaches are for limiting damage” (Muzika 2017)

“...little evidence exists to suggest that it is possible to manage for increased resistance or resilience to the array of disturbances and stresses that temperate forests may experience. Many studies suggest that forests are...more vulnerable to exogenous impacts following management” (Foster and Orwig 2006)

Biol Invasions (2017) 19:3419–3435
DOI 10.1007/s10530-017-1549-3



FOREST INVASIONS

Opportunities for silviculture in management and restoration of forests affected by invasive species

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Abstract Despite increasing interest in managing invasive species in forests, few long-term experimental studies have been conducted that reveal the value of silvicultural practices in invasive species management. There is a growing interest in including forest management practices to control or manage invasives. Rather than adhere to traditional silvicultural practices, invasive species management approaches should be tailored to the specific circumstances, e.g. invasion intensity, long-term management goals, and role of the invasive, e.g., defoliator, direct mortality agent, host stressor. Pre-emptive silvicultural approaches correspond well with ecological principles of maintaining host vigor, both in plantations and natural forests. As

dwarfed by other control efforts, such as biological control, silvicultural practices should be integrated into comprehensive management of invasive species. This paper explores a few of the limited case studies of silviculture use for managing invasive pathogens and insects, including *Sirex noctilio*, *Lymantria dispar* and *Agrius planipennis*.

Keywords Forest health · Forest management · Invasive forest pests · Forest pathogens · Gypsy moth · Emerald ash borer · European wood wasp

Preemptive and Salvage Harvesting of New England Forests: When Doing Nothing Is a Viable Alternative

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Abstract: One unexpected consequence of natural disturbances in forested areas is that managers often initiate activities that may impose greater ecosystem impacts than the disturbances themselves. By salvage logging areas affected by windstorms or other impacts, by harvesting host trees in advance of insect infestation or disease, or by preemptively harvesting forests in an attempt to improve their resilience to future disturbances and stresses, managers initiate substantial changes in the ecosystem structure and function. Much of this activity is undertaken in the absence of information on the qualitative and quantitative differences between disturbance impacts and harvesting. To provide insight for such decisions we evaluated the ecosystem consequences of two major disturbance processes in New England (U.S.A.)—intense windstorms and invasive pests and pathogens—and contrasted them with impacts from preemptive and salvage harvesting. Despite dramatic physical changes in forest structure resulting from hurricane impacts and insect infestation, little disruption of biogeochemical processes or other ecosystem functions typically follows these disturbances. Indeed, the physical and organic structures produced by these disturbances are important natural features providing habitat and landscape heterogeneity that are often missing due to centuries of land use. From an ecosystem perspective there are strong arguments against preemptive and salvage logging or the attempt through silvicultural means to improve the resistance or resilience of forests to disturbance and stress. There are often valid motivations for salvage or preemptive logging including financial considerations, human safety, and a desire to shape the long-term composition and resource-production characteristics of forests. Nonetheless, there are many ecological benefits derived from leaving forests alone when they are affected or threatened by disturbances and pest and pathogen outbreaks.

Connecticut is ranked last in the northeastern US in ‘reserved’ forests – public lands protected from management



Reserved forest - permanently prohibited from being managed for the production of wood products through statute or agency mandate; prohibition cannot be changed through decision of the land manager. [However] logging may occur to meet protected area objectives” (O’Connell et al. 2015).

Summary and Recommendations

1. Set aside **a lot** more forest land as unmanaged reserves to **store the most carbon (mitigation)** and **to create the most complex and diverse forests (adaptation)**

-- e.g., 50% of state, county, and municipal lands protected as reserves = 14-15% of CT's total forest area.
(Connecticut should be a leader in forest reserve protection, not bringing up the rear)

-- Prohibit management after natural disturbance (windstorms, insect/pathogen outbreaks, fire etc.) in forest reserves
Natural disturbances will:

- provide habitat diversity in the forest
- better resist invasive plant species than managed areas
- store abundant carbon in deadwood,
- have far less ecosystem impacts than pre or post salvage harvesting
- have little effect on the forest's ability to recover

2. Increase afforestation on abandoned agricultural land, vacant lots, and other unused fields

3. Continue to manage some of Connecticut's forests for **local** wood products.

