Leveraging State Trust Forest Lands

Acceleration of Improved Forest Management to increase forest carbon storage in the United States

December 2021

Contributing Authors:

Kathryn Fernholz and Ashley McFarland, Dovetail Partners

Jennifer Corcoran, PhD, Resource Assessment, Minnesota Department of Natural Resources

Ram Deo, PhD, Resource Assessment, Minnesota Department of Natural Resources

Scott Hillard, PhD, Resource Assessment, Minnesota Department of Natural Resources

Lucas Spaete, MS, Resource Assessment, Minnesota Department of Natural Resources

Chris Wright, PhD, Natural Resources Research Institute, University of Minnesota Duluth

Meredith Cornett, PhD, The Nature Conservancy in MN/ND/SD

Prepared by: Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD

With Support From: This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program.

Table of Contents

Executive Summary

Utilization of Improved Forest Management (IFM)[1] as a Natural Climate Solution (NCS)[2] on school trust lands in Minnesota and other state trust lands in the United States has the potential to substantially increase forest carbon sequestration, incentivized through potential forest carbon revenue. This project charts a course for scalability throughout Minnesota and on forested state trust lands across the US by assessing and piloting affordable and accessible mechanisms to enter the carbon market – including project development, recommended IFM practices, and favorable policy recommendations. Over 10 million acres of forested state trust lands exist nationwide across fifteen states.[3] The deliverables generated through this project are important for forest land managers, researchers, and decision makers at multiple entry points, for scaling up and transferring the methods elsewhere, and for providing a critical baseline for measuring outcomes of future projects.

This project engaged a diverse team of experts that examined the potential for a forest carbon project on school trust lands of Minnesota and evaluated opportunities in other states with trust land responsibilities. The objective was to conduct a Forest Carbon Opportunity Assessment by modeling the total live forest carbon stock across Minnesota's forests and then identify up to three potential project areas on School Trust Land. An estimated scale of approximately 20,000 acres each for future project development was considered in the design of the assessment. The strategies developed and knowledge gained through this project have potential for replication on forested state trust lands throughout the US, recognizing potential policy or regulatory barriers that may exist within each state. The project included an assessment of opportunities within the additional states with state trust lands and an examination of ecosystem services markets, beyond carbon sequestration, to open the door to additional conservation finance opportunities that can support IFM and accelerate NCS strategies (see Appendices B and C for additional information).

Three *Total Forest Carbon Stock Model* methods were tested, representing scenarios of available data known as "Bronze", "Silver", and "Gold". The comparison of these three model methods, and reproducing them over time, provides foundational information about the importance of the source and quality of data used to model live Total Forest Carbon Stock. For this project, Total Forest Carbon Stock included live aboveground carbon and live belowground carbon estimates. The two estimates were added together for a total live forest carbon estimate. See the model development section of the report and Appendix A for additional information. This project specifically focused on the Intergovernmental Panel on Climate Change (IPCC) carbon pools 1 and 2: live aboveground and belowground biomass, and these pools are considered most susceptible to management and policy decisions, which require more accurate modeling and frequent monitoring.

[1]Forest carbon offset projects based on IFM involve land management activities that increase or at a minimum maintain the current level of carbon stocking.

[2]"Natural climate solutions" (NCS) include at least 20 defined conservation, restoration, and/or improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands. For more information, see: Bronson W. Griscom, et al. Proceedings of the National Academy of Sciences Oct 2017, 114 (44) 11645-11650; DOI:10.1073/pnas.1710465114. Available at: https://www.pnas.org/content/114/44/11645

[3]Overall, there are 515 million acres of state trust lands, many of which are not forested.

The application of the Silver model to forest lands in Minnesota resulted in an estimate of total forest carbon stock ranges from 0 to 38 US tons per acre, with an average of 12.7 US tons per acre, adding up to an estimated total of over 1.2 million US tons of total forest carbon statewide across all Minnesota School Trust Lands. Within Minnesota, approximately 2,513,562 acres are managed on behalf Minnesota's school trust beneficiaries – over 850,000 students in K-12 public schools.[4] The project also identified and evaluated three specific potential project areas across a total of approximately 145,000 acres of school trust lands. The evaluation of these three potential project areas in the state (referred to as Leech Lake, Aitkin Area, and the North Shore near Finland, MN) resulted in the identification of a variety of potential IFM strategies, including opportunities for forest thinning, underplanting, and wildlife habitat enhancements, among other possibilities.

This project also set out to apply the strategies developed for the Minnesota opportunity assessment across nine additional states (Colorado, Idaho, Montana, North Dakota, Oregon, Utah, Washington, Wisconsin, and Wyoming) with expressed interest in carbon market opportunities on trust lands by identifying the potential for enhanced forest carbon storage through IFM. Across each of the states analyzed, there was a range of data available for running the Bronze, Silver, or Gold level forest carbon stock models. The evaluation shows that Silver level forest carbon stock models are likely achievable nationwide. Amongst the states we collaborated with on this project, the only states without data resources to consider them at the Gold level were the states with comparatively lower acreage of forest land (North Dakota and Utah). All of the other states in this project are at, or very near to, the Gold model level.

The policy analysis aspects of the project were limited, but we found that the climate policy environment varies across the ten states included in the scope of the project. At least seven of the states have a State Climate Action Plan and six are members of the US Climate Alliance. Carbon pricing is only established in one of the states (Washington) and two states (Minnesota and Oregon) have statutes enabling State Trust Lands to participate in carbon markets.

A final aspect of the project was our analysis of opportunities to market multiple ecosystem services on school trust lands in Minnesota and other state trust lands. Overall, we recommend that ecosystem services criteria be used to conduct a strategic assessment of state trust lands to identify the best and most marketable opportunities for multiple ecosystem services payments.

Through this project, many subject matter experts, land managers and others engaged in in-depth conversations about the state of carbon and ecosystem markets today, spatial data inputs and the importance of quality, the practical capacity to increase forest carbon stocks on the landscape, and on-the-ground projects that are already underway. The discussions included potential workflows to forest carbon project selection under the current planning frameworks. It is recommended that these discussions continue after the completion of this project, bringing in field foresters and other practitioners particularly when working at the forest stand scale. Deeper dives at the stand level will be needed on potential future projects as well as further exploration of the policy context.

[4]For additional information, see: MNDNR, https://www.dnr.state.mn.us and the Minnesota Office of School Trust Lands, https://mn.gov/school-trust-lands/

Project Overview

Utilization of Improved Forest Management (IFM)[5] as a Natural Climate Solution (NCS)[6] on school trust lands in Minnesota and other state trust lands in the United States has the potential to substantially increase forest carbon sequestration, incentivized through potential forest carbon revenue. This project charts a course for scalability throughout Minnesota and on forested state trust lands across the US by assessing and piloting affordable and accessible mechanisms to enter the carbon market – including project development, recommended IFM practices, and favorable policy recommendations. Over 10 million acres of forested state trust lands exist nationwide across fifteen states.[7] The information produced in this project is important for forest land managers, researchers, and decision makers at multiple entry points, for scaling up and transferring the methods elsewhere, and for providing a critical baseline for measuring outcomes of future projects.

Congress awarded trust lands to states upon their entrance into the Union (1858 for Minnesota). Revenue from managing these lands through harvests are deposited into trust funds that support state-level public institutions, primarily public schools. Entering the carbon market to generate additional revenue for forested school trust lands is increasingly viewed as consistent with the trust responsibility in Minnesota and other places and provides an unprecedented opportunity for IFM to enhance forest resilience and increase forest carbon sequestration.

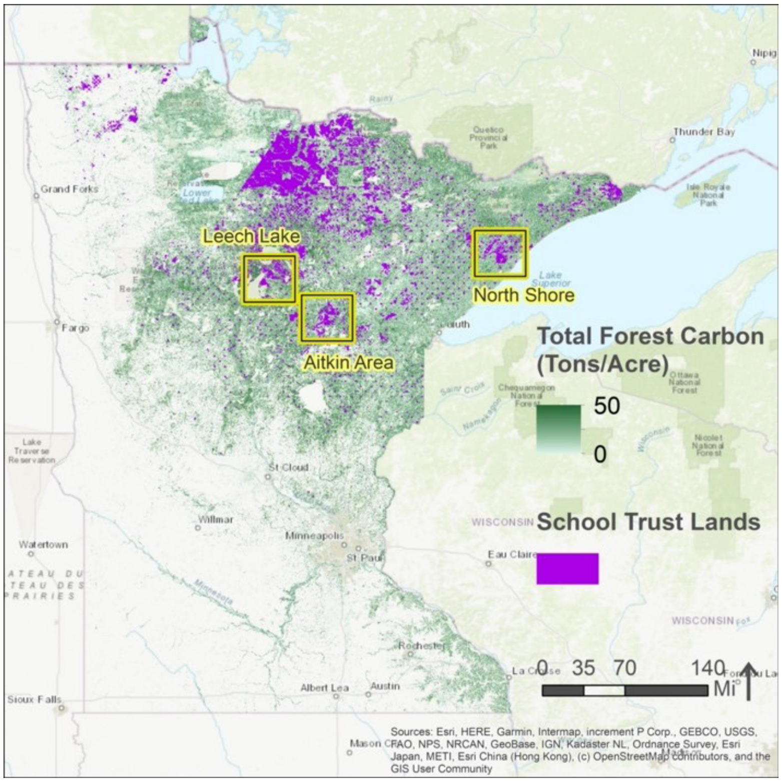


Figure 1. Extent of School Trust Lands in Minnesota shown in fuchsia, with estimates of total forest carbon shown in shades of green with values ranging from 0-50 US tons of carbon per acre. Yellow boxes highlight three potential project areas and are shown in greater detail in Figures 3-11.

This project engaged a diverse team of experts that examined the potential for forest carbon projects on school trust lands of Minnesota (Figure 1) and evaluated opportunities in other states with trust land responsibilities. The objective was to conduct a Forest Carbon Opportunity Assessment by modeling the total live forest carbon stock across Minnesota's forests and then focus on potential projects on School Trust Land at the scale of approximately 20,000 acres each for future project development. The strategies developed and knowledge gained through this process have potential for replication on state trust lands throughout the US, recognizing potential policy or regulatory barriers that may exist within each state. The project also included an assessment of opportunities within the additional states with state trust lands and an examination of ecosystem services markets, beyond carbon sequestration, to open the door to additional conservation finance opportunities that can support IFM and accelerate NCS strategies.

---

[5]Forest carbon offset projects based on IFM involve land management activities that increase or at a minimum maintain the current level of carbon stocking.

[6]"Natural climate solutions" (NCS) include at least 20 defined conservation, restoration, and/or improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands. For more information, see: Bronson W. Griscom, et al. Proceedings of the National Academy of Sciences Oct 2017, 114 (44) 11645-11650; DOI:10.1073/pnas.1710465114. Available at: https://www.pnas.org/content/114/44/11645

[7]Overall, there are 515 million acres of state trust lands, many of which are not forested.

Forest Carbon Stock Modeling and Opportunity Assessment

An initial task for the project was the development of a forest carbon stock model and approach to support the opportunity assessment, including an initial statewide assessment of Minnesota School Trust Lands utilizing the best available data.

What went into model development?

Three sources of forest inventory field data were used for the model development:

- Forest Inventory and Analysis (FIA) fuzzed plot locations,[8]
- FIA true plot locations, and
- Minnesota Department of Natural Resources (MNDNR) Plot Based Inventory (PBI).

Three *Total Forest Carbon Stock Model* methods were tested, representing scenarios of available data known as “Bronze”, “Silver”, and “Gold”. Plot level data was used with the data from various remotely sensed (RS) data to run each model (Figure 2). These RS layers include: normalized difference vegetation index (NDVI), tasseled cap (e.g., greenness and wetness); and over 40 lidar derived metrics evaluated from both low and high density lidar data (e.g., mean canopy height, 95th percentile of height, standard deviation of height).

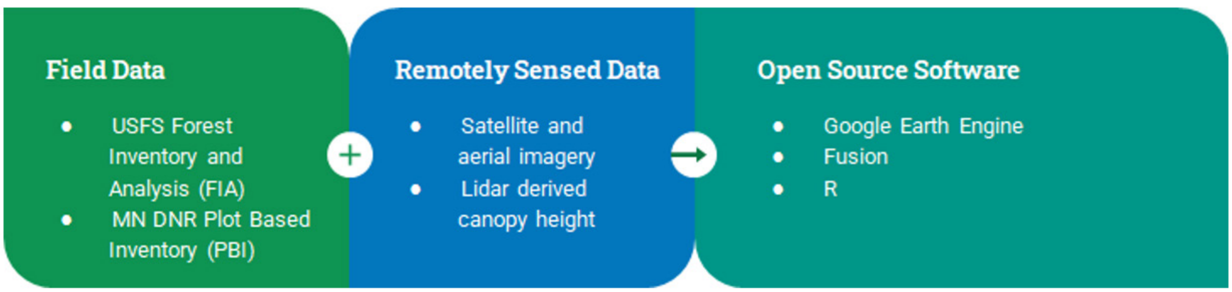


Figure 2. Visual depicting Field Data, Remotely Sensed Data, and open-source software used throughout this opportunity assessment.[9]

How were the models produced?

The data from each model method were evaluated using RandomForest (RF). Through multiple linear regression with selected layers determined by RF, an aboveground biomass (AGB) model was produced. That model was then applied to a 20 m grid across the study area and AGB was converted to live aboveground carbon (US tons per acre). Live belowground carbon was estimated (using guidelines provided by the FIA Program), and the two estimates were added together for a total live forest carbon estimate.

The three RS and field data models tested are representative of common-to-exclusive scenarios of data availability. The simplest model (Bronze) with the most freely available data layers is produced for two timeframes approximately 20 years apart with differences in undisturbed forests representing relative Forest Carbon Stock Accumulation. Comparing these methods aids in our understanding of the relative value of input data quality on forest carbon stock estimation.

[8]For more information, see: Forest Inventory and Analysis National Program, https://www.fia.fs.fed.us and https://www.fia.fs.fed.us/tools-data/spatial/Policy/index.php

[9]For a more in-depth description of model development (Figure 2), see Appendix A.

Breaking down the models

Gold, Silver and Bronze versions of aboveground live forest carbon stock maps are produced by the three model methods. The Bronze model is statewide and produced by using data from fuzzed FIA plot locations with Landsat satellite imagery derived spectral indices. The Silver model is also statewide and produced using known FIA plot locations obtained with a Memorandum of Understanding (MOU) from the USFS, paired with lidar derived height metrics and Landsat satellite derived spectral indices. The Gold model is only available in three pilot locations with new high density lidar (total ~1840 sq. miles or 1,177,582 ac) in Cass and Lake Counties, Minnesota. The Gold model uses ground sample data collected via MNDNR PBI protocol in plots 1/10th acre in size with highly accurate plot centers (horizontal errors of less than a meter).

The Silver model combined a complete cycle of the most recent FIA data collected between 2015-2019, growing season satellite data (overlapping the same years of FIA measurements), and statewide lidar (circa 2007-2012). This temporal mismatch between the field data and statewide lidar presents an important caveat for the Silver model. To overcome this challenge, filtering was applied to select the most stable FIA plots for model training, using only plots with single condition, undisturbed, and at least a 10 year age, excluding plots with zero percent canopy cover, more that 3-m average location error, and above 50 US tons/acre aboveground forest carbon.

The comparison of these three model methods, and reproducing them over time, provides foundational information about the importance of the source and quality of data used to model Total Forest Carbon. The information produced in this project is important for forest land managers, researchers, and decision makers at multiple entry points, for scaling up and transferring the methods elsewhere, and for providing a critical baseline for measuring outcomes of future projects.

Overview of total forest carbon stock model results

The statewide Silver model, using known FIA plot locations, lidar derived height metrics, and spectral indices, was summarized at the pixel and stand scales to get a baseline estimate of Total Forest Carbon Stock. Estimates of total forest carbon stock (US tons per acre) were produced across a 30-meter grid and clipped to areas classified as forest or woody wetlands in the 2016 National Land Cover Dataset (NLCD). The total forest carbon stock per pixel ranges from about 0.4 to 45 US tons per acre, with an average of 14.3 US tons per acre, adding up to an estimated total of over 262 million US tons of total forest carbon statewide across all forested lands. The total forest carbon stock per school trust lands ranges from 0 to 38 US tons per acre, with an average of 12.7 US tons per acre, adding up to an estimated total of over 1.2 million US tons of total forest carbon statewide across all Minnesota School Trust Lands.

For the detailed description of model results, see Appendix A.

Applying the Forest Carbon Opportunity Assessment to Potential Project Areas

Having developed the forest carbon stock model and following the initial statewide assessment of Minnesota School Trust Lands, the next task for the project was to identify and evaluate specific potential project areas within these forested school trust lands.

Overview of management and value of Minnesota School Trust lands

The MNDNR manages a total land portfolio of approximately 5,444,471 acres. Of this total, 4,807,921 acres are considered managed acres, meaning they have some manner of harvest or management activity occurring on them at some point in time. Of these total managed acres, 2,513,562 acres are managed on behalf of the Office of School Trust (hereafter Trust), or approximately 47% of the DNR's total managed forest acres.[10]

Over 1.4 million acres of Minnesota's school trust lands are considered productive forestlands. Of the total Trust acres considered productive forest, 54% are Aspen or Black spruce covertypes, 486,688 and 310,784 acres respectively. Productivity typically excludes the over 800,000 acres of stagnant and offsite forest types, as well as novel forest types not regularly managed for timber (e.g., Norway spruce, Hybrid poplar, Upland larch, Willow, etc.). Over the last 5 years, MNDNR harvested on average, 795,676 cord equivalent volume annually. The Trust contributed on average 392,654 cord equivalent volume or 49.3% of the total. The Trust timber value is generating, on average, $11,769,008 each fiscal year.

Harvests occur, on average, on approximately 15,000 acres of Trust land per year, and namely from productive stands with approximately 43% Aspen, 15% Black spruce, 13.5% Red (Norway) pine cover types, and over a dozen other cover-types contributing about 1-4% each of the remaining total closed sales (e.g., Ash, Tamarack, Northern hardwoods, Birch, Balsam fir). Most of these stands are in even-aged management systems, with some undergoing a mix of management depending on the age and site conditions. For example, Red pine plantations are typically thinned at regular intervals, often every decade until the final harvest and being replanted; Oak forests can have various silvicultural treatments including even-aged management, in some cases, or continuous group selection cuts or thinning.

Overview of forest carbon opportunity assessment

The results of the Silver model, showing total forest carbon (US tons/acre) at the pixel and stand scale, were used to assess conglomerates of stands that could provide potential carbon project areas of at least 20,000 acres in size within three areas of the state with predetermined interest: Leech Lake, Aitkin Area, and the North Shore near Finland, MN (Figure 1, potential project areas depicted with a yellow box and shown zoomed in, Figures 3, 6, and 9). The estimates of total forest carbon are used in two primary ways in the project: 1) as an accurate baseline with known confidence for comparisons to measure project outcomes in the future, and 2) to target potential IFM carbon projects.

The total forest carbon estimate can be used in many ways for targeting IFM project potentials, including aiding in the identification of:

- High forest carbon stock stands that are high in stem density suitable for management to begin conversion to another cover type capable of adapting to a changing climate.
- High forest carbon stock stands that are past their rotation age or are managed as uneven-aged stands suitable for thinning projects or underplanting to increase diversity of age and/or covertype, or to target areas for longer lived species.
- Low forest carbon stock stands suitable for planting, and/or management of short rotation forests to maximize forest carbon sequestration and provide wildlife related benefits.

These are just a few examples of how the total forest carbon estimate can be used to inform targeting potential IFM carbon projects.

[10] For additional information, see: MNDNR, https://www.dnr.state.mn.us and the Minnesota Office of School Trust Lands, https://mn.gov/school-trust-lands/

Internal considerations to prioritizing projects

In addition to utilizing the rich set of model results, geospatial analyses, and other ancillary data layers, discussions with key MNDNR Forestry Division personnel were facilitated. The Resource Assessment (RA) team members in conjunction with the Minnesota Office of School Trust Lands Director, and subject matter experts in the Silviculture, Timber, and Policy and Planning Sections engaged in in-depth conversations about the state of carbon and ecosystem markets today, spatial data inputs, the importance of data quality, the practical capacity to increase forest carbon stock on the landscape, and on the ground projects that are already underway. The discussions included potential workflows to forest carbon project selection under the current planning framework. It is recommended that these discussions continue after the completion of this project, bringing in field foresters particularly when working at the forest stand scale.

Deeper dives at the forest stand level will be needed on all potential future projects. Some considerations made during this project included: if a stand is considered productive or otherwise timber marketable (determined by whether a stand has an associated yield table or not); if a stand is past rotation age (if applicable, NA indicates stands managed via an uneven age system which does not include designation of a rotation age); stand density (stems per acre), and the stand cover type. We also considered whether a stand was on the current MNDNR 10-year Stand Exam Layer (SEL), and if a stand was ever on the current SEL. In addition, we considered the goals and strategies for Management Opportunity Areas (MOA) within the three potential project areas of interest.

Potential project area: Leech Lake

There are approximately 48,000 acres of Trust land across the 1600 stands shown in the zoomed-in area on Figure 3 (see Figure 1 for spatial statewide context), with about 7,500 acres in three Management Opportunity Areas (MOAs).[11] The range of total forest carbon in this area is estimated at 0-35 US tons/ac with an average of 13 US tons/ac on stands with an average size of approximately 30 acres.

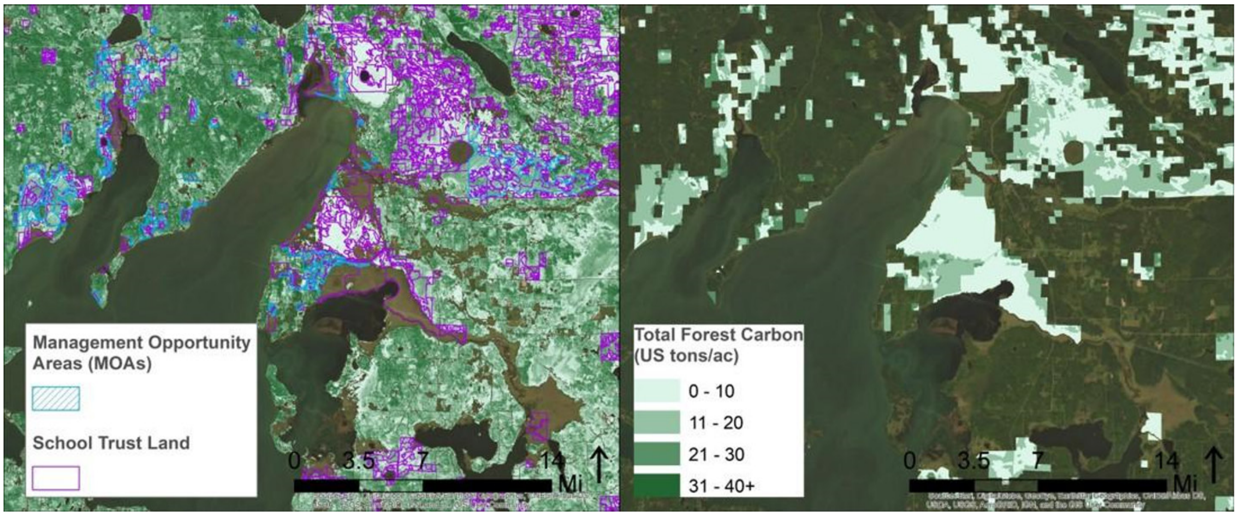


Figure 3. Zoomed-in area in the Leech Lake region of Central Minnesota. See yellow box in Figure 1 for spatial statewide context. On the left, the background depicts the Silver model total forest carbon results, ranging from 0 (light green) to 50 (dark green) US tons per acre. The left map also shows Management Opportunity Areas (MOAs) in hash-marked blue. On the right, the Silver model has been summarized with the average total forest carbon (US tons/acre) at the stand scale.

In this region of Leech Lake, most of the stands are considered productive (about 25,000 acres), and of those acres, the majority (over 14,000 acres) are above rotation age, whereas about 6,000 acres are below rotation age, and 2,100 acres are managed as uneven age forest. Most of the stands are dense with up to 1,750 stems per acre, and the majority of the stands have Aspen, Northern Hardwoods, Tamarack, and other cover types (e.g., Lowland Brush and Marsh lands). The goals of the MOAs in this region are to maintain old forest, lowland conifers, and high conservation value forests, introduce diversity through underplanting, and apply gap cuts.

[11]Management opportunity areas are incorporated into the plan after being reviewed and developed by local interdisciplinary teams and adopted by DNR leadership. Also see: https://www.dnr.state.mn.us/forestry/subsection/process.html

In Figure 4, four additional maps depict this area's relative:

- productivity,
- rotation age status,
- stem density, and
- main cover types.

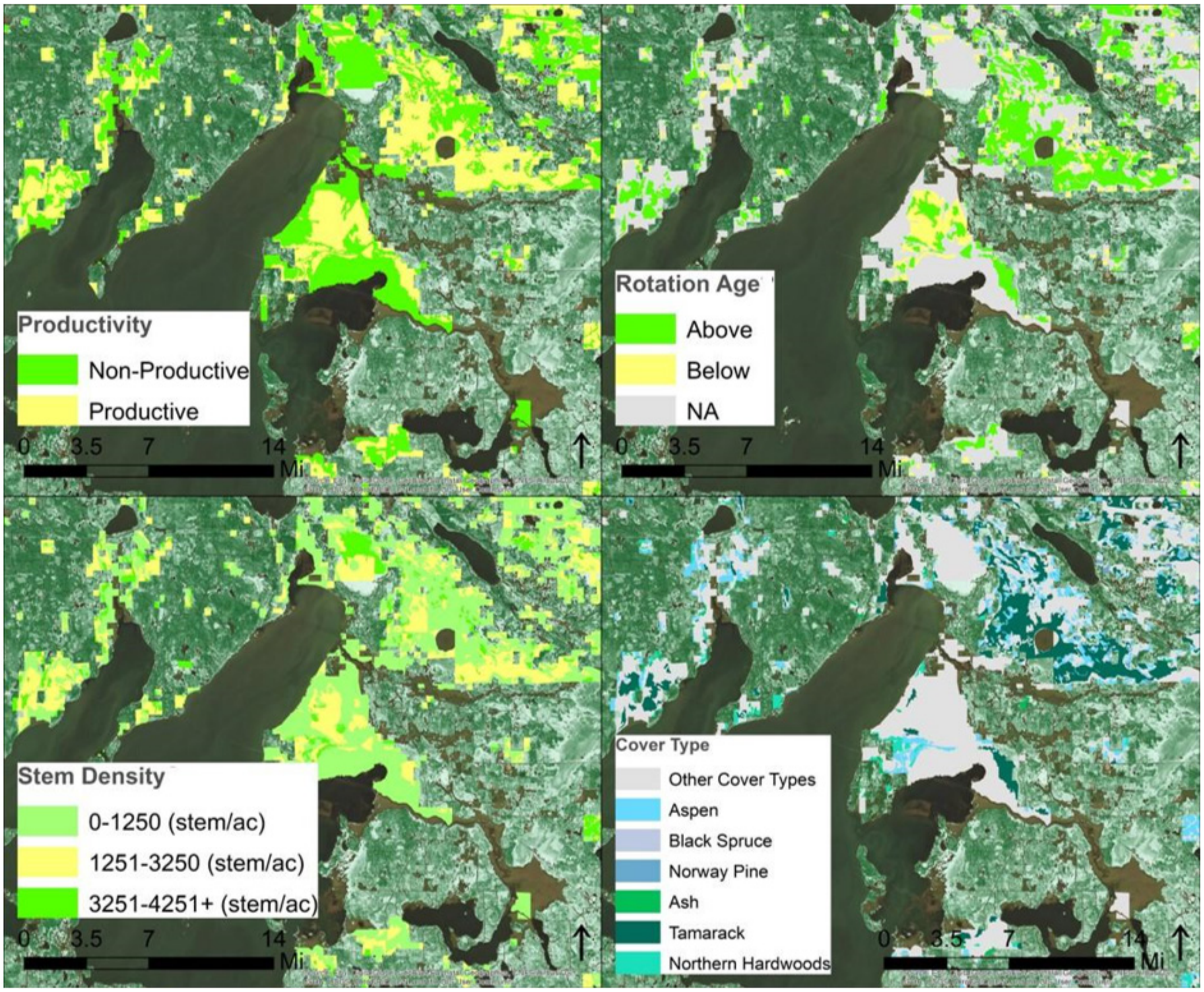


Figure 4. Zoomed-in area in the Leech Lake region of Central Minnesota. See yellow box in Figure 1 for spatial statewide context. On the top left, the relative productivity of the stand (whether or not a stand has a yield table determines its productivity). On the top right, the status of the rotation age of the stand (if applicable, NA indicates stands managed via an uneven age system). On the bottom left, stem density (stems per acre). On the bottom right, main covertypes.

Figure 5 shows four broad categories with varying ranges of current forest carbon stock of stands suitable for potential IFM, including:

- non-productive without associated yield tables (shown in shades of green);
- productive and currently managed as uneven-age forest (shown in shades of blue);
- productive and above rotation age (shown in shades of yellow); and
- productive and below rotation age (shown in shades of orange).

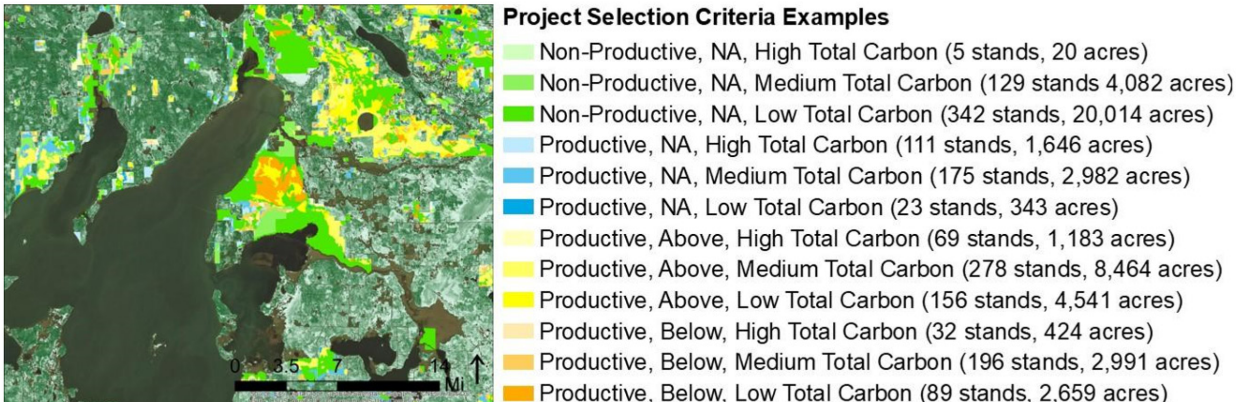


Figure 5. Zoomed-in area in the Leech Lake region of Central Minnesota. See yellow box in Figure 1 for spatial statewide context. The example shows four categories representative of different potential project types with varying ranges of current total forest carbon: 1) non-productive stands all with uneven age management (shown in green hues), 2) productive stands with uneven age management (shown in blue hues), 3) product stands above rotation age (shown in yellow hues), and 4) productive stands below rotation ages (shown in orange hues).

Based on the conditions of the stands and the goals and strategies identified in the associated MOAs of this Leech Lake region, the following IFM strategies are recommended:

- Thinning in stands with high total forest carbon and uneven age management, focusing on non-productive stands
- Underplanting in thinned stands using species expected to adapt well under a changing climate (e.g., hardwoods in the upland areas)
- Underplanting in stands with low total forest carbon, except where being managed as an open landscape
- All harvest activity to be planned to maximize connectivity and avoid edge effects

Potential project area: Aitkin Area

There are about 49,000 acres of Trust land across the approximately 1,300 stands shown in the zoomed-in area on Figure 6 (see Figure 1 for spatial statewide context), with about 30,000 acres in six MOAs. The range of total forest carbon in this area is 0-34 US tons/ac with an average of 15 US ton/ac.

The goals of the MOAs in this region are to maintain open landscapes (primarily managing for owl habitat), early successional forest (shorter rotation), and retain reserves in patches and for providing corridors/edges for bird habitat (some places avoiding conifer and some places encouraging seed trees).

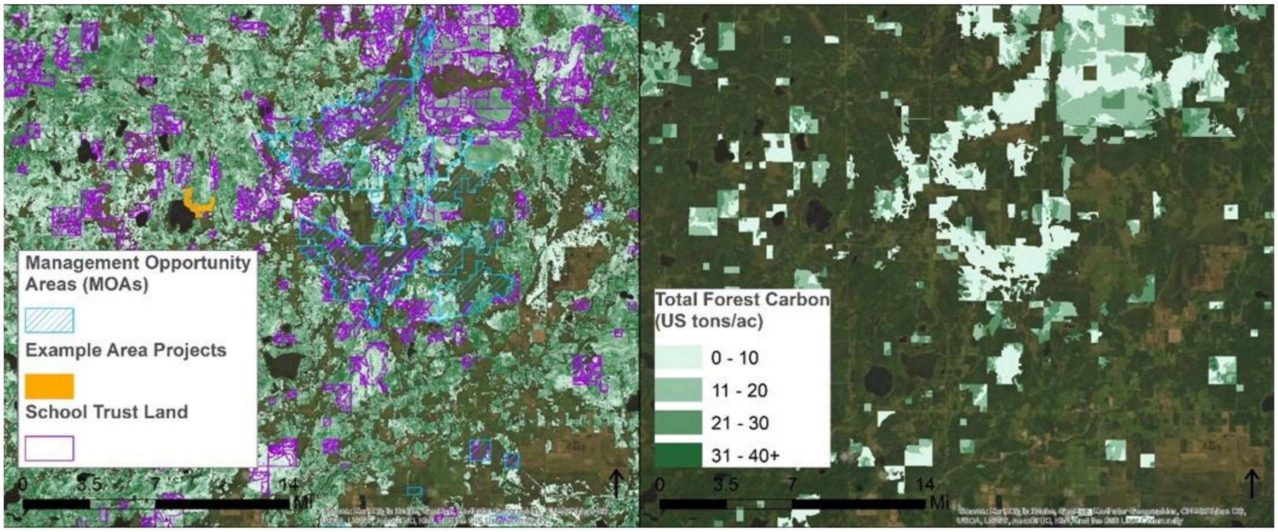
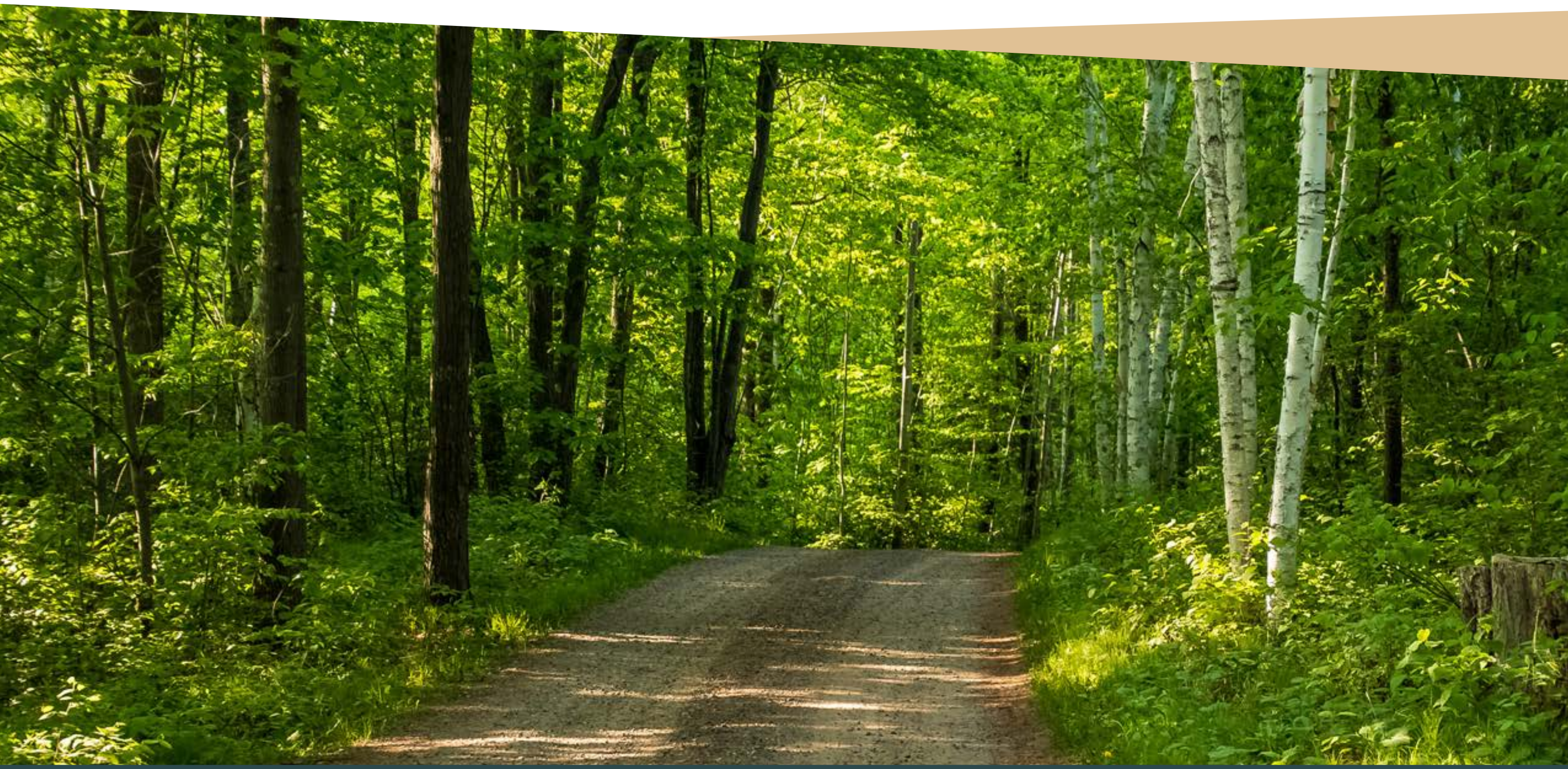


Figure 6. Zoomed-in area in the Aitkin Area of Central Minnesota. See yellow box in Figure 1 for spatial statewide context. On the left, the background depicts the Silver model total forest carbon results, ranging from 0 (light green) to 50 (dark green) US tons per acre. The left map also shows Management Opportunity Areas (MOAs) in hash-marked blue, and a prescribed fire project in orange. On the right, the Silver model has been summarized with the average total forest carbon (US tons/acre) at the stand scale.



In Figure 7, four additional maps depict this area's relative:

- productivity,
- rotation age status,
- stem density, and
- main cover types.

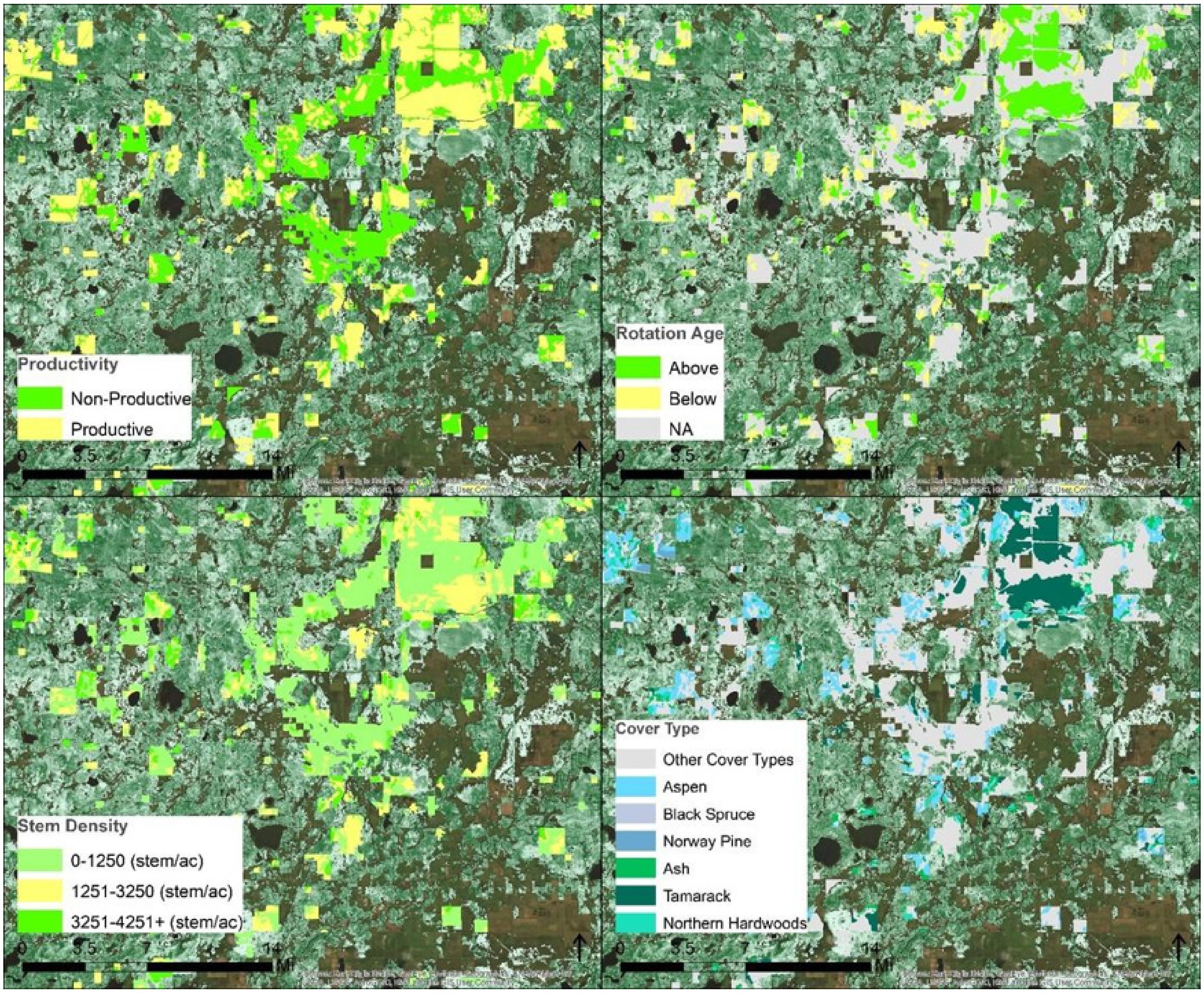


Figure 7. Zoomed-in area in the Aitkin Area of Central Minnesota. See yellow box in Figure 1 for spatial statewide context. On the top left, the relative productivity of the stand (whether or not a stand has a yield table determines its productivity). On the top right, the status of the rotation age of the stand (if applicable, NA indicates stands managed via uneven age system). On the bottom left, stem density (stems per acre). On the bottom right, main covertypes.

In the Aitkin Area (Figure 7), most of the stands are considered productive (about 25,000 acres), and of those acres 40% (about 10,000 acres) are above rotation age, whereas about 8,300 acres are below rotation age and 6,500 acres are managed as uneven age forest. Most of the stands (over 35,000 acres) are dense with up to 1,750 stems per acre, and the majority of the stands have Aspen, Northern Hardwoods, and Tamarack, and other cover types (e.g., Lowland Brush).

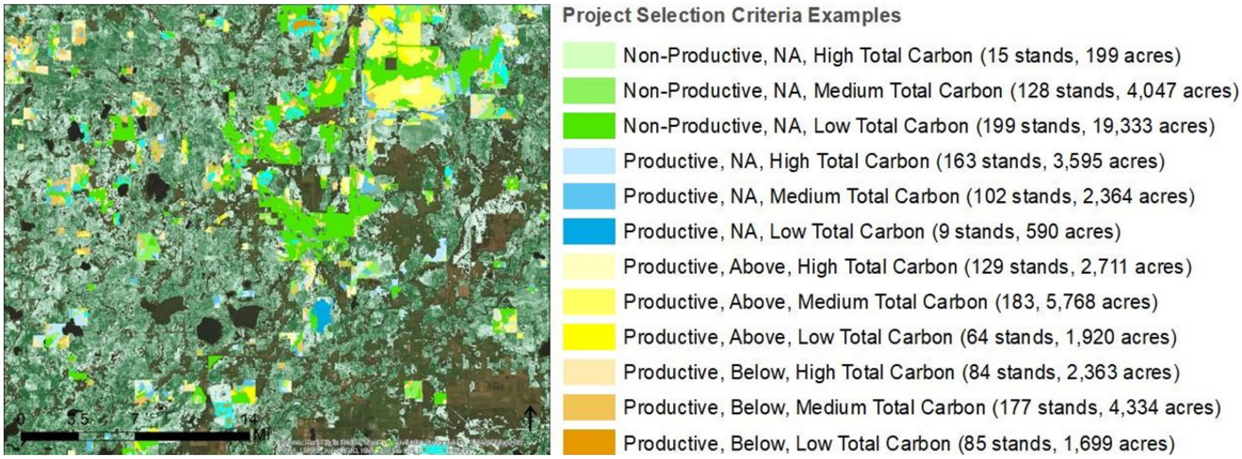


Figure 8. Zoomed-in area in the Aitkin Area of Central Minnesota. See yellow box in Figure 1 for spatial statewide context. The example shows four categories representative of different potential project types with varying ranges of current total forest carbon: 1) non-productive stands all with uneven age management (shown in green hues), 2) productive stands with uneven age management (shown in blue hues), 3) product stands above rotation age (shown in yellow hues), and 4) productive stands below rotation ages (shown in orange hues).

Figure 8 shows four broad categories with varying ranges of current forest carbon stock of stands suitable for potential IFM, including:

- non-productive without associated yield tables (shown in shades of green);
- productive and currently managed as uneven-age forest (shown in shades of blue);
- productive and above rotation age (shown in shades of yellow); and
- productive and below rotation age (shown in shades of orange).

Based on the conditions of the stands and the goals and strategies identified in the associated MOAs of this Aitkin Area, the following IFM strategies are recommended:

- Thinning in stands with high total forest carbon and those over rotation age
- Underplanting short rotation species in thinned, low density stands, or low total forest carbon stands, except where being managed as an open landscape
- Prescribed burning in open landscapes to push back encroachment (see area shown in orange in the left-hand map on Figure 6)
- All harvest activity to be planned to maximize connectivity and avoid edge effects

Potential project area: North Shore

There are about 48,000 acres of Trust land across the approximately 2,200 stands shown in the zoomed-in area on Figure 9 (see Figure 1 for spatial statewide context), with about 43,000 acres in seven MOAs. The range of total forest carbon in this area is 0-31 US tons/ac with an average of 11 US ton/ac on stands with an average size around 21 acres. The goals of the MOAs in this region are to maintain larger patches of older forest, introduce plant and tree species diversity, maintain greater than 50% tree canopy with mixed hardwood and conifer forests, minimize fragmentation, and increase connectivity.

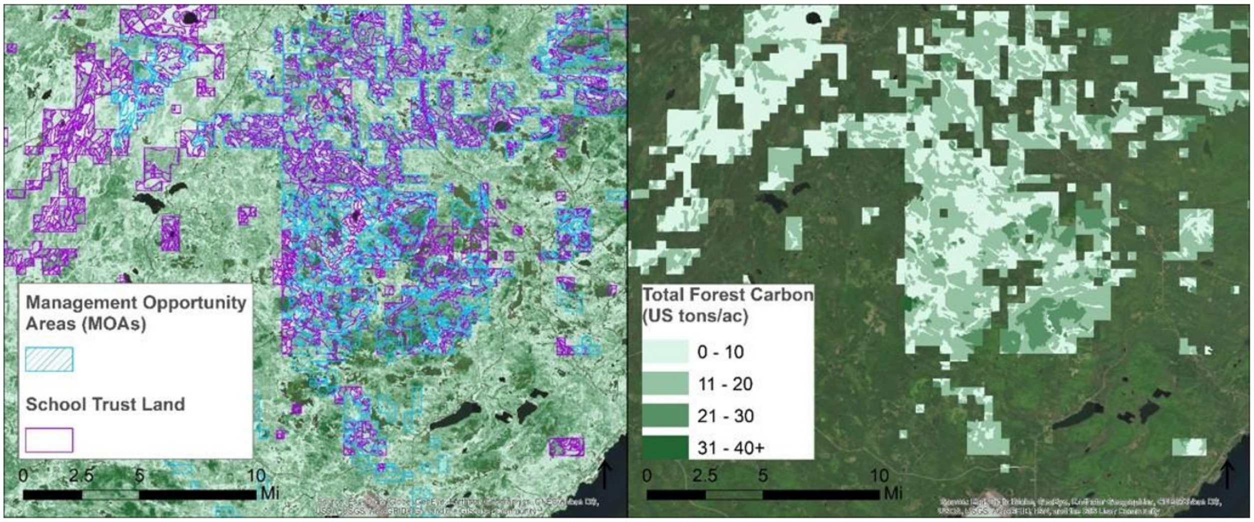


Figure 9. Zoomed-in area on the North Shore in Northeastern Minnesota. See yellow box in Figure 1 for spatial statewide context. On the left, the background depicts the Silver model total forest carbon results, ranging from 0 (light green) to 50 (dark green) US tons per acre. The left map also shows Management Opportunity Areas (MOAs) in hash-marked blue. On the right, the Silver model has been summarized with the average total forest carbon (US tons/acre) at the stand scale.

In this area of the North Shore near Finland, MN (Figure 9), most of the stands are considered productive (about 37,000 acres), and of those acres about 27% (about 10,000 acres) are above rotation age, whereas over 15,000 acres are below rotation age, and 11,000 acres are managed as uneven age forest. Most of the stands (over 31,000 acres) are dense with up to 1,750 stems per acre, and the majority of the stands have Aspen, Balsam fir, and Tamarack, and other cover types (e.g., White Cedar, Lowland Brush).

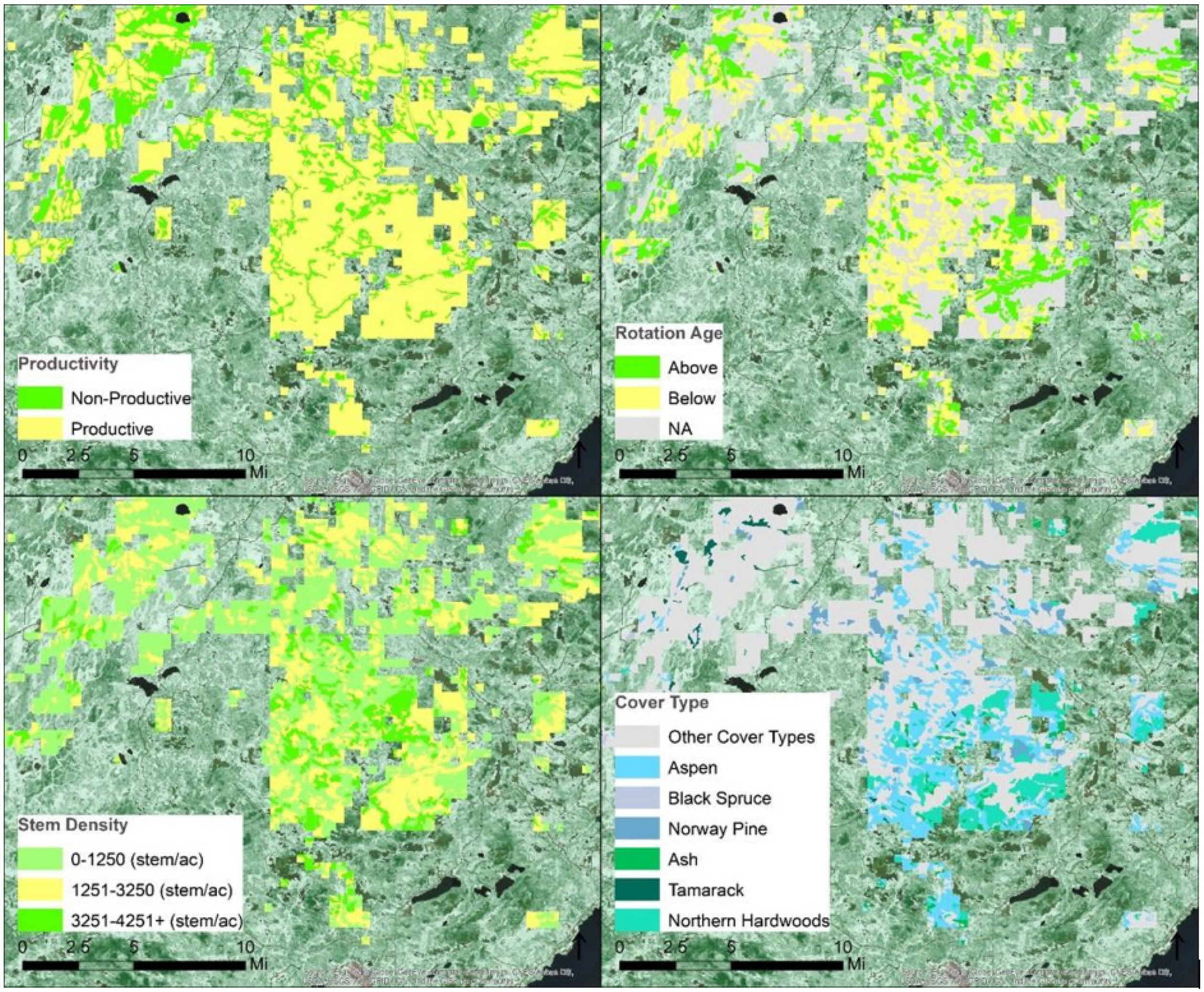


Figure 10. Zoomed-in area on the North Shore in Northeastern Minnesota. See yellow box in Figure 1 for spatial statewide context. On the top left, the relative productivity of the stand (whether or not a stand has a yield table determines its productivity). On the top right, the status of the rotation age of the stand (if applicable, NA indicates stands managed via uneven age system). On the bottom left, stem density (stems per acre). On the bottom right, main covertypes.

In Figure 10, four additional maps depict this area's relative:

- productivity,
- rotation age status,
- stem density, and
- main cover types.

Figure 11 shows four broad categories with varying ranges of current forest carbon stock of stands suitable for potential IFM, including:

- non-productive without associated yield tables (shown in shades of green);
- productive and currently managed as uneven-age forest (shown in shades of blue);
- productive and above rotation age (shown in shades of yellow); and
- productive and below rotation age (shown in shades of orange).

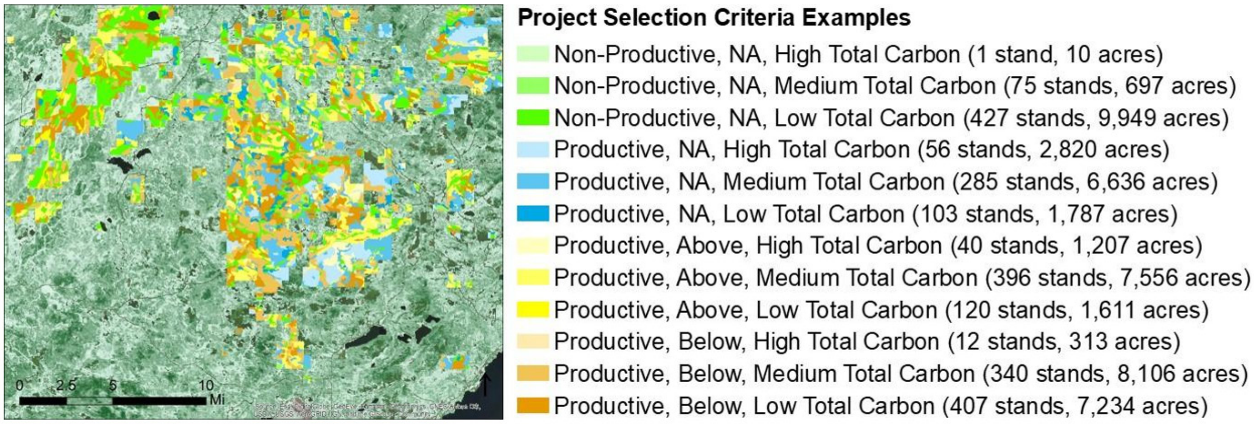


Figure 11. Zoomed-in area on the North Shore in Northeastern Minnesota. See yellow box in Figure 1 for spatial statewide context. The example shows four categories representative of different potential project types with varying ranges of current total forest carbon: 1) non-productive stands all with uneven age management (shown in green hues), 2) productive stands with uneven age management (shown in blue hues), 3) product stands above rotation age (shown in yellow hues), and 4) productive stands below rotation ages (shown in orange hues).

Based on the conditions of the stands and the goals and strategies identified in the associated MOAs of this North Shore region, the following IFM strategies are recommended:

- Thinning in stands with high total forest carbon and uneven age management, focusing on non-productive stands
- Underplanting in thinned stands using species expected to adapt well under a changing climate (e.g., hardwoods in the upland areas)
- Underplanting in stands with low total forest carbon
- All harvest activity to be planned to maximize connectivity and avoid edge effects

Applying the Forest Carbon Opportunity Assessment on Trust Lands Nationwide

Over 10 million acres of forested state trust lands exist nationwide across fifteen states.[12] This project set out to apply the strategies developed for the Minnesota opportunity assessment across nine additional states with expressed interest in carbon market opportunities on trust lands by identifying the potential for enhanced forest carbon storage through IFM (Figure 12). Those states included Colorado, Idaho, Montana, North Dakota, Oregon, Utah, Washington, Wisconsin, and Wyoming.

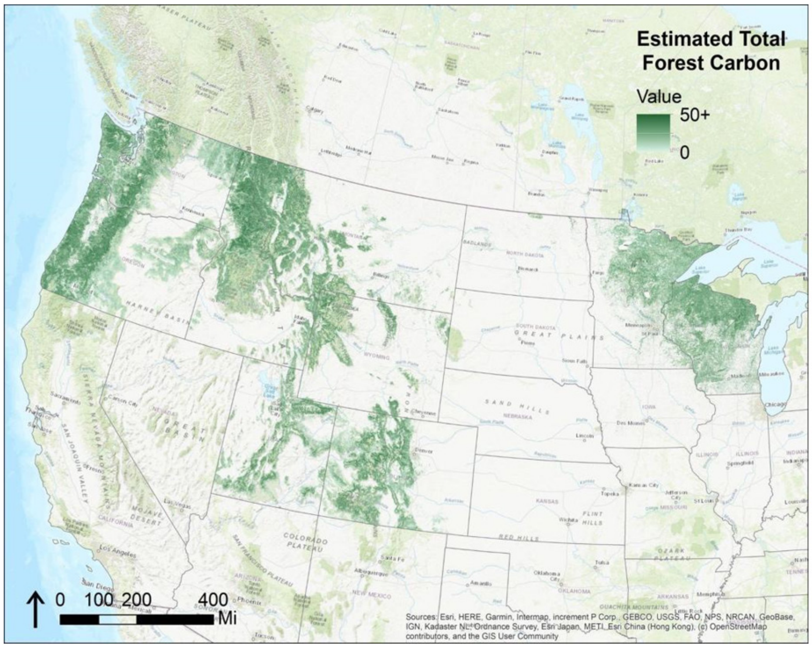


Figure 12. States where Bronze model estimates of total forest carbon stock were produced: Colorado, Idaho, Minnesota, Montana, North Dakota, Oregon, Utah, Washington, Wisconsin, and Wyoming. Each state is shown in shades of green with values ranging from 0-50 US tons of forest carbon per acre. Note: Washington and Oregon have values far exceeding other states, and have ranges from 0-200 US tons/ac.

Our work with these states commenced with an informational webinar hosted by the National Association of State Trust Lands (NASTL) in March 2021 and then in-depth meetings between our project team and relevant contacts within each state where possible. Those meetings set out to understand data availability and limitations to running the various models, a discussion on policy or regulatory barriers or opportunities, and identification of potential forest carbon project areas.

Through development of the forest carbon opportunity assessment models, we determined that the Bronze-level model could be applied to all of the cooperating states to get a baseline estimate of forest carbon stocks and sequestration potential by leveraging FIA data in combination with National Land Cover Dataset (NLCD), Landsat and Sentinel satellite imagery, National Agricultural Imagery Program (NAIP), or other free, high quality remotely sensed data, which is visualized in a Google Earth Engine (GEE). Additional work was done to clip down that assessment to include only forested pixels according to the 2016 NLCD. States were informed about the technology and data needed to run higher levels of the model (Silver, Gold), although program-wide analysis was not conducted in each state.

The results of these state collaborations are outlined in a series of fact sheets (Appendix B) highlighting the forest carbon opportunity, proposed methodology, and policy strategy for adoption. These results were shared with partners in each state and the NASTL.

[12] Overall, there are 515 million acres of state trust lands, many of which are not forested.

Findings across the states

Across each of the states analyzed, there was a range of data available for running the Bronze, Silver, or Gold level forest carbon stock models. Thanks to the US Geological Survey's 3D Elevation Program (3DEP) updated and accurate canopy height metrics from lidar will soon be available nationwide, and with the long-standing FIA program data available as well, the Silver level forest carbon stock models are achievable nationwide. Amongst the states we collaborated with on this project, the only states without data resources to consider them at the Gold level were the states with comparatively lower acreage of forest land (North Dakota and Utah). All of the other states in this project are at, or very near to, the Gold model level.

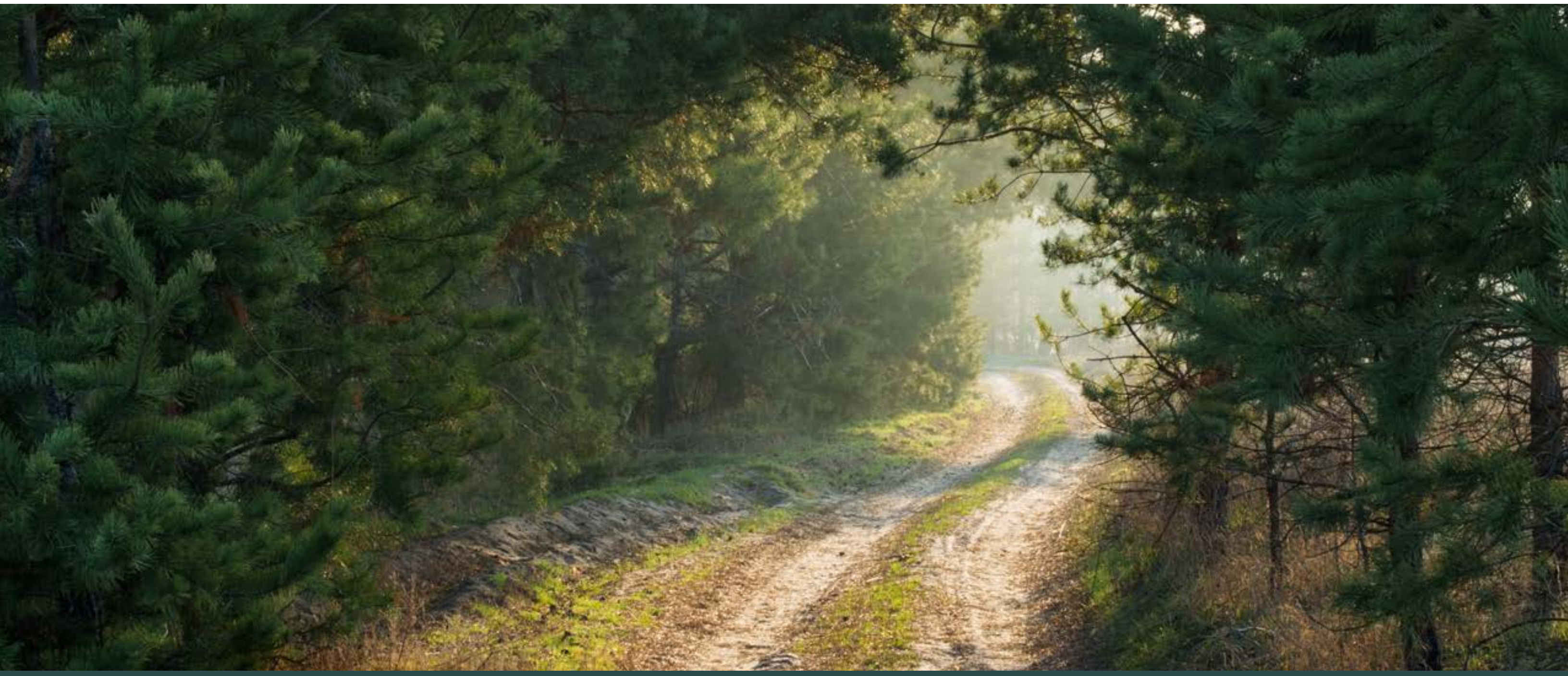
General policy environments and regulatory barriers or opportunities

As shown in Table 1, the climate policy environment varies across the ten states with state trust land responsibilities that were included in the project evaluations. At least seven of the states have a State Climate Action Plan and six are members of the US Climate Alliance. Carbon pricing is only established in one of the states (Washington) and two states (Minnesota and Oregon) have statutes enabling State Trust Lands to participate in carbon markets.[13]

Table 1. Summary of State Climate Policy Environment for 10 States with State Trust Lands

State Policy	CO	ID	MN	MT	ND	OR	UT	WA	WI	WY
Greenhouse Gas Emissions Target? (if yes, "X") (demonstrates consideration of climate change)	X		X	X		X		X		
State Climate Action Plan? (if yes, "X") (demonstrates willingness to take action on climate change)	X		X	X		X	X	X	X	
Member of the US Climate Alliance? (if yes, "X") (includes Natural and Working Lands focus)	X		X			X		X	X	
Carbon Pricing? (if yes, "X")								X		
Are State Trust Lands enabled by statute to participate in carbon markets? (If yes, "X")			X			X				

[13]For additional discussion of market-based state policies and approaches to reduce greenhouse gas emissions, see work completed by the Center for Climate and Energy Solutions (C2ES) that looked at additional US states and regions. Available at: https://www.c2es.org/content/market-based-state-policy/



Exploring additional ecosystem service market opportunities

School trust lands are public lands dating back to statehood that are managed to provide revenue to public schools; typically, through leases (agricultural, commercial, mineral, oil, and gas) and sales (timber, land, rights-of-way). School trust land managers have an opportunity to broaden their revenue portfolios by engaging with ecosystem service markets. Projects offering 'Improved Forest Management' for carbon sequestration and carbon market participation are consistent with various habitat and water quality services, providing an opportunity to 'stack' multiple ecosystem service payments. In our analysis and resulting paper (Appendix C), we discuss opportunities to market multiple ecosystem services on school trust lands in Minnesota and other states. Overall, we recommend that ecosystem services criteria be used to conduct a strategic assessment of school trust lands to identify the best and most marketable opportunities for multiple ecosystem service payments, while acknowledging that these markets change over time.

Conclusion

Utilization of Improved Forest Management (IFM) as a Natural Climate Solution (NCS) on school trust lands in Minnesota and other state trust lands in the US has the potential to substantially increase forest carbon sequestration, incentivized through potential forest carbon revenue. This project charts a course for scalability throughout Minnesota and on forested state trust lands across the US by assessing and piloting affordable and accessible mechanisms to enter the carbon market – including project development, recommended IFM practices, and favorable policy recommendations. Over 10 million acres of forested state trust lands exist nationwide across fifteen states. The deliverables generated through this project are important for forest land managers, researchers, and decision makers at multiple entry points, for scaling up and transferring the methods elsewhere, and for providing a critical baseline for measuring outcomes of future projects.

Appendix A: Methods for Forest Carbon Stock Model Development

Authors: Ram Deo, PhD, and Scott Hillard, PhD

Forest carbon modeling and mapping at the pixel level

Detailed descriptions of models

Gold, Silver and Bronze versions of aboveground and belowground forest carbon maps were produced for this project. The Gold version, dependent on high density lidar, was the most accurate but covered relatively small areas of interest (total ~1,840 sq. miles or 1,177,582 ac) in Cass and Lake Counties (Figure 13). The Silver-A and Bronze models were statewide and dependent on low density lidar and Landsat data, respectively (Table 1 and Table 4). The national forest inventory data with known actual locations of the plots measured by the FIA program of the US Forest Service was integrated with the statewide lidar and Landsat derived spatial predictors to obtain the Silver-A model (i.e., actual/true coordinates of FIA plots were used to link the ground plot measurements of biomass with corresponding remotely sensed data).

The Bronze model was a result of the integration of fuzzed FIA data with Landsat imagery derived spectral indices (i.e., fuzzed/swapped coordinates of FIA plots were used while associating the ground measurements of biomass with corresponding remotely sensed data). The "A" and "B" versions for the Silver and Bronze models (Table 1) are distinguished by the list of spatial predictors used in the models. The Silver-A used both statewide lidar and Landsat variables while Silver-B used only landsat variables, both using true FIA plot locations. Silver-A model was developed based on FIA data measured between 2015-2019, while Silver-B models were developed for two eras representing the FIA cycles between 1999-2003 and 2015-2019. Similarly, the Bronze models were also developed for the same two eras. The forest carbon models were produced for the two eras in order to understand the forest carbon dynamics over the landscape over time. For the Gold models in the three smaller areas of interest, ground sample data were collected via the PBI design of the DNR Resource Assessment Program. The plot centers in PBI were established using Trimble R2 GNSS Receiver that resulted in horizontal errors of less than a meter. FIA program still relies on traditional GPS that often results in plot location inaccuracies of more than 5m (i.e., this is what the Silver model uses).

The Silver-A model combined a complete cycle of the most recent FIA data collected between 2015-2019 with the growing seasons Landsat data (overlapping the same years of FIA measurements) and statewide lidar that was previously acquired over a five-year window from 2007-2012. This temporal mismatch between the field data and statewide lidar resulted in a caveat for the Silver-A model, hence we applied filtering to select FIA plots for model training. We selected single condition, undisturbed FIA plots that represent stands of at least 10 years age. We also excluded any FIA plots that contained zero percent canopy cover, more that 3-m average location error, and above 50 US tons/acre aboveground forest carbon.

A data sharing agreement between the RA and FIA programs has facilitated access to the actual plot locations measured in the past three consecutive cycles up until 2019 (5,557 FIA plots). The FIA plots (phase-2) consist of four circular sub-plots each of 7.31-m (24-foot) radius where every tree of five inch and larger diameter at breast height (DBH) are measured for diameter, total height, crown dimensions, age and other qualities including site index. The sub-plots are separated 120-foot apart with one central and three peripherals located at 3600, 1200 and 2400 azimuths, respectively. The FIA program has maintained double intensity sampling design in Minnesota where each FIA plot is representative of about 3,000 acres of land area.

The PBI sample data were collected in the summers of 2017, 2018, and 2019 using one-tenth acre circular plots that were distributed in a systematic grid design in the high-density single photon lidar AOI in Cass County and the linear lidar AOI in Lake County, but in a random design in the single photon lidar AOI in the Lake County. The PBI plot distribution represented one plot for approximately 1,100 acre of land area. Altogether 581 sample plots were established and measured in the three high-density lidar AOIs. The sample tree attributes for the PBI plots were measured following the standard FIA protocols and the same FIA methodology was used to calculate tree-level aboveground and belowground biomass and carbon. The tree-level carbon values were summed-up to get the total plot-level forest carbon on a per acre basis.

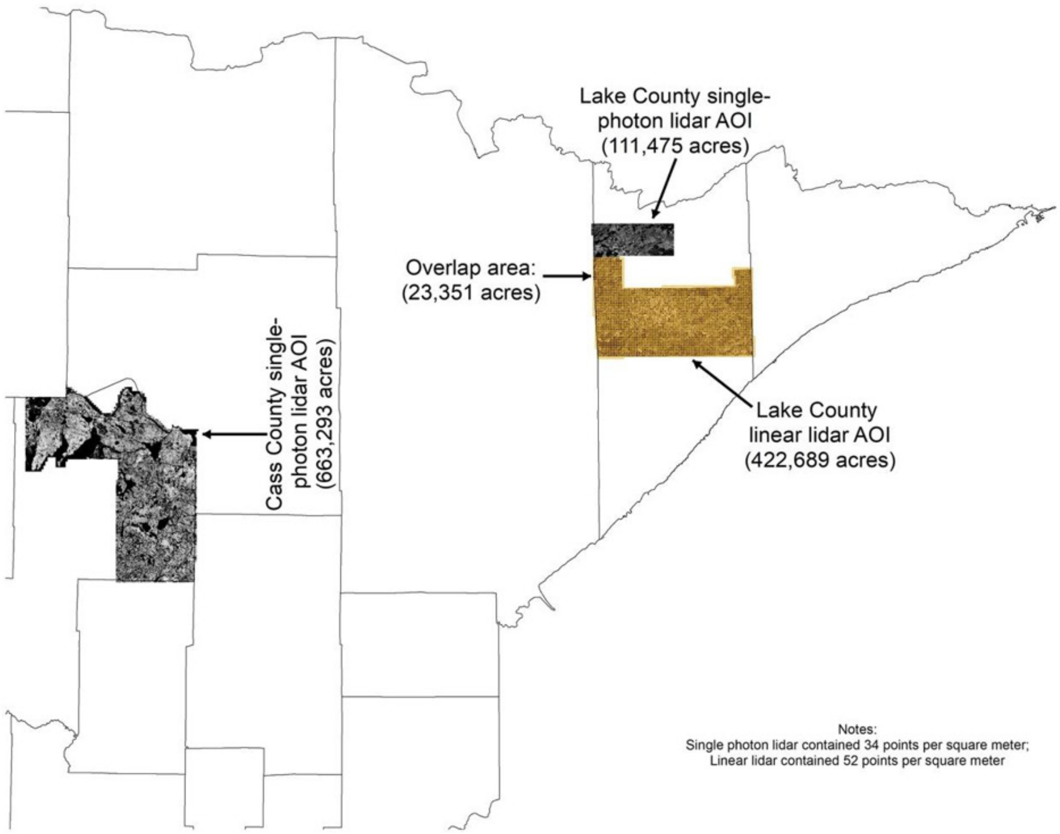


Figure 13. High-density lidar acquisition areas in Cass and Lake Counties of Minnesota.

Table 1. Details of the Gold, Silver and Bronze models

Model	AOI	Input RS data	No. of plots	Plot data type
Gold (2017)	Cass-SPL	High density single photon lidar	333	PBI
Gold- (2017)	Lake-SPL	High density single photon lidar	81	PBI
Gold (2018)	Lake-Linear	High density linear lidar	152	PBI
Silver-A (2015-19)	Statewide	Low density lidar-2011, Landsat predictors	1457	True FIA coordinates
Silver-B (2015-19)	Statewide	Several Landsat predictors	1451	True FIA coordinates
Silver-B (1999-03)	Statewide	Several Landsat predictors	1343	True FIA coordinates
Bronze-A (2015-19)	Statewide	Landsat predictors as in Silver-B	1456	Fuzzed FIA coordinates
Bronze-A (1999-03)	Statewide	Landsat predictors as in Silver-B	1456	Fuzzed FIA coordinates
Bronze-B (2015-19)	Statewide	Only significant Landsat predictors	1346	Fuzzed FIA coordinates
Bronze-B (1999-03)	Statewide	Only significant Landsat predictors	1346	Fuzzed FIA coordinates

Remotely sensed data processing

The high-density single photon and linear lidar data, acquired in the falls of 2017 and 2018, possessed density of about 32 and 52 points per square meter, respectively. The low-density statewide lidar was acquired over a window of five years between 2007 and 2012 that contained 1 to 1.5 points per square meter. Numerous grids metrics describing elevation distributions, strata density and cover variables were derived at 20-m resolution from all the lidar datasets. See Table 2 for the list of lidar derived predictors.

The Landsat derived spectral predictors included tasseled cap brightness, greenness and wetness indices, NDVI and middle infrared band. These variables were produced in GEE using the LandTrendr tool.

Table 2. List of grid metrics (at 20-m resolution) derived from lidar datasets.

Lidar-derived Grid metrics	Description
CRR	Canopy relief ratio [(mean - min) / (max – min)]
ElevAAD	Average absolute deviation of elevations of all non-ground returns per 20-m cell
ElevAv	Average of elevations of all non-ground returns per 20-m cell
ElevCM	Cubic mean of elevations of all non-ground returns per 20-m cell
ElevCV	Coefficient of variation of elevations of all non-ground returns per 20-m cell
ElevIQ	Interquartile range of elevations of all non-ground returns per 20-m cell
ElevKurt	Kurtosis of elevations of all non-ground returns per 20-m cell
ElevMADmed	Median of the absolute deviations from the overall median of elevations per 20-m cell
ElevMADmod	Median of the absolute deviations from the overall mode of elevations per 20-m cell
ElevMax	Maximum of elevations of elevations of all non-ground returns per 20-m cell
ElevMode	Mode of elevations of all non-ground returns per 20-m cell
ElevP50	50th percentile of elevations of all non-ground returns per 20-m cell
ElevP90	90th percentile of elevations of all non-ground returns per 20-m cell
ElevP95	95th percentile of elevations of all non-ground returns per 20-m cell
ElevP99	99th percentile of elevations of all non-ground returns per 20-m cell
ElevQM	Quadratic mean of elevations of all non-ground returns per 20-m cell
ElevSD	Standard deviation of elevations of all non-ground returns per 20-m cell
ElevSkew	Skewness of elevations of elevations of all non-ground returns per 20-m cell
ElevVar	Variance of elevations of elevations of all non-ground returns per 20-m cell
Perc_Cover	Percent of all returns above 3m (i.e., all returns above 3m * 100/ total count of all re-turns); this is a proxy for canopy cover

Stratum1	Proportion of total returns in the vertical interval from ground to 1.37m aboveground per 20-m cell
Stratum2	Proportion of total returns in the vertical interval from 1.37 to 5m aboveground per 20-m cell
Stratum3	Proportion of total returns in the vertical interval from 5 to 10m aboveground per 20-m cell
Stratum4	Proportion of total returns in the vertical interval from 10 to 15m aboveground per 20-m cell
Stratum5	Proportion of total returns in the vertical interval from 15 to 20m aboveground per 20-m cell

Model development

The plot-level forest carbon (US tons/acre) values were linked to the co-located lidar and Landsat variables and reference data frames were obtained separately for aboveground carbon (AGC) and belowground carbon (BGC). We created three data frames to model aboveground and belowground carbon, one each for Gold (Table 3), Silver (Table 4), and Bronze (Table 5). The modeling steps included pruning of collinear predictors using random forest-based model selection algorithm followed by backward-forward stepwise regression methods. After identifying the significant predictor variables, either random forest or linear regression models were used to spatially predict the forest carbon estimates across the landscape. The Gold version aboveground carbon prediction/mapping was based on linear regression model and all other prediction were based on random forest model. The Gold version of aboveground carbon was produced using linear regression method long before the inception of this project, so we simply utilized the previously done output in this research. Our analysis has revealed that stand-level forest carbon estimated based on random forest and linear regression are similar.

Table 3. Selected predictors and fit statistics of the RF based Gold models

Model	Number of plots used in RF modeling	Predictors selected in RF models	%Variance explained by RF model	RMSE of RF model (US tons/ac)
Cass-SPL 2017AGC	333	ElevMax, Stratum1, Stratum5, Stratum6	66.39	428.46
Cass-SPL 2017BGC	333	ElevMax, Stratum1, Stratum5, Stratum6	60.14	74.86
Lake-SPL 2017 AGC	81	ElevMax, ElevIQ, Stratum4	58.65	299.34
Lake-SPL 2017BGC	81	ElevMax, ElevIQ, Stratum4	59.68	47.69
Lake-Linear 2018AGC	152	ElevMax, ElevMean, Stratum5	63.86	147.85
Lake-Linear 2018BGC	152	ElevMax, ElevMean, Stratum5	64.65	29.63

Table 4. Selected predictors and fit statistics of the RF based Silver models

Model	Number of plots used in RF modeling	Predictors selected in RF models	%Variance explained by RF model	RMSE of RF model (US tons/ac)
SilverA-2015-2019 AGC	1457	Stratum4, El-evAv, ElevSkew, ElevCV, NIR2015, TCW2016	57.37	260.09
SilverA-2015-2019 BGC	1457	Stratum4, ElevAv, ElevSkew, ElevCV, NIR15, TCW16	58.23	53.43
SilverB-1999-2003 AGC	1343	NDVI1999, TCA1999, TCB1999, TCB2003, TCW1999	30.87	393.63
SilverB-1999-2003 BGC	1343	NDVI1999, TCA1999, TCB1999, TCB2003, TCW1999	31.07	80.02
SilverB-2015-2019 AGC	1451	NIR2015, NDVI2015, TCB2016, TCG2019, TCW2016, TCW2017, TCW2018, TCW2019	20.79	354.36
SilverB-2015-2019 BGC	1451	NIR2015, NDVI2015, TCB2016, TCG2019, TCW2016, TCW2017, TCW2018, TCW2019	21.85	73.08

Table 5. Selected predictors and fit statistics of the RF based Bronze models

Model	Number of plots used in RF modeling	Predictors selected in RF models	%Variance explained by RF model	RMSE of RF model (US tons/ac)
AGC (1999-2003)	1346	TCB, TCW, TCA, TCG, NDVI	3.29	465.97
BGC (1999-2003)	1346	TCB, TCW, TCA, TCG, NDVI	2.11	95.42
AGC (2015-2019)	1456	TCB, TCW, TCA, TCG, NDVI	-4.12	406.50
BGC (2015-2019)	1456	TCB, TCW, TCA, TCG, NDVI	-4.93	84.69

Methods for Stand Level Assessment of Model Results

Attributing stands with error estimates and model for comparisons and evaluation

Stand level estimates of forest live forest carbon (aboveground, belowground, and total live) were developed for each model based on the coverage areas for MN DNR stands that are under a trust status, meaning they are owned by the Office of School Trust, but managed by the DNR for the benefit of the trust.

In total, there are approximately 99,622 stands demarcated by the DNR, that are managed on behalf of the Trust statewide. Two statewide models were evaluated for stand attribution; these are the SilverA and SilverB models. There were 99,586 Trust stands in the SilverA model, and 99,854 stands evaluated in the SilverB model. Three areas of interest (AOI) were used to create the Gold model, including 4,903 trust stands in the Cass-SPL AOI, 339 trust stands in the Lake-SPL AOI, and 1,965 trust stands in the Lake-Linear AOI.

Stand level values were derived through a model assisted approach, where a random forest model was developed for aboveground and belowground live forest carbon, relating inventory estimates measured on forest inventory plots to remote sensing metrics, and then imputed across the landscape based on coverage of the remote sensing data. Using this model assisted approach raster model estimates were developed for the coverage of the remote sensing data. Stand polygons were used to extract mean values using zonal statistics functions in ArcGIS.

This resulted in an average estimate for above and belowground carbon in pounds per acre (lbs/acre) as well as a total forest carbon in US tons for each stand. A confidence interval for each pixel level prediction was estimated using an implementation of the infinitesimal bootstrap method (Wagner et. al. 2014) using the “ranger” package (Wright 2017) in R statistical software (R core team 2021). This produced a standard error in lbs/acre and 90% confidence interval as a percent of the estimated mean of above and belowground carbon in lbs/acre was developed for each pixel, based on the random forest model. This was repeated for all the pixels covered by each of the five models listed above. Average CI for the pixels within each stand were also used for comparison between models.

In addition to estimating stand level values for live forest carbon, model observed versus predicted comparisons were also conducted. Independent data sets were leveraged, which in the case of Gold models were true FIA plots within the respective boundaries of the Gold models. Likewise, Silver models were evaluated within the boundaries of the Gold models, but leveraging PBI plots instead of FIA plots used to build the Silver A&B models. Models were evaluated based on three metrics; the coefficient of variation or R2, root mean square error (RMSE), and mean absolute error (MAE). Above and belowground carbon models could not be compared for the Bronze models, since Bronze models were only developed for total live forest carbon.

Stand level assessment results

Aboveground carbon 90% confidence intervals were approximately, 20-30% lower for the Cass and Lake AOI compared to the Silver A&B models within the same AOI. The linear AOI models showed the greatest difference in CI intervals between the Gold and Silver models, with the average CI for the Gold model attributed stands being 60% lower compared to the Silver models (see Figure 14).

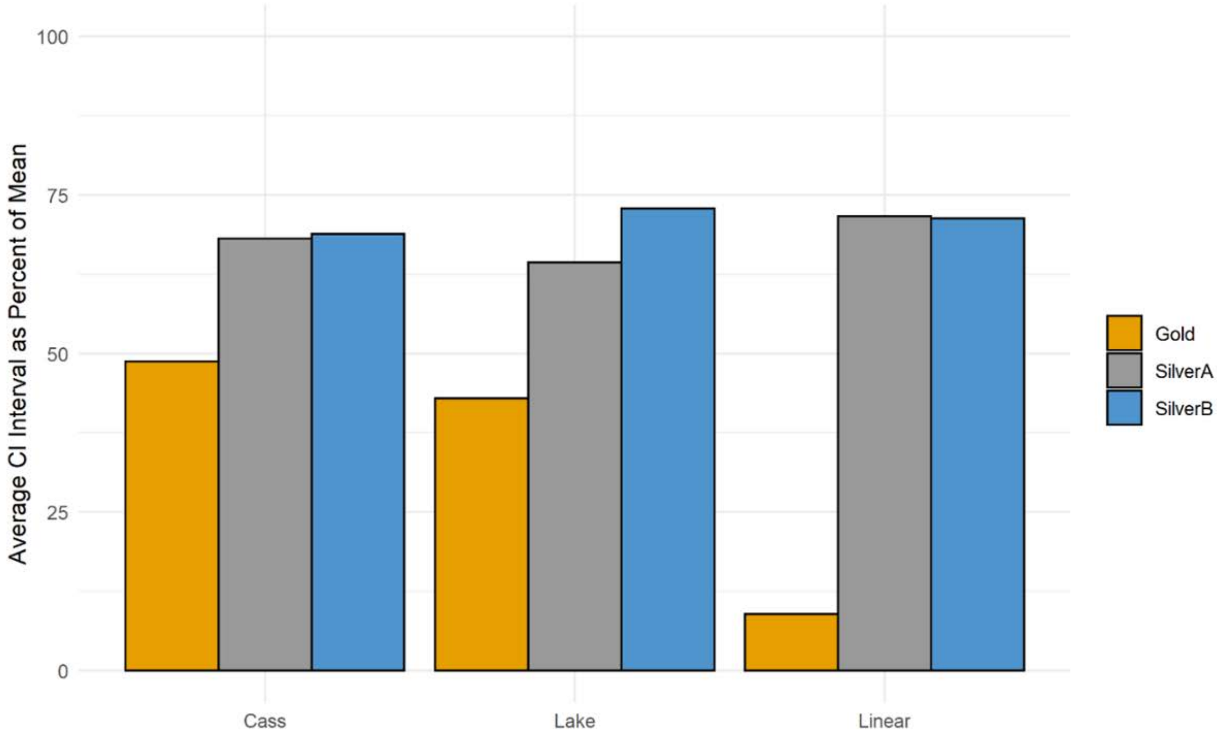


Figure 14. Comparison of Gold to Silver models for each Gold AOI.

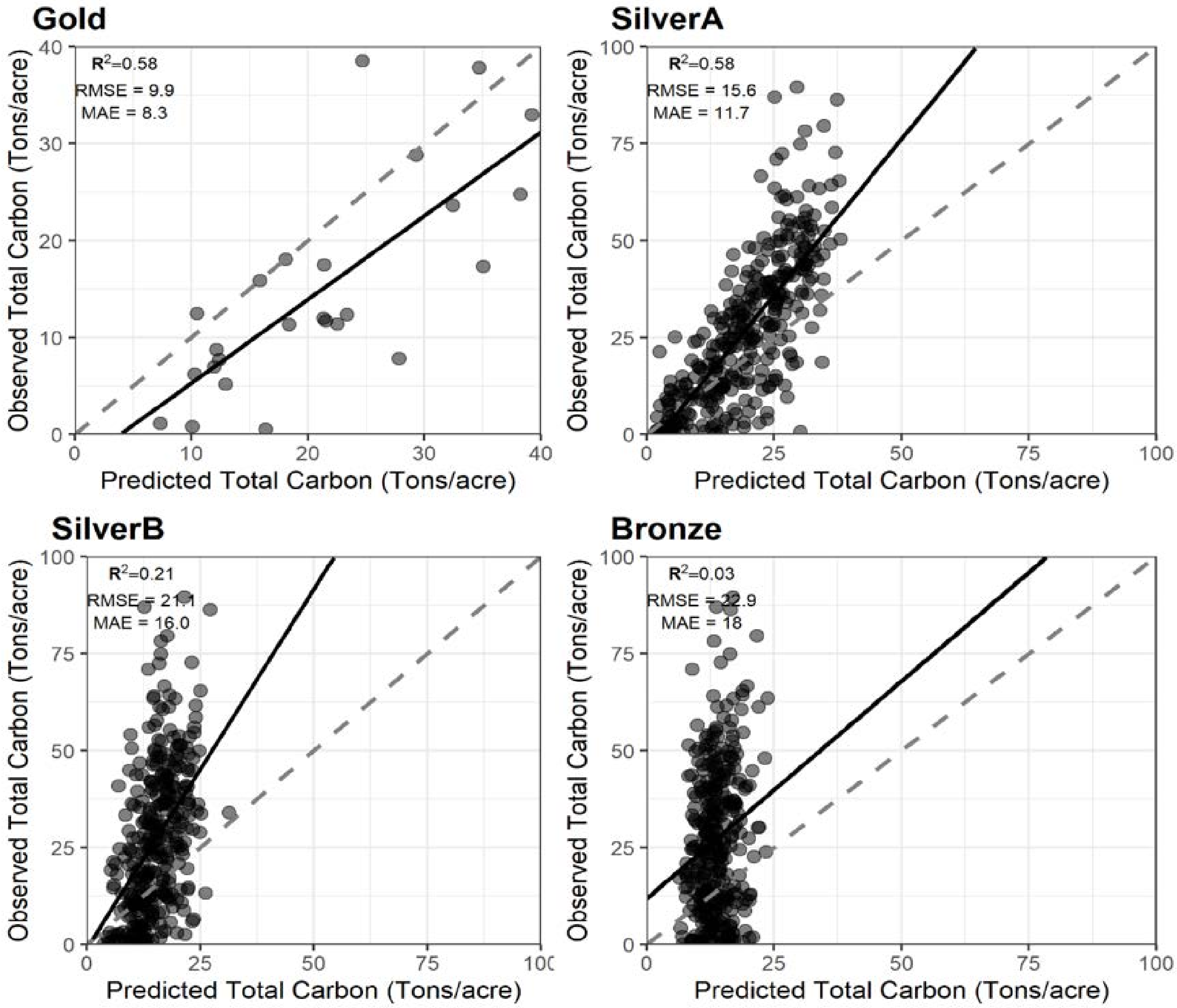
The largest differences over all were between the Gold and Silver models for all three AOIs evaluated, while the in two out of the three AOIs (Cass and Lake AOI) the Silver A model had a slightly lower average CI interval as a percent of the mean compared to Silver B. Differences between average Silver model CI intervals was not as pronounced with the largest difference in the Lake AOI, with an approximately 8% difference (72.84% Silver B to 64.33% Silver A), while the Linear AOI had the smallest difference between Silver models (71.67% for Silver A to 71.31% to Silver B).

Observed vs predicted evaluations showed more agreement between observed and predicted values for Gold and SilverA models, with decrease in R2 and increase in RMSE and MAE in SilverB and Bronze models when compared to SilverA and Gold models (Table 6). Overall, the Cass AOI showed the most consistent pattern of decreases in R2 and increases in RMSE and MAE between comparisons from Gold to Bronze models (Figure 15). Linear models showed a similar pattern, for SilverA to Silver B and Bronze models with decreases in R2, as well as increases in RMSE and MAE, however the Gold to SilverA in the Linear models was slightly higher, with lower RMSE and MAE values. Overall model performance as measured by higher R2 values and reduced RMSE and MAE was achieved by models with structural information from lidar metrics (Figures 15-17). Models that had either True FIA locations or PBI plots were improved over models with imprecise forest inventory location data.

Table 6. Comparison of stand level estimates of the three models, Gold, SilverA, SilverB, and Bronze.

		Cass-SPL				Lake-Linear				Lake-SPL			
		AGB	BGB	Tot	N	AGB	BGB	Tot	N	AGB	BGB	Tot	N
Gold	R sq. (adj)	0.59	0.56	0.58	27	0.47	0.44	0.47	47	---	---	---	---
	RMSE	18096.3	2525	9.9	27	14817.1	3566.5	9.18	47	---	---	---	---
	MAE	15185.5	1883.1	8.3	27	10250.1	2483.4	6.36	47	---	---	---	---
SilverA	R sq. (adj)	0.58	0.54	0.58	333	0.58	0.57	0.57	152	0.45	0.42	0.45	81
	RMSE	28041.5	3680.8	15.6	333	12637.32	3033.3	7.82	152	16262.6	2799.2	9.19	81
	MAE	21237.1	2610.9	11.74	333	10391.81	2559.72	6.46	152	12937.6	2232.5	7.3	81
SilverB	R sq. (adj)	0.21	0.19	0.21	333	0.1	0.12	0.1	152	0.02	0.01	0.02	81
	RMSE	37398.4	5119.6	21.11	333	12341.74	2686.51	7.49	152	21945.3	3464.1	12.5	81
	MAE	28467.1	3827.7	16.01	333	9895.11	2146.04	6	152	17489.1	2928.3	10	81
Bronze 2015-2019	R sq. (adj)	---	---	0.03	333	---	---	0.08	152	---	---	-0.01	81
	RMSE	---	---	22.9	333	---	---	6.5	152	---	---	13.1	81
	MAE	---	---	18	333	---	---	5.16	152	---	---	10.5	81

Figure 15. Cass AOI model comparison observed vs predicted. Clockwise from left, Gold, SilverA, Bronze, and SilverB model.



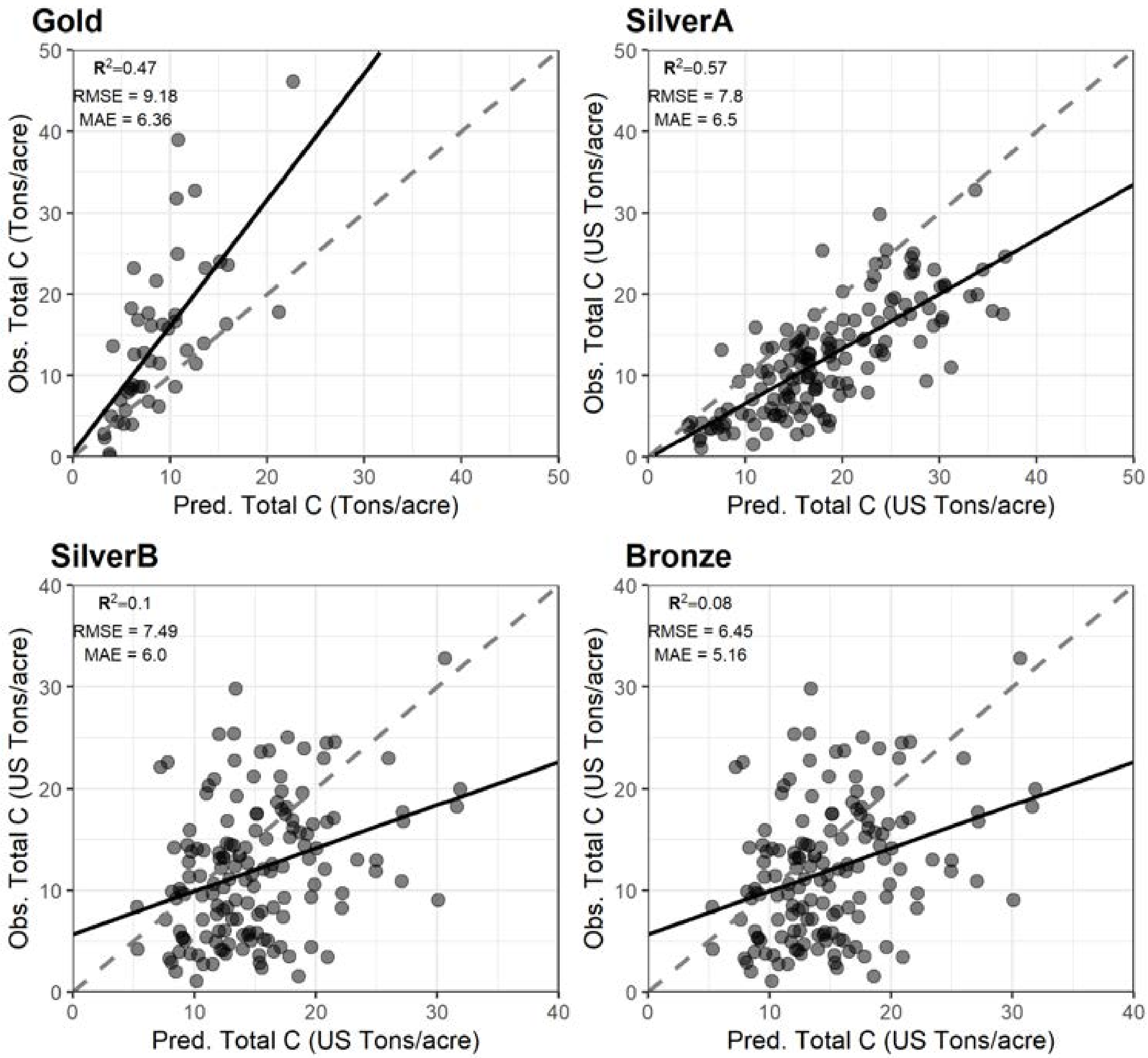


Figure 16. Linear AOI model comparison observed vs predicted. Clockwise from left, Gold, SilverA, Bronze, and SilverB model.

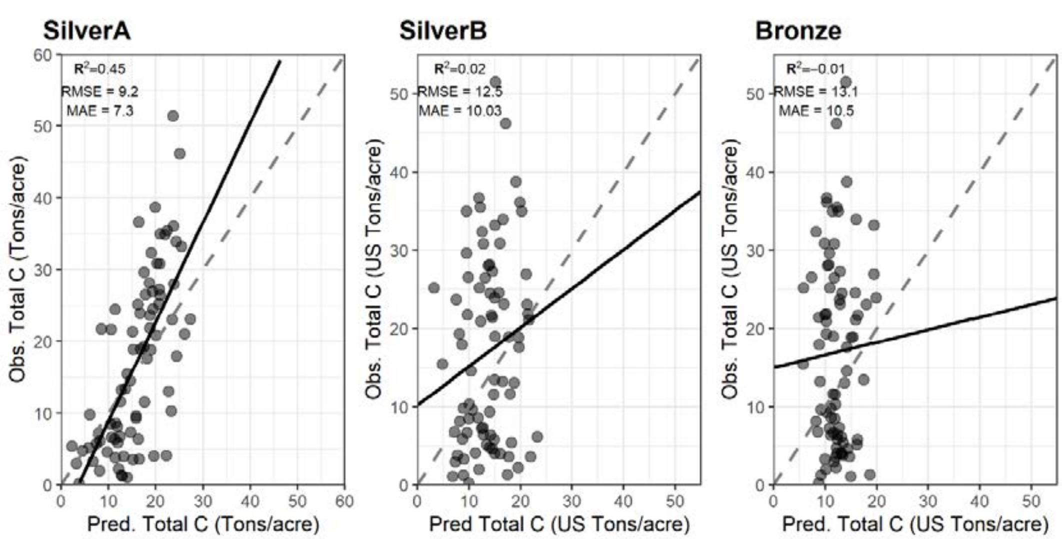


Figure 17. Lake AOI model comparisons for total carbon from left to right SilverA, SilverB and Bronze model.

Bibliography:

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Wager, S., Hastie T., & Efron, B. (2014). Confidence Intervals for Random Forests: The Jackknife and the Infinitesimal Jackknife. J Mach Learn Res 15:1625-1651. http://jmlr. org/papers/v15/wager14a.html.

Wright, M. N. & Ziegler, A. (2017). ranger: A Fast Implementation of Random Forests for High Dimensional Data in C++ and R. J Stat Softw 77:1-17. https://doi.org/10.18637/ jss.v077.i01.

Appendix B

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Colorado

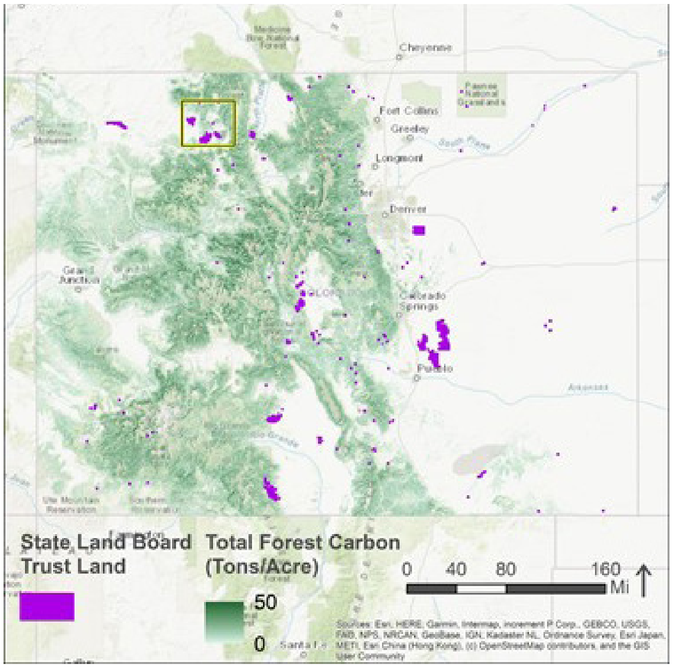


Figure 1. Forest carbon and the extent of state trust lands in Colorado. Yellow box shows zoom-in area featured in Fig. 2

Managing Agency: Colorado State Land Board (CSLB). An innovative land trust, CSLB has funded Colorado schools since 1876. The CSLB leases its forested land to the Colorado State Forest Service (CSFS), a service and outreach agency of the Warner College of Natural Resources at Colorado State University , for stewardship and management. Historically, a portion of CSLB's forestland has been swapped out with U.S. Forest Service lands to help both parties consolidate ownerships (Figure 1).

Acreage: 2.7 million (surface) (Figure 1). Approximately 350,000 acres in forestland within the Southern Rockies ecoregion in the western part of the state.

Beneficiary: Public schools (98%)

Subsurface Considerations: 4 million acres of mineral resources. Oil and gas are the significant earning assets.

Policy Considerations: Colorado has several conditions in place that facilitate carbon project development on state trust lands (Table). The State Climate Action Plan mentions the possibility of entering carbon markets, specifically--pertaining to agriculture and the Ecosystem Services Marketplace Consortium, as well as Soil Health at the state level through the Colorado Department of Agriculture. Carbon capture on grazing systems in rangelands is also part of the climate discussion in Colorado. Additionally, the CSLB has initiated a geo-sequestration carbon capture storage (CCS) leasing program through its mineral program and forest carbon leasing through its ecosystem services program. The CSLB will approve its first forest carbon planning lease in December 2021.

Greenhouse Gas (GHG) Emissions Target? [1]	**Yes**	In 2019, Colorado set a statutory target to reduce GHG emissions by 26% by 2025, 50% by 2030, and 90% by 2050, all compared to 2005 levels.
State Climate Action Plan?[1]	**Yes**	In 2021, Colorado released its Greenhouse Gas and Pollution Reduction Roadmap, which mentions to the role of Natural and Working Lands and Natural Climate Solutions (NCS) – including the importance of implementing NCS equitably.
Member of the US Climate Alliance?[2]	**Yes**	US Climate Alliance states have pledged to manage natural and working lands, including forests, farms, rangelands, and wetlands, to be resilient carbon sinks and protect the communities, economies, and ecosystems that depend on them.

1 https://www.c2es.org/content/state-climate-policy/; 2 http://www.usclimatealliance.org/nwlchallenge

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in Colorado

In Colorado, the CSFS has assumed leadership of the federal Interior West-Forest Inventory and Analysis (FIA) program. Inventory has been completed for a first 10-year cycle of data collection, including 4,500 permanent plots. Light Detection and Ranging (LiDAR) coverage is available for roughly half the state through the GIS Coordination and Development Program (gis.colorado.gov/confluence/).

Bronze Model Results

Estimates of total forest carbon stocks in Colorado range from 2.2 to 48.1 tons per acre, with an average of 14.5 tonsper acre on forested lands. That's an estimated total of more than 272 million tons of forest carbon in Colorado!

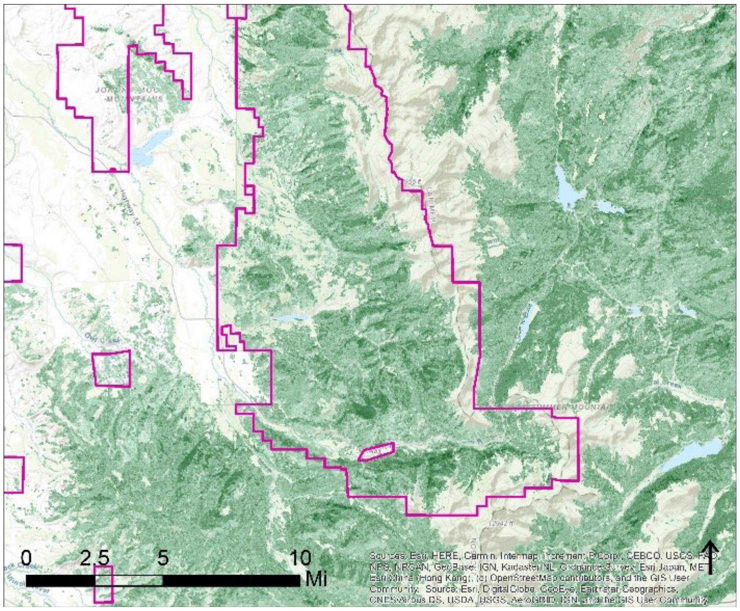


Figure 2. Zoomed-in area in Northern Central Colorado (~40,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 50 (dark green) tons/acre.

Forest Carbon Opportunity Example

Only 11% of Colorado's state trust lands are forested, and forests are relatively slow-growing. Significant portions of Colorado's forested landscapes have experienced wildfire in recent years, the frequency and severity of which have been worsened by drought, pine bark beetle, and spruce budworm outbreaks. The parcels with the highest carbon stocks are concentrated in the northern part of the state, with additional clusters throughout the Rocky Mounains. Let's zoom in on the mountainous region of North Central Colorado (Figure 2). This is the southern end of the 72,000-acre State Forest State Park. Surrounded by the White River and Routt National Forests, state trust parcels cover approximately 28,000 acres.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels and fuel treatments to reduce the risk of carbon loss through wildfire. In addition, given the proximity to National Forests and the State of Wyoming, Shared Stewardship and collaborative landscape scale management plans are highly recommended. The CSLB also plans to capture revenue through reforestation of lands burned in recent large wildfires.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Given the availability of statewide FIA plots and LiDAR data for roughly half the state, Colorado's spatial data resources may support silver level modeling for carbon stocks. With the addition of more fixed-radius plots inventory plots (beyond FIA) and completion of LiDAR coverage for all forested areas, the state would have the option of running gold-level forest carbon models to help identify areas for which forest carbon projects warrant further exploration through a detailed feasibility analysis. To view Colorado's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/orcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Idaho

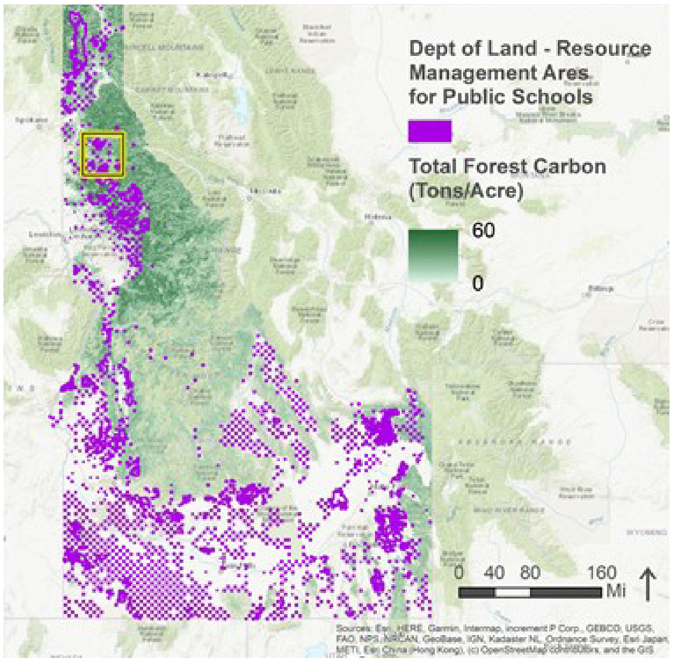


Figure 1. Forest carbon and the extent of state trust lands in Idaho. Yellow box shows zoom-in area featured in Fig. 2

Managing Agency: Idaho Department of Lands (IDL). The IDL manages the state's endowment trust lands, which are entrusted to the State's Board of Land Commissioners. The state Constitution specifies that Idaho trust lands will be managed "...in such a manner as will secure the maximum long-term financial return to the institution to which (it is) granted." (https://www.idl.idaho.gov/about-us/understanding-endowment-land/)

Acreage: 2.5 million (surface) (Figure 1). Timber sales are the major earning asset.

Beneficiary: Public schools (85%)

Subsurface Considerations: 3.3 million acres of mineral resources

Policy Considerations: Policy Considerations: Idaho lacks many of the policy elements that would smooth the way for state trust lands to participate in carbon markets. For example, the state does not have a Greenhouse Gas Emissions reduction target or a state climate action plan, which are two of the enabling conditions that could facilitate an exploration of carbon markets to generate revenue. Although state trust lands are not barred from participating in carbon markets, enabling language specifically for participation in such markets does not yet exist.

Nonetheless, IDL is open to the opportunity posed by carbon markets. The board will consider the opportunity to earn carbon revenue off forested state trust lands as it would most other opportunities to generate revenue. In Idaho, the initial thinking is that less productive forest stands may be better candidates for carbon project development. In addition, potential collaborations between state and federal forestlands (e.g., Shared Stewardship, Good Neighbor Authority) should be weighed when considering the potential for carbon revenue.

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in Idaho

Idaho has an extensive plot-based inventory system that has been maintained since the 1950s: the Continuous Forest Inventory (CFI). They are planning to verify all stand-level data with high-quality remotely sensed data (within 3% error). Light Detection and Ranging (LiDAR) data have been acquired for 95% of the state's forestland—of which most has been captured very recently and ~75% had already been processed as of fall, 2021). IDL is considering acquiring LiDAR data for rangeland in the future. Statewide Photogrammetric Detection and Ranging (PhoDAR) data have also been acquired. The high-quality stand data and remote sensing information lend themselves to running the gold model in Idaho to identify options for forest carbon project development.

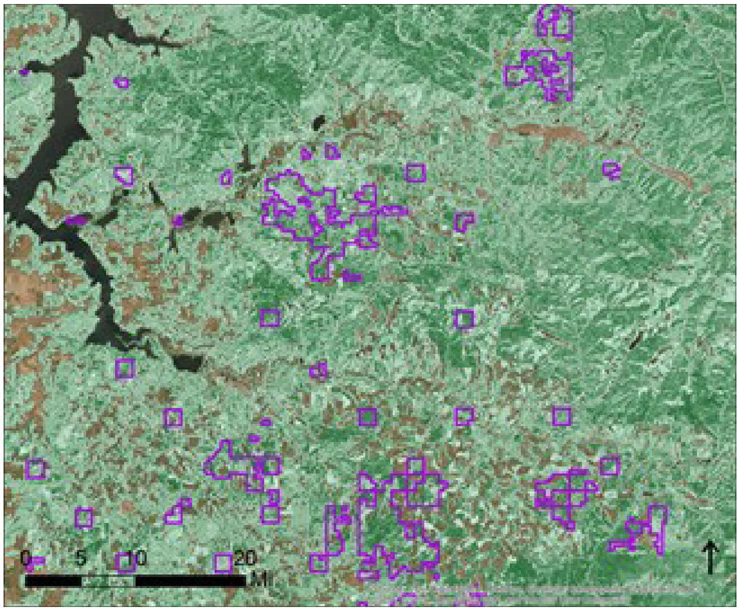


Figure 2. Zoomed-in area in Northern Idaho (~55,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 60 (dark green) tons/acre.

Bronze Model Results

Estimates of total forest carbon stocks in in Idaho range from 2.3 to 57.8 tons of carbon per acre, with an average of 24.6 tons per acre on forested lands. That's an estimated total of more than 427 million tons of forest carbon in Idaho!

Forest Carbon Opportunity Example

Let's zoom in on the forested wetland region of Northern Idaho, near Coeur D'Alene Lake surrounded by National Forests on almost all sides (approximately 55,000 acres of parcels, Figure 2). Throughout this region there are many parcels with high total forest carbon stocks, with a bimodal distribution peaking at 40 tons per acre.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels and fire suppression techniques. In addition, given the proximity to a National Forest and the State of Washington, Shared Stewardship and collaborative landscape scale management plans are highly recommended.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Idaho's spatial data resources are well-founded to run models at the gold level in order to help identify areas for which forest carbon projects that warrant further exploration through a detailed feasibility analysis. To view the results of Idaho's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/orcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Minnesota

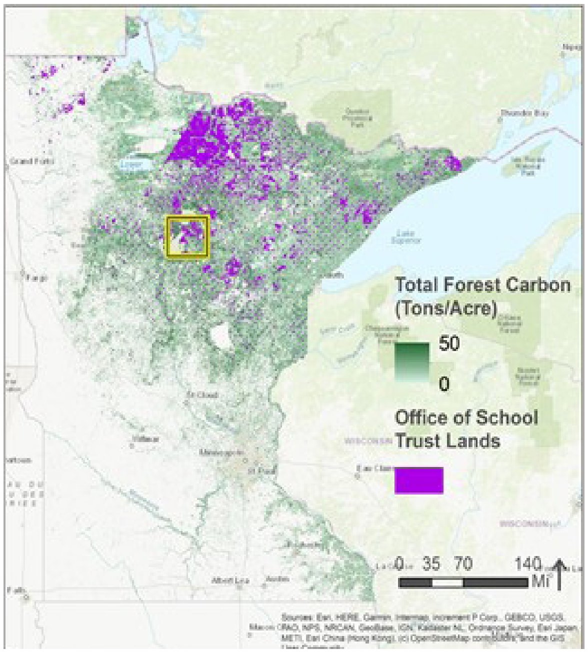


Figure 1. Forest carbon and the extent of state trust lands in Minnesota. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: Department of Natural Resources (DNR). The Office of School Trust Lands is a separate state agency that focuses its work on ensuring management plans for school trust lands are implemented consistently with a focus on long-term economic returns. OSTL's mission is to develop and advocate for sustainable asset management strategies that maximize long-term revenue for Minnesota's public schools. The OSTL's vision is increased public school funding from a diverse set of activities on Minnesota's school trust lands.

Acreage: 2.5 million (surface) with >92% located in Minnesota's 10 northern-most counties.

Beneficiary: K-12 Public schools

Subsurface Considerations: 6.2 million acres of mineral resources (note that there is some concern that developing carbon projects could limit access to mineral resources).

Policy Considerations: In 2019, Governor Walz signed the Climate Change Executive Order (19-37), reinforcing the size and the scope of the climate crisis and the need to protect all Minnesotans from the most severe economic, health, and ecological impacts of climate change (climate.state.mn.us/).

In 2021, The Minnesota Legislature passed a law with enabling language for state lands to participate in ecosystem services markets – including carbon markets. The OSTL collaborated with lawmakers to enact this policy language. Introduced as a single ecosystem services bill, in the final omnibus bill (SF 959) the language appears in three parts: 1) Conveyance of conservation easements (84.625); 2) Conservation planning leases (92.503); 3) a line establishing a new strategic goal that OSTL "advance strategies on school trust lands to capitalize on ecosystem services markets" (127A.353 subd.4(a)(6)(vi).

Greenhouse Gas (GHG) Emissions Target?[1]	**Yes**	Minnesota has statutory targets to reduce GHG emissions 30% below 2005 levels by 2025 and 80% below 2005 levels by 2050, which were enacted in 2007**.**
State Climate Action Plan?[1]	**Yes**	Minnesota released a *Climate Action Plan* in October 2020 updated to include actions aimed at meeting its GHG reduction goal of 45% by 2030 and carbon neutrality by 2050. Increasing nature-based carbon sequestration and building resilience to climate impacts are key aspects of the plan. Minnesota released its previous report, *Climate Solutions and Economic Opportunities*, in 2015.
Member of the US Climate Alliance?[2]	**Yes**	US Climate Alliance states have pledged to manage natural and working lands, including forests, farms, rangelands, and wetlands, to be resilient carbon sinks and protect the communities, economies, and ecosystems that depend on them.
Carbon Pricing?[1]	**No**	

1 https://www.c2es.org/content/state-climate-policy/; 2 http://www.usclimatealliance.org/nwlchallenge

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

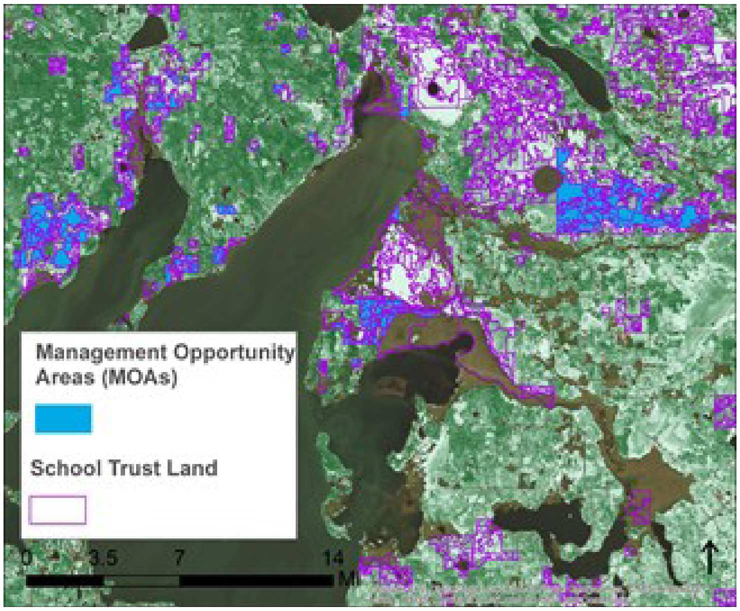


Figure 2. Zoomed-in area in Central Minnesota (~48,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 50 (dark green) tons/acre.

Data Availability in Minnesota

Since 2020, DNR has been transitioning to an efficient, accurate, data-rich forest inventory method that combines plot-based forest inventory (PBI) and high-density light detection and ranging (lidar) data. The PBI gathers precise forest metrics on the ground at locations distributed on a grid, each plot representing approximately 1,500 acres of forest. Combining lidar and PBI provides much more accurate forest inventory information—yielding gold model results. However, for comparative purposes with the other 9 states, here we share results from the bronze model.

Bronze Model Results

Estimates of total forest carbon stocks in in Minnesota range from 0.4 to 45 tons per acre, with an average of 14.3 tons per acre on forested lands. That's an estimated total of more than 262 million tons of forest carbon in Minnesota!

Carbon Project Opportunity Example

Let's zoom in on Central Minnesota near Leech Lake and the Chippewa National Forest (Figure 2). Throughout Minnesota there are several clusters of parcels like this with moderately high total forest carbon stock, often in or surrounded by wetlands.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels and underplanting to benefit age class distribution and biodiversity. In addition, given the proximity to National Forests and a Tribal Nation—the Leech Lake Band of Ojibwe, there may be opportunities to explore shared stewardship and other options for collaboration.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Minnesota's spatial data resources are well-founded at the gold level. To view the results of Minnesota's bronze model online, please visit this website: https://lspaete.users.earthengine.app/view/orcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:

An Opportunity Assessment for Montana

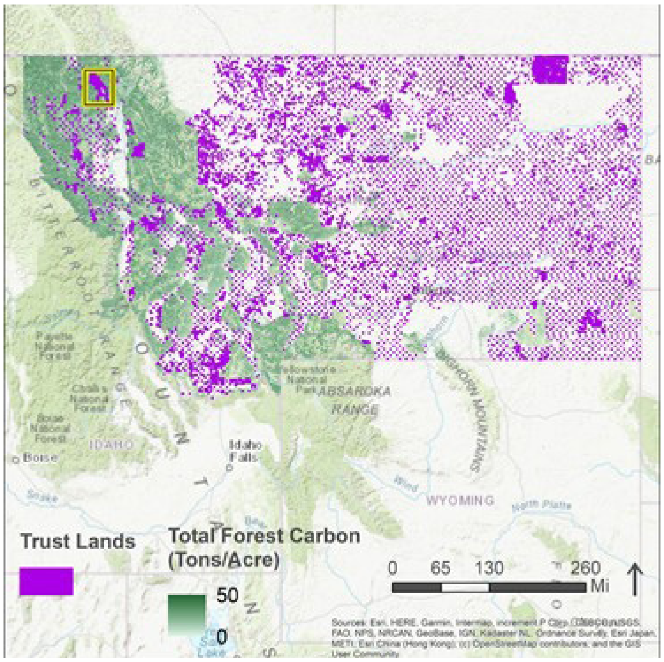


Figure 1. Forest carbon and the extent of state trust lands in Montana. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: Department of Natural Resources and Conservation (DNRC). DNRC's mission is to manage the State of Montana's trust land resources to produce revenues for the trust beneficiaries while considering environmental factors and protecting the future income-generating capacity of the land. Each section of state trust lands is assigned to a specific trust - the beneficiaries of which could consider advocating for specific revenue tools, such as carbon markets.

Acreage: 5.2 million (surface) (Figure 1). Earning assets are distributed among timber, minerals, and agricultural and grazing leases. Subsurface Considerations: 6.2 million acres of mineral resources (note that there is some concern that developing carbon projects could limit access to mineral resources).

Beneficiary: Public Schools

Subsurface Considerations: 6.2 million acres of mineral resources (note that there is some concern that developing carbon projects could limit access to mineral resources).

Policy Considerations:

Greenhouse Gas (GHG) Emissions Target (GHG)?[1]	**Yes**	In 2020, Montana announced its executive target to reach economy-wide GHG neutrality between 2045-2050.
State Climate Action Plan?[1]	**Yes**	Montana released its *Climate Solutions Plan* in August 2020. The plan includes policies and strategies to help the state achieve economy-wide GHG neutrality between 2045-2050. The plan references Natural and Working Lands: "Build the Resilience of Montana's Private Working Lands (Farms, Forests, and Rangelands) and Support Voluntary and Incentive-Driven Efforts for Climate-Smart Management that Reduces Risks, Improves Bottom Lines, and Enhances Carbon Storage in Soils, Forests, and Wood Products" (p. 16)
Are State Trust Lands enabled by statute to participate in carbon markets?	**No**	Statutory language enabling participation in carbon markets is not currently in place. However, carbon markets are referenced in the state climate action plan for private landowners: "Explore opportunities for Montana farmers, ranchers, and forest landowners to diversify income streams through emerging GHG markets by developing pilot projects or programs that aggregate and quantify enhanced GHG management. Consider other creative efforts that reward producers for climate resilience and GHG management, such as cost-share or insurance premium reduction payments, marketing and labeling tools, and others." (1E, p. 18)

1 https://www.c2es.org/content/state-climate-policy/; 2 http://www.usclimatealliance.org/nwlchallenge

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

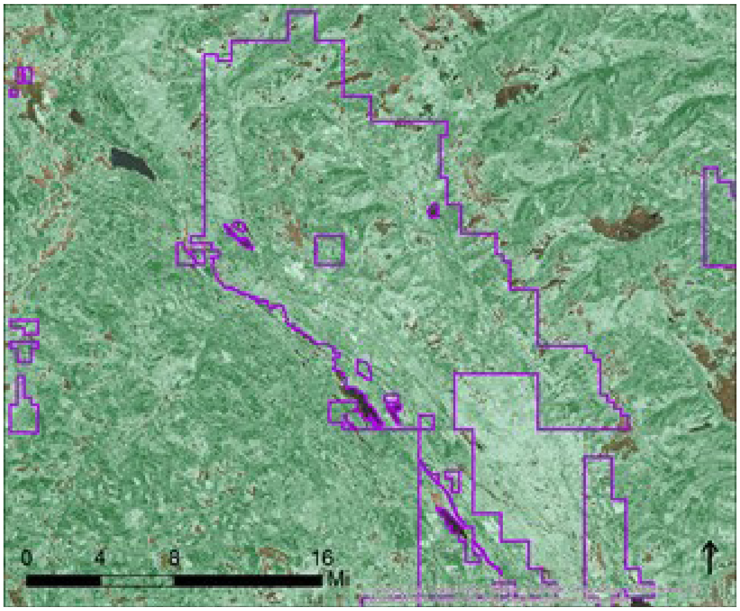


Figure 2. Zoomed-in area Northwestern Montana (~92,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 50 (dark green) tons/acre.

Data Availability in Montana

Although Forest Inventory and Analysis (FIA) plots are available in Montana, the state does not have detailed plot-based data, such as Plot-Based Inventory. There is a stand-based inventory on forested state lands. This inventory consists of walk-throughs on the West side of the state, and aerial photo-interpreted plots on the East side. Montana is currently working toward a remotely sensed inventory platform.

Bronze Model Results

Estimates of total forest carbon stocks in Montana range from 1.1 to 49.7 tons per acre, with an average of 17.4 tons per acre on forested lands. That's an estimated total of more than 367 million tons of forest carbon in Montana!

Forest Carbon Opportunity Example

Let's zoom in on the mountainous region of Northwestern near Glacier National Park in the Lazy Swift valley (approximately 92,000 acres of parcels, Figure 2). Throughout this region there are many parcels with high total forest carbon stocks, grouped into fairly large 10,000-40,000 acre clusters.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels and fuel reduction strategies to lower the risk of wildfire. In addition, given the proximity to several National Forests, the States of Idaho and Wyoming, Shared Stewardship and collaborative landscape scale management plans are highly recommended.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Montana's 3D spatial data resources are well-established to run forest carbon models at the silver level. With enhancements to the field data collection protocols, gold level models could be easily achieved. Investments in additional field inventory to complement the existing 3D spatial resources could be very worthwhile as a means to help identify areas for which forest carbon projects warrant further exploration through a detailed feasibility analysis, especially given the vast extent of Montana's forested trust lands. To view the results of Montana's bronze model online or download the results, please visit this website https://lspaete.users.earthengine.app/view/orcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for North Dakota

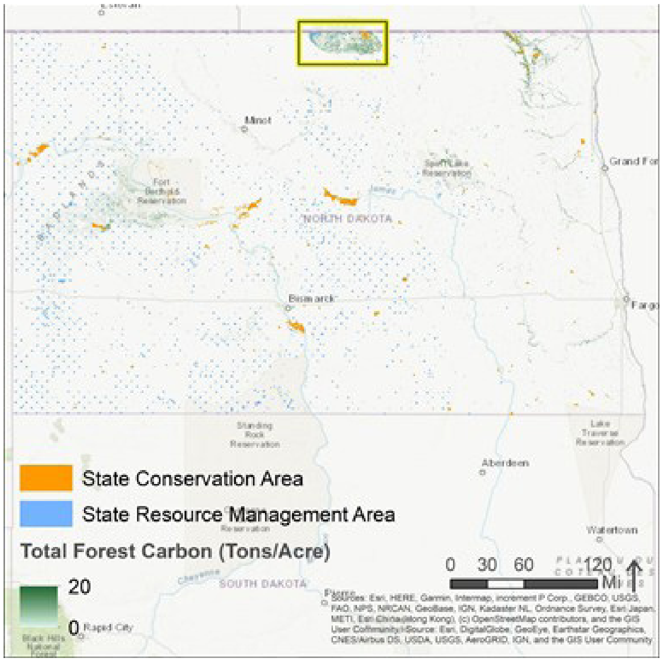


Figure 1. Forest carbon and the extent of state trust lands in North Dakota. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: North Dakota Department of Trust Lands (NDDTL). The mission of the Board of University and School Lands is to prudently and professionally manage assets of the permanent trusts in order to preserve the purchasing power of the funds, maintain stable distributions to fund beneficiaries, and manage all other assets and programs entrusted to the Board in accordance with the North Dakota Constitution and applicable state law.

Acreage: 706,604 (surface) (Figure 1). Trust lands occur primarily in the western 2/3 of the state, and are predominantly leased for pasture and meadow purposes.

Beneficiary: K-12 public schools

Subsurface Considerations: 2.8 million acres of mineral resources. Oil and gas royalties are the main earning asset.

Policy Considerations: North Dakota lacks policy instruments that could smooth the way for state trust lands to participate in carbon markets. For example, the state does not have a Greenhouse Gas Emissions reduction target or a state climate action plan, which are two of the enabling conditions that could facilitate an exploration of carbon markets to generate revenue. Although state trust lands are not barred from participating in carbon markets, enabling language specifically for participation in such markets does not yet exist. There is strong interest in exploring carbon offsets among key policymakers and energy sector companies operating in ND. Governor Burgum set a goal in 2021 for North Dakota to be carbon-neutral by 2030 - requiring significant investments in carbon reduction and sequestration.

In North Dakota, there are several unleased, forested Trust Land tracts for which a new revenue source could be considered, given that there is relatively little forest industry activity in the state. Below-ground mineral assets may already be obligated through oil and gas leases on these tracts. There may be concerns on the part of the state over potential carbon project agreement terms - in particular the length of the agreements. North Dakota state law currently limits surface lease terms to 5 years. Heavily forested tracts often remain unleased due to the underdeveloped forest industry and the tracts' unsuitability for conventional cattle production. NDDTL maintains management authority on leased and unleased tracts, but unleased tracts offer more opportunity to explore revenue alternatives

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in North Dakota

North Dakota has limited data availability. For example, there are insufficient Forest Inventory and Analysis (FIA) plots containing measurable trees for an accurate assessment of stand-level metrics. The Great Plains Tree and Forest Invasives Initiative (GPI, 2018) evaluated tree resources throughout a four-state region, including North Dakota. The GPI expanded the state's inventory of forests or trees outside forested acreage from 800,000 acres to 1.6 million acres. The availability of Light Detection and Ranging (LiDAR) data for North Dakota is unknown, but there is better coverage for areas that are hydrologic priorities

Bronze Model Results

Estimates of total forest carbon stocks in North Dakota range from 1.5 to 19.8 tons per acre, with an average of 9.9 tons per acre on forested lands. That's an estimated 5.2 million tons of total forest carbon in North Dakota!

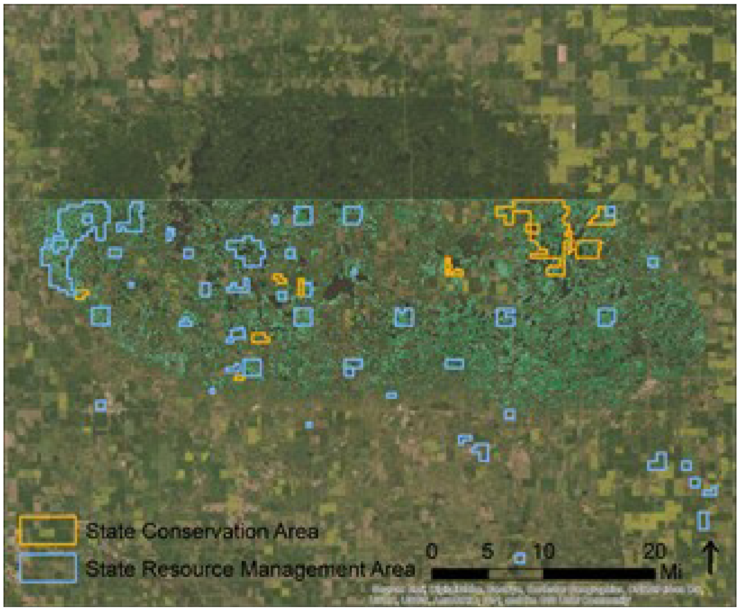


Figure 2. Zoomed-in area in North Central North Dakota (~25,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 20 (dark green) tons/acre.

Forest Carbon Opportunity Example

Let's zoom in on one of the only forested regions of North Central North Dakota on the US-Canada border in an area known as Turtle Mountain (approximately 25,000 acres of parcels shown in Figure 2). Throughout this region there are very few remaining undisturbed forests. As an example of remaining forest, there are 3 sections (640 acres each) of over-mature aspen that intermingle with small, glacial lakes. Where forests do exist, the above-ground carbon stock is often not very high.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this area may include underplanting to increase biodiversity or increasing stocking levels where canopy cover is <25%. In addition, given the proximity to a Tribal Nation—the Turtle Mountain Band of Chippewa—and Canada, the opportunity for trans-national collaborative landscape scale projects may be considered.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. North Dakota does not have sufficient Forest Inventory and Analyses (FIA) or LiDAR data for the silver or gold models. Forest inventory field work collected continuously to extend the use of existing FIA data and collecting high density LiDAR data as part of the USGS 3D Elevation Program are recommended. To view the results of North Dakota's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/orcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Oregon

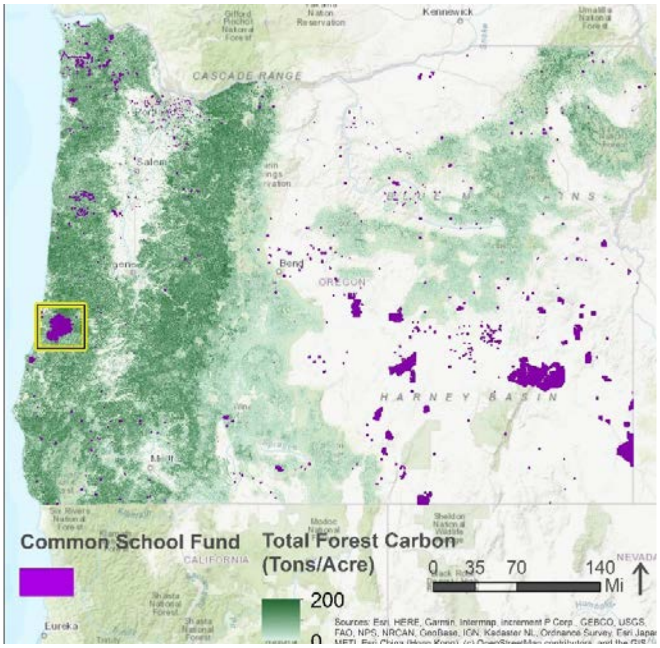


Figure 1. Forest carbon and the extent of state trust lands in Oregon. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: Oregon Department of State Lands (ODSL). ODSL ensures a Common School Fund legacy through sound management of our trust responsibilities and the protection of waters of the state.

Acreage: 772,600 (surface). Forestland occurs primarily in western Oregon. The eastern half of the state has significant acreage in agricultural and rangeland.

Beneficiary: Public Schools (100%)

Subsurface Considerations: 767,700 acres of mineral and energy resources. This is a significant earning asset; all state-owned lands are available to search for minerals.

Policy Considerations: Oregon has all the elements needed to establish a forest carbon project on state trust lands.

Greenhouse Gas Emissions (GHG) Target?[1]	**Yes**	Oregon has targets of reducing GHG emissions 45% below 1990 levels by 2035 and 80% below 1990 levels by 2050, which were set in 2020. Additionally, the state has statutory targets of reducing emissions 10% below 1990 levels by 2020 and 75% below 1990 levels by 2050, which were enacted in 2007.
State Climate Action Plan?[1]	**Yes**	Oregon issued the *Oregon Climate Action Plan* in 2020. "The way we manage our forests" is highlighted as an area to address.
Member of the US Climate Alliance?[2]	**Yes**	US Climate Alliance states have pledged to manage natural and working lands, including forests, farms, rangelands, and wetlands, to be resilient carbon sinks and protect the communities, economies, and ecosystems that depend on them.
Carbon Pricing?[1]	**No**	However, Oregon has a history of attempting to establish a state-level price on carbon that dates back to the early 2000s. See A Brief History of Carbon Pricing in Oregon.

1 https://www.c2es.org/content/state-climate-policy/; 2 http://www.usclimatealliance.org/nwlchallenge

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in Oregon

A comprehensive analysis for Oregon's forest carbon stocks and flux has already been completed as a collaboration between the federal Forest Inventory and Analysis (FIA) program, the ODF and the Governor's climate policy office. Roughly half the state (western forests) has Light Detection and Ranging (LiDAR) available and were used in the above effort.

Bronze Model Results

Estimates of total forest carbon stocks in Oregon range from 1.2 to 198.2 tons of total carbon per acre, with an average of 54.3 tons per acre on forested lands. That's an estimated total of more than 1.6 billion tons of forest carbon in Oregon!

Forest Carbon Opportunity Example

Let's zoom in on southwestern Oregon, near Siuslaw National Forst and within the Elliot State Forest (approximately 82,000 acres, Figure 2). This contested forest area has been identified as a potential experimental site for balancing timber production with conservation to help resolve a long-standing controversy (nature.com/articles/d41586-021-01256-9). Carbon revenue may have a role to play given the Elliot State Forest's concentration of relatively high-carbon stock forests.

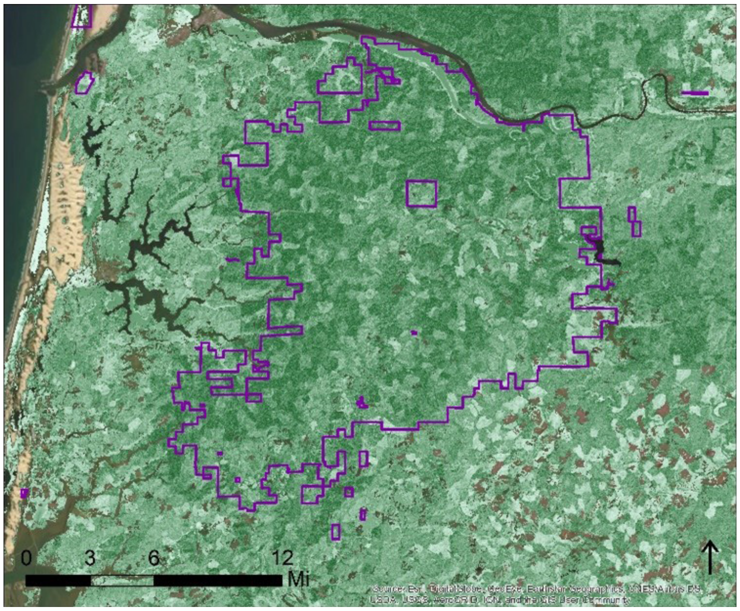


Figure 2. Zoomed-in area in southwestern Oregon within the Elliot State Forest (82,000 acres of parcels).See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 200 (dark green) tons/acre.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region could include increasing rotation age, thinning to release growth in the high carbon stock parcels, and underplanting to enhance age class diversity.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Oregon has already made a considerable investment in accurate site scale models to establish a baseline for forest carbon. Oregon's spatial data resources are an example of gold-level modeling that could be applied in other states to identify areas warranting further exploration for forest carbon project development through a detailed feasibility analysis. To view the results of Oregon's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/orcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Utah

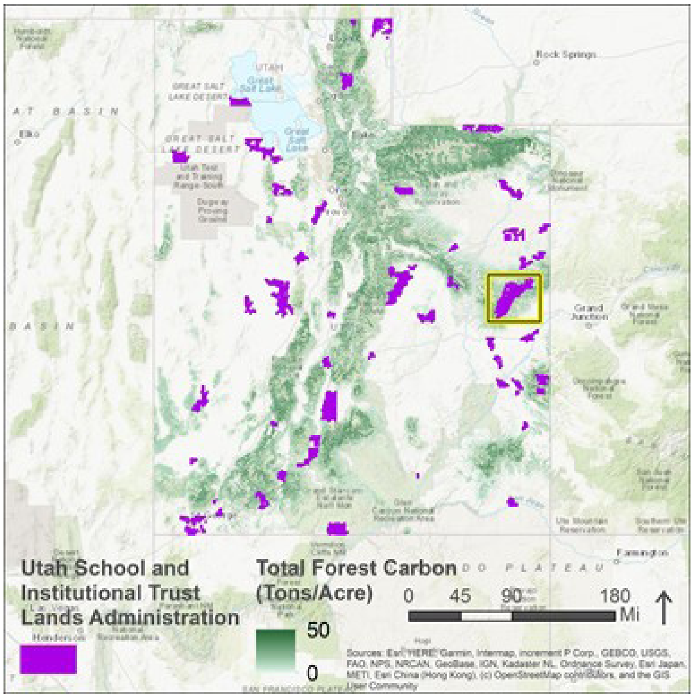


Figure 1. . Forest carbon and the extent of state trust lands in Utah. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: State of Utah School and Institutional Trust Lands Administration (SITLA). SITLA administers trust lands prudently and profitably for Utah's schoolchildren and other trust beneficiaries.Acreage: 3.5 million (surface) (Figure 1)

Acreage: 3.4 million (surface) (Figure 1)

Beneficiary: K-12 public schools (96%)

Subsurface Considerations: 4.4 million acres of mineral resources - main earning asset oil and gas

Policy Considerations: Utah lacks many of the policy elements that would smooth the way for state trust lands to develop carbon projects. For example, the state does not have a Greenhouse Gas Emissions reduction target or statutory language specifically enabling participation in ecosystem services markets. However, Utah does have a state climate action plan in place, the Utah Roadmap (2020). The plan details strategies to help the state meet its goals of reducing carbon dioxide emissions statewide—25 % by 2025, 50% by 2030, and 80 % by 2050, from a 2005 baseline. Among the key aspects of the plan, "leading discussions for market-based solutions to reduce carbon emissions" is mentioned alongside creating a premier air quality and climate solutions laboratory, expanding electric vehicle infrastructure, and providing economic assistance to rural communities. The Roadmap does not reference natural climate solutions or improved forest management but does recommend additional funding for reforestation –as well as compact development that avoids forested areas (Center for Climate and Energy Solutions, https://www.c2es.org/content/state-climate-policy/).

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in Utah

There are 8,853 permanent forest inventory plots in Utah, and about one-third of these plots contain accessible forest land that will continue to be measured by field crews every 10 years. Utah is part of the Interior West Forest Inventory & Analysis (FIA). Light Detection and Ranging (LiDAR) data are currently available for a limited portion of the state's forestlands.

Bronze Model Results

Estimates of total forest carbon stocks in Utah range from 2 to 29.7 tons of total carbon per acre, with an average of 11.3 tons per acre on forested lands. That's an estimated total of more than 136 million tons of forest carbon in Utah!

Forest Carbon Opportunity Example

Let's zoom in on an area in West Central Utah near the border of Colorado and not far from the Arches National Park (approximately 138,000 acres of parcels, Figure 2). Throughout Utah there are many large clusters of state trust land parcels like this, but most have desert-like conditions and without forest carbon stock with the exception of this region.

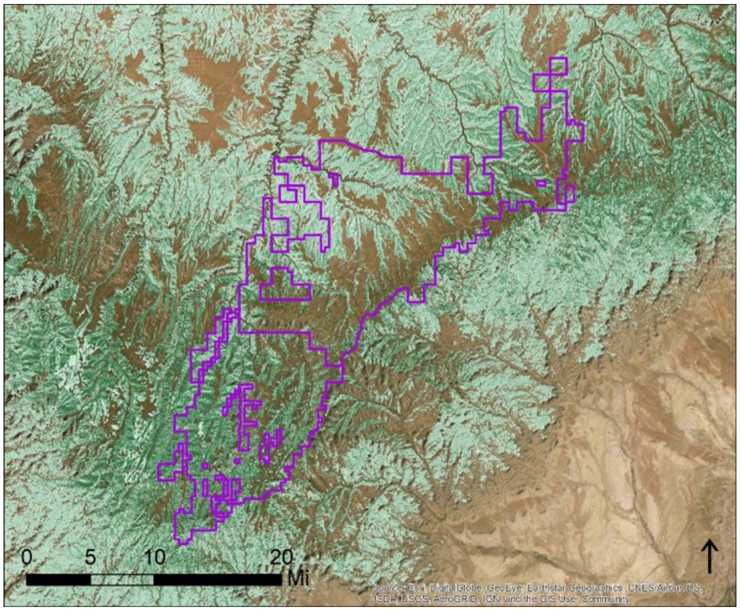


Figure 2. Zoomed-in area in West Central Utah near Arches National Park. See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 30 (dark green) tons/acre.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels, fuel reduction treatments to minimize the risk of wildfire, and underplanting to increase the diversity of age classes and biodiversity.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Utah's spatial data resources are well-founded at the silver level. Improving the results of the silver model and including higher precision forest inventory data will be important for higher confidence estimates at the local level. To view the results of Utah's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/utcarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:

An Opportunity Assessment for Washington

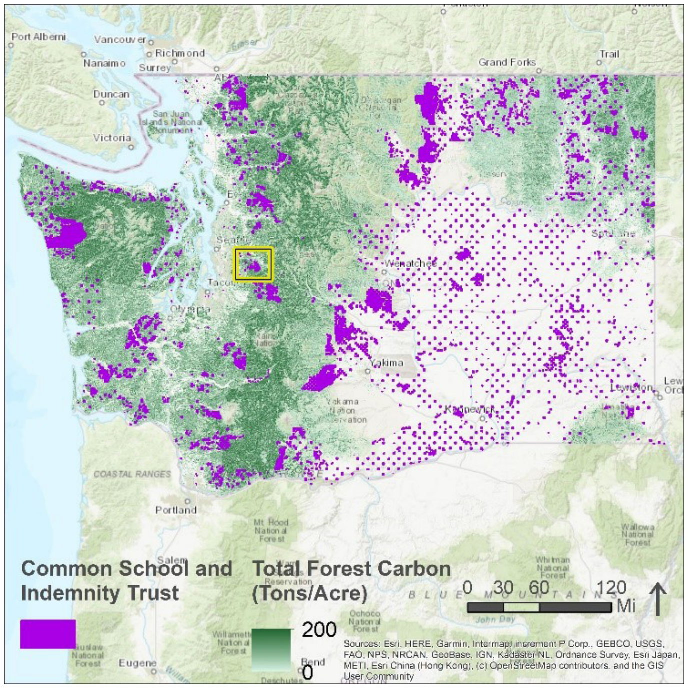


Figure 1. Forest carbon and the extent of state trust lands in Washington. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: Washington State Department of Natural Resources (DNR). Trust lands managed by the DNR come with a legal responsibility to generate revenue for their designated beneficiaries, such as schools, counties and critical local services. dnr.wa.gov/

Beneficiary: DNR manages several trusts with different beneficiaries. Proportionally, the majority of the acreage (~60%) is for the K-12 Common School Trust, followed by ~20% in the State Forest Land Trust. Other trusts include the Scientific School Trust, Normal School Trust, Capitol Building Trust, Charitable, Educational, Penal and Reformatory Institutions Trust, University Trust and Agricultural School Trust.

Acreage: 3.1 million (surface) (Figure 1). Timber is the major earning asset.

Subsurface Considerations: 2.6 million acres of mineral resources

Policy Considerations: The state of Washington has many of the policy pieces in place to enable the participation of trust lands in carbon markets, as well as a new cap-and invest program. Although statutory language specifically enabling state trust lands to access carbon markets is not in place, the Executive Branch is supportive of carbon projects generally and DNR staff are actively seeking a revenue-generating forest carbon project to pursue on state lands. The state has contracted with a firm to run feasibility analyses for a few potential project areas.

Greenhouse Gas (GHG) Emissions Target?[1]	Yes	In 2020, Washington set new statutory targets to reduce GHG emissions 45% by 2030, 70% by 2040, and 95% by 2050, all compared to 1990 levels, which were enacted in 2020. The targets also aim for net-zero GHG emissions by 2050.
State Climate Action Plan?[1]	Yes	Washington released the *Report on the Work of the Climate Legislative and Executive Workgroup* in 2014. The report provides recommendations to help the state meet its then goal of reducing GHG emissions to 1990 levels by 2020, 25% below 1990 levels by 2035, and 50% below 1990 levels by 2050. Washington set new GHG goals (above) but has not yet released an action plan to meet these new targets.
Member of the US Climate Alliance?[2]	Yes	US Climate Alliance states have pledged to manage natural and working lands, including forests, farms, rangelands, and wetlands, to be resilient carbon sinks and protect the communities, economies, and ecosystems that depend on them.
Carbon Pricing?[1]	Yes	Washington's Climate Commitment Act requires the Department of Ecology to create and implement a cap-and-invest program limiting emissions from covered entities, distributing allowances, and establishing a climate investment account for revenues from allowances. The program begins on January 1, 2023, using total statewide anthropogenic GHG emissions from 2015–2019 as the baseline. Caps will be based on the state's existing GHG limits (see above). The program covers entities emitting more than 25,000 MMTCO2e.

1 https://www.c2es.org/content/state-climate-policy/; 2 http://www.usclimatealliance.org/nwlchallenge

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in Washington

Washington has a mature forest inventory dataset. The WA DNR collects ground-level field data, which are used to ground-truth metrics such as tree height and canopy closure for Photogrammetric Detection and Ranging (PhoDAR) assessments on nearly 100% of forested state lands.

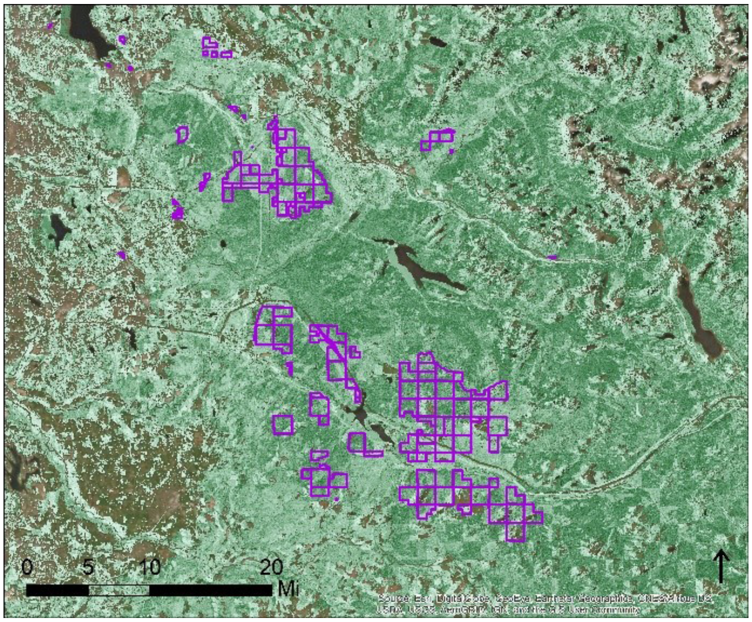


Figure 2. Zoomed-in area near Seattle (~37,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 200 (dark green) tons/acre.

Bronze Model Results

Estimates of total forest carbon stocks in Washington range from 5.4 to 194.5 tons per acre, with an average of 54.3 tons per acre on forested lands. That's an estimated total of more than 1.2 billion tons of forest carbon in Washington!

Forest Carbon Opportunity Example

Let's zoom in on an area just outside Seattle, near Tiger Mountain and Snoqualmie National Forest (approximately 37,000 acres of parcels, Figure 2). Throughout Washington there are many clusters of parcels like this with high total forest carbon stock, with a bimodal distribution peaking at 40 tons per acre.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels and fuel reduction measures to reduce the risk of wildfire. In addition, given the proximity to National Forests, there may be many opportunities for Shared Stewardship. Creative recreation-based solutions that engage Seattle area residents may also be worth exploring.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Washington's spatial data resources are consistent with what is needed to run the gold model. However, Washington is already well on its way to identifying potential carbon projects on forested state trust lands and may already have surpassed the point at which such models are needed. To view the results of Washington's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/wacarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Wisconsin

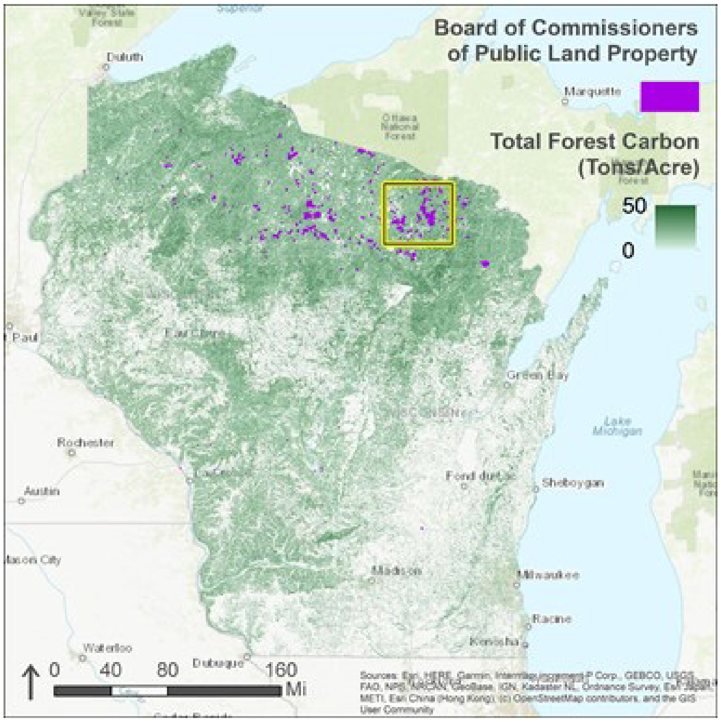


Figure 1. Forest carbon and the extent of state trust lands in Wisconsin. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: Board of Commissioners of Public Land (BCPL). The BCPL, Wisconsin's oldest state agency, comprises the Secretary of State, State Treasurer and Attorney General. The BCPL is committed to a constitutionally protected form of public education financing, originating from millions of acres of land granted by the federal government (bcpl.wisconsin.gov).

More than 100 years ago, Wisconsin sold nearly all its School Trust Lands. The School Trust Fund was established with the proceeds. Today the remaining School Trust Lands generate revenue for the Normal School Fund from timber production.

Beneficiary: Normal School Fund (University of Wisconsin System)

Acreage: 77,000 with a majority occurring in the 3 northern-most counties (Figure 1). Timber is the major earning asset, with 36,000 acres in a manageable timber base.

Subsurface Considerations: N/A

Policy Considerations: Wisconsin has several conditions in place that could facilitate carbon project development on state trust lands. Although not excluded from participating in carbon markets, state trust lands are not specifically enabled to do so through legislative or other policy language. A state statute enables the use of easements on state lands Wis. Stat. 24.39.

Greenhouse Gas Emissions (GHG) Target?[1]	No	Although GHG emissions reduction target is not set by statute or executive, the updated Climate Action Plan sets a reduction goal for 26-28% below 2005 levels by 2025 and 1005 carbon-free energy by 2050.
State Climate Action Plan?[1]	Yes	Climate Change Report (2020) (updated from 2008). Includes a recommendation to "Implement climate-focused forest management" (#45).
Member of the US Climate Alliance?[2]	Yes	US Climate Alliance states have pledged to manage natural and working lands, including forests, farms, rangelands, and wetlands, to be resilient carbon sinks and protect the communities, economies, and ecosystems that depend on them.
Carbon Pricing?[1]	No	However, the Climate Change Report (2020) recommends "....conducting a complete analysis and creating a pathway to participate in or implement carbon pricing that is optimal for Wisconsin." (#35)

1 https://www.c2es.org/content/state-climate-policy/; 2 http://www.usclimatealliance.org/nwlchallenge

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Management Considerations for State Trust Lands in Wisconsin

Many state trust lands in Wisconsin are managed as high conservation value forests (HCVFs), with the majority enrolled in the Forest Stewardship Council (FSC) certification program. A number of these lands are situated in small, isolated parcels—for example swamps that are considered unmanageable. Wetland forested acres may provide a niche opportunity for preservation credits.

Data Availability in Wisconsin

Wisconsin has an extensive plot-based inventory system: the Continuous Forest Inventory (CFI). Forest attributes are measured on the ground within variable radius plots of 10-20 foot Basal Area Factor (BAF) within stands. In addition, coverage of 3D Elevation Program (3DEP) high-quality Light Detection and Ranging (LiDAR) is nearly statewide, and stereo National Agriculture Imagery Program (NAIP) is also available. Given the stand-level CFI and 3D remote sensing information, Wisconsin has sufficient data to run the gold model should it choose to do so.

Bronze Model Results

Estimates of total forest carbon stocks in in Wisconsin range from 2.6 to 43.5 tons of carbon per acre, with an average of 16.8 tons per acre on forested lands. That's an estimated total of more than 311 million tons of forest carbon in Wisconsin!

Forest Carbon Opportunity Example

Let's zoom in on the forested wetland region of North Eastern Wisconsin (Fig. 2). A large concentration of state trust land occurs as scattered parcels in and around the Nicolet National Forest—near the border with Michigan. Throughout this region there are few parcels with high total forest carbon stock. The majority of parcels are at or below average.

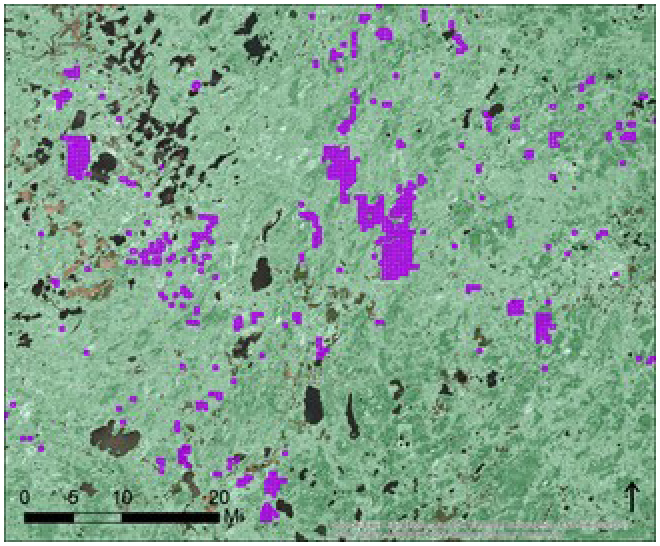


Figure 2. Zoomed-in area in Northeastern Wisconsin (~30,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 50 (dark green) tons/acre.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels and underplanting to increase diversity in cover type and age classes in parcels with mid-range total carbon stock (particularly the forested wetland areas). In addition, given the proximity to a National Forest and the State of Michigan, shared stewardship and collaborative landscape scale management plans are highly recommended.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Improving the results of the bronze model and including higher precision forest inventory data and 3D information will be important for estimates at the local level. Wisconsin's spatial data resources are at the silver level. With statewide high-density LiDAR and fixed radius plots of forest inventory data, gold-level models could be run to identify areas for which forest carbon projects warrant further exploration through a detailed feasibility analysis. To view the results of Wisconsin's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/wicarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

WY

Leveraging Improved Forest Management (IFM) as a Natural Climate Solution on State Trust Lands:
An Opportunity Assessment for Wyoming

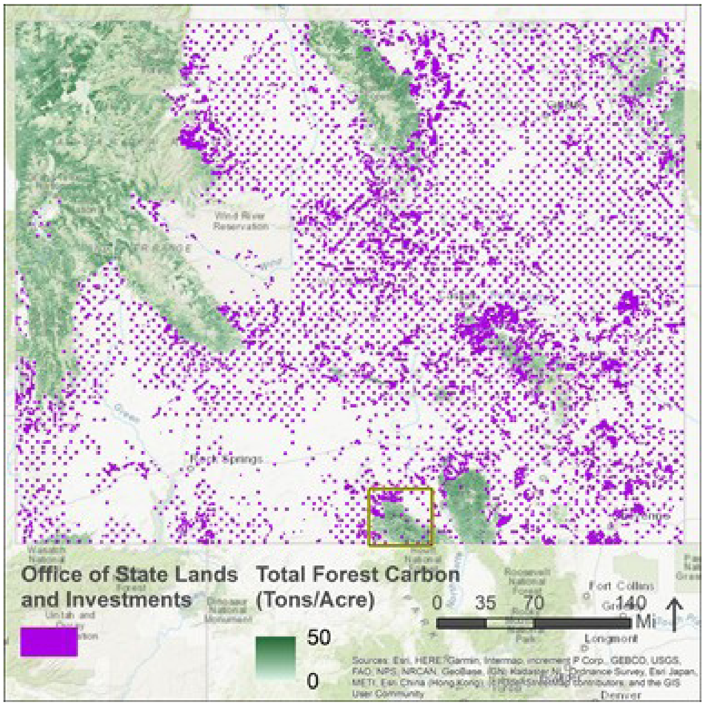


Figure 1. Forest carbon and the extent of state trust lands in Wyoming. Yellow box shows zoom-in area featured in Fig. 2.

Managing Agency: Office of State Lands and Investments (OSLI). OSLI serves as the administrative arm of the Board of Land Commissioners (BLC) and the State Loan and Investment Board (SLIB) and is a fiduciary agency for the State of Wyoming and the State's trust beneficiaries.

Beneficiary: Public schools (86%)

Acreage: 3.5 million (surface) (Figure 1)

Subsurface Considerations: 3.9 million acres of mineral resources. The main earning asset is mineral leasing and royalties, particularly oil and gas.

Policy Considerations: Wyoming lacks the policy elements that could smooth the way for state trust lands to participate in carbon markets. For example, the state does not have a Greenhouse Gas Emissions reduction target or a state climate action plan, which are two of the potential entry points for considering carbon markets. Although state trust lands are not barred from participating in carbon markets, enabling statutory language for participation in such markets does not exist.

This project sought to develop cost-efficient methods for identifying potential opportunity areas for forest carbon projects and to deploy these methods across the U.S., with a focus on states with significant amounts of state trust lands. We developed models to estimate carbon stocks at a gold (best), silver (intermediate) and bronze (coarse) level that can be applied depending on a state's data availability. The bronze model was run for a set of ten states with forested trust lands in the Midwest (MN, WI), Great Plains (MT, ND, WY), Pacific Northwest (WA, OR, ID), and the Southwest (CO, UT) for a high-level comparison using readily available data.

Data Availability in Wyoming

There are 9,956 permanent forest inventory plots in Wyoming, of which nearly 2,000 plots fall on forested lands. Wyoming is part of the Interior West Forest Inventory & Analysis (FIA). As interest and financial support increase, a state plan for acquiring Light Detection and Ranging (LiDAR) data will be developed for Wyoming.

Bronze Model Results

Estimates of total forest carbon stock in Wyoming range from 1.5 to 50.5 tons per acre, with an average of 20.1 tons per acre on forested lands. That's an estimated total of more than 153 million tons of forest carbon in Wyoming!

Forest Carbon Opportunity Example

Let's zoom in on an area in South Central Wyoming, near the border of Colorado in the Sierra Madre Range (approximately 11,000 acres of parcels, Figure 2).

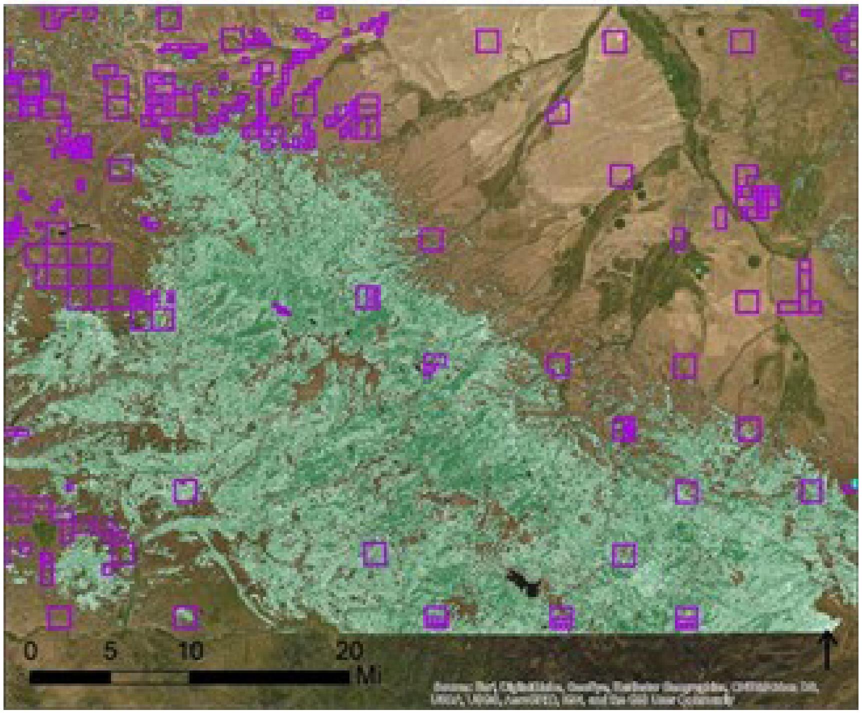


Figure 2. Zoomed-in area in South Central Wyoming (~11,000 acres of parcels). See yellow box in Figure 1 for spatial context. Background is forest carbon ranging from 0 (light green) to 50 (dark green) tons/acre.

Throughout Wyoming there are many small clusters of scattered state trust land parcels like this example, around 8,000-12,000 within a 1600 square mile area. With the exception of a few regions like this one (Figure 2), most of these parcels fall within high plains arid and desert-like settings, with little forest carbon stock.

Improved Forest Management (IFM) is the primary methodology available for revenue-generating forest projects in voluntary and compliance carbon markets. IFM techniques in this region may include thinning to release suppressed growth in the high total carbon stock parcels, fuel reduction to lower the risk of wildfire, or underplanting to increase biodiversity and age class diversity.

Comprehensive estimates of forest carbon stocks across the full extent of state trust ownership are an important first step in identifying opportunity areas for potential carbon project development. Wyoming's spatial data resources will lend themselves well to the silver level of forest carbon modeling once LiDAR data are available. Improving the results of the silver model and including higher precision forest inventory data will be important for higher confidence gold-level estimates at the local scale. To view the results of Wyoming's bronze model online or download the results, please visit this website: https://lspaete.users.earthengine.app/view/wycarbonviewer

This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

November 2021

Appendix C

Improved Forest Management:

An Opportunity to Stack Multiple Ecosystem Services on School Trust Lands

Author: Chris Wright, Ph.D

November 2021

Acknowledgments: This project was made possible through the generous support of the Doris Duke Charitable Foundation and The Nature Conservancy's Natural Climate Solutions Accelerator program. Project partners include Dovetail Partners, the Minnesota Department of Natural Resources Resource Assessment Program, University of Minnesota Duluth Natural Resources Research Institute, the Minnesota Office of School Trust Lands, and The Nature Conservancy-MN-ND-SD.

EXECUTIVE SUMMARY

School trust lands are public lands dating back to statehood that are managed to provide revenue to public schools; typically through leases (agricultural, commercial, mineral, oil and gas) and sales (timber, land, rights-of-way). School trust lands have an opportunity to broaden their revenue portfolios by engaging with ecosystem services markets. So-called 'Improved Forest Management' for carbon sequestration and carbon market participation is also consistent with various habitat and water quality services, providing an opportunity to 'stack' multiple ecosystem services payments. Here we discuss opportunities to market multiple ecosystem services on school trust lands in Minnesota and other states. Overall, we recommend that ecosystem services criteria be used to conduct a strategic assessment of school trust lands to identify the best and most marketable opportunities for multiple ecosystem services payments.

INTRODUCTION

School trust lands are an important and broadly misunderstood category of land ownership across the nation. They are publicly owned and managed, yet have a different legal purpose than other public lands. Just as state parks, wildlife management areas or other types of public land have legally defined objectives, so do school trust lands. They were established in multiple state constitutions to be held in trust for a single and specific purpose: to generate revenue for public schools. Legislation adopted by the U.S. Congress in 1785 established a framework under which states and territories reserved lands to help pay for public schools. Currently, twenty states still retain significant areas of trust lands, primarily in the western United States.

When Minnesota became a state in 1858, the federal government granted sections 16 and 36 of every township, or their equivalent, to the state for the use of schools. Today, Minnesota's school trust lands total approximately 2.5 million acres, the majority forestlands in the northern portion of the state (Fig. 1), with a statutory goal to "secure the maximum long-term economic return from the school trust lands consistent with the fiduciary responsibilities imposed by the trust relationship established in the Minnesota Constitution, with sound natural resource conservation and management principles[.]" (Minnesota Statutes, section 127A.31). This fiduciary responsibility is met primarily through mineral leases and royalty payments, with timber sales accounting for approximately 10% of annual trust revenues. In addition, recent legislation enables the Minnesota School Trust to "advance strategies on school trust lands to capitalize on ecosystem services markets[.]" (Minnesota Statutes, section 127A.353).

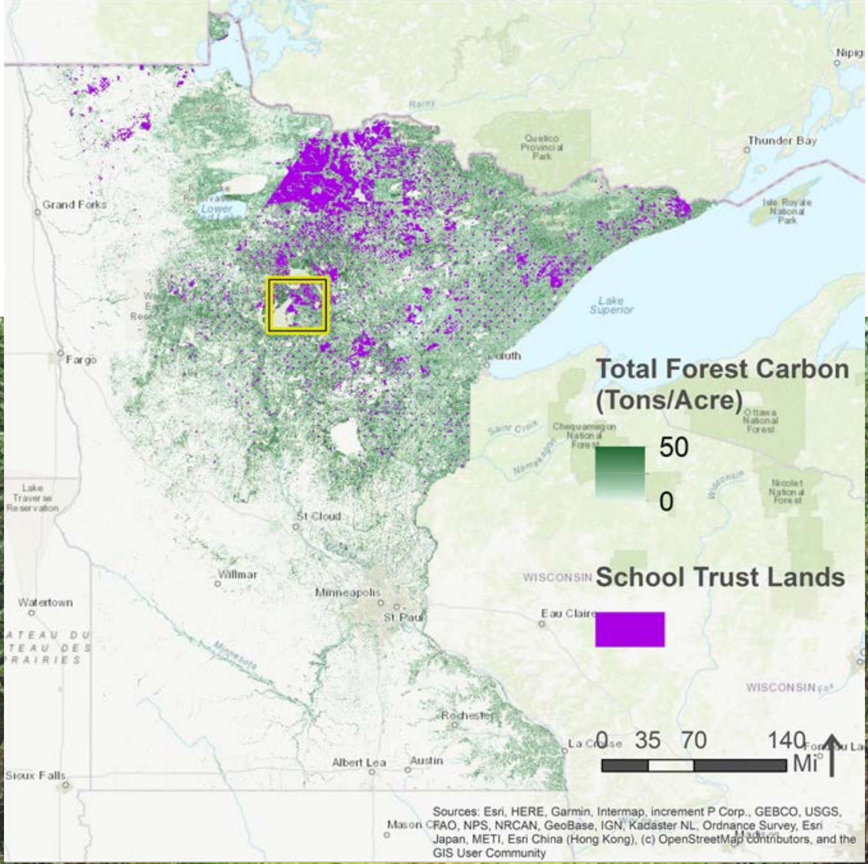


Figure. 1. Location of school trust lands in the state of Minnesota, along with estimates of aboveground forest carbon stocks. Yellow inset area is featured in Figure 2.

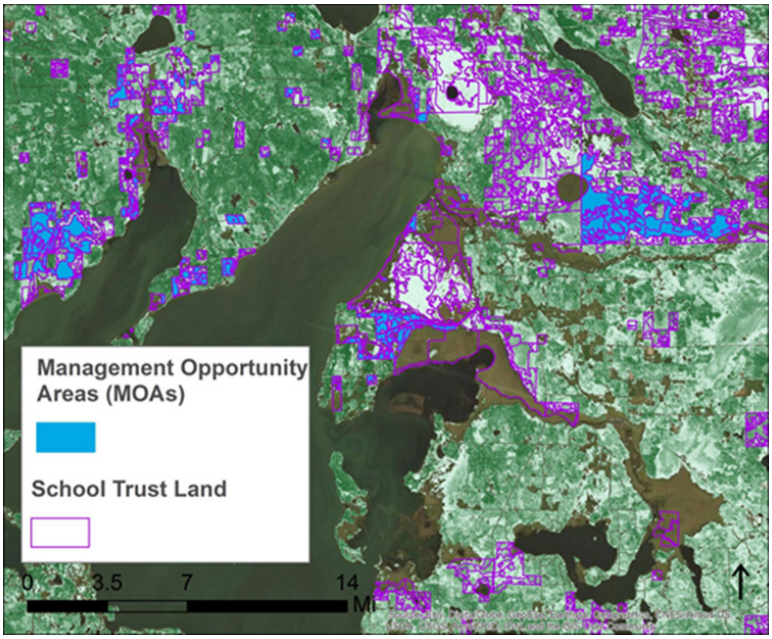


Figure. 2. Zoomed-in area in north-central Minnesota; partially surrounding Leech Lake, one of Minnesota's largest lakes. See yellow box in Figure 1 for spatial context. Background is estimated forest carbon stocks ranging from 0 (light green) to 50 (dark green) tons/acre. Management opportunity areas, in blue, are areas identified as having high potential for forest carbon sequestration projects on school trust lands.

In addition to timber and mineral resources, school trust forestlands provide the public with a host of other environmental benefits; including wildlife habitat, water quality protection, and climate regulation as well as offering the general public recreational opportunities. These benefits that humans receive from nature are sometimes called 'Ecosystem Services', and their monetary value may be considerable. In Minnesota, Polasky et al. (2011) found that including the value of forest carbon sequestration and water quality protection strongly favored forest-remaining-forest as the highest value land use as compared to conversion to agriculture. As another example, Moore et al. (2011) estimated that the state of Georgia's 22 million acres of private forestland generated non-timber ecosystem services valued at more than $37.7 billion per year, or more than $1,700 per acre per year.

In light of recent climate change, the climate regulation service provided by forests is of increasing importance. Annually, U.S. forests absorb around 14% of the country's CO_2 emissions, converting it to tree growth (Domke et al. 2021). Globally, it is estimated that forest protection and carbon-centric forest management could provide nearly 25% of the greenhouse gas emissions reductions required under the Paris Climate Accord to hold warming to less than 1.5 degrees Celsius (Griscom et al. 2017). In order to incentivize such reductions, carbon markets have emerged. Carbon markets allow greenhouse gas emitters to offset their emissions by investing in projects that remove CO_2 from the atmosphere by increasing forest carbon stocks above business-as-usual levels by implementing 'Improved Forest Management' (IFM) practices across a forest carbon project area. IFM practices that achieve higher carbon stocks include a range of silvicultural management actions such as: thinning for stand improvement, increasing the time between forest harvests (extended rotation length), uneven-aged stand management (patch cut, shelterwood, leave trees), or diversifying species within stands through planting to increase stocking rates (Kaarakka et al. 2021).

Importantly, IFM practices implemented to qualify for carbon credits may also increase the value of other ecosystem services. For example, extended rotations increase tree canopy cover at the landscape scale; thereby reducing storm runoff and increasing water filtration services. Uneven aged stands are more structurally complex than even aged stands, and thus provide diversified wildlife habitat. Lastly, diversifying species within a stand carries with it a host of potential ecosystem benefits, e.g., providing wildlife habitat, and potentially increasing ecosystem resilience to climate change through the planting of species better adapted to a changing environment.

Linked to implementation of IFM, these increases in benefits across a range of ecosystem services raise an important possibility – could carbon market participation enable participation in other ecosystem services markets? The marketing of multiple ecosystem services is known as 'benefit stacking'. Below we will review opportunities for benefit stacking on school trust lands in Minnesota, present examples from other parts of the U.S., discuss challenges to implementing benefit stacking, and suggest directions forward.

MARKET SECTORS

In addition to carbon markets, three other categories of ecosystems services markets exist: 1. Wetland mitigation banking, 2. Water quality trading, and 3. Species habitat banking. Section 404 of the Clean Water Act (CWA) mandates wetland protection through mitigation, restoration and replacement of wetlands through wetland banks. The CWA, and similar state laws, require land developers to mitigate any losses of wetland habitats (above a de minimis level) as a result of land development. Mitigation is accomplished by purchasing wetland mitigation credits from owners of restored wetlands, i.e. wetland banks. Historically, Minnesota has been a leader in wetland banking with more than $100 million in wetland mitigation credits sold from 1979-2013 (Forest Trends' Ecosystem Marketplace 2016). Additionally, the Minnesota Board of Water and Soil Resources operates a public commercial entity, the Minnesota Wetland Bank, which sells wetland credits to the public.

The CWA also allows the state of Minnesota to implement a water quality trading program whereby pollution point sources may offset releases into impaired waters by investing in non-point source reductions (Doucette et al. 2021); such as paying to plant riparian vegetation for streambank stabilization. In another type of water quality trading, it may be more cost-effective for a municipal water treatment plant to forgo expensive plant upgrades and instead pay forest landowners to implement certain practices that protect water quality, in what are known as 'Payments for Watershed Services' (Walls & Kuwayama 2019). A number of municipalities across the country have embraced such payments as a means to maintain forestland cover within reservoir catchment areas (Fernholz et al. 2021).

Lastly, the wetland banking concept can be applied more generally to habitat banking. Under the Endangered Species Act, a habitat bank is a parcel of protected land set up to meet mitigation requirements for threatened or endangered species (Bean et al. 2008). One example is the Nevada Conservation Credit System, designed to mitigate losses of sage grouse habitat (State of Nevada 2016).

OPPORTUNITIES

The development of projects involving multiple ecosystem services payments appears to be rare. For example, of 2,921 ecosystems services projects surveyed across the U.S., only 111 included multiple ecosystem asset types; none of which included a forest carbon component (Forest Trends' Ecosystem Marketplace 2016). In the area of green finance, there is not a mechanism to invest in green forestry bonds combining traditional timber production along with other ecosystem services such as water-quality protection and carbon sequestration (Bernknopf & Broadbent 2020). Nevertheless, there does appear to be a substantial opportunity to stack multiple ecosystem service payments in Minnesota, centered on forests. Recently, the Forest Trends' Initiative scored forested lands, nationwide, for their wetland restoration potential, habitat conservation potential and carbon sequestration potential. Minnesota's northern forests, including 1.5 million acres of productive school trust forestlands, score high across these categories (Forest Trends' Ecosystem Marketplace 2018). One such area includes the Leech Lake area in north-central Minnesota with a confluence of high forest carbon stocks and wetlands (Fig. 2). Other regions with similarly high scores include the Pacific Northwest and the Four Corners Region of the Southwestern U.S. in Utah, Colorado, New Mexico, and Arizona (Forest Trends' Ecosystem Marketplace 2018).

Minnesota has a novel watershed planning program, 'One Watershed, One Plan', which aligns local water-quality planning along major watershed boundaries (Board of Water and Soil Resources 2019). From a selection of four watershed plans, different types of opportunities for ecosystem services projects can be identified (Table 1). In the Pine River and Mississippi Headwater watersheds, there is an emphasis on preventing forest losses through conservation easements and enrollment for payments under Minnesota's Sustainable Forest Incentive Act (Table 1). In the Lake Superior North and Nemadji River watersheds, there appear to be opportunities for biodiversity and water quality projects (Table 1).

Table 1. Ecosystem services and mitigation measures identified from a selection of One Watershed, One Plan planning documents.

Watershed Name	Ecosystem Services	Mitigation Measures Proposed in Plan
Pine River (Rufer 2021)	Water Quality	Maintain forest as forest by purchasing conservation easements on undeveloped forestland; or purchase land outright
Mississippi Headwaters (Gutknecht et al. 2021)	Water Quality	Maintain forest as forest by enrolling land in the Sustainable Forest Incentive Act program
Lake Superior North (Cook and Lake Counties 2021)	Biodiversity; Water Quality	Manage forest density in riparian zone to extend snowmelt period and reduce flooding; plant conifers in areas with paper birch declines
Nemadji River (Bomier 2021)	Biodiversity; Water Quality	Manage forests to increase tree species diversity; enhance/restore riparian forest buffers to increase shading on priority trout streams

One example of a multiple ecosystem services trading system is the Willamette Partnership's Ecosystem Credit Accounting System in Oregon (Willamette Partnership 2017). The Willamette Partnership establishes three categories of ecosystem services for mitigation trading: 1) Aquatic habitat - including floodplain, wetland, and salmon habitat; 2) Upland habitat - including oak woodland, sagebrush, and prairie habitat; and 3) Water quality - with nitrogen, phosphorus, and thermal categories. One example of this trading system in operation is the Tualatin River thermal trading regime, where warm water discharge from the city of Medford, Oregon's wastewater treatment plant has been mitigated through the planting of riparian trees that shade and cool the Tualatin River (Willamette Partnership 2012). Although the Willamette Partnership system has been applied primarily in the western U.S., it seems entirely possible that a similar framework could be implemented in Minnesota and elsewhere.

CHALLENGES

Cooley & Olander (2012) identify 'Double Counting' as an important issue when stacking ecosystem services payments. Double counting occurs when stacked credits include overlapping ecosystem services. For example, suppose a restored peatland is marketed for carbon offset credits. Then, suppose the same restored peatland is marketed for wetland mitigation credits. However, wetland mitigation credits encompass the entire suite of ecosystem services performed by wetlands; including water quality protection, carbon sequestration, and biodiversity services. In this case, the carbon sequestration service has already been marketed as a carbon offset credit. Thus, double counting has occurred. Suppose instead that a biodiversity credit had been marketed rather than a wetland mitigation credit. With no overlap between the carbon and biodiversity services, there is no double counting.

The concept of 'Additionality' is typically encountered in carbon markets, where one objective is to avoid crediting landowners with carbon sequestration that would have occurred irrespective of a carbon payment. In other words, a carbon offset project must increase sequestration above business-as-usual levels. In the example above, one might argue that there is no additionality associated with the biodiversity credit, i.e., the restored peatland would have provided new habitat irrespective of whether a biodiversity credit was paid out. Cooley & Olander (2012) make an economic argument to resolve the additionality question: if a project is infeasible without two revenue streams from two different ecosystem services markets then the additionality condition is met, since neither project could occur in isolation.

One potential way to avoid issues with double counting and additionality is to clearly delineate each ecosystem service that is being marketed, with specific metrics for each service (Robertson et al. 2014). For example, the Willamette Partnership scheme very clearly subdivides upland habitat into different habitat types, as well as specifying different water-quality parameters for watershed services.

Payments for carbon sequestration services and wetland mitigation services come from well-defined, established markets. Watershed payments from a point-source emitter to a non-point source mitigation project are also straightforward, with a market that matches buyers with sellers. By contrast, other types of payments for watershed services appear to rely on more ad-hoc, less transparent markets. For example, a water treatment plant might collect user's fees to pay forest owners to implement certain practices or purchase conservation easements (Walls & Kuwayama 2019). Or, payments for watershed services might come directly from state conservation funds, as would be the case for potential projects in Table 1. In these cases, it is unclear whether recent enabling legislation would allow school trust lands to participate in ad-hoc water quality markets.

OTHER STATES

About 85% of all state-managed trust lands in the U.S. are found in nine states in the Intermountain West: Arizona, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, Washington, and Wyoming. At the same time, Federal land management agencies have embraced ecosystem services concepts in what Ruhl & Salzman (2020) term "a quiet revolution in natural resource management" in the Intermountain West. Lastly, climate change and rapid urbanization raise a need for broad, landscape-scale conservation. The challenge, as some see it, is to integrate state trust land management practices with large-scale conservation efforts on federal lands in ways that meet state's fiduciary obligations to their beneficiaries (Culp & Marlow 2015).

One way to address this challenge is to allow municipalities or non-governmental organizations to purchase or lease state trust lands at fair-market value for conservation purposes. States that allow this include Arizona and Idaho. All nine Intermountain West states allow the purchase of temporary conservation easements on trust lands in order to provide recreational opportunities or to protect natural values, air quality, or water quality (Culp & Marlow 2015). That is, these states allow a form of temporary easement for ecosystem services. Another example where ecosystem services on trust lands are indirectly marketed is Washington's Trust Land Transfer program, which transfers low-revenue-producing trust lands, with high conservation values, into protected status (Culp & Marlow 2015). Lastly, some western states have a unique situation with state trust lands located in close proximity to rapidly growing urban areas; making real estate sales and commercial leasing an attractive option to meet fiduciary responsibilities. In this case, a 'Master Planning' process in which a portion of trust land is set-aside as open space is one way to maintain some ecosystem services (Culp & Marlow 2015).

To the best of our knowledge, only the state of Colorado is actively considering direct participation in ecosystems services markets on state trust lands (Sonoran Institute 2012). However, as we have shown, other Intermountain West states are in essence indirectly marketing ecosystem services via leases, sales, conservation easements, and transfers.

RECOMMENDATIONS

Compared to private land managers, who may be under economic pressures to maximize short-term gains, state trust managers have the advantage of being large landholders with a duty to maximize trust assets for long-term economic returns for their beneficiaries. In essence, state trust managers must manage state trust lands sustainably to ensure revenue streams for future beneficiaries. We recommend that state trust managers use this flexibility to not only consider forest carbon market participation but other ecosystem services markets as well.

In an analysis of ecosystem services potential on Colorado State Trust Lands, a number of summary recommendations were made by the Sonoran Institute (2012). Below we paraphrase those recommendations, as we see them applying to trust lands in Minnesota and other states.

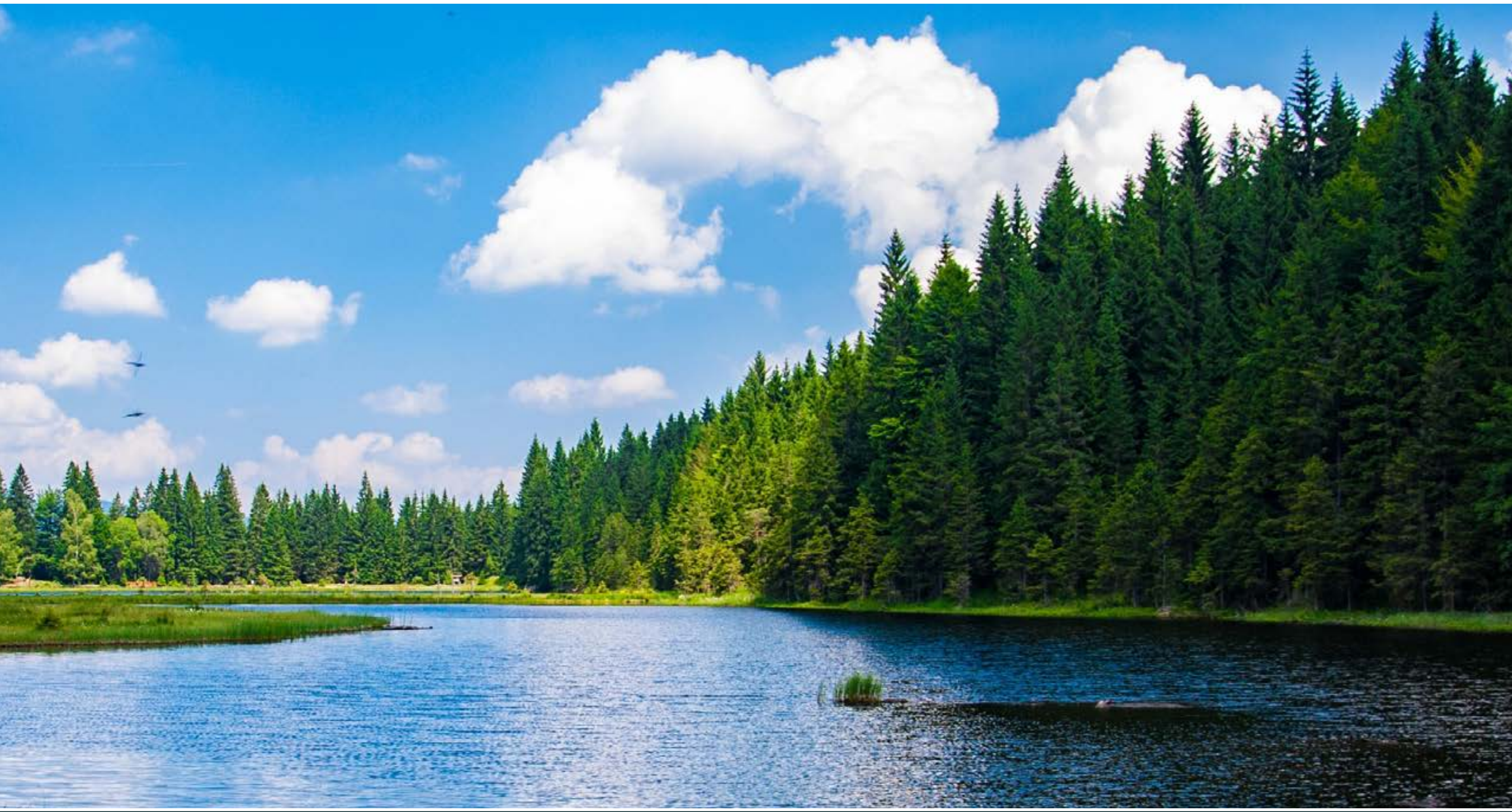
1. Adopt a consistent set of criteria for wetland mitigation, endangered species mitigation, and carbon market transactions to guide identification of lands for ecosystem services.

2. Use ecosystem services criteria to conduct a strategic assessment of state trust lands to identify the best and most marketable opportunities for ecosystem services.

3. Develop internal expertise and experience with ecosystem services markets to effectively evaluate opportunities.

4. Establish a policy to guide the use of real estate investments, like conservation easements, to enable lands to qualify for mitigation banking credits.

Keeping in mind the potential for double counting, and issues related to additionality, we recommend that state trust managers evaluate their resource base within a framework comparable to the Willamette Partnership's focus on different categories of ecosystem services. State trust managers should explore potential legal issues surrounding involvement in ad hoc water quality markets such as payments for watershed services from municipal water agencies. Also, there may be room for creative real estate transactions as seen in the Intermountain West. Lastly, Minnesota's One-Watershed, One-Plan system provides a useful template for identifying potential market opportunities and partners. Ultimately, the goal of stacking multiple ecosystem services payments should be to enhance the revenue stream of state trust lands by rewarding good land stewardship.



References

Bean M, Kihslinger R, Wilkinson J. 2008. Design of U.S. Habitat Banking Systems to Support the Conservation of Wildlife Habitat and At-Risk Species. Washington, DC: Environmental Law Institute. Available from https://www.eli.org/sites/default/files/eli-pubs/d18_02.pdf

Bernknopf RL, Broadbent CD. 2020. Estimating forest sustainability bond prices for natural resources and ecosystem services markets. J. Environmental Investing 10. Available from https://thejei.com/jei-vol-10-no-1-2020/

Board of Water and Soil Resources. 2019. One Watershed, One Plan: Plan Content Requirements. State of Minnesota. Available from https://bwsr.state.mn.us/sites/default/files/2019-12/1w1p_plan_content_requirements_2.1_0.pdf

Cook and Lake Counties. 2021. Lake Superior North: One Watershed One Plan. Available from https://www.co.lake.mn.us/wp-content/uploads/2020/08/Lake-Superior-North-One-Watershed-One-Plan-20170523.pdf

Cooley D, Olander L. 2012. Stacking ecosystem services: Risks and solutions. Environmental Law Reporter 42:10150-10164.

Culp S, Marlow J. 2015. Conserving State Trust Lands: Strategies for the Intermountain West. New York: Columbia University Press. Available from https://www.lincolninst.edu/sites/default/files/pubfiles/conserving-state-trust-lands-full.pdf

Deal RL, Cochran B, LaRocco G. 2012. Bundling of ecosystem services to increase forestland value and enhance sustainable forest management. Forest Policy and Economics 17:69-76.

Domke GM, Walters BF, Nowak DJ, Smith JE, Nichols MC, Ogle SM, Coulston JW, Wirth JW. 2021. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2019. Resource Update FS-307. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. Available from https://doi.org/10.2737/FS-RU-307

Doucette E, Graziani M, Henningsgaard B, Luckstein A, Peck J. 2021. Water Quality Trading Guidance: A Guide for the Implementation of Water Quality Trading Alternatives to Achieve Watershed Protection and Regulatory Authority. Saint Paul, MN: Minnesota Pollution Control Agency. Available from https://www.pca.state.mn.us/sites/default/files/wq-gen1-15.pdf

Fernholz K, McFarland A, and Klang J. 2021. Understanding Payments for Ecosystem Services: Opportunities for Forests, Water and Private Landowners in Georgia and the Southeastern United States. St. Paul, MN: Dovetail Partners. Available from https://dovetailinc.org/upload/tmp/1634217203.pdf

Forest Trends' Ecosystem Marketplace. 2016. An Atlas of Ecosystem Markets of the United States. Washington, DC: Forest Trends Association. Available from https://www.forest-trends.org/wp-content/uploads/2017/03/doc_5440.pdf

Forest Trends' Ecosystem Marketplace. 2018. Screening New Market Opportunities for Sustainably Managed State, Private, and Tribal Working Lands. Washington, DC: Forest Trends Association. Available from https://www.forest-trends.org/wp-content/uploads/2018/08/Screening-New-Market-Opportunities-for-Sustainably-Managed-State-Private-and-Tribal-Working-Forests-1.pdf

Forest Trends' Ecosystem Marketplace. 2021. 'Market in Motion', State of Voluntary Carbon Markets 2021, Installment 1. Washington, DC: Forest Trends Association.

Gutknecht Z, FitzGerald M, Mathisrud C. 2021. Mississippi River Headwaters Watershed Comprehensive Plan. Board of Water and Soil Resources. Available from https://headwatershed.org/plan

Kaarakka L, Cornett M, Domke G, Only T, Dee LE. 2021. Improved forest management as a natural climate solution: A review. Ecological Solutions and Evidence 2:e12090.

Mercer DE, Cooley D, Hamilton K. 2010. Taking Stock: Payments for Forest Ecosystems Services in the United States. Washington, DC: Forest Trends. Available from https://www.forest-trends.org/publications/taking-stock-payments-for-forest-ecosystem-services-in-the-united-states/

Moore R, Williams T, Rodgriguez E, Hepinstall-Cymmerman J. 2011. Quantifying the Value of Non-Timber Ecosystem Services from Georgia's Private Forests. Georgia Forestry Foundation.

Polasky S, Nelson E, Pennington D, Johnson KA. 2011. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the State of Minnesota. Environmental Resource Economics 48:219-242.

Robertson M, BenDor TK, Lave R, Riggsbee A, Ruhl JB, and Doyle M. 2014. Stacking ecosystem services. Frontiers in Ecology and the Environment 12:186-193.

Rufer M. 2021. Pine River Watershed: One Watershed One Plan. Board of Water and Soil Resources. Available from https://www.crowwing.us/DocumentCenter/View/17315/Pine-River-One-Watershed-One-Plan-Final-Pan?bidId=

Ruhl JB, Salzman J. 2020. Ecosystem services and federal public lands: A quiet revolution in natural resource management. University of Colorado Law Review 91:677-708.

Sonoran Institute. 2012. Analysis of Ecosystem Services Potential on Colorado State Trust Lands. Phoenix Arizona. Available from https://sonoraninstitute.org/files/pdf/analysis-of-ecosystem-services-potential-on-colorado-state-trust-lands-02022012.pdf

State of Nevada. Department of Conservation and Natural Resources. Sagebrush Ecosystem Program. 2016. Nevada Conservation Credit System Manual v1.1. Prepared by Environmental Incentives, LLC. South Lake Tahoe, CA.

Walls M, Kuwayama Y. 2019. Evaluating payments for watershed services programs in the United States. Water Economics and Policy 5:1950003.

Willamette Partnership. 2012. In it Together: A How-To Reference for Building Point-Nonpoint Water Quality Trading Programs. Case Studies (Part 3 of 3). Hillsboro, OR: Willamette Partnership. Available from https://willamettepartnership.org/wp-content/uploads/2014/09/In-It-Together-Part-3_2012-07-31.pdf

Willamette Partnership. 2017. Ecosystem Credit Accounting System. Portland, OR: Willamette Partnership. Available from https://willamettepartnership.org/wp-content/uploads/2014/06/General-Crediting-Protocol-v2.0_2013_updated-2017-1.pdf