Effects of Changing Tree Species Composition on Nitrate Leaching and Carbon Storage in Northeastern Forests

Summary Report

December 2016

Report Number 16-40

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Effects of Changing Tree Species Composition on Nitrate Leaching and Carbon Storage in Northeastern Forests

Summary Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Gregory Lampman
Senior Project Manager

Prepared by:

Cary Institute of Ecosystem Studies

Millbrook, NY

Katherine F. Crowley,
Gary M. Lovett

Project Managers

NYSERDA Report 16-40 NYSERDA Contract 40508 December 2016

Notice

This report was prepared by the Cary Institute of Ecosystem Studies in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter “NYSERDA”). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of reports that they write, in compliance with NYSERDA’s policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Information contained in this document, such as web page addresses, are current at the time of publication.

Preferred Citation

NYSERDA. 2016. “Effects of changing tree species composition on nitrate leaching and carbon storage in Northeastern forests,” NYSERDA Report 16-40. Prepared by. Katherine F. Crowley, Gary M. Lovett (Cary Institute of Ecosystem Studies, Millbrook, NY). nyserda.ny.gov/publications

Acknowledgments

We would like to thank numerous researchers in the Northeast whose work has provided data needed to develop, parameterize, and test the Spe-CN model. We also thank our funding sources: New York State Energy Research and Development Authority, U.S. National Science Foundation, and USDA Agriculture and Food Research Initiative Program.

Table of Contents

List of Figures

List of Images

1 Project Focus

Atmospheric nitrogen pollution from fossil fuel combustion or agricultural activities can exceed the forest's ability to store nitrogen, ultimately releasing harmful amounts of nitrogen in forms that can acidify streams and lakes or pollute estuaries and coastal waters. Disturbances to forests can also change the amount of carbon a forest can store, therefore feeding back to climate change. The main focus of this project was to model the effects of different tree species on the amount of nitrogen that leaches into waterways over time, and the amount of carbon forests can store in vegetation and soils.

2 Context

Elevated levels of atmospheric nitrogen deposition can acidify soils, change the movement of nitrogen through forests, and increase leaching of nitrate (a highly mobile form of nitrogen) that can acidify streams and lakes and pollute downstream estuaries and coastal waters. Limiting nitrogen deposition to levels that prevent ecosystem harm—i.e., establishing effective critical loads of nitrogen for nitrate leaching—requires understanding what level of added nitrogen will cause leaching to increase, and over what time period.

Individual tree species strongly influence how nutrients move through a forest, changing the amount of nitrate released into waterways or the amount of carbon stored in vegetation or soils. Therefore, the level of nitrogen deposition that elevates leaching to harmful levels may also vary among forests dominated by different species. Similarly, differences among tree species alter the extent to which forests can store carbon, which influences carbon dioxide levels in the atmosphere and feeds back to climate change. Due to differences in nutrient use and processing among tree species, replacing one tree species with another can considerably alter the extent to which forests mitigate environmental impacts.

Tree species composition in New York State (NYS) and throughout the Northeastern U.S. is changing due to several factors, which include climate change, land use, and invasion by non-native insects and diseases. For example, beech bark disease has affected American beech trees across the Northeastern U.S. since the 1890s (Image 1). In the Catskill Mountains of New York, decline of beech has resulted in an increasing abundance of sugar maple, which cycles nitrogen and carbon very differently from beech. Hemlock woolly adelgid is a more recent insect invader that has spread rapidly since the 1950s, killing hemlock trees (Image 2). Replacement of hemlock with typical associates, such as yellow birch, may increase rates of movement of carbon and nitrogen and alter patterns of nutrient retention or release. Since its introduction in the Detroit, Michigan area in the early 1990s, the emerald ash borer has spread throughout the Northeastern, Central, and Rocky Mountain States of the U.S., where it causes the rapid death of ash trees and their replacement by neighboring species (Images 3 and 4). Overall, such changes in tree species composition have potential to alter nitrate leaching, therefore changing the critical load of nitrogen deposition for leaching into downstream waters, and to alter the extent to which forests store carbon.

Image 1. Bark cankers on a beech tree with beech bark disease

Beech bark disease is caused by the scale insect *Cryptococcus fagisuga* in combination with pathogenic fungi of the genus *Neonectria.*

Source: USDA Forest Service – North Central Research Station, Bugwood.org

Image 2. Hemlock twigs infested with hemlock woolly adelgid (*Adelges tsugae)*

Source: Pennsylvania Department of Conservation and Natural Resources – Forestry, Bugwood.org

Image 3. Adult emerald ash borer (*Agrilus planipennis*) on an ash tree

Source: Pennsylvania Department of Conservation and Natural Resources – Forestry, Bugwood.org

Image 4. Emerald ash borer larval galleries

Source: Michigan Department of Agriculture, Bugwood.org

Because of the life span of tree species, these long-term effects of change are difficult to study in the field. One approach to this problem is to use a forest ecosystem model, which predicts changes in processes such as nitrate leaching or carbon storage based on differences in the characteristics of tree species. This project used a new forest ecosystem model, called Spe-CN, to simulate carbon and nitrogen cycling in the forest as tree species change.

3 Goals and Objectives

The main goal of this project was to investigate how carbon storage and nitrate leaching vary across forests dominated by different tree species and subject to tree species change. Specific objectives were:

- To investigate how nitrate leaching varies among forests dominated by different tree species and receiving different inputs of nitrogen from deposition to guide establishment of critical loads of nitrogen for leaching.
- To determine how nitrate leaching varies with tree species changes due to invasive insects and diseases.
- To predict the effects of pest-induced tree species change on long-term carbon storage in plants and soils.

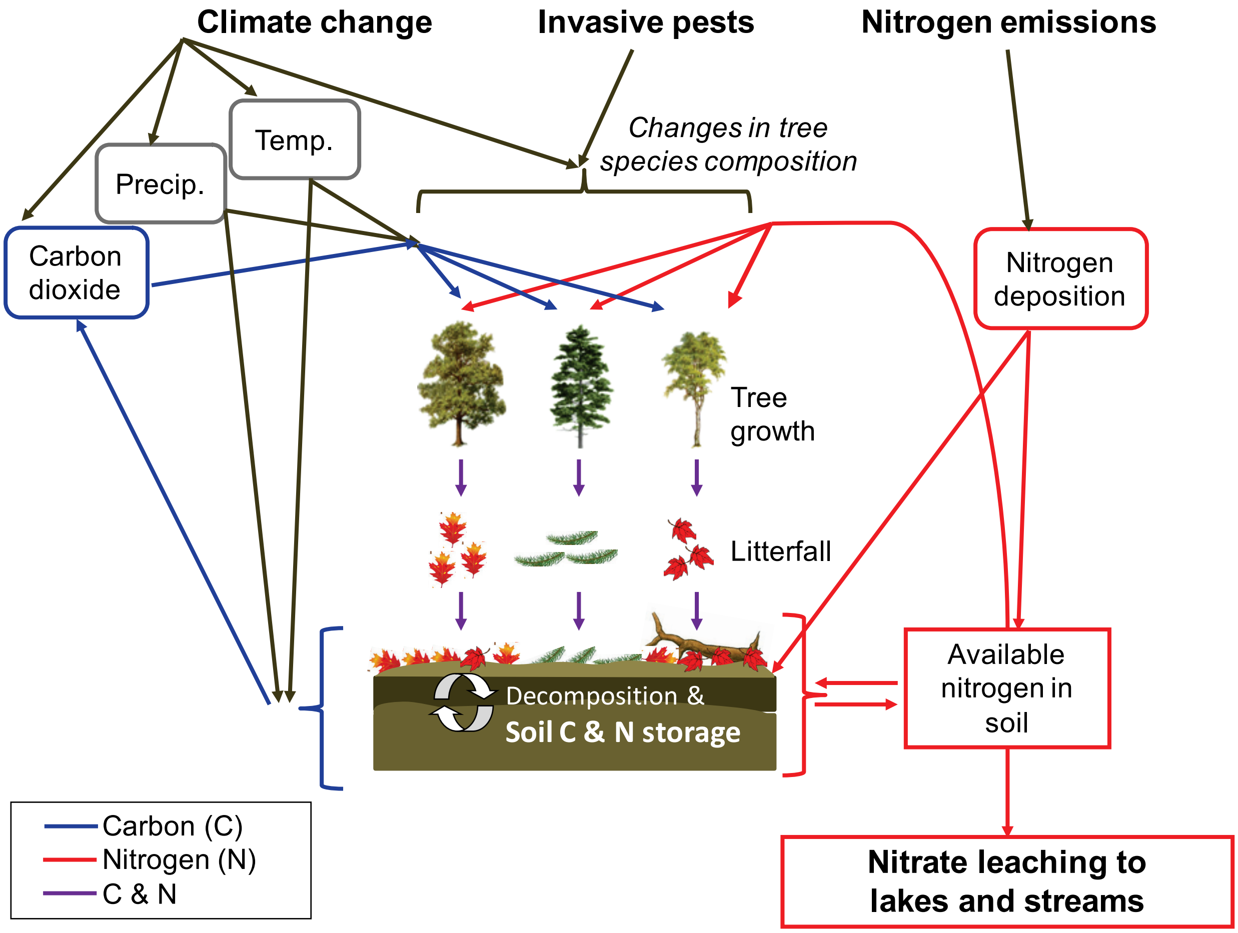
4 Study Methodology

To address these objectives, we developed a new forest ecosystem model called Spe-CN that simulates the movement of carbon and nitrogen through the forest as tree species change. To develop and test the model, we took advantage of extensive available data from research studies performed across the Northeastern U.S., including large data sets from the Catskill Mountains in NYS. Like other forest ecosystem models, Spe-CN incorporates the processes of plant growth and nitrogen use, litter production (i.e., transfer of leaves, wood, and roots to soil), decomposition (i.e., breakdown of litter), and incorporation of remaining litter material into soil (Figure. 1). Spe-CN differs from other forest ecosystem models typically used in the Northeastern U.S. primarily by incorporating individual tree species that change over time, rather than constant forest types. The user specifies when tree species increase or decrease in abundance, and the model plays out the long-term consequences for movement of carbon and nitrogen through the forest. As tree species shift, the model simulates the changing plant growth, nutrient use, and soil processes that gradually alter carbon and nitrogen cycling on the site, ultimately leading to differences in storage of carbon or nitrogen in plants and soils or nitrate leaching to waterways.

To determine how nitrate leaching might vary across forests dominated by different tree species, we used the Spe-CN model to simulate both single-species stands (i.e., constant tree species composition through time) and tree species replacements. While the model is generally applicable throughout the Northeast, we focused this analysis on the forests of the Catskill Mountains, where excellent data are available for model parameterization and testing, and where the forests are threatened by both atmospheric nitrogen deposition and multiple invasive insects and diseases. Scenarios for tree species replacements were driven by current or expected forest insect and disease invasions in the Catskills. Model runs included an initial harvest to simulate past disturbance of these second-growth forests; then, model simulations of changing tree species or different levels of nitrogen deposition were imposed on the re-growing forest. Atmospheric nitrogen deposition was set to realistic Catskill Mountain levels, increasing from a low level through 1940 (0.2 g N m^{-2} $year^{-1}$) to a peak in 1990 (1.11 g N m^{-2} $year^{-1}$), then declining either to a mean 2010 level (0.67 g N m^{-2} $year^{-1}$) or to a range of hypothetical 2010 levels.

Figure 1. Schematic of the Spe-CN forest ecosystem model

Colored lines show movement of carbon (blue), nitrogen (red), or both carbon and nitrogen (purple), respectively. Carbon (C) and nitrogen (N) move among pools in the atmosphere, plants, and soils. Images of different trees represent different species, which are tracked individually in the vegetation and shallow soils. Nitrogen released from decomposing plant material may be stored in soil or taken up by plants, and any remaining nitrogen (as nitrate) leaches into adjacent waterways. Direct effects of carbon dioxide, precipitation, and temperature on plant growth are currently being incorporated in the model.



5 Project Findings

For a given level of nitrogen deposition, predicted nitrate leaching rates varied widely among 12 tree species abundant in Northeastern U.S. forests (Figure. 2). Nitrate leaching rates were predicted to increase either with increasing nitrogen deposition or with forest age, but the amount of each leaching increase varied by species. Leaching increases were generally larger for species such as sugar maple or red maple than for species such as red spruce, hemlock, or red oak (Figure. 2). The species with the lowest leaching rates had threshold levels of nitrogen deposition beyond which leaching increases were abruptly larger in magnitude. For example, in a 100-year-old red spruce forest, leaching increased by a larger extent when nitrogen deposition exceeded 0.85 g m^{-2} yr^{-1} (Figure 2a). More species reached such leaching thresholds as the forest aged (Figure 2b).

These leaching patterns reflected particular characteristics of each tree species. For example, high leaching rates in sugar maple stands resulted from several interacting factors, including: (1) relatively slow growth rates and low nitrogen concentrations in leaves, wood, and roots relative to other deciduous species, making sugar maple trees comparatively slow to store nitrogen; (2) large trees, which continued to store nitrogen even when nitrogen deposition was high; (3) high quality leaf litter, causing fast breakdown of plant material; and (4) a low ratio of carbon to nitrogen in soil, resulting in high production of nitrate that leached from the forest. In contrast, low leaching rates in a hemlock stand resulted from lower nitrogen concentrations in vegetation and lower quality leaf litter, leading to slow breakdown of plant material and considerable nitrogen storage in soil, and a high ratio of carbon to nitrogen in soil, resulting in low production of nitrate.

Reflecting these different leaching rates associated with different tree species, the Spe-CN model also predicted that invasive forest pest activity would change the amount of nitrate leaching. The model predicted that replacing beech with sugar maple due to beech bark disease or hemlock with yellow birch due to hemlock woolly adelgid would cause large increases in nitrate leaching, but the timing of the leaching increase would vary with tree species (Figure 3, 4). For three emerald ash borer scenarios, the model predicted wide variation in leaching response: (1) much greater leaching if ash was replaced by sugar maple; (2) much lower leaching if ash was replaced by red oak; and (3) very little change if ash was replaced by American beech (Figure 5).

Figure 2. Nitrate leaching predicted by the Spe-CN model from forest areas dominated by each of 12 tree species at (a) 100 years and (b) 300 years of age

For each model run, nitrogen (N) deposition was held constant at 0.2 g m^{-2} yr^{-1} of N through 1940, increased to 1.11 by 1990, and stabilized at a final level ranging from 0.25 to 1.25 g m^{-2} yr^{-1} of N in 2010 and thereafter. Each color/symbol on the graph represents a single 2010 N deposition level, across all species considered. Stabilization at 0.65 g m^{-2} yr^{-1} represents the approximate N deposition trajectory for the Catskill Mountains (actual 2010 Catskills value was 0.67 g m^{-2} yr^{-1} of N). WP=white pine; BF=balsam fir; RO=red oak; EH=eastern hemlock; RS=red spruce; WA=white ash; YB=yellow birch; BB=black birch; AB=American beech; PB=paper birch; SM=sugar maple; RM=red maple.

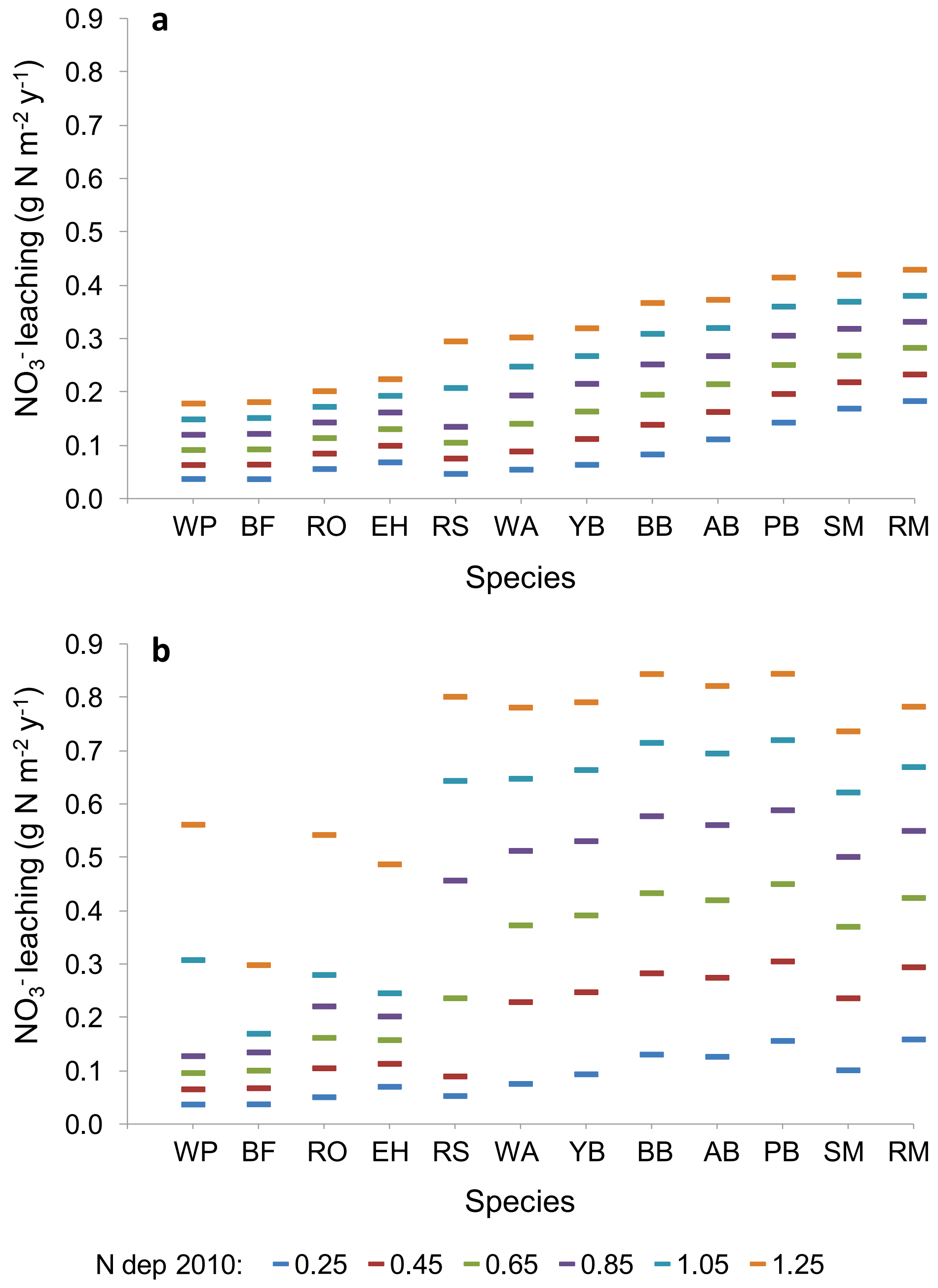


Figure 3. Comparison of Spe-CN model predictions of (a) carbon (C) pools in plants and shallow soils (FF, or forest floor) and (b) nitrate leaching between an un-invaded American beech stand and a stand where sugar maple replaces beech due to beech bark disease

Changes over time are in response to an 80% harvest in 1910; an increase in nitrogen (N) deposition from 0.2 to 1.11 g m^{-2} year^{-1} of N from 1940 to 1990, decreasing to 0.67 g m^{-2} year^{-1} of N by 2010; and a transition from American beech to sugar maple from 2020 to 2070.

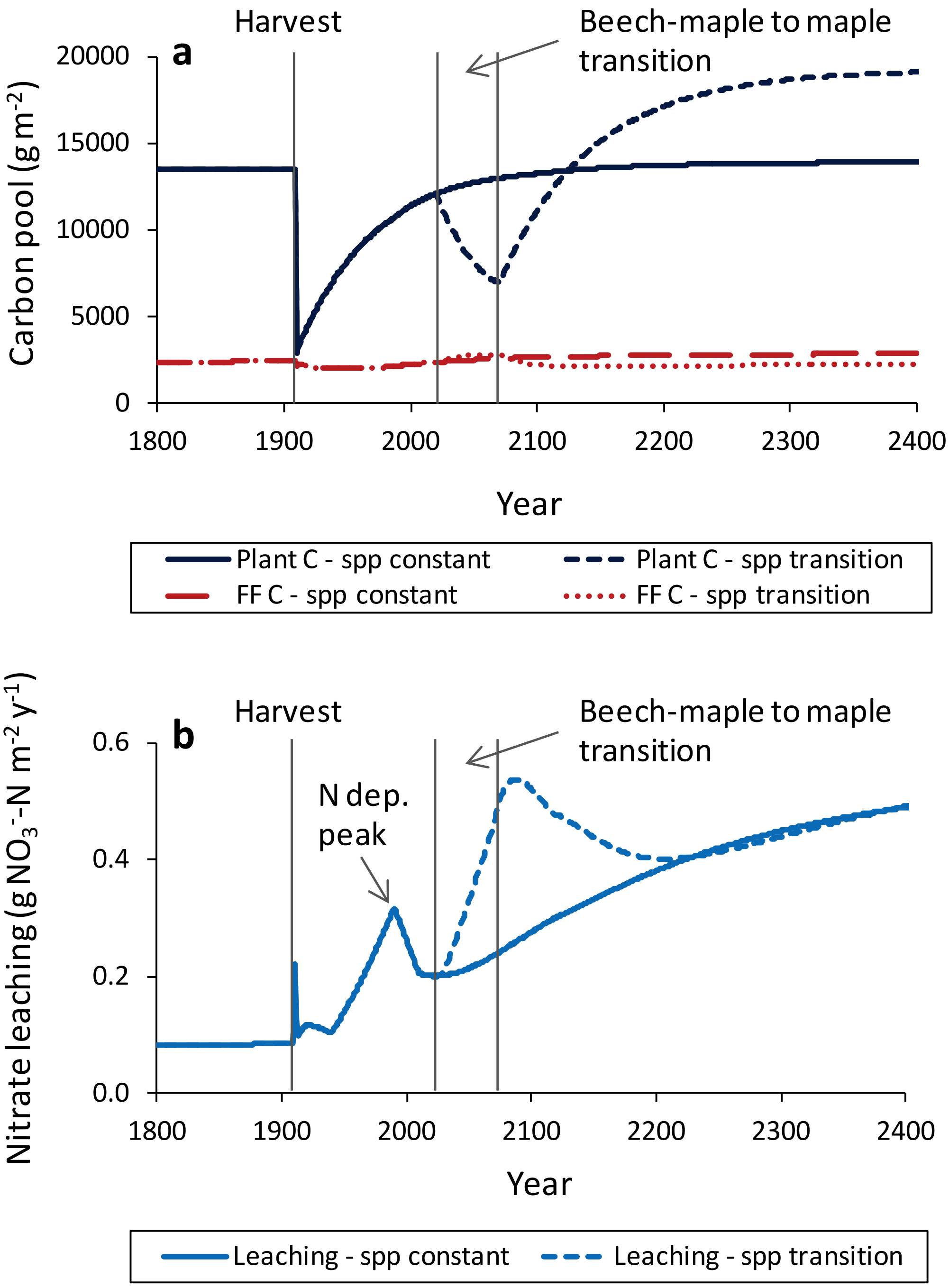


Figure 4. Comparison of Spe-CN model predictions of (a) carbon (C) pools in plants and shallow soils (FF, or forest floor) and (b) nitrate leaching between an un-invaded eastern hemlock stand and a stand where yellow birch replaces hemlock due to hemlock woolly adelgid

Changes over time are in response to 100% mortality of hemlock in 1850; an increase in nitrogen (N) deposition from 0.2 to 1.11 g m^{-2} year^{-1} of N from 1940 to 1990, decreasing to 0.67 g m^{-2} year^{-1} of N by 2010; and a transition from hemlock to yellow birch from 2020 to 2050.

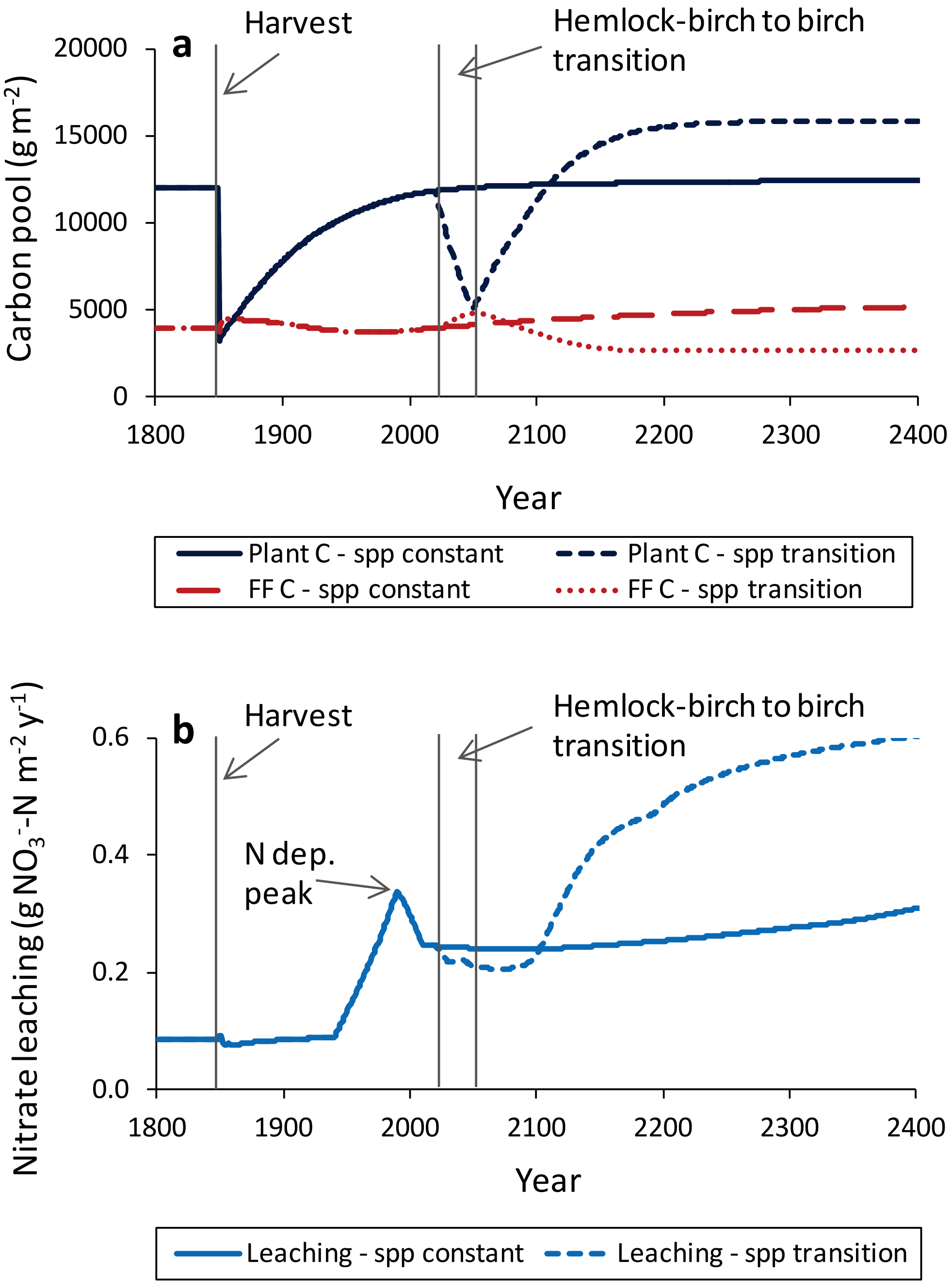
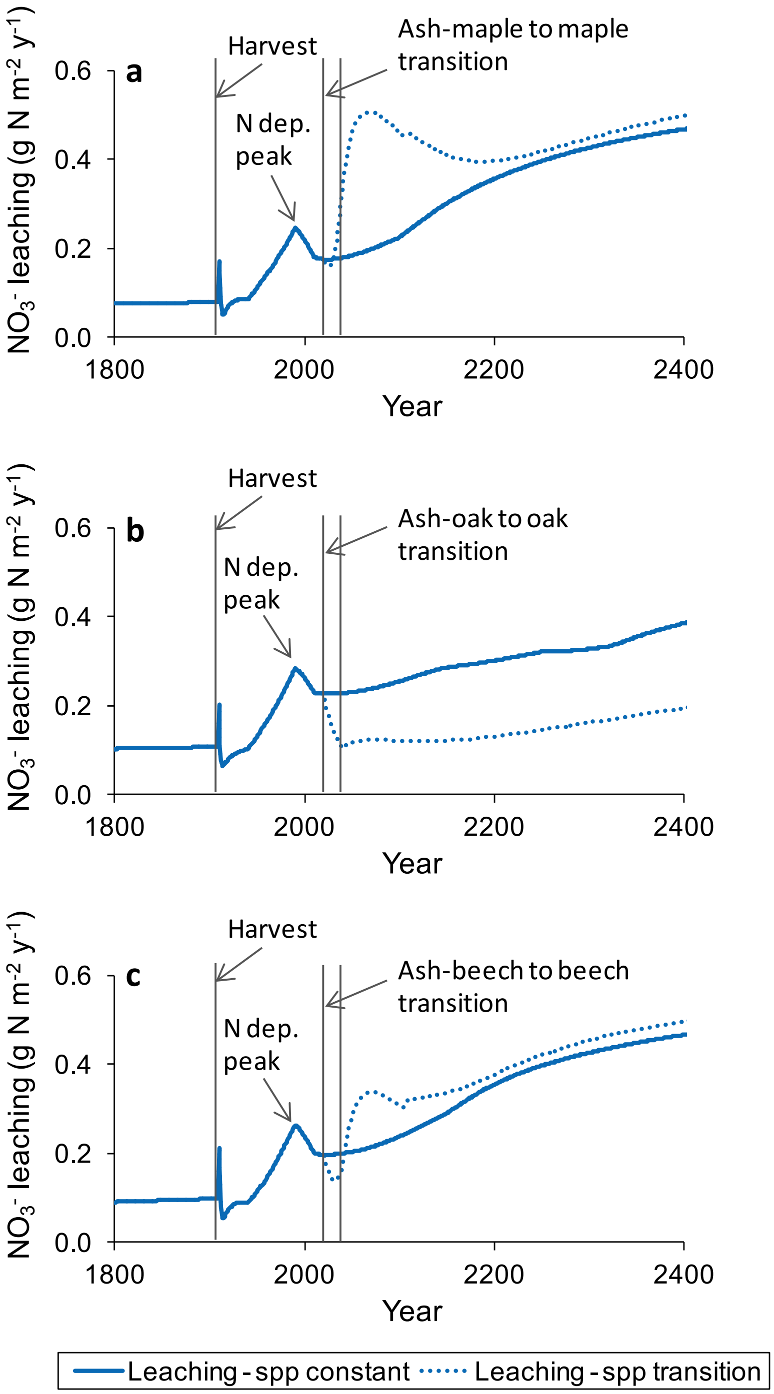


Figure 5. Nitrate leaching predicted by the Spe-CN model for forest areas transitioning from white ash (80% ash, 20% replacing species) to an area dominated by (a) sugar maple, (b) red oak, or (c) American beech, due to emerald ash borer

Changes over time are in response to an 80% harvest in 1910; an increase in nitrogen (N) deposition from 0.2 to 1.11 g m^{-2} year^{-1} of N from 1940 to 1990, decreasing to 0.67 g m^{-2} year^{-1} of N by 2010; and a transition from ash to each of three potential replacing species from 2020 to 2040.



Similar to nitrogen, the amount of carbon the forest stored or lost also depended on tree species identity and the number of years since the invasion began. One hundred years following beech bark disease invasion, new sugar maple forest stored less carbon in plants and soils than did corresponding, un-invaded beech-maple forest (Figure 3). As the forest continued to age, however, an older (300 years post-invasion) sugar maple forest stored more carbon, particularly in trees, than its un-invaded beech-maple counterpart (Figure 3). One hundred years following hemlock woolly adelgid invasion, new yellow birch forest stored less carbon in plants and particularly in soils than did a corresponding, un-invaded hemlock-birch forest (Figure 4). This pattern changed with forest age, such that 145 years post-invasion, carbon storage was greater in yellow birch forest than in un-invaded hemlock-birch forest; and by 300 years post invasion, invaded and un-invaded forest areas were very similar (Figure 4).

6 Project Implications

Predicted changes in nitrogen and carbon dynamics with tree species change have important implications for the establishment of critical loads of nitrogen deposition for leaching, and for management of Northeastern forests for carbon storage. These model simulations suggest the following:

- Forests dominated by different tree species vary considerably in nitrate leaching and will therefore vary in the critical load of nitrogen deposition that is predicted to increase leaching to harmful levels.
- For any specific ecological threshold level of nitrate in waterways, the amount of nitrogen deposition that would cause threshold exceedance will vary depending on the tree species composition of the adjacent forest.
- Forest composition is changing due to invasive insects and disease, climate change, and other factors; thus, the amount of nitrogen deposition that will cause threshold exceedance will change as the forest changes.
- Specific tree species replacements, due to factors such as invasive forest pests or other sources of disturbance, may cause leaching to increase above or fall below harmful levels, even when nitrogen deposition remains constant.
- Effects of tree species change on critical forest functions, such as nitrate leaching or carbon storage, vary with both species identity and the age of the forest. Patterns of response change as the forest ages post-disturbance.
- Management aimed to reduce nitrate leaching to waterways or to maximize carbon storage may need to adjust over time. In light of species changes across the landscape, managers and policy makers should be prepared to reevaluate critical loads of nitrogen deposition and carbon storage targets periodically.
- Models that predict critical loads and net carbon storage or loss should account for changes in tree species.

7 Next Steps

Forest change over the next 50–100 years will unfold in concert with changes in many environmental factors, including nitrogen deposition, atmospheric carbon dioxide, and climate, which will influence critical loads of nitrogen deposition and trajectories for carbon storage. Future development of the Spe-CN model will incorporate the direct effects of carbon dioxide, temperature, and water availability on plant growth and decomposition; these alterations to the model are in progress. These model refinements will enable questions regarding interactions between tree species transitions (due to invasive insects and pathogens, climate change, or other disturbances) and the direct effects of nitrogen deposition, climate change, and other environmental impacts to Northeastern U.S. forests.

8 References

Crowley, K.F., Lovett, G.M., Arthur, M.A., and Weathers, K.C. 2016. Long-term effects of pest-induced tree species change on carbon and nitrogen cycling in northeastern U.S. forests: A modeling analysis. Forest Ecology and Management 372: 269-290.

Crowley, K.F., and Lovett, G.M. 2017. Effects of nitrogen deposition on nitrate leaching from northeastern U.S. forests will change with tree species composition. Accepted by Canadian Journal of Forest Research.

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | John B. Rhodes, President and CEO