CLIMATE IMPACTS OF INDUSTRIAL FOREST PRACTICES IN NORTH CAROLINA

Synthesis of best available science and implications for forest carbon policy

PART 1—SEPTEMBER 2019

DOGWOOD ALLIANCE

CENTER FOR SUSTAINABLE ECONOMY
Building the DNA of the New Economy

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Industrial logging and wood product manufacturing emit enormous quantities of greenhouse gases.

A wetland forest clearcut near Woodland, NC to feed a nearby Enviva wood pellet facility.

SUMMARY AND KEY FINDINGS

Each year, roughly 201,000 acres of forestland in North Carolina are clearcut to feed global markets for wood pellets, lumber, and other industrial forest products.

Roughly 2.5 billion board feet of softwood and hardwood sawtimber are extracted annually, an amount equivalent to over 500,000 log truckloads.[1] The climate impacts of this intensive activity are often ignored in climate policy discussions because of flawed greenhouse gas accounting and the misconception that the timber industry is carbon neutral.

The reality, however, is that industrial logging and wood product manufacturing emit enormous quantities of greenhouse gases and have significantly depleted the amount of carbon sequestered and stored on the land. In addition, industrial tree plantations pose a serious threat to North Carolina's climate change resiliency because they make the effects of floods, droughts, heat waves, storms, and disease more severe.

This two-part report synthesizes and analyzes the best available climate science on the impacts of industrial forest practices in North Carolina. It aims to serve as an evolving source of technical information and inform policies to encourage climate smart forest practices. As more and better data become available, they will be incorporated in subsequent versions.

Part 1 of the report discusses how industrial forest practices disrupt nature's carbon cycle and provides an overview of three key climate impacts—loss of carbon storage, increased emissions, and loss of carbon sequestration capacity. Several key findings emerge:

[1] See, e.g. Howard, J.L., Quevedo, E., Kramp, A., 2005. Use of Indexing to Update U.S. Annual Timber Harvest by State. Research Paper FPL-RP-653. Madison, WI: USDA Forest Service, Forest Products Laboratory; NC State Extension Service: North Carolina Lumber Production, Consumption, and Revenue Trends 1998 to 2016. Available online at: https://content.ces.ncsu.edu/north-carolina-lumber-production-consumption-and-revenue-trends.

- Industrial forest practices, including clearcutting, timber plantations, application of chemicals and fertilizers, and construction of dense networks of logging roads disrupt natural forest carbon cycles by reducing the buildup of carbon stored in vegetation and soils, reducing carbon sequestration capacity and generating major quantities of greenhouse gases.
- North Carolina's industrial forestlands store far less carbon than the native forests they have replaced. On intensively managed timberlands and tree plantations the amount stored has been reduced by roughly 50%.
- Afforestation, reforestation, and proforestation (letting forests grow to maturity) have the potential to sequester and store nearly 3 billion metric tons of carbon dioxide (CO_2). This is equivalent to 20 years of North Carolina's currently reported greenhouse gas emissions.
- CO_2 emissions from logging and wood products are a major missing component of North Carolina's greenhouse gas inventory. Emissions from the release of carbon in wood products, forgone sequestration capacity, decay of logging residuals, and fertilizer likely top 44 million metric tons of carbon dioxide each year, making this sector the third most carbon intensive in the state.
- Short rotation timber plantations for paper, pellets, and low-quality timber have created vast carbon sequestration dead zones encompassing 2.6 million acres. As a result, North Carolina's forestlands sequester far less carbon than their natural capacity would allow.
- Extending rotation periods would reduce the extent of carbon sequestration dead zones, produce more timber per acre, and could double the carbon sequestration rate of a given watershed.

Part 2 of the report will discuss the various ways industrial forest practices amplify the effects of climate change by making the landscape more susceptible to droughts, wildfire, floods, insects, disease, water pollution and the risks associated with harmful algae blooms. Part 2 will also review a list of climate smart forest practices that provide economically attractive alternatives to short rotation timber plantations for landowners and rural communities. Part 2 will also provide an overview of policy interventions the State of North Carolina can make to enroll forests in its overall climate agenda, properly account for logging and wood products emissions, and scale up these climate smart alternatives so that they become the norm and not the exception.

HOW INDUSTRIAL FOREST PRACTICES DISRUPT NATURE'S FOREST CARBON CYCLE

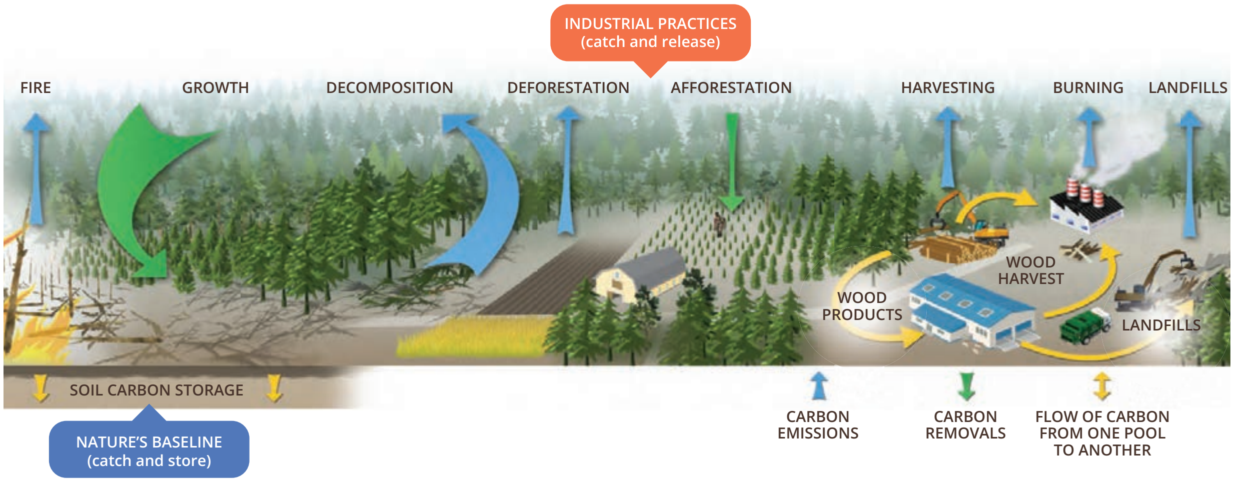
Industrial forest practices in North Carolina and other high timber output regions disrupt nature's forest carbon cycle and undermine the resiliency of the landscape to climate change. An illustration by Natural Resources Canada serves well as a stylized representation of these facts. Nature's forest carbon cycle—nature's baseline—is illustrated on the left-hand side of Figure 1. Natural forests sequester large amounts of carbon from the atmosphere (green arrow) and release small amounts from natural disturbances such as wildfires, storms, insects, and disease and more significant amounts from the natural decay of dead and downed wood on the forest floor. But the net amount of carbon sequestered is always positive and is so for many centuries.[2] Importantly, this allows the buildup of carbon stocks in forest soils. As such, we can think of nature's baseline as a forest carbon "catch and store" regime.

[2] In a comprehensive analysis of data from old growth forest plots across North America, Luyssaert et al. (2008) found that even in forests as old as 800 years "the net carbon balance of the forest and soils is usually positive—meaning they absorb more carbon dioxide than they release." See Luyssaert, S., Schulze, D.E., Knohl, A., Hessenmoller, D., Law, B.E., Ciais, P., Grace, J., 2008. Old growth forests as global carbon sinks. Nature 455, 213-215 (11 September 2008).

What role do forests play in the carbon cycle?

The "carbon cycle" is the movement of carbon from land and water through the atmosphere and all living things. Carbon in the atmosphere exists as CO_2, a greenhouse gas (GHG). Trees absorb carbon during photosynthesis and store it in their stems, branches and roots, removing large amounts of carbon from the atmosphere. A large proportion of this stored carbon also ends up in forest soil through natural processes such as annual leaf fall and tree death.

FIGURE 1



Trees release carbon back into the atmosphere during respiration, when they die and decay, and if they are burned in a forest fire. This dynamic process of absorbing and releasing carbon constantly affects Earth's carbon balance.

Forests are considered to be "carbon sinks" when they absorb more carbon than they release; and "carbon sources" when they release more carbon than they absorb. How humans manage forests and use wood also affects this balance.

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In contrast, the industrial forest landscape can be thought of as a "catch and release" regime as illustrated on the right-hand side of Figure 1. Carbon is sequestered by plantations established on cropland (afforestation) or forestlands (reforestation). Most of that carbon is eventually released through timber harvest, wood products manufacturing, burning of woody biomass for energy, and decay in landfills. Clearcutting deforests the land, reduces net sequestration, and removes natural, climate resilient forests. Accumulation of carbon in the soil is eliminated or significantly reduced. As compared with nature's baseline, the industrial forest landscape stores less carbon, sequesters less carbon, emits more carbon into the atmosphere, and is more vulnerable to climate change.

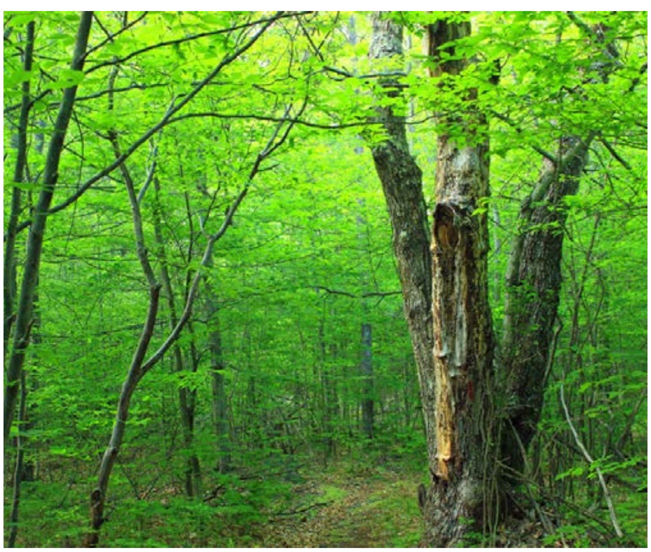
Over the past decade or so, there have been significant advances in the ability to monitor changes in this forest carbon cycle through satellites, ground-based surveys, and modeling. This allows us to quantify impacts on various geographic scales, including states. In the sections that follow we summarize what the data show for North Carolina.

IMPACT 1

REDUCTION IN FOREST CARBON STORAGE ON THE LAND

The United States Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis Program (FIA) is a ubiquitous and widely used source of data on forest carbon stocks and flows for each state and ecological region within them. The FIA data can be extracted and analyzed with various tools. For our analysis, we relied on data extracted by the EVALIDator tool for North Carolina by Sam Davis, Ph.D., Dogwood Alliance's Conservation Scientist. Forest carbon stocks are expressed in tons of carbon per acre (tC/ac) and estimated for various ownership categories and ecological regions. In North Carolina, the data are organized by seven ownership categories and seven ecological regions.

What these data show is consistent with what is reported in the literature: because most North Carolina forestlands have been stripped of their original, old growth forests, the amount of carbon stored on the land is significantly reduced from nature's baseline.[3] Figure 2 illustrates the point by displaying forest carbon densities on various ownerships in the Central Appalachian Piedmont (CAP) ecoregion relative to "nature's baseline" carbon densities once present in old growth forests.



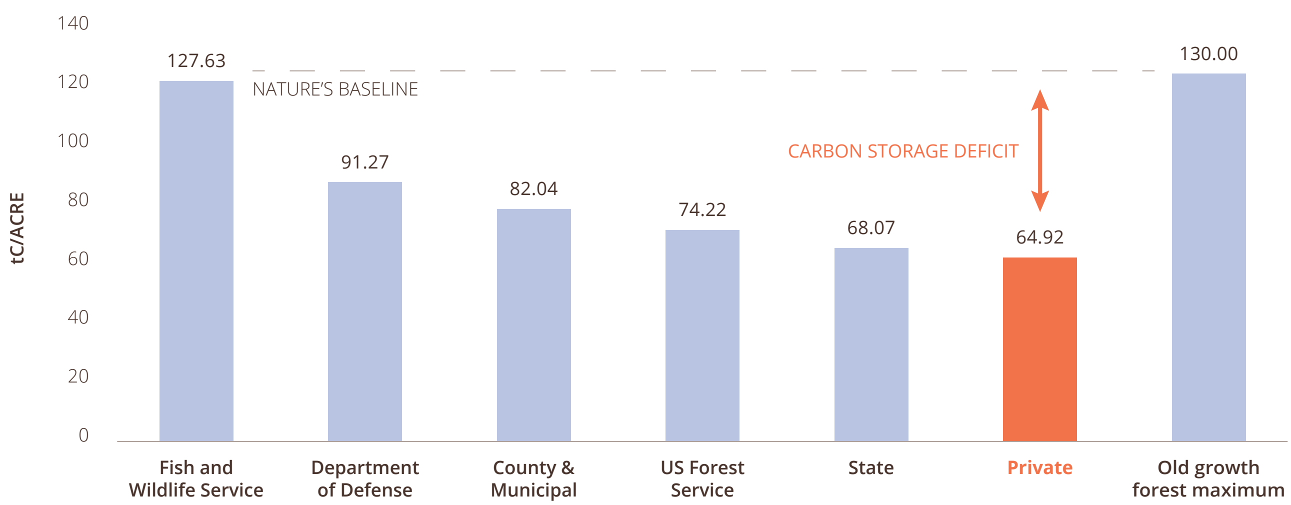
3 For example, Brown (1999) found that "[a]lthough the total biomass density of eastern hardwood forests spans a wide range, their average biomass density is less than half of what it could be because they lack numerous large diameter trees as is typical for old-growth forests." Brown, S.L., Schroeder, P., Kern, J.S., 1999. Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management* 123: 81-90.

Establishing nature's baseline density is somewhat difficult because old growth forests now only exist in small remnants. Nonetheless, combining the few studies relevant to North Carolina's forest types with FIA data on maximum carbon densities found in the state suggest that a baseline figure of 130 tC/ac is a reasonable figure for the CAP ecoregion.[4] As shown in Figure 2, existing carbon densities range from quite near this maximum for National Wildlife Refuge (NWR) lands (i.e. Pee Dee and Roanoke Rapids NWRs) to less than 50% of nature's baseline on private lands where industrial forest practices are being implemented.

The resulting forest carbon deficit gives an indication of how much more carbon can potentially be captured and stored through climate smart forest practices. Climate smart practices simultaneously reduce emissions associated with logging, increase forest carbon storage on land, increase annual sequestration, and make the landscape more resilient to climate change.[5] Afforestation (reestablishing forests on land converted to agriculture a long time ago), proforestation (letting existing forests grow to maturity), reforestation (planting real forests not tree plantations), long rotations and thinning dense tree plantations to expedite their development into late successional and old growth forests are examples.

FIGURE 2

FIA CARBON DENSITY BY OWNERSHIP: CENTRAL APPALACHIAN PIEDMONT, NC



[4] Baseline estimates for hardwood ecosystems were taken from: McGarvey, J.C., Thompson, J.R., Epstein, H.E., Shugart, H.H. Jr., 2015. Carbon storage in old growth forests of the Mid-Atlantic: toward better understanding the eastern forest carbon sink. *Ecology* 96(2): 311-317. Baseline estimates for long leaf and loblolly pine were taken from: Bragg, D.C., 2012. Developing contemporary and historical live tree biomass estimates for old pine-hardwood stands of the Midsouth, USA. *Forest Ecology and Management* 281: 32-40.

[5] Talberth, J., 2017. Oregon Forest Carbon Policy: Scientific and technical brief to guide legislative intervention. Portland, OR: Center for Sustainable Economy. Available online at: https://sustainable-economy.org/wp-content/uploads/2017/12/Oregon-Forest-Carbon-Policy-Technical-Brief-1.pdf.

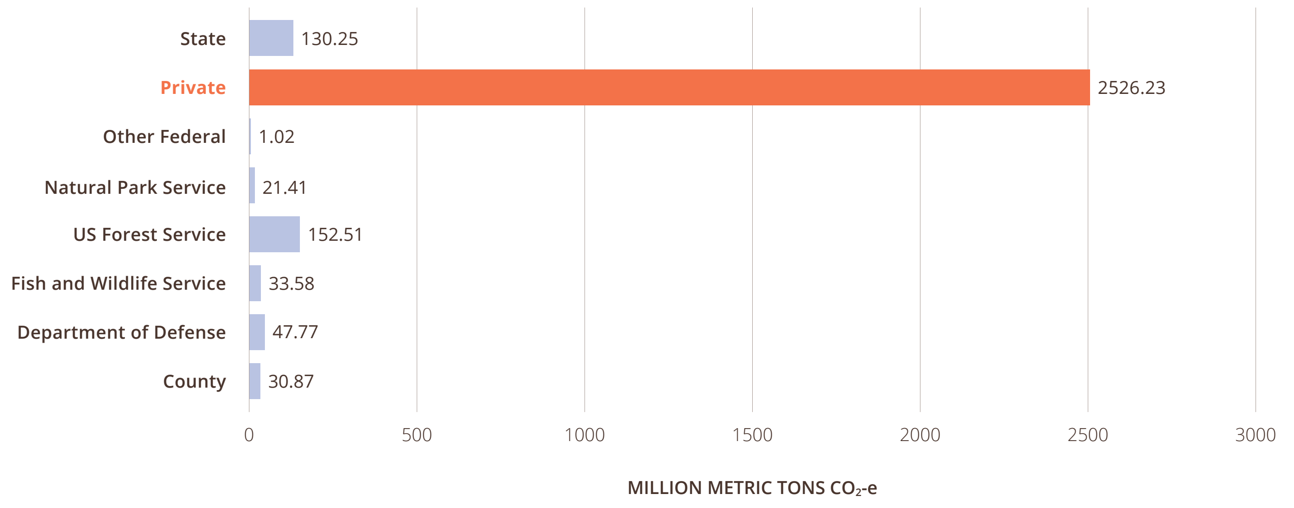
Within each ownership and ecoregion, we subtracted existing forest carbon densities from nature's baseline and then multiplied the difference by the number of acres in each ownership type. This allowed us to estimate how much more carbon could be stored on forestlands in North Carolina if these climate smart practices were implemented across the board. As shown in Figure 3, we estimate this amount to be nearly 3 gigatons of CO_2 (3 Gt CO_2-e)—equivalent to 20 years of North Carolina's currently reported greenhouse gas emissions.

The vast majority of the potential gain (2.5 Gt CO_2-e) is on private lands.

While it may be unreasonable to assume that climate smart practices could be implemented on every acre of private forestlands, this figure may still be a good target because it does not include the additional amounts that could be captured and stored through afforestation.

FIGURE 3

ADDITIONAL FOREST CARBON STORAGE POTENTIAL BY OWNERSHIP NORTH CAROLINA STATEWIDE

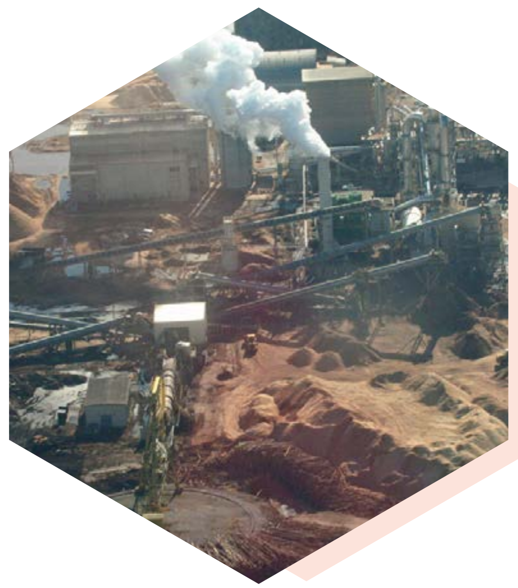


Paper, packaging and other short-lived products release most of their carbon in a decade.

IMPACT 2

GREENHOUSE GAS EMISSIONS FROM LOGGING AND WOOD PRODUCTS

Trees are half carbon by weight. As long as they stay in the forest, they continue to accumulate and store this carbon in leaves, needles, branches, trunks, and roots. When they die, some of the carbon is converted into CO_2 and emitted into the atmosphere, but most stays on site accumulating in the soil. As illustrated by Figure 1, industrial logging activities disrupt this natural carbon cycle and, as a result, most of the carbon that would have been stored in the forest and soils is released into the atmosphere.



Carbon is not stored very long in wood products, rather, it is converted to CO_2 and released in accordance with well-established timeframes that depend on the type of product produced. Burning woody biomass releases stored carbon immediately. Paper, packaging, and other short-lived products release most of their carbon in a decade. The half-life of carbon stored in longer lived wood products like structural lumber is generally fifty years or less, so most is gone at the end of the standard 100-year carbon accounting framework.

In addition to the release of CO_2 from wood products, forests that would otherwise have continued to accumulate carbon are clearcut. The land not only loses carbon sequestration capacity (this foregone sequestration capacity is considered an indirect emission under carbon accounting rules) but becomes a net source of CO_2 emissions due to the decay of logging slash left behind and disturbed soils. Finally, another tranche of emissions result from transportation of logs to the mills, manufacturing processes, and the use of pesticides, herbicides, and fertilizers associated with timber plantations. Given all this, it is not surprising that logging and manufacturing wood products are very carbon intensive activities.

In 2015 and again in 2017, the Center for Sustainable Economy (CSE) and its partners estimated the carbon emissions associated with industrial logging activities in western Oregon. Conservatively, we estimated emissions to be about 33 million metric tons CO_2 equivalent per year (33 MMT CO_2-e/yr), making this sector the most carbon intensive in the state.[6] A subsequent analysis by an Oregon State University team, using

[6] Talberth, 2017, Note 5.

a somewhat different methodology, also estimated this same level of emissions.[7] In the remainder of this section, we replicate the CSE methodology to produce preliminary estimates of the carbon emissions associated with logging and wood products in North Carolina.

For this analysis, we limited timber harvest emission calculations to those associated with harvesting (wood products decay minus the residual that continues to be stored after 100 years), foregone sequestration capacity, decay of logging residuals, and use of forest fertilizers. We excluded transportation and manufacturing emissions as they are already assigned to other sectors (i.e. transportation and industrial processes) in North Carolina's existing greenhouse gas (GHG) inventory. Emissions from soil disturbance, pesticides, and herbicides are also difficult to quantify at this time. So, for purposes of this analysis, preliminary logging and wood products emissions are calculated as follows:

LWP = (REM – STOR) + FS + DR + FER, where:

LWP = logging and wood products related emissions (MMT CO_2-e/yr)
REM = CO_2-e removed from site by timber harvest
STOR = CO_2-e removed from site and stored in long-lived (100+ years) wood products
FS = Foregone sequestration from recently clearcut lands
DR = Decay and combustion of logging residuals
FER = Emissions associated with forest fertilizers

Timber harvest removals (REM)

The amount of forest carbon stored on site and removed by timber harvesting or clearing land for agriculture or development is reliably measured by multiple forest carbon monitoring platforms. The most ubiquitous is the FIA database. According to the most recent FIA data for North Carolina extracted using the EVALIDator tool, REM has averaged 35.27 MMT CO_2-e per year between 2000 and 2018. Raw removals data from EVALIDator is given by weight—short tons, about 21 million per year—and so has to be converted into CO_2-e units.[8] The standard process involves three basic steps: (1) converting short tons to metric tons by multiplying the former by 0.9072; (2) taking half this amount as the carbon component, and (3) multiplying this value by 3.67 to convert carbon to carbon dioxide equivalent. Alabama's Forestry Commission provides an excellent resource for walking forestland owners through these conversions.[9]

The vast majority (96%) of removals were from private and corporate lands[10] and from three primary ecoregions—Central Appalachian Piedmont (33%), North Atlantic Coastal Flatwoods (23%), and Middle Atlantic Coastal Flatwoods (18%).

[7] Law, B.E., Hudiburg, T.W., Berner, L.T., Kent, J.J., Buotte, P.C., Harmon, M.E., 2018. Land use strategies to mitigate climate change in carbon dense temperate forests. PNAS April 3rd, 2018 115 (14): 3663-3668.

[8] For this analysis, we limited removals to trees over 1" dbh and ignored below ground removals since much of this is related to land clearing for development purposes.

[9] Alabama Forestry Commission. 2009. Guidelines to Measure Carbon Sequestration in Alabama Forests. Montgomery, AL: AFC. Available online at: www.forestry.alabama.gov/Pages/Management/Forms/Carbon_Baseline_Inventory_Procedures.pdf.

[10] In North Carolina, the FIA classifies ownership by certain types of corporations—including Timber Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs)—under a "N/A" category. We thus consider the N/A ownership category in our analysis to be private.

Carbon stored in long-lived wood products (STOR)

Forest carbon removed from site during timber harvest has one of two ultimate fates over a 100-year period:[11] (1) through biomass combustion and decay of waste or wood products, it ends up in the atmosphere, or (2) a portion of it survives intact in long-lived wood products like structural lumber or furniture or remains buried in landfills. STOR estimates the second. In a nationwide analysis, Ingerson (2009) estimated STOR to range from zero to 21% of REM depending upon assumptions about the disposition of harvested wood.[12] Forest Service data tables for the Southeast estimate that 30% (hardwoods) to 34% (softwoods) of the embodied carbon in sawlogs is retained after 100 years in longer-lived wood products and landfills, and 14% (softwoods) to 18% (hardwoods) of the embodied carbon in pulpwood is retained 100 years after harvest in short-lived wood products and landfills.[13]

A recent (2016) analysis by the USDA Southern Research Station estimated the product output from North Carolina forestlands to be distributed as such: softwood—pulp and bioenergy products (31%); softwood—sawlogs, veneer, and other industrial products (43%); hardwood—pulp and bioenergy (8%), hardwood—sawlogs, veneer, and other industrial products (18%).[14] Multiplying these percentages by REM (which distributes REM to each product category) and then by the 100-year residual factor for each product type yields a weighted average value for STOR of 26% of REM, or 9.13 MMT CO_2-e/yr, largely corroborating Ingerson (2009). What this suggests is that out of the 35 million metric tons of CO_2 taken out of North Carolina's forests each year by timber harvesting and land clearing, about 9 million metric tons can be expected to be stored long term (>100 years) with the rest emitted into the atmosphere in a relatively short period of time.

[11] The 100-year framework is standard for GHG accounting in the US and for forest carbon offset projects. Generally, offset projects need to ensure that storage is guaranteed for at least this long. See, e.g. Ecotrust: A Landowner's Guide to Carbon Offsets (http://archive.ecotrust.org/forests/fco_intro.html).

[12] Ingerson, A., 2009 Wood Products and Carbon Storage: Can Increased Production Help Solve the Climate Crisis? Washington, DC: The Wilderness Society.

[13] Smith, J.E., Heath, L.S., Skog, K.E., Birdsey, R.A., 2006. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. Gen Tech. Rpt. NE-343. Morgantown, WV: USDA Forest Service, Northeastern Research Station.

[14] Gray, J.A., Bentley, J.W., Cooper, J.A., Wall, D.J., 2017. North Carolina's timber industry—timber product output and use, 2013. e-Science Update SRS—116. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 4 p.

Foregone sequestration from clearcut units (FS)

When timber is harvested from a site, sequestration is reduced or eliminated until a new stand is established. If all other factors are held constant, the atmosphere will experience an increase in CO_2 concentration merely because the carbon dioxide once removed from the atmosphere by forest carbon sequestration at the site of harvest no longer occurs. FS measures this indirect emission. Measuring FS is a standard technique for evaluating the carbon emissions of land conversion, including conversion of natural forests to short rotation biofuel crops. Consideration of foregone emissions and the loss of associated economic benefits are also consistent with federal guidelines for economic analysis, which require use of a "with and without" framework. In particular, for an analysis of a proposed federal action, including a federal logging project, the guidelines require consideration of the stream of sequestration benefits that would have occurred in its absence.

Research has demonstrated that in multiple North American forest regions where even-aged (clearcut) techniques prevail, sequestration capacity is eliminated for an extended period after harvest. That period varies, and in Southeastern forests, can be as little as 3 years and as many as 15. In particular, net ecosystem productivity (NEP)—sequestration by young seedlings and brush minus emissions from decay and combustion of logging residuals—is actually negative for 3 to 15 years after clearcutting, meaning that these lands are not only carbon sequestration dead zones but net emissions sources. In Oregon, Turner et al. (2004) found that this period was about 13 years across western Oregon, where plantation logging practices were most heavily concentrated. We adopt that 13-year placeholder here pending more detailed information from North Carolina. As such, for each acre clearcut, FS is simply the pre-harvest sequestration value multiplied by 13.

[15] Air Resources Board. 2014. Staff Report: Initial Statement of Reasons for Proposed Rulemaking. Appendix I, Detailed Analysis for Indirect Land Use Change. Sacramento, CA: California Environmental Protection Agency.

[16] Circular A-4 requires an analytical framework of with and without. Regulatory actions should be evaluated "by determining the net benefits of the proposed regulation with and without it." Circular A-4, Section E(3).

[17] Johnsen, K.H., Leyser, T.L, Butnor, J.R., Gonzalez-Benecke, C.A., Kaczmaret, D.J., Maier, C.A., McCarthy, H.R., Ge Sun, 2014. Productivity and Carbon Sequestration of Forests in the Southern United States, Chapter 8 in: Climate change adaption and mitigation management options: A guide for natural resource managers in Southern forest ecosystems CRC Press - Taylor and Francis (pp. 193–248) 56 p.

[16] Turner, D.P., Guzy, M., Lefsky, M.A., Ritts, W.D., Van Tuyl, S., Law, B.E., 2004. Monitoring forest carbon sequestration with remote sensing and carbon cycle monitoring. *Environmental Management* 33(4): 457–466.

North Carolinians rally for forest protections in Charlotte, NC.

There are multiple sources of information about pre-harvest sequestration rates in North Carolina, but the most accessible is the FIA data itself. The FIA data accessed via EVALIDator provides estimates of CO_2 accumulated by forests in each ecoregion via growth as well as what is lost through natural decay and disturbance processes. For each ecoregion, subtracting the latter from the former provides a good way to estimate the carbon sequestration rates actually achieved by unlogged stands and, thus, is a basis for estimating FS.

The FIA data suggest sequestration rates that range from a low of 2.88 tons CO_2-e per acre per year (2.88 tCO_2-e/ac/yr) for forests in the Blue Ridge Mountain ecoregion to a high of 4.87 tCO_2-e/ac/yr in the Mid Atlantic Coastal Flatwood ecoregion. A weighted average of these values based on ecoregion-specific REM figures (to ensure that the sequestration value is calibrated to where timber harvest activities are concentrated) yields a statewide figure of 4.49 tCO_2-e/ac/yr that can be used as a basis for estimating FS. Total FS associated with a typical clearcut unit in North Carolina is therefore 4.49 x 13 or, 58.37 tCO_2-e per acre.

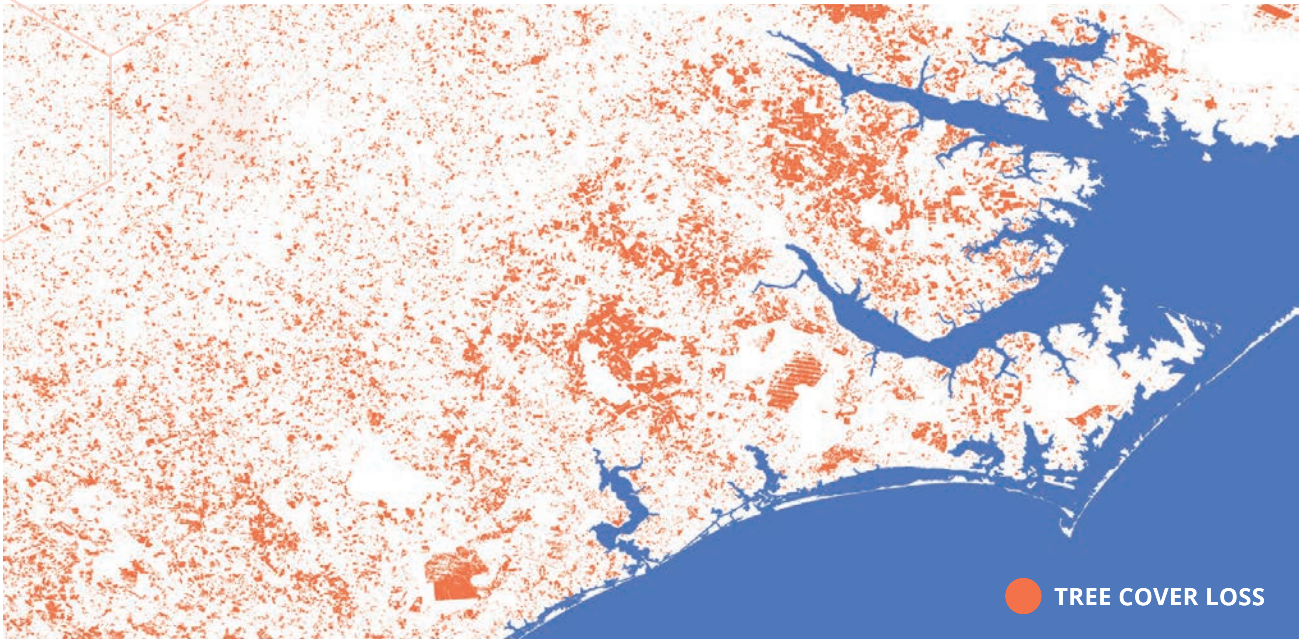
The final step in calculating FS is to multiply the annual acres clearcut each year by 13 and then by this statewide weighted average sequestration rate. Satellite data can be used to estimate the amount of land clearcut each year. World Resources Institute's Global Forest Watch project (GFW) provides a convenient and easy to access tool to do this. It measures forest cover loss and gain annually and allows users to select the canopy closure thresholds particular to the forest type they are analyzing. GFW data suggest an annual average rate of clearcutting of 231,357 acres during the 2000–2018 time frame. However, some of this is due to clearing for agriculture and urban development as well as storms and other natural disturbances. The latest FIA report for North Carolina (2015) estimates this figure to be 201,700 per year for final timber harvests, and so we adopt this as a more conservative figure that nets out non-timber harvest related sources of forest cover loss.

[19] Global Forest Watch interactive map and analysis tools are available online at: www.globalforestwatch.org.

[20] Brown, M.J., Vogt, J.T., North Carolina's Forests, 2013. Knoxville, TN: USDA Forest Service, Southern Research Station, FIA Research Work Unit.

FIGURE 4

SEQUESTRATION DEAD ZONES 2018, EASTERN NORTH CAROLINA



Areas in orange were clearcut within the last 13 years and emit more carbon than they sequester.

Hansen, M.C. et al. (2013) High-resolution global maps of 21st-century forest cover change. Science 342, 850–853.

Multiplying this by the statewide weighted per acre forgone sequestration value implies an FS figure of at least 11.77 MMT CO_2-e/yr. This value is conservative because it does not account for loss of sequestration for any other type of harvest unit other than clearcutting, even though thinning or selective harvesting also reduces sequestration at a site, albeit in a less dramatic fashion. Either way, tracking and mapping the amount of land that has been cleared over the past 13 years or so provides a rough indication of the extent of carbon sequestration dead zones that can be illustrated with use of the GFW platform (Figure 4). If we assume that the FIA final harvest estimate (201,700 acres per year) is about right, then it suggests that the current extent of these carbon sequestration dead zones is over 2.6 million acres.

Decay and combustion of logging residuals (DR)

As noted above, recently clearcut lands are net emissions sources, not sinks, for an extended period after harvest, largely as a result of the decay of logging residuals—slash, stumps, wasted logs, and dead roots—as well as their combustion when burned. NEP data can be used to estimate these emissions. For this analysis, we compiled post-logging NEP data from a variety of sources in different North American settings. For example, in Oregon, Turner et al. (2004) estimated post-logging emissions (indicated by a negative NEP value) to average -2.1 tCO_2/ac/yr for a 13-year period in Western Oregon. Grant et al. (2007) modeled post-harvest NEP at three sites in British Columbia to average about -9.2 tCO_2/ac/yr, also over a 13-year period.[22] Summarizing post-harvest NEP measured in several Southern US sites, Johnsen et al. (2014) indicated values as low as -30 tCO_2/ac/yr in a few years after logging that quickly reverted to rather high levels of net sequestration (> 11 tCO_2/ac/yr) in fertilized pine plantations but with far less recovery for unfertilized stands.

[21] Turner et al., 2004, note 18.

[22] Grant, R.F., Black, T.A., Humphreys, E.R., Morgenstern, K., 2007. Changes in net ecosystem productivity with forest age following clearcutting of a coastal Douglas-fir forest: testing a mathematical model with eddy covariance measurements along a forest chronosequence. *Tree Physiology* 27: 115-131.

Since the Johnsen et al. (2014) data are most relevant for North Carolina, we used this general NEP scenario (significant emissions for a few years transitioning into rapid sequestration after eight years) as a basis for a post-harvest NEP placeholder for this analysis. This is a conservative approach since it assumes that all acres logged in a given year are replanted with fast growing, fertilized plantations that maximize their growth. Averaged over 13 years, the data suggest a value of about -2.5 tCO_2/ac/yr. Multiplying this by the current acreage of carbon sequestration dead zones (2.6 million acres) yields a value of 6.56 MMT CO_2-e as an estimate of emissions associated with the decay and combustion of logging residuals in North Carolina each year.

Emissions associated with forest fertilizers

Timber plantations throughout North Carolina are routinely sprayed with a variety of herbicides, pesticides, and fertilizers to maximize their growth. Each of these chemicals has a carbon footprint that can be calculated on a life cycle basis. Unfortunately, data about the volume and types of chemicals applied are not easily accessible. One exception is forest fertilizers, such as urea. Data published by North Carolina's Forest Service suggest that each year, about 128,000 acres are treated with nitrogen and phosphorous fertilizers with application rates at about 225 pounds per acre.[23]

The carbon footprint of these applications includes all of the energy and materials used to produce the fertilizers and apply them in the field in addition to the gases released by the fertilizers themselves. However, most of these data are not readily available. But one aspect of the carbon footprint that can be estimated is the effect on nitrous oxide (N_2O) emissions—through microbial processes fertilizers generate N_2O, a gas with a global warming potential 300 times stronger than CO_2. Recent estimates of this effect suggest that for every metric ton of fertilizer applied, between 1.75% and 5% of that weight is converted into N_2O emissions. As a placeholder value, we assumed a 3% emissions figure for this analysis.

If approximately 225 pounds are applied per acre per year to an average of 128,000 acres, this implies an annual N_2O emission of about 444 metric tons per year. Multiplying this by 300 converts into 0.13 MMT CO_2-e/yr. While insignificant compared with other sources of logging related GHG emissions, the application of fertilizers to watersheds already overstressed from nutrient pollution has important implications for climate resiliency that will be discussed in Part 2 of this report. Also, it is important to note that this figure does not capture most of the life cycle emissions associated with production and application of fertilizers, nor does it include emissions associated with any of the other forest chemicals routinely used on North Carolina's forestlands. In subsequent updates of this analysis, we expect to include more of these data.

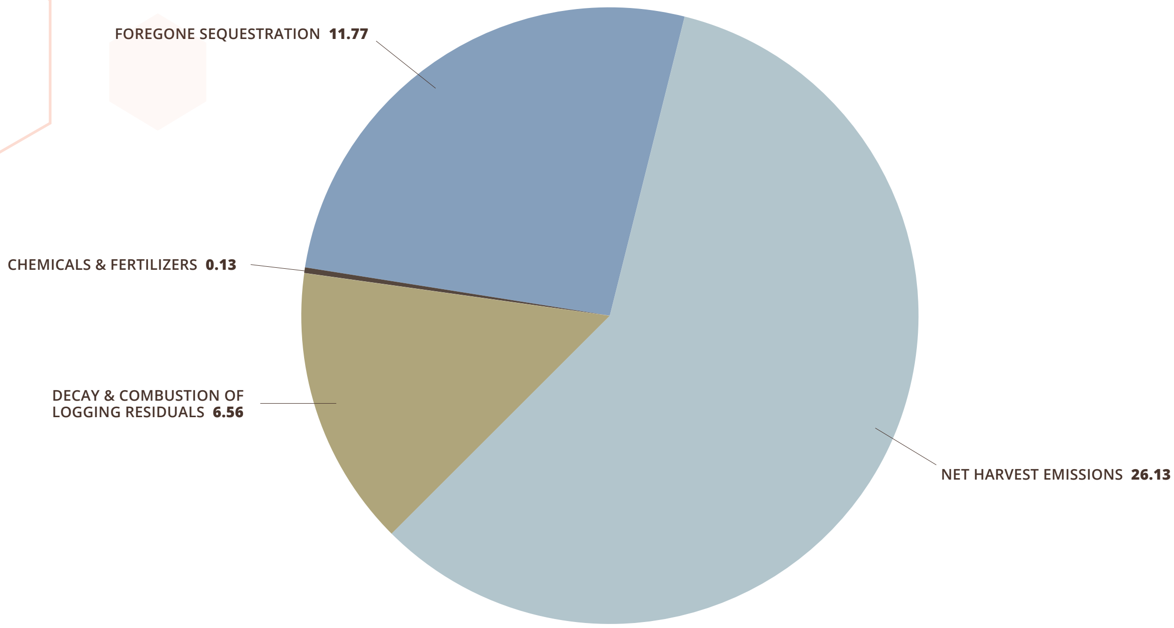
Total emissions related to timber harvest (ETH)

Combining emissions associated with timber harvest removals (REM), storage in long-lived wood products (STOR), foregone sequestration (FS), and decay and combustion of logging residuals (DR) suggest that emissions associated with logging and wood products in North Carolina averaged 44.59 MMT CO_2-e per year between 2000 and 2018 (Figure 5). This is a minimum figure since it includes an optimistic figure (26% for STOR) and only assigns forgone sequestration to a portion of the landscape affected by clearcutting. Putting this figure into perspective, it represents the third largest source of emissions statewide (Figure 6, Figure 7). This aligns well with national level findings. Across the U.S., and just counting REM minus STOR, timber harvest emissions are larger than emissions from the residential and commercial sectors combined.

[23] Pickens, B., 2018. Silvicultural Research in the News. Summary of the Current State of Knowledge of Forest Fertilization in the Southeast. Raleigh, NC: North Carolina Forest Service; North Carolina State University Extension Service, 2011; Using Animal Manures in Forest Fertilization. Publication AG-738. Available online at: https://content.ces.ncsu.edu/using-animal-manures-in-forest-fertilization.

FIGURE 5

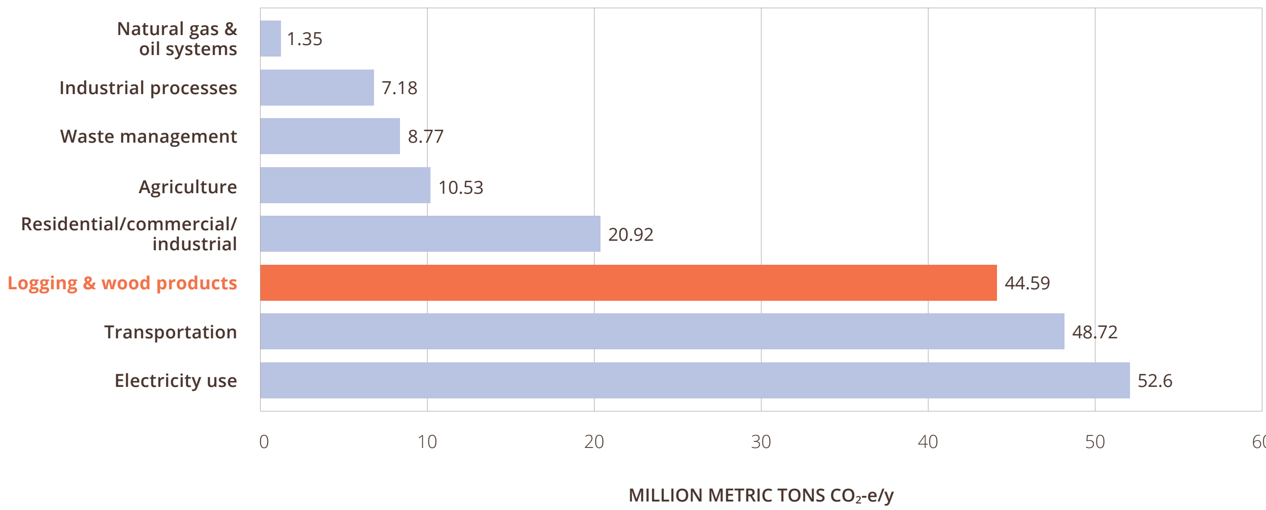
COMPOSITION OF LOGGING AND WOOD PRODUCTS EMISSIONS IN NORTH CAROLINA (ALL VALUES ARE IN MMT CO_2-E PER YEAR)



There are several ways to put this figure into perspective to help communicate the results to the public and decision makers. Since clearcutting is one of the most visible and concerning logging practices in North Carolina, it is useful to quantify the level of emissions associated with a typical clearcut unit. If we assume that all 201,797 acres of final harvest in North Carolina are clearcut units (a figure more or less in line with satellite-based estimates of forest cover loss), it means that logging and wood products related emissions amount to about 222 tons CO_2-e per acre logged. While clearcut unit sizes vary, a typical industrial scale unit is about 180 acres, which translates into about 40,000 metric tons CO_2-e.

FIGURE 6

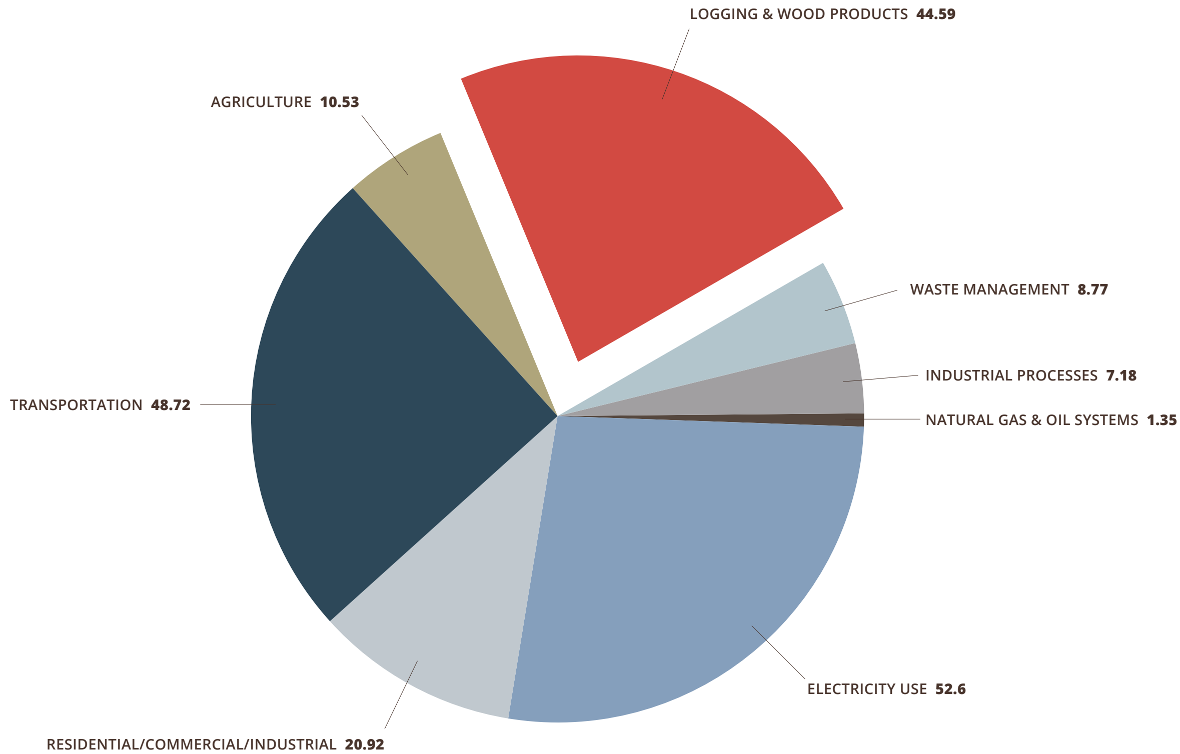
ADJUSTED GHG INVENTORY FOR NORTH CAROLINA: INCLUSION OF LOGGING AND WOOD PRODUCTS EMISSIONS (ALL VALUES ARE IN MMT CO_2-E PER YEAR)



Clearcut logging along the Nottoway River, Northeastern NC.

FIGURE 7

ADJUSTED GHG INVENTORY FOR NORTH CAROLINA: INCLUSION OF LOGGING AND WOOD PRODUCTS EMISSIONS (ALL VALUES ARE IN MMT CO_2-E PER YEAR)



As noted previously, the weight of wood taken from North Carolina's forestlands over the 2000-2018 period averaged about 19 million metric tons. This translates into about 2.34 tons CO_2-e per metric ton removed. Lastly, North Carolina's timber harvest has averaged about 2.5 billion board feet per year. This translates into about 18 tons CO_2-e for every thousand board feet (mbf) harvested. These figures not only help visualize the emissions impact of logging and wood products but are useful in considering regulatory approaches for reducing these emissions, such as a carbon tax levy on each thousand board feet of logging. These options

Clearcut forests have created carbon sequestered dead zones that may currently encompass 2.6 million acres or more.

IMPACT 3

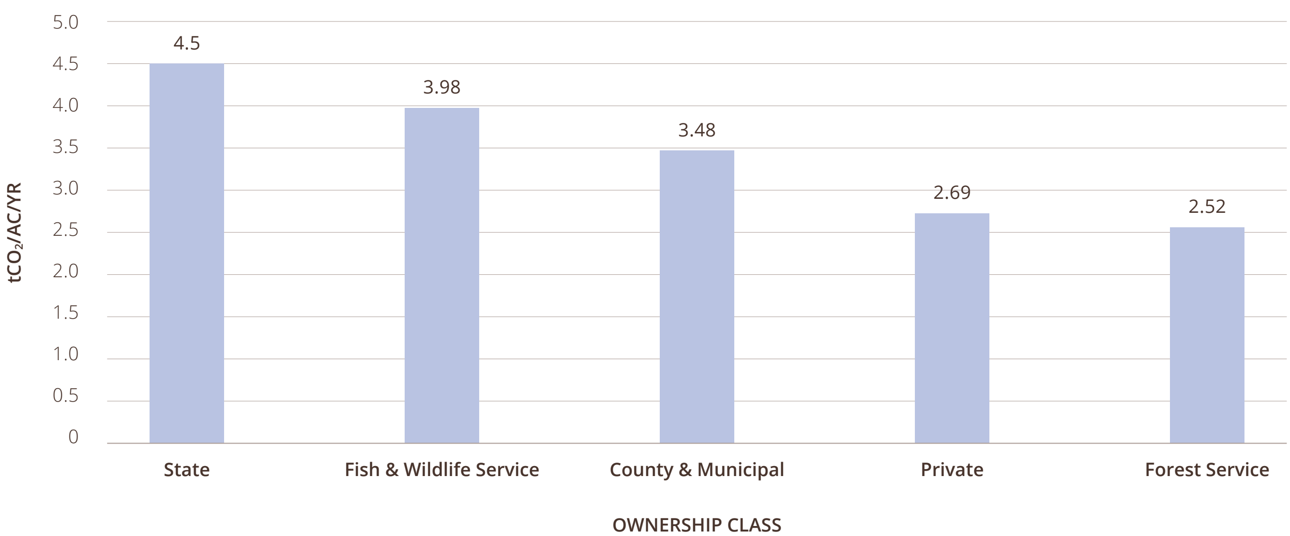
will be discussed in more detail in Part 2 of this report.

LOSS OF CARBON SEQUESTRATION CAPACITY

As discussed above, widespread clearcutting of North Carolina's forestlands has created vast carbon sequestration dead zones that may currently encompass 2.6 million acres or more. This is because each clearcut acre locks in a decade or more (13 years in our analysis) where that site is not functioning as a carbon sink but rather a source of emissions as residual stumps, roots, branches, leaves, and vegetation decays in the drastically altered microclimate left behind after logging. Such carbon sequestration dead zones were not part of nature's baseline conditions and so modern landscapes where industrial forest practices are being implemented are likely sequestering considerably less carbon than before. Some of the FIA data we extracted suggest this.

FIGURE 8

SEQUESTRATION RATES: CENTRAL APPALACHIAN PIEDMONT



For example, Figure 8 displays net carbon sequestration rates (growth minus mortality minus removals and decay of logging residuals) for the Central Appalachian Piedmont ecoregion. The highest sequestration rates are found on state, Fish and Wildlife Service, and County lands while private and Forest Service lands are sequestering the least. On Forest Service lands, it is likely that a high proportion of much older forests exist. While older forests store vastly more carbon than younger forests the annual rate of sequestration naturally declines and so the data may reflect this process. On private lands, however, the reasons are likely due to timber harvest and associated carbon sequestration dead zones that occupy a significant share of the landscape. However, if reforested, these areas can start sequestering carbon again. Depending on the age of the trees that were cut, a landscape can have higher sequestration rates than the forests they have replaced. It all depends on rotation age—the number of years trees are allowed to grow between harvests. At short rotation ages more of the landscape is occupied by carbon sequestration dead zones, which more than offset any sequestration gains associated with managing for younger stands. With long rotations, the extent of dead zones is minimized but there are also fewer younger stands with higher sequestration rates. Table 1 illustrates this tradeoff with data taken from the previous sections.

TABLE 1

NET LANDSCAPE SCALE (10,000 ACRES) SEQUESTRATION BY ROTATION AGE

ROTATION AGE (YRS)	CLEARCUT ACRES/ YEAR	DEAD ZONE ACRES	DEAD ZONE %	DZ EMIT (TCO_2/YR)	RESID NEP (TCO_2/AC)	RESID SEQ (TCO_2/YR)	NET SEQ (TCO_2/YR)
20	500	6,500	65.00%	16,250	7	24,500	8,250
30	333	4,333	43.33%	10,833	6	34,000	23,167
40	250	3,250	32.50%	8,125	5	33,750	25,625
50	200	2,600	26.00%	6,500	5	37,000	30,500
60	167	2,167	21.67%	5,417	5	39,167	33,750
70	143	1,857	18.57%	4,643	4	32,571	27,929
80	125	1,625	16.25%	4,063	4	32,571	29,438
90	111	1,444	14.44%	3,611	4	34,222	30,611
100	100	1,300	13.00%	3,250	3	26,100	22,850
120	83	1,083	10.83%	2,708	3	26,750	24,042

The table presents estimates of net carbon sequestration in tons of CO_2-e per year attainable on a hypothetical North Carolina forested landscape of 10,000 acres with rotation age varying between 20 and 120 years in ten-year increments. For each rotation age, the table displays (1) the number of acres clearcut each year; (2) the resulting extent of carbon sequestration dead zones (assuming again the 13 year negative NEP duration on each acre clearcut); (3) the percent of the landscape occupied by these dead zones; (4) the emissions associated with these dead zones at a rate of 2.5 tons CO_2-e per year as discussed above; (5) an estimate of the sequestration rate (NEP) on residual forests outside dead zones; (6) the amount of CO_2 sequestered by these lands, and, lastly; (7) the net sequestration effect. Estimates of residual NEP were taken from various North Carolina and

nationwide studies, all of which depict a general trend of an initial spike in NEP at a young age, a relative rapid decline from that peak for a while, and then a slower decline at mid to old age.[26]

While the model presented in Table 1 is based on regional averages and is therefore no substitute for analysis of particular tracts with site specific data, the results clearly illustrate the drawbacks of managing the land on increasingly short rotation ages, as is happening in North Carolina. The movement to shorter and shorter rotation ages and more forestlands devoted to short-lived forest products like pellets and pulp results in a lower carbon sequestration capacity. With the assumptions embodied in Table 1, landscape-scale sequestration is maximized at a rotation age of 60 years with a secondary peak around 90 years. Short rotations below 30 years—which is becoming widespread in North Carolina—can be expected to capture about half of what can be achieved at longer rotations.

And while a focus on annual carbon sequestration is useful, the most important policy goal should not be maximizing landscape scale sequestration but rather forest carbon storage on the land.

It is this, ultimately, that will permanently reduce atmospheric CO_2 concentrations back toward the upper limit of 350 parts per million advocated for by the scientific community. Letting forests mature into old growth condition—despite lower sequestration rates—is the key to replenishing these forest carbon stocks. Longer rotation lengths can take us part of the way there, but, ultimately, as long as forests are managed with an eye towards logging (even if once every 90 years), captured carbon will eventually be re-emitted into the atmosphere.

[26] Johnsen et al., 2014, note 17.

The logging and wood products sector in North Carolina is the third most carbon intensive in the state.

CONCLUDING THOUGHTS

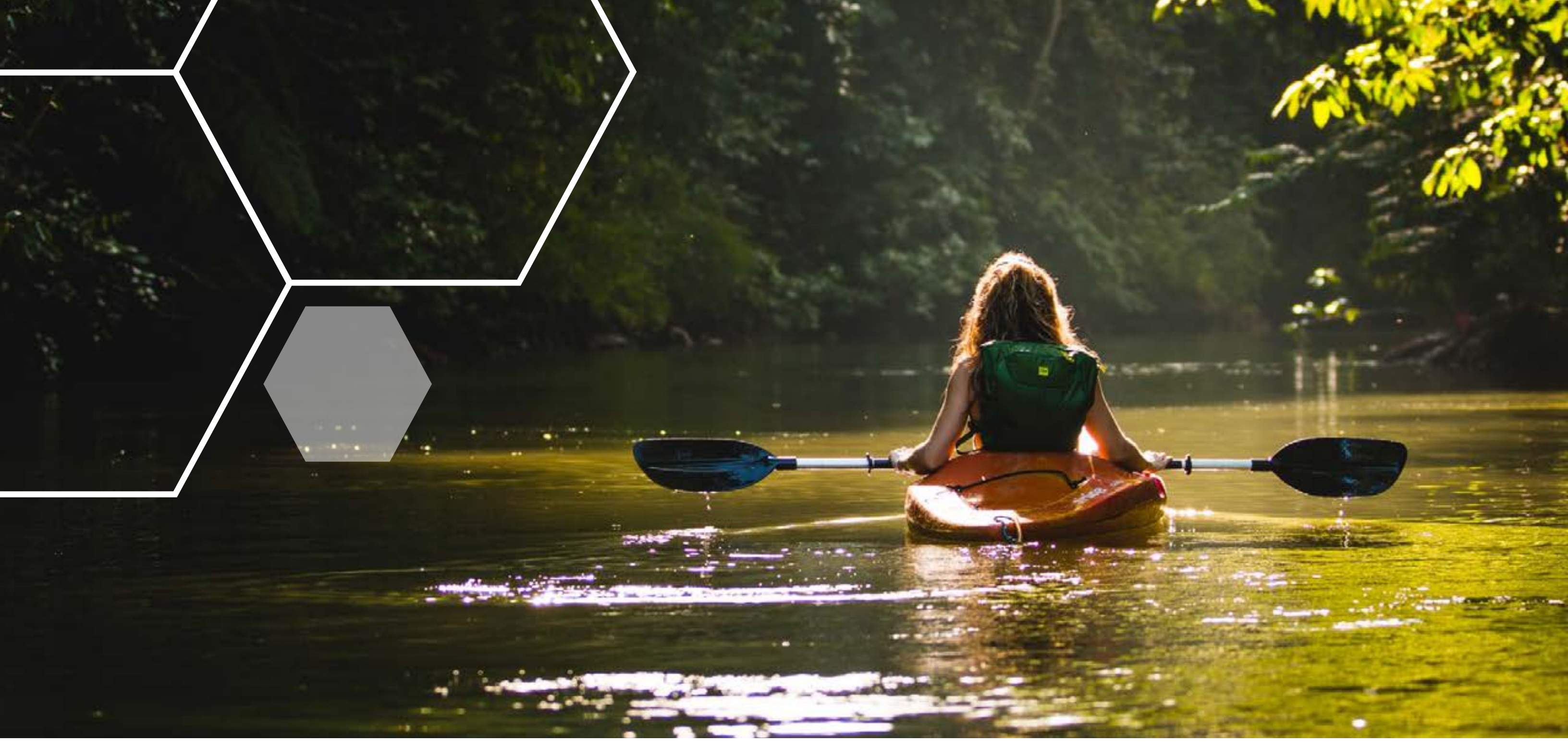
Industrial scale logging and wood products manufacturing in North Carolina are very carbon intensive, yet emissions from this sector are ignored in the state's GHG inventory.

Trees are half carbon by weight. When they are cut and converted into wood products, the vast majority of embodied carbon is released into the atmosphere as CO_2. For short-lived wood products like paper and pellets burned for energy, embodied CO_2 is released within a few short years after logging. For longer-lived wood products, the release is more gradual but nearly complete 100 years after logging due to the natural decay of wood products.

In addition, for ten to fifteen years after a forest is clearcut, the CO_2 released by the decay and burning of logging slash is greater than the CO_2 uptake by newly established trees and vegetation. As such, clearcut lands are not only carbon sequestration dead zones but net emissions sources for long after they are logged. Moreover, since these lands were previously sequestering rather than emitting CO_2, the atmosphere experiences a drop in the amount of CO_2 being taken out each year, which increases atmospheric CO_2 concentrations. This foregone sequestration effect is considered a form of indirect emission under standard GHG protocols but has never been incorporated into emissions inventories for the logging and wood products sector.

Additional logging and wood products related emissions come from the application of fertilizers, pesticides, and herbicides—all of which generate carbon emissions during their manufacture and use and, in the case of fertilizers, can react with the atmosphere or biological processes in the soil to generate nitrous oxide (N_2O), a gas with a warming potential 300 times more powerful than carbon dioxide. Other emissions are associated with the energy used in the manufacturing and transport of logs and wood products, but these emissions are already included in the state's GHG inventory.

This report compiled the best scientific and technical information available on sources of GHG emissions for the logging and wood products sector in North Carolina that are currently excluded from the state's GHG inventory. We estimate these additional annual emissions to exceed 44 million metric tons CO_2 equivalent each year, making this sector the third most carbon intensive in the state, not counting emissions associated with wood products manufacturing and transport. More research is needed to turn these preliminary estimates into a figure that can be folded into North Carolina's annual GHG inventory. As new and more precise information becomes available, this report will be modified to reflect it.



In this report, we have also documented how logging and industrial forest practices have significantly depleted forest carbon stocks and reduced the amount of CO_2 annually sequestered. Mirroring findings from other Eastern forests, we estimate that forest carbon stocks have been depleted by about 50% relative to nature's baseline—a baseline best measured by the carbon densities found in the few remaining tracts of old growth forest. The good news is that if these carbon stocks were replenished through climate smart practices, over 3 billion metric tons of CO_2 can likely be taken out of the atmosphere over the next fifty years—an amount equivalent to 20 years of North Carolina's currently reported GHG emissions. Such practices, like long rotations, will also help boost annual carbon sequestration capacity by greatly reducing the extent of carbon sequestration dead zones.

Policy interventions—such as forest carbon storage targets for industrial forestland owners—can help catalyze the transition to these climate smart alternatives. In Part 2 of this report, we will discuss carbon storage targets as well as other policy options available to decision makers in North Carolina to expedite this transition and help the state simultaneously reduce logging and wood products related emissions, boost forestland carbon storage, increase annual sequestration rates, and make the forested landscape more resilient to climate change.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