Pathway: Resilience

Resilience actions focus on increasing the capacity of the ecosystem to cope with climate change and other stressors while maintaining its fundamental character. Resilience actions are designed to enable ecosystems to withstand a variety of stressors and to bounce back from disturbance. For example, greater diversity in ecosystems (in terms of species composition, species functional traits, or age distribution) is generally expected to increase resilience by allowing for multiple pathways for recovery after a disturbance. Resilience is a commonly discussed adaptation option and can be valuable in many systems, but it may not be appropriate in all situations. As with the resistance pathway, greater levels of impact and disturbance from climate change and other stressors will likely create greater challenges to maintaining the current ecosystems using resilience strategies alone.

Because oak forests are highly adaptable to many disturbances, resilience actions can be effective for many forests where conditions have not been too severely altered. You may also want to consider what capability you have to resist change in the current forest and compare this option with the **Resistance** and **Transition** pathways to determine what option best meets your management goals and objectives.

Actions for Forests Health and Productivity ⇳

Here are some examples of adaptation actions that can help maintain oak forests to meet objectives for general forest health to provide wood products and other benefits. The specific actions used in a particular location will vary based on local site conditions, management goals, and climate risks. Additional actions are described in the Adaptation Strategies and Approaches for Forests.

Condition	Adaptation Approach	Example Action
Invasive plants are present at low levels or nearby.	▪ 2.2 Prevent the introduction and establishment of invasive plant species and remove existing invasive species	▪ Remove existing invasive species with mechanical treatment to promote the current plant community ▪ Use monitoring to support early detection and rapid response to eliminate new infestations
High levels of invasive plants are affecting the natural or desired plant community	▪ 2.2 Prevent the introduction and establishment of invasive plant species and remove existing invasive species	▪ Remove existing invasive species with mechanical or chemical treatment to promote the current plant community
Site exposed to wind	▪ 3.3. Alter forest structure to reduce severity or extent of wind and ice damage.	▪ Use thinning or other silvicultural treatment to reduce tree density and increase the windfirmness of

		the residual trees and increase age and structural diversity
Stand is overstocked and/or susceptible to drought or forest pests	▪ 2.1. Maintain or improve the ability of forests to resist pests and pathogens. ▪ 1.4. Reduce competition for moisture, nutrients, and light.	▪ Thin trees or release crop trees to reduce tree density
Forest regeneration is desired; advance regeneration is dominated by maple, black birch or other mesic species	▪ 5.1. Promote diverse age classes. ▪ 5.2. Maintain and restore diversity of native species. ▪ 8.2. Favor existing genotypes that are better adapted to future conditions. ▪ 9.1. Favor or restore native species that are expected to be adapted to future conditions. ▪ 9.3. Guide changes in species composition at early stages of stand development.	▪ Harvest using patch cuts (at least 1/2 acre) to favor oak and hickory regeneration ▪ Use prescribed fire, mechanical scarification, or herbicide to reduce competition of mesic species ▪ Retain underrepresented species to increase diversity, emphasizing species expected to be suitable for future conditions ▪ Plant current- and future-adapted native species, such as oaks, hickories, or American chestnut to diversity composition. ▪ Protect seedlings from browse, as needed.
Forest regeneration is desired; advance regeneration is primarily oak	▪ 5.1. Promote diverse age classes. ▪ 5.2. Maintain and restore diversity of native species. ▪ 8.2. Favor existing genotypes that are better adapted to future conditions. ▪ 9.1. Favor or restore native species that are expected to be adapted to future conditions. ▪ 9.3. Guide changes in species composition at early stages of stand development..	▪ Use group selection, patch cuts, or final shelterwood cut to release oak regeneration ▪ Retain underrepresented species to increase diversity, emphasizing species expected to be suitable for future conditions ▪ Retain cavity trees and down wood
Forest regeneration is desired; no advance regeneration or lack or regeneration following harvest	▪ 8.1. Use seed, germplasm, and other genetic material from across a greater geographic range	▪ Harvest using shelterwood system to release crowns of overstory trees and create light conditions favorable for regeneration ▪ Plant existing oak species using seed stock from southerly populations (e.g.,

		Mid-Atlantic states) for artificial regeneration ▪ Retain cavity trees and down wood
Regeneration of future-adapted species desired	▪ 9.3. Guide changes in species composition at early stages of stand development.	▪ Select species consistent with native plant community, may consider southern genotypes ▪ Reintroduce American chestnut on suitable sites ▪ Plant current- and future-adapted native species suited to site (e.g., soils, light conditions) and management goals ▪ Plant larger seedlings to the extent possible ▪ Protect seedlings from browse, as needed
Forest condition is highly degraded as a result of pests or other disturbance	▪ 9.1. Favor or restore native species that are expected to be adapted to future conditions. ▪ 9.3. Guide changes in species composition at early stages of stand development. ▪ 10.2. Allow for areas of natural regeneration to test for future-adapted species	▪ Reinitiate stand using clearcut (with reserves) where existing seedlings, stump sprouts, or nearby seed source can provide source of natural regeneration ▪ Remove all competing vegetation ▪ Retain trees of desired species as seed source
Tree mortality resulted in substantial standing or down dead wood	▪ 3.1. Alter forest structure or composition to reduce risk or severity of wildfire.	▪ Evaluate need for intervention ▪ Remove downed or damaged trees as necessary to meet management goals ▪ Retain some portion of dead trees and downed wood for forest structure and heterogeneity, as appropriate to management goals and forest condition
Disturbance has significantly impacted forest	▪ 3.4. Promptly revegetate sites after disturbance.	▪ Remove downed or damaged trees as necessary, with retention of some portion of wood based on management goals and forest condition ▪ Plant current- and future-adapted native species suited to site (e.g., soils, light conditions) and management goals ▪ Plant larger seedlings to the extent possible

	▪ Protect seedlings from browse, as needed

Actions for Wildlife ⇳

Here are some examples of adaptation actions that can help maintain oak forests to meet objectives for wildlife habitat. The specific actions used in a particular location will vary based on local site conditions, management goals, and climate risks. Additional actions are described in the Adaptation Strategies and Approaches for Wildlife (in review).

Condition	Adaptation Approach	Action
Forest lacks age class or structural diversity	▪ 8.1. Manage for plant species diversity and complexity ▪ 8.7. Create or maintain sources of food, water, and cover in a variety of locations across the landscape ▪ 8.8. Maintain or mimic natural disturbance regimes to enhance habitat quality	▪ Use shelterwood system to create gaps or openings for regeneration to increase age class diversity and patchiness ▪ Retain snags and live trees with cavities or other features for wildlife ▪ Retain or increase down wood during harvest by retaining tree tops in the forest or by girdling or felling live trees
Forests lacks downed wood	▪ 8.1. Manage for plant species diversity and complexity ▪ 8.7. Create or maintain sources of food, water, and cover in a variety of locations across the landscape ▪ 8.8. Maintain or mimic natural disturbance regimes to enhance habitat quality	▪ Retain tree tops in woods or return tops to woods following harvest ▪ Fell trees for new source of dead wood ▪ Reserve standing live or dead trees, particularly of a large size, for future dead wood
Forest lacks tree and plant diversity	▪ 8.1. Manage for plant species diversity and complexity ▪ 8.2. Promote plant genetic diversity	▪ Use forest harvest to create and tend regeneration of a variety of species ▪ Retain conifers and underrepresented tree species during harvest
Rare or sensitive species are present (e.g., plants, turtles)	▪ 10.4. Orient suites of protected areas in ways that span gradients in climate ▪ 10.5. Create protected areas that maximize topographic and geologic variety	▪ Establish reserves that run up and down slope to cut across narrow climate zones associated with elevation and water availability. ▪ Create reserve areas around wetlands steep slopes, and other landforms that add variety in an otherwise uniform landscape.

Raptors present	▪ 8.7. Create or maintain sources of food, water, and cover in a variety of locations across the landscape	▪ Retain trees with multi-limbed tree crotches or “basket forks” in live hardwood crowns during harvest

Actions for Water ⇳

Here are some examples of adaptation actions that can help maintain oak forests to meet objectives for water resources. The specific actions used in a particular location will vary based on local site conditions, management goals, and climate risks. Additional actions are described in the Adaptation Strategies and Approaches for Forested Watersheds.

Condition	Adaptation Approach	Action
Riparian areas, vernal ponds, and other sensitive wetlands	▪ 1.5 Maintain and restore forested wetlands and lowland areas ▪ 1.1 Maintain and enhance infiltration and water storage capacity of forest soils ▪ 5.2 Enhance the ability of systems to retain water	▪ Restore or promote a diversity of tree and plant species to increase stream shading, provide sources of woody debris, stabilize the soil, restore fluvial processes, and provide habitat and connectivity for wildlife ▪ Leave dead and downed wood (coarse woody debris) in upland and riparian areas to enhance soil moisture ▪ Re-engineer or design roads and infrastructure to discharge runoff into natural areas and hillslopes slopes to increase water capture, reduce water losses and minimize runoff velocities
Areas of low vegetative cover	▪ 3.2 Promptly revegetate areas after disturbance ▪ 5.3 Adjust systems to cope with increased water abundance, and high-water levels	▪ Plant native vegetation to slow overland flows and improve water infiltration ▪ Target invasive species control in newly flood-prone areas to retain or recruit desirable riparian species
Tree mortality in riparian areas	▪ 3.1 Maintain or restore forest and vegetative cover in riparian areas ▪ 3.7 Identify, maintain, and enhance important habitats for fish and wildlife ▪ 3.6 Enhance species age classes and structural diversity in forests ▪ 4.3 Disfavor species that are distinctly maladapted	▪ Prioritize stream restoration activities in areas most likely to retain cool late-summer flows that may buffer the survival of aquatic organisms during extreme weather conditions, and at particular life history stages ▪ Focus salvage operations on creating desired residual stand structures following disturbance, even if less merchantable timber is removed as a result

		▪ Protecting healthy trees that fail to regenerate while deemphasizing their importance in the mix of species being promoted for regeneration
Man-made ponds, embankments, etc.	▪ 6.3 Incorporate natural or low-impact development into designs	▪ Use bioretention systems to capture runoff, recharge groundwater, and reduce pollutant loads ▪ Strategically grade soil where needed and avoid disturbance of soils if unnecessary to preserve soil porosity and natural drainages

Actions for Recreation and Forest Roads and Trails ⇳

Here are some examples of adaptation actions that can help maintain oak forests to meet objectives related to forest roads and trails used for recreation and other purposes. The specific actions used in a particular location will vary based on local site conditions, management goals, and climate risks. Additional actions are described in the Adaptation Strategies and Approaches for Recreation.

Condition	Adaptation Approach	Action
Erosion on forest roads and trails following extreme rain	▪ 2.2 Enhance the capacity of natural systems to accommodate variable precipitation ▪ 2.3 Minimize impacts of existing roads and trails that are compromised by changing conditions	▪ Avoid machine or foot traffic in vulnerable areas ▪ Use water bars or increase number used to divert water from road surfaces ▪ Use vegetation or rock armoring along roadsides to minimize erosion and reduce risk of failure
Flooding of forest roads and trails	▪ 2.2 Enhance the capacity of natural systems to accommodate variable precipitation ▪ 2.3 Minimize impacts of existing roads and trails that are compromised by changing conditions	▪ Harden surfaces or elevate roads/trails
Water crossings missing or undersized on woods roads	▪ 2.2 Enhance the capacity of natural systems to accommodate variable precipitation	▪ Add or replace stream crossings to enhance drainage ▪ Use vegetation or rock armoring along roadsides to minimize erosion and reduce risk of failure

Actions for Forest Carbon

Here are some examples of adaptation actions that can help maintain oak forests to meet objectives for general forest health to provide carbon sequestration and storage, along with other benefits. The specific actions used in a particular location will vary based on local site conditions, management goals, and climate risks. Additional actions are described in the Adaptation Strategies and Approaches for Forest Carbon.

Condition	Adaptation Approach	Action
Potential for land use change	▪ 1.1 Avoid forest conversion to nonforest land uses	▪ Use conservation easements or other land use restrictions to prevent land use change or development.
Mix of agriculture and forest lands on property	▪ 1.4 Increase or implement agroforestry practices	▪ Integrate trees and shrubs into agricultural landscapes, such as within riparian buffers
Forest of high conservation value and large trees or healthy, mature forest subject to few stressors	▪ 5.1 Prioritize low-vulnerability sites for maintaining or enhancing carbon stocks ▪ 5.2 Establish reserves on sites with high carbon density	▪ Create no-harvest reserve areas (passive management) when consistent with landowner goals and site capability ▪ Implement forest harvests at lower intensities (e.g., light thinning) ▪ Delay harvest or extend time between forest harvest entries
Stand is overstocked and/or susceptible to drought or forest pests	▪ 2.4: Maintain or improve the ability of forests to resist pests and pathogens	▪ Thin to reduce competition for light or soil moisture to enhance resistance to stressors
Forest harvest to meet other management goals (e.g., habitat, timber)	▪ 2.1: Reduce impacts to soils and nutrient cycling ▪ 2.2: Maintain or restore hydrology	▪ Minimize the area (footprint) of forest roads and trails ▪ Alter the timing of forest operations to reduce potential impacts on water, soils, and residual trees, especially in areas that rely on particular conditions for operations that may be affected by a changing climate ▪ Retain coarse woody debris (e.g., tree tops, harvest residue) to maintain soil moisture, nutrients, and enhance soil organic matter pools ▪ Use soil amendments to restore or improve soil quality

	▪ Restore native herbaceous groundcover following management activities in order to retain soil moisture and reduce erosion

On-the-Ground Examples

- Adaptive Silviculture – Southern New England Oak Forests
    - The Adaptive Silviculture for Climate Change (ASCC) study sites in southern New England include resistance, resilience, transition, and no action treatments in oak forests that are representative of forests across much of the region. The treatments were developed by a team of scientists and managers working to identify options relevant to smaller parcel sizes and varied ownership.
- Massachusetts Department of Conservation & Recreation: Bristol Lot Timber Sale
    - Drought conditions have limited the effectiveness of a soil borne fungus that controls *Lymantria dispar*, making this oak-dominated stand highly susceptible to further heavy defoliation and mortality. In addition to planting blight-resistant American chestnut, managers are encouraging a mix of species, age classes, and stand structures to reduce the availability of host species for pests and pathogens.
- Massachusetts Dept. of Conservation & Recreation: Protecting Riparian Zones with a Focus on Stream Crossings
    - Many of the culverts for streams that enter the Deerfield River within the South River State Forest have already failed or are threatened by increasingly heavy precipitation events. Managers are removing failing culverts and replacing them with bridges, while ensuring stream connectivity and a naturalized stream bottom.
- Massachusetts Dept. of Conservation & Recreation: Protecting Riparian Zones with a Focus on Stream Crossings
    - Many of the culverts for streams that enter the Deerfield River within the South River State Forest have already failed or are threatened by increasingly heavy precipitation events. Managers are removing failing culverts and replacing them with bridges, while ensuring stream connectivity and a naturalized stream bottom.