Guide for a Forest Management/Stewardship Plan Addendum for Forest Carbon and Climate Resiliency

Securing Northeast Forest Carbon Program is an effort by the State forestry agencies of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island and Vermont to provide the latest forest carbon information to forestry professionals and landowners so that forest carbon management and sales decisions are made with full knowledge. The Program encourages foresters and landowners to add a forest carbon and climate resiliency[1] addendum to forest management and stewardship plans so that these important issues are taken into consideration in the management of forestland in the northeast U.S., resulting in more forest carbon being secured across the region and a more resilient forest.

We encourage the following steps in updating a forest management/stewardship plan to address climate change resiliency and forest carbon sequestration[2] and storage[3]:

1. Introductory section on climate impacts, vulnerabilities and forest carbon including carbon pools

Develop a narrative that describes:

a. Climate Change Impacts and Vulnerabilities: Provide a description of climate change impacts and associated property-level vulnerabilities that are expected over the next 50+ years for all major forest communities that are present on the property. These may include items such as:

- extreme rainfall and flooding/soil erosion risks,
- storms,
- altered seasonality,
- drought stress,
- introduction of non-native invasive pests, and
- tree species changes.

We need to look at these issues because management for forest carbon needs to consider the risks that the stand may face from climate change and other stressors in order to ensure that carbon management has long-term outcomes.

Resources to help develop the narrative:
Northern Institute of Applied Climate Science (NIACS) Adaptation Handbook - https://adaptationworkbook.org/
Vulnerability Assessment for the Northern Forest Region - https://www.fs.usda.gov/research/treesearch/55635

[1] Resiliency - the ability of a forest to absorb disturbances and change to maintain similar functioning and structure.
[2] Sequestration - process of removing carbon from the atmosphere through photosynthesis and storing it in another form that cannot immediately be released - wood.
[3] Storage - the total amount of carbon contained in a forest both aboveground (trees) and below ground (soil) at a given time.

Example narrative[4] - see Appendix A

b. Climate Change Challenges and Opportunities for Management: Based on expected climate change impacts and vulnerabilities for the property, identify:

- Major climate change challenges and opportunities with regards to management objectives, including situations where climate change may create significant barriers to achieving the landowners' goals.
- Potential effects, positive or negative, of climate change impacts on forest carbon—with a more robust discussion when the landowner identifies this as a management goal.
- The general management approach, to resist climate change, build ecosystem resilience, and/or help transition forests toward future conditions.

Resources to help develop the narrative:

NIACS Adaptation Handbook - https://adaptationworkbook.org/

Example narrative – see Appendix A

c. Forest Carbon Sequestration and Storage Options: There are many silvicultural methods to maintain or increase forest carbon sequestration and storage in your forest. Some options include:

- Thinning to remove lower quality and suppressed trees to improve growth on remaining trees;
- Pre-commercial thinning to speed the time to get the site fully stocked – not overstocked - with trees;
- Extending rotation age – i.e. age from time forest stand is established to when it is harvested;
- Reserves – setting aside areas where harvesting is not conducted – at least for very long periods of time if not permanently.

Example narrative – see Appendix A

2. Update landowner goals/objectives to reflect forest carbon/climate mitigation

Based on the vulnerabilities identified above, add goals/objectives to the plan that address these issues and reflect the landowner's desired direction relative to climate change mitigation and forest carbon.

Example goal/objectives:

Goal:
Address climate change effects on forests and manage for forest carbon sequestration and storage.

Objectives:

a. **Climate resiliency** – Take action to diversify species composition in all age/size classes and ensure structural complexity. Through species and structural tree size class manipulation, assure that the species, size and age classes that dominate the forest are well suited to the changes in climate that this area is experiencing.

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[4] Narrative from Massachusetts Department of Conservation and Recreation

b. **Forest carbon sequestration and storage:**
   1. Assure that young to middle age stands are not over or understocked. Use thinnings to remove lower vigor, disease or insect prone, and least climate adapted species to assure maximum sequestration.
   2. In middle to older aged stands, assure that stands are allowed to age to maximize carbon storage.
   3. For stands that will be harvested, place extra effort to assure that as much timber ends up in solid wood markets to assure long-term storage of harvested wood.
   4. Ensure prompt establishment of climate-adapted tree species following any regeneration harvest. Consider the impacts of deer herbivory and invasive species on regeneration success and failure and take measures to mitigate those impacts (e.g. deer fencing, large openings to overwhelm deer, routine monitoring for invasive species, rapid detection and response to invasive plants).

3. Inventory/carbon estimation

Once the forests' climate **vulnerabilities** are identified and the **challenges and opportunities** are developed, existing **forest inventory data and information can be expanded** to include forest carbon estimates.

Options:

- Stand by stand carbon stocks estimation summary if stand level data isavailable for carbon;
- Property wide carbon data;
- Carbon stocks estimation by carbon pools.

Depending on the amount of inventory data already collected for the property, the accuracy desired for this calculation, different methods for estimating carbon are available. These include[5]:

a. The Nature Conservancy's **Resilient Land Tool** - https://maps.tnc.org/resilientland/ - this is a powerful parcel specific tool to estimate standing forest carbon and sequestration rates. This tool allows users to explore site-specific estimates of stored forest carbon and average annual rates of carbon sequestration in all forest carbon pools for the years 2010 and 2050. Users can upload a shapefile of a property forest parcel or draw a polygon of the property on the map. *Important notes:* if there have been any significant changes since 2010, the data will not reflect that and carbon values may need adjusting. 2050 values are extrapolated from 2010 values based on standard growth curves. These are estimates and modeled values that may not reflect on-the-ground conditions.

And alternative to TNC's tool is the Trust for Public Land's Carbon Conservation Map online tool.

b. If you already have forest inventory data for the property, two main approaches can be used to estimate carbon (these only estimate live biomass carbon):

Approach A:

Two options from the USFS:

1. Calculate biomass directly from stand growing-stock volume (GSV) based on factors developed for each forest type and region.

[5] We suggest the reader go to the Securing Northeast Forest Carbon Program website page on estimating forest carbon to see a full suite of forest carbon estimating options, apps and tools at https://www.northeastforestcarbon.org/forest-carbon-estimators-and-calculators/

2. Calculate biomass expansion factor (BEF) based on volume and type from Hoover et al 2021 https://www.fs.fed.us/nrs/pubs/jrnl/2021/nrs_2021_hoover_001.pdf .
   Stand GSV is volume of trees >5 in DBH to 4 in at treetop (or point where stem breaks into limbs.

   Source paper for detailed methods: https://www.nrs.fs.usda.gov/pubs/gtr/gtr_nrs18.pdf

   Approach B:

   Calculate biomass from individual tree DBH, See Jenkins 2004 https://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2004/ne_gtr319.pdf

   Approach C:

   Newer Method: Big BAF sampling for carbon:

   Two angle gauges are used in big BAF sampling

   - Small angle gauge is used to select count trees and estimate BA per unit area (count BAF)
   - Larger BAF angle gauge is used to select trees for detailed measurement of volume (measure BAF) using BEF or allometric equations.

Source paper for detailed methodology: https://forestecosyst.springeropen.com/articles/10.1186/s40663-019-0172-4

4. Forest Carbon and Climate Management recommendations/future actions with timeline

Once all of the previous work is complete on your plan addendum (vulnerabilities, opportunities, goals & objectives and carbon estimating), it is time to develop actual recommendations for future action and a timeline to complete climate and carbon related tasks. Key areas to cover include:

a. Actions to address **keeping forests as forests** – The most important action a forest landowner can take for climate resiliency and carbon is to assure their forest remains as forest. Actions to explore include:
   - Family voluntary commitment to keep the forest as forest for a time period;
   - Legal restrictions to assure the forest is kept as forest during the current owner's lifetime;
   - Legal action to donate or sell a conservation easement to assure permanent restrictions keep the land in forest perpetually.

b. Actions to address **resiliency of the forest** to changes brought on by climate change – There are many possible actions that can be taken to improve on the resiliency of the forest:
   - Change species make-up to favor species (oaks, maples and other hardwoods) that are likely to do well as climate changes. Red maple will likely do much better than sugar maple. See Appendix and Forest Adaptation https://forestadaptation.org/assess/tree-species-risks for species lists;
   - Increase tree species diversity if forest currently is dominated by a few species;

- Improve structural diversity to assure multi-age stands or various age and size-class stands in the forest (if the desire is to maintain more even-aged stands rather than convert to more multi-age stands);
- Improve forest health through thinnings focused on removing unhealthy or insect infested trees, while assuring a dead wood component is retained;
- Address significant invasive species problems;
- Upgrade water crossings and other BMPs to accommodate larger storm water volume.

Note: *these actions can be done property wide or tied to specific stands.*

c. Actions to address landowner goals related to **forest carbon**:

- To increase carbon sequestration -
- Thinnings in stands of high carbon species (oaks, maple etc.) to increase growth rates;
- Regenerating older stands as part of other forest management objectives and actions and encouraging regenerating species that are both adaptive and appropriate to climate change and significant species for sequestration and carbon storage.
- To increase carbon storage –
- Grow carbon intensive species to longer rotation ages;
- Identify set-aside areas appropriate for no-harvest options;
- Harvest species and size classes that will encourage the largest proportion of trees going into solid wood products to assure carbon storage in products.
- Forest carbon markets – Explore the small-landowner options for selling forest carbon through:
- Forest Carbon Works
- Family Forest Carbon Program
- CORE Carbon
- NCX.

5. Monitoring

Any forest management plan of action needs to include a monitoring protocol to assure the planned action yields the desired result. For each plan objective and action, a monitoring action and timeline should be identified. Examples of this might be as follows:

Management Plan Objective/Action	Monitoring Action
a. Keeping forests as forests – The most important action a forest landowner can take for climate resiliency and carbon is to assure their forest remains as forest.	Annual visiting of actions taken to secure the land as forest.
b. Actions to address **resiliency** of the forest to changes brought on by climate.	Every 5 years, list the forest management actions taken that address resiliency. Discuss effectiveness.
c. Actions to address landowner goals related to **forest carbon**:	Every 5 years, list the forest management actions taken that address carbon. Discuss effectiveness.

Appendices

Appendix A

Example narratives:

a. Climate Change Impacts and Vulnerabilities: Provide a description of climate change impacts and associated property-level vulnerabilities that are expected over the next 50+ years for all major forest communities that are present on the property. These may include items such as: extreme rainfall, storms, altered seasonality, drought stress, and tree species changes.

Example narrative[6]:
All available climate models agree that temperatures will increase across all seasons in the Northeast region over the next century. The projected increase in annual temperature ranges from 3 to 10°F by the end of the century. While it is difficult to predict how future precipitation will change, total annual precipitation is generally expected to increase over the next 100 years. The greatest precipitation increases are expected to occur during the winter, where warmer temperatures will result in more winter precipitation falling as rain instead of snow. There is more uncertainty as to whether precipitation will increase or decrease during the growing season. Even with moderate increases in rainfall, there may be more frequent droughts in the summer and/ or fall because higher temperatures will lead to greater water loss from evaporation and transpiration.

Anticipated impacts on northeast forests, with consideration of how each may affect this woodlot include:

- Extreme precipitation and more frequent and intense weather events are expected in the Northeast region throughout the next century.
- Soil moisture patterns will change, with greater risk of drier soil conditions or drought later in the growing season.

The property is characterized by moderate to steep slopes that are often associated with vulnerability to intense windstorms, but the overall northwest aspect significantly reduces this risk as storms typically do not come from this direction. In this region, southeast-facing slopes are in the most vulnerable position to hurricane winds.

Soils underlying the property are of glaciofluvial origin and include the Hinckley, Canton, and Gloucester series, which range from well-drained to excessively-drained. The western portion of the tract is mostly Hinckley soils, while Canton and Gloucester soils dominate the eastern portion. These soils include sandy till and are generally deeper at the bottom of the hill, while they become thinner and rockier towards the upper parts of the property. Soil drainage conditions mean that the property has a relatively low vulnerability to erosion and sedimentation associated with extreme precipitation events, especially given the topography. However, it is vulnerable to drier soil conditions and drought, which can hinder seed germination and establishment.

- Forest insect pest and pathogen outbreaks are expected to increase in occurrence and inflict more damage
- Low-diversity systems are at greater risk

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[6] Narrative from Massachusetts Department of Conservation and Recreation

The topography of the woodlot is highly varied, especially on the western side. Considering the whole property, forest composition is fairly diverse with a range of conifers (e.g., white pine, hemlock) and hardwoods (e.g., oaks, hickories, maples, birch species, white ash, poplar, black cherry) represented. In the near-term, the most vulnerable species is hemlock due to the level of infestation of invasive elongate hemlock scale, along with some hemlock woolly adelgid. Much of the relatively small component of white ash will likely succumb to the emerald ash borer, with this beetle confirmed to be present locally. Oaks and hickories are expected to grow well in future conditions, while impacts from pests such as Lymantria dispar (spongy moth) are hard to predict.

- Many northern tree species will face increasing stress from climate change;
- Conditions may become more favorable for some southern tree species;
- Species and forest types that are more tolerant of disturbance have less risk of declining across the landscape.

The largest stand (Stand 1) is dominated by white pine and hemlock, two species which are projected to have poor capability for adapting to changing climate conditions. With hemlock facing many stressors, from invasive insects and being a species that does not respond to disturbance well unless it is fully established as an understory tree, it is a species at high risk on the property. Other northern species on the property which may not compete as well due to lengthening growing season and regeneration failure are eastern white pine, due to warmer winters and increased spring precipitation increasing native needle cast fungi, and white ash due to a variety of health issues. Trees on the property that may adapt well to the changing climate are red oak and sugar maple, especially on the more mesic soils and protected areas. Birch, poplar, and black cherry respond well to disturbance and are less of a concern on the Sample property.

- Populations of key herbivores will be affected

White-tailed deer populations are relatively high in the woodlot area and deer will likely benefit from milder winters, while moose are uncommon and projected to become increasingly less so at the southern edge of their range. Deer browse is already observed to be heavy on oak seedlings, while less so on black birch and maple. Protecting oak seedlings from browse will be an important part of maintaining species diversity on the Sample property.

- Many non-native, invasive species will increase

Invasive plants are present on the property and mostly found at moderate levels at the top of the hill in Stands 2 and at a higher density along the woods road at the southern edge of the property (Stand 3) that was grazed by a tornado approximately 10 years ago. The present non-native species include Asiatic bittersweet, autumn olive, Japanese barberry, and winged euonymus. Well-adapted to changing conditions, these invasives are likely to expand their populations, especially in areas where disturbance occurs. Controlling the existing invasives and monitoring for future infestations will be an important part of the management of the property.

b. <u>Climate Change Challenges and Opportunities for Management</u>: Based on expected climate change impacts and vulnerabilities for the property, identify:
   - Major climate change challenges and opportunities with regards to management objectives, including situations where climate change may create significant barriers to achieving the landowners' goals.

- Potential effects, positive or negative, of climate change impacts on forest carbon—with more robust discussion when the landowner identified this as a management goal.
- The general management approach, to resist climate change, build ecosystem resilience, and/or help transition forests toward future conditions.

Example narrative:

This property is a good match for promoting an overall "resilience" approach to managing with projected future climate conditions in mind. This approach will allow for the forest on the property to experience some changes with the goal of retaining existing species and habitat characteristics as much as possible, while understanding that some characteristics will change. Secondary strategies include "resisting" climate change in the vulnerable habitat along the stream and potentially promoting "transition" to future-adapted species and plant communities as the property is monitored for regeneration successes/failures.

Protecting the regeneration capacity of the forest is an important goal and objective at the property, as it is in most other managed forests. Successful regeneration is a basic indicator of forest sustainability that refers to the ability of mature forest trees to produce seed that germinates into young trees that have the capability to grow into the canopy and ultimately replace the older trees as they decline or die or regeneration from stump sprouting in hardwood trees – or both seed and sprouting sources. While species composition may shift over time, regeneration is essential to maintaining a healthy natural forest. Unfortunately, forest regeneration on the property faces some common threats or resource concerns, including forest insect pests, deer herbivory, and invasive plants. These are described in the paragraphs above, below, and in the more detailed stand descriptions.

Challenges

Managing the forest, largely stocked with species projected to have poor climate adaptation capability, presents a significant challenge. Stand 1 comprises of 80% of property by land area and is dominated by two species, hemlock and white pine, that are anticipated to decline over different time horizons. As the elongate hemlock scale and adelgid-infested hemlock declines and experiences more significant mortality, the family is interested in conducting pre-emptive salvage harvesting that will require careful planning and execution. While hemlock is under stress from both climate changes and exotic pests, it is also an important component of our forests, providing a unique habitat type for wildlife and shade conditions for upper-level streams. The family is interested in a resistance strategy to attempt to maintain hemlock on the landscape where feasible.

Opportunity

While it is expected that over the long-term hemlock and white pine will decrease in numbers, oaks and other hardwoods may expand their range. Since red oak, hickories, and other hardwoods are a secondary component of the property, this provides an opportunity for the family to experiment with silvicultural strategies.

While market conditions are favorable for the harvest of hemlock and white pine, there is an opportunity to regenerate parts of the property improving stand structure and enhancing resilience. Creating and maintaining access from Main Road for periodic timber management should be considered before the next entry.

Although regenerating oak is already difficult with current levels of deer herbivory and may become more so in the future, there is room for expanding existing approaches and trying new ones. The Samples do allow hunting with permission. The next logical step would be to monitor deer impacts and hunting more closely, and then to intensify deer hunting if warranted. If possible, coordinating efforts with nearby large landowners will help increase the success of hunting initiatives. The use of tree shelters, planting tree seedlings, constructing deer exclosures, and leaving tree tops and brush after harvesting can also aid the regeneration of oak, as well as other species, to maintain and increase tree diversity.

Since invasive plant species are likely to spread, monitoring both the relatively concentrated population of invasives in the southwestern corner of the property and outlying invaders will become increasingly important. Since invasives can aggressively colonize disturbed areas, this will be especially critical in areas that experience natural disturbance (e.g., canopy gaps resulting from windthrow) and those where timber harvesting is carried out. Projects the family have agreed to pursue are a chemical treatment with follow up hand-pulling or cutting, and various types of monitoring of the invasives.

c. Forest Carbon Sequestration and Storage Options

Example narrative:

Forests of the northeast are an important part of climate mitigation through the sequestering and storing of carbon. Those managed for climate resiliency are even likely more capable of sequestration and carbon storage. The family's forest currently stores more than an estimated 2800 tons of carbon in live above and below-ground carbon, an amount equivalent to the CO_2 emissions released from burning more than 1 million gallons of gasoline. This amount is not static, as living vegetation continually net absorbs more carbon dioxide while decaying plants release it back into the atmosphere. The challenge is to increase forest carbon sequestration and storage over the long-term while accounting for inevitable reductions resulting from different types of disturbances, both natural and those caused by humans. Due to past harvests, the basal area of the forest is on the low to moderate end (10th -70th percentile, depending on stand), compared to other stands in this part of northeast. However, because the trees are taller than they would be in an unmanaged stand of equivalent basal area, carbon stocks are likely to be slightly higher than the basal area suggests. Considering the range of younger to older stands on the forest, this tract is in a position for great per acre sequestration than the average acre due to a significant component of younger, fully stocked stands.

Considering current forest health issues and looking at the projections for the most common tree species on the property, the family's have an opportunity to increase long-term carbon storage and overall sequestration by continuing active management, which includes timber harvesting to achieve their biodiversity goals. Without active management, declining vigor of hemlock due to pest infestations will lead to lower sequestration rates, and ultimately the loss of carbon stocks as trees succumb to mortality. While periodic harvests will lead to short-term carbon loss, this strategy will aim to regenerate species projected to grow well in the future and maintain an overstory of healthy trees needed to meet both storage and sequestration goals. Increased growth in remaining trees, as well as new seedlings that become established after harvest, will increase sequestration rates. Over the long-term, shifting species composition towards a forest more dominated by oaks and other hardwoods, while still maintaining white pine and as much hemlock as possible as a major species, will create a more complex forest structure that can sequester and store more carbon per acre than the average acre in the region. Small natural disturbances may help to increase sequestration rates. However, if disturbances are significant enough to lead to an undesirable decrease in carbon stocks, harvest schedules can be adjusted.

The soil carbon pool is one of the largest pools in the forest ecosystem. The soil carbon will be protected during timber harvesting by ensuring that the soil is in a stable condition, either frozen or dry, during operations. Where soils have higher soil moisture, these areas will either be avoided or timber mats will be used to prevent impacts. The number of skid roads will be minimized through careful, advanced planning.

Control or removal of invasive plant species that compete with native regeneration will also improve sequestration rates and carbon stocks over the long-term. Since this practice is resource intensive, care should be taken on deciding which species to treat, by what means and when.

Appendix B

Tree Species climate resiliency and carbon characteristics

(from NY Dept. of Environmental Conservation (DEC))

Table 5. Expected tree habitat availability change by 2100 under high and low emissions climate change scenarios in the Mid-Atlantic (New York south of the Adirondacks to Maryland) and Northeast (Adirondacks in New York and Connecticut to Maine). Decline: ⇩ Large decline: ⬇ Increase: ⇧ Large increase: ⬆ Pest/disease: 🐞

Tree species	Mid-Atlantic		Northeast		Model reliability	Other threats
	Low emissions	High emissions	Low emissions	High emissions		
American basswood		⇩		⬆	Medium	
American beech	⇩	⬇		⇩	High	🐞
American elm		⇧	⇧	⬆	Medium	🐞
American holly		⇩		⬆	Medium	
American hornbeam				⬆	Low	
American mountain ash	⬇	⬇		⬇	Low	
Atlantic white cedar		⇩			Low	
Balsam fir	⬇	⬇	⇩	⬇	High	🐞
Balsam poplar	⇩	⇩	⇩	⬇	Medium	
Bigtooth aspen		⬇		⇩	Medium	
Bitternut hickory		⬆		⬆	Low	
Black ash	⬇	⬇	⇩	⇩	Medium	🐞
Black cherry		⬇		⇧	Medium	
Black locust			⬆	⬆	Low	
Black maple	⇩	⬇		⇩	Low	
Black oak		⬆	⇧	⬆	High	🐞
Black spruce	⇩	⬇	⬇	⬇	High	
Black walnut	⇧	⇧	⇧	⬆	Low	
Black willow		⬆	⇧	⬆	Low	
Black gum	⇧	⇧		⬆	Medium	
Boxelder		⇧		⬆	Low	
Bur oak		⬆		⬆	Medium	🐞
Chestnut oak			⇧	⬆	High	🐞
Cottonwood		⬆	⇧	⬆	Low	
Cucumber tree	⇧	⇩			Low	
Eastern hemlock	⇩	⬇		⇩	High	🐞
Eastern hophornbeam				⇧	Low	
Eastern red cedar	⇧	⬆	⬆	⬆	Medium	
Eastern redbud		⬆	⇧	⇧	Low	
Eastern white pine	⇩	⬇		⇩	High	🐞
European larch	⇩	⬇	⇩	⇩	No model*	
Flowering dogwood	⇧	⬆	⬆	⬆	Medium	
Gray birch	⇩	⇩		⇩	Low	
Green ash		⬆		⬆	Low	🐞
Hackberry	⇧	⬆		⬆	Medium	
Honey locust		⬆		⬆	Low	

Tree species	Mid-Atlantic		Northeast		Model reliability	Other threats
	Low emissions	High emissions	Low emissions	High emissions		
Jack pine	⬇	⬇	⇩	⇧	Medium	
Japanese larch	⇩	⇩	⇩	⇩	No model*	
Mockernut hickory		⬆	⇧	⬆	Medium	
Mountain maple	⇩	⬇	⇩	⬇	Low	
Northern red oak			⇧	⇧	Medium	🪲
Northern white cedar	⬇	⬇	⇩	⬇	High	
Norway spruce	⇩	⬇	⇩	⇩	No model*	
Paper birch	⬇	⬇	⇩	⬇	High	
Pignut hickory		⇧	⇧	⬆	Medium	
Pin cherry	⇩	⬇		⇩	Low	
Pin oak	⇧	⬆	⇧	⬆	Low	🪲
Pitch pine				⇧	High	🪲
Post oak	⬆	⬆			High	🪲
Quaking aspen	⇩	⬇		⬇	High	
Red maple		⬇		⇩	High	
Red mulberry		⬆	⬆	⬆	Low	
Red pine	⇩	⬇		⬆	Medium	
Red spruce	⇩	⇩	⇩	⬇	High	
River birch					Low	
Sassafras	⇧	⇧	⬆	⬆	Low	
Scarlett oak	⇧	⇧	⇧	⬆	Medium	🪲
Serviceberry		⇩		⇧	Low	
Shagbark hickory	⇧	⬆	⇧	⬆	Medium	
Silver maple	⇩	⬆	⇧	⬆	Low	
Slippery elm		⇧	⇧	⬆	Low	
Striped maple		⬇		⬇	Medium	
Sugar maple		⇩		⇩	High	
Swamp white oak				⇧	Low	🪲
Sweet birch		⬇	⇧	⇧	High	
Sweetbay					Medium	
Sycamore	⇧	⬆		⬆	Low	
Tamarack	⇩	⇩	⇩	⇩	High	
Virginia pine					High	🪲
White ash		⇩			Medium	🪲
White oak		⇧	⇧	⬆	Medium	🪲
White spruce	⇩	⇩	⇩	⬇	Medium	
Yellow birch		⬇		⬇	High	
Yellow (tulip) poplar	⇧	⇩	⬆	⬆	High	

References: Iverson et al 2008, Wolfe et al 2011; Tetra Tech 2013; Butler-Leopold et al 2018, Janowiak et al 2018, Swanston et al 2018, & Iverson et al 2019. *Estimates from Levesque et al 2013, Tei et al 2014, Hartl-Meier et al 2014, Obojes et al 2018, & Bosela et al 2021.

Appendix C – Sample Forest Management Recommendations

From NY DEC

Recommendations for all forest areas

These recommendations can apply to all forests, including those listed in the additional sections below.

Recommendations	Climate resilience	Carbon storage	Carbon sequestration

• Maintain and increase forest area
  • Forest conversion leads to the greatest emissions and loss of carbon benefits
  • Consider land use trade-offs and permanence of protection
  • Long-term forest land ownership
  • Keep forests as forests
  • Reforestation
  • Afforestation
  • Urban forestry
  • Agroforestry
	✓	✓	✓

	Butler-Leopold et al 2018, Janowiak et al 2018, Swanston et al 2018		
• Maintain and increase forest connectivity	✓		
	Butler-Leopold et al 2018, Janowiak et al 2018, Swanston et al 2018		
• Promote landowner knowledge • Including forest management benefits, BMPs, and legacy planning	✓	✓	✓
	Crokett et al 2021, Park et al 2021		
• Maintain native herbaceous vegetation abundance and diversity to protect soil health	✓	✓	
	Horton et al 2015		

• Avoid and restrict high intensity recreation that will damage regeneration, understory, and soils, especially in sensitive habitats or soil types
  • Look for signs of excessive wear and poor trail siting that need time for revegetation and soil stabilization
  • Consider soil impact of different types of recreation on the forest
  • Encourage recreators to stay on trail
	✓	✓	✓

	Horton et al 2015, Swanston et al 2016		
• Reduce the number of roads to less than 15% of a water basin • Avoid road construction in wet weather and when stream flow is high	✓		
	Horton et al 2015		

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• Identify and manage cooler and wetter locations and areas with high species, geological, soil, and other diversity • Limit harvests in potential refugia and locations with uncommon and at-risk species	✓		
	Swanston et al 2016		
• Restore or maintain use of prescribed fire in fire-adapted ecosystems including the establishment of fuel breaks	✓		
	Ontl et al 2020		
• Use thinning to lower tree stress in areas expected to experience droughts, areas with drought-sensitive tree species, and when it will reduce risk of wildfire, pests, and diseases • Typically remove <25% BA over 20 years (between A and B line for fully stocked stands)	✓	✓	✓
	Yaussy et al 2013, Horton et al 2015, Gleason et al 2017		
• Postpone silviculture treatments that will increase tree stress if damaging pest populations are expected or present in an area	✓	✓	
	Horton et al 2015		
• Retain disturbance-generated structure and tree survivors of pest and disease outbreaks	✓	✓	
	Horton et al 2015		

Restoration Projects

Planting and Natural Regeneration

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• Consider introducing genotypes and species adapted to future conditions, especially in declining stands	✓		
	Horton et al 2015, Swanston et al 2016, Ontl 2020		
• Collect seeds and other genetic materials from at-risk species for genetic repository	✓		
	Swanston et al 2016		
• Avoid or minimize scarification and tillage to protect existing soil carbon stocks – especially on previously uncultivated forest sites	✓	✓	
	Nave et al 2009 Picchio et al., 2012, Jevon et al 2019, Grandy and Robertson 2006		

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• Reduce deer and/or moose pressure in areas they are over browsing and preventing adequate regeneration • Consider use of exclosures and/or tree tubes for high value sites or sites with very poor regeneration	✓	✓	✓
			Horton et al 2015
• Monitor regeneration and implement plantings and deer exclosures in areas showing regeneration failure 2-5 years after harvests	✓	✓	✓
			Kern et al 2013, Horton et al 2015

Understocked forests

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• Restore degraded or poorly stocked stands, including those impacted by high grading • Specific practices may include crop tree release, timber stand improvement, and reforestation fill planting which favor an increase in diameter of crop trees • With caution, consider limited scale use of rehabilitation clear cuts on areas with the poorest residual stocking	✓	✓	✓
			Russell-Roy et al 2014, Kenefic et al 2014

Forests with low species diversity

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• Underplant with conifers in suitable sites with low proportion of conifers and areas where conifer cover is critical	✓	✓	✓
			Horton et al 2015

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• Use gap cutting to improve species compositional, structural, age, functional and other diversity ◦ Specific practices may include individual selection, group selection, irregular shelterwood, two-aged management, seed-tree, variable-retention harvests, and structural complexity enhancement ◦ Consider the diversity of surrounding seed sources to help determine if natural regeneration will be sufficient or if planting will be needed to increase diversity ◦ Typically, 5-15% of stand, <20% over a 20-year period ◦ Protect regeneration in areas of high deer browse and low regeneration success	✓		✓
	Horton et al 2015, Ford and Keeton 2017, Knapp et al 2021		
• Increase plantation complexity through underplanting and natural regeneration of other species	✓	✓	✓
	Horton et al 2015		
• Target failing pine stands and plantations with regeneration cuts to increase species diversity and revitalize tree growth	✓	✓	✓

For thinning and harvests

The table below lists recommendations that should be considered for all thinning and harvests. For thinning, it is recommended that <25% BA is removed over 20 years (between A and B line for fully stocked stands). Additional information and recommendations are also included in a separate table further below following a discussion on high vs low-intensity management.

Recommendations	Climate resilience	Carbon storage	Carbon sequestration
• **Retain and favor more southern-adapted species like oaks and hickories and species that are successful under a wide-range of growing conditions**	✓	✓	
	Horton et al 2015, Swanston et al 2016, Ontl 2020		

Recommendations	Climate resilience	Carbon storage	Carbon sequestration

• Maintain and increase heterogeneity in species composition, structure, and function during thinning
  • Increase biodiversity in retention guidelines
  • Thin from below or proportionally; do not high-grade
	✓	✓	

	Nyland 2007, D'Amato et al 2011, Horton et al 2015		
• **Prevent damage to understory retention trees**	✓	✓	✓
	Horton et al 2015		
• **Protect trees from wind damage by retaining additional trees at the edge of a harvest, conducting harvests over multiple years, and shaping canopy gaps to protect them from prevailing winds**	✓	✓	
	Horton et al 2015, Swanston et al 2016		
• **Increase proportion of harvested materials sent for use in durable, long-lived wood products**		✓	
• **Consider using cut-to-length harvesting to reduce wood processing at landing sites, which leads to methane emissions**		✓	
	Vantellingen and Thomas 2021		
Regeneration			
• **Ensure that advanced regeneration is abundant before removing the overstory when implementing even-aged or large-gap forest management**	✓	✓	✓
	Kern et al 2013, Horton et al 2015, Knapp et al 2021		
• Treat invasive species and competing vegetation prior to thinning or harvesting to increase regeneration success • If harvest cannot be avoided and propagules still exist on site, conduct harvests when conditions will limit the spread, such as when there is heavy snow cover • Clean equipment before moving from one site to another to prevent the movement of invasive plants and tree diseases	✓	✓	✓
	Horton et al 2015		
• **Control beech suckers and sprouts in areas with beech bark disease prior to thinning or harvesting to increase regeneration success**	✓	✓	✓
	Swanston et al 2016		

Recommendations	Climate resilience	Carbon storage	Carbon sequestration

• Reduce deer and/or moose pressure in areas they are over browsing and preventing adequate regeneration
    • Consider use of exclosures and/or tree tubes for high value sites or sites with very poor regeneration
    • Time harvests to match low points in deer density and high points in seed crop productions
    • Leave treetops intact after harvests, particularly over desired deciduous species stumps or construct slash walls around the perimeter of harvest areas for exclusion
    • Harvest multiple nearby parcels at the same time to overcome local deer pressure
• Use multiple gap and patch clearcuts (these clearcuts typically go up to 10 acres each) over the landscape to allow regeneration
	✓	✓	✓

			Horton et al 2015, Smallidge et al 2021
• **Minimize the number of skid roads and pre-bunch harvest trees to minimize skid trails**	✓	✓	
			Horton et al 2015, Crawford et al 2021
Soils			
• **Leave tops and course and fine woody materials in place to improve nutrient load, soil carbon, and soil moisture**	✓	✓	
			Horton et al 2015
• **Do not harvest or construct skid trails on wet sites or right after frequent and/or intense rain events**	✓	✓	
			Horton et al 2015
• **Only harvest on sensitive soils when soils are covered by snow (>1ft) or frozen (6in) or during drought periods** • **Avoid harvesting on spodosols, which are particularly vulnerable to disturbance and take a long time to recover**	✓	✓	
			Nave et al 2009, Horton et al 2015, James and Harrison 2016
• **Minimize the number of skid roads and pre-bunch harvest trees to minimize skid trails**	✓	✓	
			Horton et al 2015, Crawford et al 2021

Recommendations	Climate resilience	Carbon storage	Carbon sequestration

• Avoid soil displacement and be sure skid trails are on stable ground
  • Use brush and/or corduroy to help build and stabilize skid trails. Lay materials perpendicular to the trail
  • When possible, allow for the trail to freeze-in before skidding begins
  • Use light, tracked equipment on soils with low bearing capacity, shallow bedrock, and have a low rock fragment content to reduce rutting
  • Maintain water bars on steep slopes during harvest operations and consider reinforcing them with logs, rocks, etc. to keep them in place
• For soils with O horizons, use slash mats and rubber-tired machines for harvests and route trails parallel to slope gradients
• On soils without O horizons, use slash mats and tracked machines
• Use portable truck bridges to protect stream areas when crossed during harvests
	✓	✓	

	Horton et al 2015, Crawford et al 2021, Nave et al 2021		
• **Closeout roads immediately after completion of harvests to reduce potential for soil erosion and sedimentation**	✓		
	Horton et al 2015		
• **Remove culverts after harvest operations on low-use roads to help restore natural hydrology**	✓		
	Horton et al 2015		
• **Consider using tillage to remediate log landings to mitigate anoxic soil conditions that lead to methane emissions**		✓	
	Vantellingen and Thomas 2021		

From MA Dept. of Conservation and Recreation:

Management Recommendations Options for your property

ST#	Obj Code	Desired Condition	Management Action	Benefits			Value/Cost/Cost Sharing Opportunity
				Bird Habitat & Focal Birds	Climate Change Adaptation	Forest Carbon	
1	STEW	Larger canopy openings help increase oak and hickory in addition to retaining pine and hemlock	Group & single tree Selection harvest; (NRCS practice = Forest Stand Improvement)	Canopy openings benefit birds and other wildlife species	Shift composition towards a higher % of species and varied structure better adapted to future conditions	Short-term reduction; long term gain	Likely net $ gain; eligible for NRCS EQIP practices 655, 666
2	STEW	Canopy openings favor healthy trees and create a new age class; stream corridor protected	Single tree & group selection harvest (NRCS practice = Forest Stand Improvement)	Canopy openings benefit birds and other wildlife species	Shift composition toward species and varied structure better adapted to future conditions	Short-term reduction; long term gain	Likely net $ gain; eligible for NRCS EQIP practices 655, 666
1	STEW	Increased abundance of young oaks, hickories, and possibly other hardwoods	Enrichment planting of desired native tree species in canopy gaps; seedling protection and deer exclosure fencing (NRCS practice = Tree and Shrub Establishment)	If successful, more acorns and hickory nuts provide food for birds and wildlife	Increased abundance of young trees of species adapted to future conditions	Gain for planted trees that survive and grow to maturity	Eligible for NRCS practice 612;
1, 2	STEW	Standing dead trees, brush piles, and bird boxes provide and enhance habitat features	Girdling trees; creating brush piles; installing bird boxes (NRCS practice = Structures for Wildlife)	Create and enhance habitat for birds and other wildlife species	Enhance habitat for bird and wildlife species amidst changing conditions	Negligible; more dead wood left onsite	Eligible for NRCS EQIP practice 649

ALL	STEW	Reduced deer impacts on regeneration, especially oak and other preferred hardwoods	Monitor both deer impacts on vegetation; and deer hunting and, if possible, increase deer hunting opportunities Tree shelters	N/A	Successful natural regeneration and increase of trees and plants (esp. oaks) with good adaptation capacity	Long term gain if regen conditions improve	Significant effort; may be a combination of contractor and landowner NRCS tree shelters
ALL	STEW	Reduced levels of invasive plant populations and associated impacts on native plant regeneration	Invasive Plant Monitoring and Control (NRCS practice = Brush Management)	Increased abundance of native trees and plants providing food and habitat for birds and wildlife	Successful regeneration and growth of native trees and plants, especially those with good adaptation capacity	Long term gain	Eligible for NRCS practice 314
ALL	STEW	Increased awareness of forest conditions and climate impacts	Monitoring of conditions and potential climate impacts	Opportunity to note bird & wildlife and habitat changes and respond with climate-adaptive practices to benefit species	Opportunity to note changes and respond with climate-adaptive practices	Opportunity to increase forest carbon over the long term	Significant effort; may be aided by Sample family

Sources:

New York Division of Lands and Forests (DEC)

Massachusetts Department of Environment and Conservation

Resources to help develop the narrative:
Northern Institute of Applied Climate Science (NIACS) Adaptation Handbook - https://adaptationworkbook.org/

Vulnerability Assessment for the Northern Forest Region - https://www.fs.usda.gov/research/treesearch/55635