US forests:
- Absorb 15% of CO$_2$ emissions from fossil fuels
- Contain 68% of terrestrial carbon stocks
- Represent 90% of land sector sequestration capacity

Woodall et al. 2015; Lui et al. 2014; USEPA 2016
A changing climate puts those forests and the carbon they sequester at risk.
Climate change impacts forest carbon through effects on:

- Carbon sequestration (forest productivity)
- Carbon storage (biomass in trees, roots, soil)
THE GOOD:
Longer growing seasons.

Keenan et al. 2014
Effects on Forest Carbon

**THE GOOD:**
Longer growing seasons.

*Adapted from Wolfe et al. 2018*
THE GOOD: Longer growing seasons mean more carbon uptake in forests.

Figure from Singh et al. 2017
Effects on Forest Carbon

**SHIFTING SEASONS | SHIFTING SPECIES | SHIFTING STRESSORS**

**THE GOOD:**
Longer growing seasons.

**THE BAD:**
Shorter, warmer winters.
Effects on Forest Carbon

SHIFTING SEASONS | SHIFTING SPECIES | SHIFTING STRESSORS

THE BAD:
Shorter, warmer winters.

Drier conditions & drought
Warmer temperatures drive moisture deficits
Effects on Forest Carbon

**SHifting SEASONS | SHIFting SPECIES | SHIFting STRESSORS**

**THE BAD:**
Shifting precipitation patterns

Butler-Leopold et al. 2018
Effects on Forest Carbon

**SHIFTING SEASONS | SHIFTING SPECIES | SHIFTING STRESSORS**

**THE BAD:**
Soil moisture stress

Impact on tree health, productivity, forest regeneration, ...

*Angel et al. 2018*

**RESEARCH ARTICLE | ECOLOGY**

*Increased atmospheric vapor pressure deficit reduces global vegetation growth*

Wenping Yuan1,2,*, Yi Zheng1, Shilong Piao3, Philippe Ciais4, Danica Lombardozzi5, Yingping Wang6,7, Youngryel Ryu3, Guixi...

*See all authors and affiliations*

*Science Advances 14 Aug 2019: Vol. 5, no. 8, eaax1396*

DOI: 10.1126/sciadv.aax1396

*Projected Increases in Vapor Pressure Deficit*

- (b) Lower Scenario (RCP4.5)
- (c) Higher Scenario (RCP8.5)

*Angel et al. 2018*
Effects on Forest Carbon

SHIFTING SEASONS | SHIFTING SPECIES | SHIFTING STRESSORS

THE GOOD: Longer growing seasons.

THE BAD: Shorter winters, drier conditions.

THE UGLY: More extreme events.
Many northern species are projected to decline in the region.

Many species common farther south are expected to see increased or new habitat.
Effects on Forest Carbon

SHIFTING SEASONS | SHIFTING SPECIES | SHIFTING STRESSORS

50% Reduction in Habitat:

- Habitat reduced equally
- Best habitats remain

suitable habitat
Climate change is a “threat multiplier”.

- Chronic stress
- Disturbances
- Insect pests
- Forest diseases
- Invasive species

Interactions make all the difference.
Synergies between Mitigation & Adaptation
Synergies between Mitigation & Adaptation

Considering extended time-scales can reveal synergies between adaptation and mitigation

McKinley et al. 2011
Synergies between Mitigation & Adaptation

Consideration of climate vulnerability may increase the effectiveness of management actions on enhancing forest carbon

Adler Fire, Yellowstone NP (NPS)  
[www.nrs.fs.fed.us/atlas/tree/]
Synergies between Mitigation & Adaptation

Carbon is often one of many desired forest benefits
1. Maintain or increase extent of forest ecosystems.
2. Sustain fundamental ecological functions.
3. Reduce carbon losses from natural disturbance, including wildfire.
4. Enhance forest recovery following disturbance.
5. Prioritize management of locations that provide high carbon value across the landscape.
6. Maintain or enhance existing carbon stocks while retaining forest character.
7. Enhance or maintain sequestration capacity through significant forest alterations.
Strategy 6: Maintain or enhance existing carbon stocks while retaining forest character

6.1 Increase structural complexity through retention of biological legacies in living and dead wood

6.2 Increase stocking on well-stocked or understocked forest lands

6.3 Increase harvest frequency or intensity due to greater risk of tree mortality

6.4 Disfavor species that are distinctly maladapted

6.5 Manage for existing species and genotypes with wide moisture and temperature tolerances

6.6 Promote species and structural diversity to enhance carbon capture and storage efficiency

6.7 Use seeds, germplasm, and other genetic material from across a greater geographic range
Strategy 6: Maintain or enhance existing carbon stocks while retaining forest character

6.1 Increase structural complexity through retention of biological legacies in living and dead wood

Examples of adaptation tactics are:

• Retaining the oldest and largest trees with good vigor during forest management activities

• Retaining survivors of pest and disease outbreaks, droughts, windthrow events, or other disturbances during salvage operations

• Retaining down logs, snags, and other dead wood during forest management, or leaving trees of poor health that are expected to contribute to dead wood pools

• Not salvage logging where risks from fires or to forest health are low
Strategy 3: Reduce carbon losses from natural disturbance, including wildfire

**Approach 3.1 Restore or maintain fire in fire-adapted ecosystems**

**Approach 3.2** Establish natural or artificial fuelbreaks to slow the spread of catastrophic fire

**Approach 3.3** Alter forest structure or composition to reduce the risk, severity, or extent of wildfire

**Approach 3.4** Reduce the risk of tree mortality from biological or climatic stressors in fire-prone systems

**Approach 3.5** Alter forest structure to reduce the risk, severity, or extent of wind & ice damage
Questions?
Impact of Forest Management on Carbon Sequestration and Storage in Pennsylvania and Maryland

Carbon Budget Model

Disturbance Events
- Harvesting
- Deforestation
- Afforestation
- Natural Disturbances

RESULTS DATABASE

Growth and Yield Curves

Land-Use Changes

Detailed Forest Inventory
What forest management & adaptation practices should we include?

• Controlling invasive species and vines
• Managing deer browse
• Thinning overstocked stands
• ...
• [Insert your idea here]

Please tell me what you think!

Kendall DeLyser
kdelyser@americanforests.org
Thank you!

Kendall DeLyser
kdelyser@americanforests.org
## Conservation Practice 666: Forest Stand Improvement

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Approach</th>
<th>Tactic (from CSP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategy 2: Sustain fundamental ecological functions</strong></td>
<td>2.1 Reduce impacts to soils and nutrient cycling</td>
<td>Close unneeded roads and limit off-road vehicular traffic to avoid displacing the forest litter layer.</td>
</tr>
<tr>
<td><strong>Strategy 2: Sustain fundamental ecological functions</strong></td>
<td></td>
<td>Adopt techniques for maintaining and/or improving soil quality, specifically retention of organic carbon.</td>
</tr>
<tr>
<td><strong>Strategy 6: Maintain or enhance existing carbon stocks while retaining forest character</strong></td>
<td>6.1 Increase structural complexity through retention of biological legacies in living and dead wood</td>
<td>Retain all snags and downed woody debris of 6” diameter or larger at the base.</td>
</tr>
<tr>
<td><strong>Strategy 6: Maintain or enhance existing carbon stocks while retaining forest character</strong></td>
<td>6.1 Increase structural complexity through retention of biological legacies in living and dead wood</td>
<td>Identify leave-trees or clumps of trees that will be retained on site throughout their life span.</td>
</tr>
<tr>
<td><strong>Strategy 7: Enhance or maintain sequestration capacity through significant forest alterations</strong></td>
<td>7.2 Alter forest composition or structure to maximize carbon</td>
<td>Transition from even-aged to uneven-aged management.</td>
</tr>
</tbody>
</table>
**Strategy Approach Tactic (from CSP)**

**Strategy 1: Maintain or increase extent of forest ecosystems**
1.2 Reforest lands that have been deforested and afforest suitable lands
Trees and shrubs will be planted on selected areas within any land use.

**Strategy 2: Sustain fundamental ecological functions**
2.5 Reduce competition for moisture, nutrients, and light
Trees and shrubs will be planted in areas with adequate sunlight.

**Strategy 4: Enhance forest recovery following disturbance**
4.2 Restore sites with a diversity of species that are adapted to future conditions
Trees will be selected for their rate of growth and suitability for use in durable manufactured products as well as their adaptability to site conditions.

**Strategy 6: Maintain or enhance existing carbon stocks while retaining forest character**
6.2 Increase stocking on well-stocked or understocked forest lands
Increase stocking levels in forests that are not fully stocked.

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**Conservation Practice 612: Tree/Shrub Establishment**