Adaptation Strategies and Approaches (Forest)

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  - Realign significantly disrupted ecosystems to meet expected future conditions

Strategy 1: Sustain fundamental ecological functions

Climate change will have substantial effects on a suite of ecosystem functions, such as carbon storage, nutrient cycling, habitat, or water provisioning. As a result, many management actions will need to work both directly and indirectly to maintain the integrity of ecosystems in the face of climate change. This strategy seeks to sustain fundamental ecological functions, especially those related to soil and hydrologic conditions.

Reduce impacts to soils and nutrient cycling

Maintaining both soil quality and nutrient cycling are already common tenets of sustainable forest management (Burger et al. 2010, Oliver and Larson 1996) and can help improve the capacity of ecosystems to persist under new conditions. Physical and chemical changes can result from a variety of forest management and recreation activities, as well as from climate-related processes including fire, drought, and flooding. Examples of physical impacts to soil are compaction, mixing of soil layers, removal of organic layers, rutting, erosion, and landslides. Complex interactions among climate, vegetation, and landforms can result in changes in nutrient cycling, including the leaching or fixation of nutrients and changes in soil biota. Many existing guidelines and best management practices describe actions that can be used to reduce impacts to soil and water; many of these actions are also likely to be beneficial in the context of adaptation, either in their current form or with modifications to address potential climate change impacts.

Examples

- Altering 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 (e.g., frozen soil, or dry conditions)
- Modifying forest operations techniques and equipment (e.g., using pallets, debris mats, or float bridges) to minimize soil compaction, rutting, or other impacts on water, soils, and residual trees
- Retaining coarse woody debris to maintain moisture, soil quality, and nutrient cycling
- Restricting recreational access in areas that show signs of excessive wear on natural resources in order to allow for revegetation or soil stabilization

- Using soil amendments to restore or improve soil quality (e.g., using lime to increase base cations in the soil profile in areas affected by long-term acid deposition)
- Restoring native herbaceous groundcover following management activities in order to retain soil moisture and reduce erosion.

Maintain or restore hydrology

Projected changes in precipitation and temperature are expected to alter hydrologic regimes through changes in streamflow, snowpack, evapotranspiration rates, soil moisture, surface runoff, infiltration, flooding, and drought (Jones 2011). Hydrologic changes could occur gradually or rapidly through extreme events. Some ecosystems are very susceptible to stress from drought, which may increase in frequency, severity, duration, or extent as a result of changing precipitation patterns. Other ecosystems are susceptible to flooding and ponding. Maintaining sufficient water levels and flow patterns is critical to ecosystem function. Hydrology can be altered by infrastructure (e.g., dams, roads, and other impervious surfaces), excessive groundwater extraction, stream channelization, and even invasive plants (Massachusetts Division of Fisheries and Wildlife 2006). Existing infrastructure that diverts water, or otherwise alters hydrology, may need to be reevaluated to compensate for changes in water levels or flows (Brandt et al. 2012, Furniss et al. 2010, Galatowitsch et al. 2009). Infrastructure will also need to be designed to accommodate greater hydrologic extremes in the future. It is important to keep in mind that modifications to maintain hydrology at one site may have negative impacts on hydrology at another site.

Examples

- Upgrading culvert size and cleaning culverts regularly to accommodate changes in peak flow and thus reduce damage to infrastructure and the environment during heavy rain events. This example may also incorporate ecologically based stream crossing designs that allow passage for aquatic organisms.
- Reducing or eliminating agricultural drainage improvements near wetlands
- Reducing groundwater withdrawals in recharge areas of calcareous fens
- Installing berms or dikes to divert surface water to a lowland area affected by decreased precipitation
- Removing or modifying dams, especially as they become defunct, and if they have little hydroelectric or irrigation value

- Decommissioning or temporarily closing roads to reduce erosion and sedimentation and to restore permeability and soil hydrology.

Maintain or restore riparian areas

Forests located within riparian areas serve important ecosystem functions, such as decreasing soil erosion, filtering water, and storing and recycling organic matter and nutrients (Barling and Moore 1994, Brandt et al. 2012, Castelle et al. 1994). Trees in riparian areas also provide shade, which helps to buffer stream temperatures. Forested riparian areas can serve as corridors for wildlife and plant species migrating across otherwise fragmented landscapes (Heller and Zavaleta 2009). Many of these functions and benefits may be degraded if riparian forests undergo decline or exacerbated stress from climatic shifts and extreme events. The use of protective guidelines, such as best management practices and riparian management zones, can be used to avoid damage or additional stress to riparian areas during management activities.

Examples

- Restoring or promoting a diversity of tree and plant species to increase stream shading, provide a source of woody debris, stabilize the soil, and provide habitat and connectivity for wildlife
- Anchoring with fabric, wire, or natural materials in order to stabilize eroding stream banks
- Creating buffers along riparian areas with reduced or no harvest based on the landform, hydrology, and vegetation of the riparian zone in addition to any recommended buffer distance
- Restoring or reforesting riparian areas adjacent to agricultural areas in order to reduce erosion and nutrient loading into adjacent water bodies
- Managing water levels to supply proper soil moisture to vegetation adjacent to the stream during critical time periods, either by manipulation of existing dams and water control structures or restoration of natural dynamic water fluctuations
- Reconnecting floodplains to rivers and restoring natural floodplain conditions and associated native habitats (e.g., bottomland forest, wetlands, and wet prairie and other grasslands) in order to restore fluvial processes

Reduce competition for moisture, nutrients, and light

Competition for resources between plants is established as one of the main mechanisms in plant succession and evolution (Weiner 1990). Competition occurs aboveground as plants compete for light, and belowground as they compete for water and mineral nutrients (Casper and Jackson 1997). Climate change is expected to affect many of the competitive relationships in forest ecosystems. Productivity may increase because of the positive effects of carbon dioxide (CO_2) fertilization and longer growing seasons. But not all species will be able to take equal advantage of these positive effects (Evans and Perschel 2009). Reducing competition for resources can enhance the persistence of desired species and increase the ability of ecosystems to cope with the direct effects (drought stress, temperature increases) and indirect effects (increased damage from pests and disease) of climate change (Dwyer et al. 2010, Evans and Perschel 2009).

Examples

- Using herbicide or mechanical thinning to prevent the encroachment of woody competitors and invasive species, especially after disturbance
- Thinning forest stands to remove crowded, damaged, or stressed trees in order to reduce competition for light, nutrients, and water
- Using prescribed fire to maintain growing space for fire-tolerant species or to increase nutrient turnover
- Fertilizing or amending soil to address nutrient deficiencies. Although the benefit is faster
- Controlling beech suckers, sprouts, and brush with herbicides or mechanical treatment in areas affected by beech bark disease in order to reduce competition with the regeneration of other species.

Restore or maintain fire in fire-adapted ecosystems

Long-term fire suppression leads to shifts in ecosystem structure and composition, which may disproportionately favor certain species and reduce biodiversity (Nowacki and Abrams 2008). Restoring fire regimes that attempt to mimic natural disturbance in fire-adapted systems can enhance regeneration and encourage stronger competition by fire-dependent and fire-tolerant species (Abrams 1992). These actions can simultaneously foster more complex ecosystem structure and reduce the risk of severe wildfire. Projecting the effects of climate change on fire regimes in forest ecosystems is an area of active research. The wildfire season is expected to lengthen in much of the Midwest and Northeast, and wildfires may occur more frequently (Flannigan et al. 2009a, 2009b; Guyette et al. 2014; Moritz et al. 2012; Tang et al. 2014). Helping fire-adapted ecosystems tolerate these potential changes may be the focus of adaptation actions.

Examples

- Using prescribed fire to reduce ladder fuels, invasive species, and understory competition
- Promoting fire- and drought-adapted species and ecosystems in areas that are expected to have increased fire risk as a result of climate change
- Using natural or prescribed fire to restore the open character of oak woodlands and glades
- Shifting prescribed burn seasons to align with projected seasonal precipitation changes, thereby reducing the risk of unintended wildfire conditions.

Strategy 2: Reduce the impact of biological stressors

Biological stressors such as insects, pathogens, invasive species, and herbivores can act individually and in concert to amplify the effects of climate change on ecosystems. Forest managers already work to maintain the ability of forests to resist stressors. As an adaptation strategy, these efforts receive added effort and focus, with an emphasis on anticipating and preventing increased stress before it occurs. Climate change has the potential to add to or intensify the impact of many biological stressors, such as forest pests and invasive plant species, which heightens the importance of responding to these issues. Dealing with these existing stressors is a relatively high-benefit, low-risk strategy for climate change adaptation, in part because of the existing body of knowledge about their impacts and solutions (Climate Change Wildlife Action Plan Work Group 2009).

Maintain or improve the ability of forests to resist pests and pathogens

Even modest changes in climate may cause substantial increases in the distribution and abundance of many insect pests and pathogens, potentially leading to reduced forest productivity or increased tree stress and mortality (Ayres and Lombardero 2000, Dukes et al. 2009). Impacts may be exacerbated where site conditions, climate, other stressors, and interactions among these factors increase the vulnerability of forests to these agents (Spittlehouse and Stewart 2003). Actions to manipulate the density, structure, or species composition of a forest may reduce susceptibility to some pests and pathogens (Spies et al. 2010).

Examples

- Thinning to reduce the density of a pest's host species in order to discourage infestation, based on the knowledge that species are especially susceptible to pests and pathogens at particular stocking levels
- Adjusting rotation length to decrease the period of time that a stand is vulnerable to insect pests and pathogens, based on the knowledge that species are especially susceptible to pests and pathogens at particular ages
- Creating a diverse mix of forest or community types, age classes, and stand structures to reduce the availability of host species for pests and pathogens
- Using pesticides or biological control methods to manage pest populations (e.g., gypsy moth, Asian longhorned beetle, or hemlock woolly adelgid) in heavily infested areas
- Restricting harvest and transportation of logs near stands already heavily infested with known pests or pathogens
- Using impact models and monitoring data to anticipate the arrival of pests and pathogens and prioritize management actions.

Prevent the introduction and establishment of invasive plant species and remove existing invasive species

Hundreds of nonnative invasive plant species are currently present in the Midwest and Northeast (Chornesky et al. 2005, Natural Resources Conservation Service 2012). Climate change is expected to increase habitat for many of these species, which may be poised to outcompete native species (Chornesky et al. 2005, Millar et al. 2007). Current methods for controlling nonnative invasive species emphasize early detection and rapid response to new infestations (Hellmann et al. 2008). Management of highly mobile nonnative invasive species may require increased coordination across property boundaries and over larger geographic areas, and is likely to require an increasing budget for eradication efforts. As a resistance or resilience strategy, this approach may work for a while. Over the long term, limitations in available resources may require managers to prioritize which species to eradicate and which species to allow to occupy a site.

Examples

- Increasing monitoring for known or potential invasive species to ensure early detection, especially at trailheads, along roads, and along other pathways known for infestation

- Eradicating existing populations or seed sources (e.g., upstream) of invasive plants through physical or chemical treatments
- Cleaning equipment prior to forest operations in order to prevent the spread of invasive plants during site preparation, harvesting, or other activities
- Maintaining closed-canopy conditions to reduce the ability of light-loving invasive species to enter the understory
- Educating staff and volunteers on identification and eradication of current and potential invasive species.

Manage herbivory to promote regeneration of desired species

Climate change has the potential to exacerbate many forest stressors and alter regeneration patterns. Additionally, climate change will probably have direct and indirect effects on populations of forest herbivores such as moose (generally expected to decrease) and white-tailed deer (generally expected to increase). Because herbivores preferentially browse on particular species, it may be increasingly important to protect regeneration of desired species from deer, moose, and other herbivores. Much of the available information on forest herbivores focuses on white-tailed deer and moose, which are considered keystone species capable of dramatically altering forests across the Midwest and Northeast (Frerker et al. 2014, Horsley et al. 2003, Mladenoff and Stearns 1993, Rooney and Waller 2003, Stromayer and Warren 1997). Managing herbivory alone may not promote desired species. Thus, this approach may be combined with other approaches that release advance regeneration or stimulate new regeneration.

Examples

- Applying repellant or installing fences, bud caps, and other physical barriers to prevent herbivory
- Promoting abundant regeneration of multiple species in order to supply more browse than herbivores are expected to consume
- Using tree tops from forest harvest or plantings of nonpalatable tree species as locations for “hiding” desirable species from herbivores to reduce browse pressure
- Partnering with state wildlife agencies to monitor herbivore populations or reduce populations to appropriate levels.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances

Climate change is projected to increase the potential for severe disturbance events, such as wildfire, extreme wind, and ice storms (Intergovernmental Panel on Climate Change [IPCC] 2012, Moritz et al. 2012, Uriarte and Papaik 2007). These disturbances have the ability to alter community composition and structure over large landscapes. Disturbances can interact with other stressors (Papaik and Canham 2006). For example, extreme wind events can cause tree damage and mortality, which increase the risk of pest outbreaks or wildfire (Gandhi et al. 2007, Woodall and Nagel 2007). Even as trends continue to emerge, management will need to adjust appropriately to the changes in natural disturbance dynamics (Heller and Zavaleta 2009).

Alter forest structure or composition to reduce risk or severity of wildfire

Forest structure and composition may interact with longer and drier growing seasons to increase the risk of wildfire. Mortality from climate-related disturbances can lead to increases in fuel loading, which can increase the risk or severity of fire. Although some forest types are tolerant of or dependent on fire, extremely hot fires can destroy seed banks, sterilize soils, induce hydrophobic soil conditions, or cause tree mortality (Nitschke and Innes 2008, Noss 2001). Management actions to alter species composition or ecosystem structure may reduce susceptibility to these threats (Hulme 2005, Spittlehouse and Stewart 2003).

Examples

- Using prescribed fire and thinning to reduce surface fuels, increase height to live crown, decrease crown closure, and create a more open forest structure that is expected to be less vulnerable to severe wildfire
- Using prescribed fire to maintain open conditions in ecosystems at lower elevations as a means of reducing fuels and the risk of wildfire in ecosystems at higher elevations
- Promoting fire-resistant species, such as hardwoods, in buffer zones between more flammable conifers to slow the movement of wildfires
- Physically removing dead or dying trees or other vegetation to reduce surface and ladder fuels, while minimizing exposure to invasive plants, pests, or pathogens.

Establish fuelbreaks to slow the spread of catastrophic fire

Projected increases in fire occurrence as a result of climate change are expected to increase demand on fire-fighting resources and may force prioritization of fire suppression efforts to targeted areas (Millar et al. 2007, Spittlehouse and Stewart 2003). Managers may seek to reduce the spread or intensity of fire by using a fuelbreak, which is a physical barrier such as a road, bulldozer line, or water body. Establishing fuelbreaks can be complementary with actions to reduce the fuel load of the forest itself (Agee et al. 2000). Fuelbreaks can be created to lessen fire spread and intensity in specific areas, such as the wildland-urban interface, but also have the potential to increase fragmentation.

Examples

- Using prescribed fire or mechanical thinning to lower the volume of dense vegetation and reduce flammability within a buffer zone of appropriate size for the landscape
- Creating fire lines (i.e., areas where all vegetation is removed down to mineral soil) between a flammable stand and the wildland-urban interface or a fire-intolerant stand
- Establishing fuelbreaks along roads, power lines, and other existing features in order to reduce the spread of wildfire while minimizing additional fragmentation
- Replacing vegetation with nonflammable materials (e.g., replacing vegetation with local rocks) around high-priority areas
- Removing edge vegetation and lower branches of perimeter trees of flammable stands (e.g., pine islands) to arrest the path of fire from the ground surface to the tree crown.

Alter forest structure to reduce severity or extent of wind and ice damage

Wind disturbance is a fundamental process in many forest ecosystems across the Midwest and Northeast (Frelich 2002, Seymour et al. 2002). Wind events and the ensuing effects on forests are expected to become more frequent and severe under climate change (Fischlin et al. 2009, Frelich and Reich 2010), although there are many challenges in predicting the size, frequency, and intensity of these events. Some stands may have structures poorly suited to withstand projected increases in storm intensity. Silvicultural techniques exist to alter forest composition and structure for increased resistance to blowdown or ice damage, or to avoid sudden exposure of retained trees to wind (Burton et al. 2008, Everham and Brokaw 1996, Mitchell 2013).

Examples

- Retaining trees at the edge of a clearcut or surrounding desirable residual trees to help protect trees that have not been previously exposed to wind
- Conducting forest harvest over multiple entries in order to gradually increase the resistance of residual trees to wind
- Using directional felling, cut-to-length logging, and other harvest techniques that minimize damage to residual trees
- Creating canopy gaps that have an orientation and shape informed by the prevailing winds in order to reduce the risk of windthrow.

Promptly revegetate sites after disturbance

Potential increases in the frequency, intensity, and extent of large and severe disturbances may disrupt regeneration and result in loss of forest cover, productivity, or function in the long term. Prompt revegetation of sites following disturbance helps reduce soil loss and erosion, maintain water quality, and discourage invasive species in the newly exposed areas. These efforts can also provide an opportunity to promote natural regeneration or foster species that may be better adapted to future conditions.

Examples

- Planting species expected to be adapted to future conditions and resistant to insect pests or present pathogens
- Creating suitable physical conditions for natural regeneration through site preparation, for example by chaining after a burn to promote seed establishment
- Monitoring areas of natural regeneration on a more frequent basis, and prioritizing planting or seeding where natural regeneration is slow to succeed
- Planting larger individuals (saplings versus seedlings, or containerized versus bare-root stock) to help increase survival in sites where dry conditions are expected

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Strategy 4: Maintain or create refugia

Refugia are areas that have resisted ecological changes occurring elsewhere, often providing suitable habitat for relict populations of species that were previously more widespread (Keppel et al. 2012, Millar et al. 2007). Climate refugia are often formed by topography (e.g., north sides of slopes, or sheltered ravines), proximity to large water bodies, or connection to groundwater (Ashcroft 2010, Dobrowski 2011). During previous periods of rapid climate change, at-risk populations persisted in refugia that avoided extreme impacts (Keppel et al. 2012, Millar et al. 2007, Noss 2001). These populations allowed species to persist until more favorable climatic conditions returned and species were able to expand into newly available habitats. This strategy seeks to identify and maintain ecosystems that: (1) are on sites that may be better buffered against climate change and short-term disturbances, and (2) contain communities and species that are at risk across the greater landscape (Millar et al. 2007, Noss 2001).

Prioritize and maintain unique sites

Some sites host a higher diversity of species than adjacent sites, have many endemic species, have a sheltered topographic position, or have retained species through past periods of climate change (Keppel et al. 2012). These potential refugia are formed through spatial, geophysical, and biological variation on the landscape and may be identified as unique sites that are expected to be more resistant to change. These sites may provide the best chance to retain habitat for native species under future climate change (Anderson et al. 2012). Species at these sites are not necessarily sensitive or at-risk, although they may face increased stress under future climate on some landscape positions. Committing additional resources may be necessary to ensure that the characteristic site conditions are not degraded by invasive species, herbivory, fire, or other disturbances.

Examples

- Identifying and managing cooler and wetter locations that are expected to be more resistant to changes in climate as refugia for maintaining native plant communities into the future
- Limiting harvest or management-related disturbance in areas that may be buffered from climate change (e.g., spring-fed stands sheltered in swales or valleys)
- Identifying and protecting a network of sheltered mountain slopes, valleys, or forests with continuous shading canopy
- Identifying areas with a high diversity of geology, landform, vegetation, or soils for increased protection or conservation

- Protecting areas that have been generally undisturbed by humans, such as those within old-growth forest, peatlands, barrens, or prairie, in order to preserve a reference condition or legacy.

Prioritize and maintain sensitive or at-risk species or communities

Many species are projected to decline as a result of climate change. For example, northern and boreal species are widespread in northern portions of the Midwest and Northeast, but are likely to lose habitat because they are already at the southern extent of their range (Swanston et al. 2011). Other species may be more vulnerable due to their dependence on a narrow range of site conditions. Identifying and maintaining sensitive or at-risk species as long as possible may help them persist until new long-term sites can be located and populated.

Examples

- Using impact models and monitoring data to identify and prioritize management of species expected to decline under future conditions
- Retaining individuals of a priority species across many diverse sites representing various environmental conditions or within differing forest types
- Rerouting roads or trails away from at-risk communities to reduce damage from traffic or reduce the risk of introducing invasive species
- Minimizing harvest and other disturbances to species with dispersal or migration barriers, such as high-elevation or lowland conifer species, in order to protect viable populations where they currently occur
- Monitoring regeneration to detect migration of plant populations or communities to adjacent areas.

Establish artificial reserves for at-risk and displaced species

Species already exist outside their natural habitats in nurseries, arboretums, greenhouses, botanical gardens, and urban environments around the world. These highly controlled environments may be used to support individuals or genetic lineages that are no longer able to survive in their former location, or to serve as interim refugia for rare and endangered plant species that have specialized environmental requirements and low genetic diversity (Fiedler and Laven 1996, Havens et al. 2006, Millar 1991, Vitt et al. 2010). These artificial reserves may in some cases maintain species until they can be moved to new suitable habitat. Although a controlled environment would probably require substantial resources, this approach may be critical for at-risk species (Coates and Dixon 2007).

Examples

- Using an existing artificial reserve to cultivate species after suitable habitat has shifted and when they face considerable lag time before new habitat may become available
- Collecting seeds and other genetic material of at-risk species to contribute to a genetic repository
- Planting individuals in a protected location expected to provide suitable habitat in a natural setting, such as a stand on a partner's property
- Planting individuals in a controlled setting, such as a climate-controlled arboretum or botanical garden.

Strategy 5: Maintain and enhance species and structural diversity

Land managers already work to increase structural and species diversity in many cases, and as an adaptation strategy this general goal receives added effort and focus (Mooney et al. 2009). Structural and species diversity may buffer a community against the susceptibility of its individual components to climate change (Peterson et al. 1998). In other words, a community may still experience stress as individual components fare poorly, but the redundancy of particular roles and variability among all species' responses contribute to the resilience of the community (Elmqvist et al. 2003). Although a forest is often defined by its dominant or most abundant species, even rare species can act as keystone species or contribute to the suppression of invasive exotic plants (Mooney et al*.* 2009).

Promote diverse age classes

Species are vulnerable to stressors at different stages in their life cycle. Even-aged stands are often more vulnerable to insect pests and diseases, many of which are likely to increase in range and severity as a result of climate change. In uneven-aged systems, a smaller proportion of the population may be exposed to a particular threat at any one time, which can increase the resistance or resilience of a stand to a wider range of disturbances (O'Hara and Ramage 2013). Maintaining a mix of ages, sizes, or canopy positions will help buffer vulnerability to stressors of any single age class, as well as increase structural diversity within stands or across a landscape (Noss 2001).

Examples

- Emulating aspects of disturbances through forest management techniques such as variable-density treatments or irregular return intervals in order to encourage the development of multiple age cohorts
- Focusing salvage operations on creating desired residual stand structures following disturbance, even if less merchantable timber is removed as a result
- Using site scarification, planting, or other techniques to support adequate regeneration
- Maintaining a variety of age classes of a given forest type across a larger landscape.

Maintain and restore diversity of native species

Diverse communities may be less vulnerable to climate change impacts and disturbances because they distribute risk among multiple species, reducing the likelihood that the entire system will decline even if one or more species suffer adverse effects. This may be especially important in communities with low diversity; even small increases in diversity may increase resilience without greatly altering species composition (Anderson and Chmura 2009, Cadotte et al. 2012, Wilkerson and Sartoris 2013). Forests with higher levels of species diversity are also expected to be less vulnerable to declines in productivity due to climate change (Duveneck et al. 2014).

Examples

- Using silvicultural treatments to promote and enhance diverse regeneration of native species
- Transitioning plantations to more complex systems by underplanting or promoting regeneration of a variety of native species expected to do well under future conditions
- Planting desired native species within an area that is otherwise expected to regenerate naturally in order to add diversity
- Restoring native vegetation on areas that have been severely altered by anthropogenic activities, such as abandoned agricultural areas or surface mines
- Planting species with diverse timing of phenological events (e.g., flowering, fruiting, leaf out, leaf drop) to provide necessary resources over a longer timeframe to forest-dependent wildlife species.

Retain biological legacies

Biological legacies are organisms, structures, or patterns inherited from a previous ecosystem and often include mature trees, snags, and down logs remaining after natural disturbance or harvesting (Society of American Foresters 2008). Biological legacies can enhance species and structural diversity, serve as a seed source, or provide nurse logs for seed germination (Gunn et al. 2009). Mature trees can often survive through periods of unfavorable climate, even while conditions become unsuitable for seedling establishment (Brubaker 1986). In a changing climate, biological legacies may play a critical role in a species' persistence or colonization of new habitat (Gunn et al. 2009).

Examples

- Retaining the oldest and largest trees with good vigor during forest management activities
- Retaining survivors of pest or disease outbreaks, droughts, windthrow events, or other disturbances during salvage or sanitation operations
- Retaining individual trees of a variety of uncommon species to maintain their presence on the landscape.

Establish reserves to maintain ecosystem diversity

Some areas with exemplary combinations of soil, hydrologic, and climatic variation support a correspondingly high degree of species diversity. Ecosystems in the areas may be protected through the establishment of reserves. Reserves are traditionally defined as natural areas with little to no harvest activity that do not exclude fire management or other natural disturbance processes (Halpin 1997). However, the use and definition of reserves may need to be evaluated within the context of changing climate and forest response. It may be valuable to retain explicit flexibility in management practices, so long as management directly supports the justifications and goals for establishing the reserve. This approach may also be used as a "control" for monitoring adaptation actions implemented in other forest stands.

Examples

- Identifying areas with high diversity or other desirable attributes that can be set aside as a reserve on an existing ownership
- Setting a minimum requirement for percentage of land in reserve
- Prioritizing areas where riparian corridors connect core areas to other reserves and habitats

- Providing a large reserve based on a species' known optimum conditions in order to preserve a species.

Strategy 6: Increase ecosystem redundancy across the landscape

Some losses are inevitable, whether due to catastrophic events or unforeseen interactions of management, climate change, and forest response. Increasing ecosystem redundancy attempts to lower the overall risk of losing a species or community by increasing the extent, number of occurrences across the landscape, and diversity of regeneration stages (Akçakaya et al. 2007). This strategy may benefit greatly from developing partnerships with other land management organizations and coordinating landscape-scale conservation practices.

Manage habitats over a range of sites and conditions

The suitable site conditions for a community or species may shift on the landscape as climate changes, resulting in new combinations of locations and species aggregations. This may increase opportunities for successful regeneration and the likelihood of persistence of a species or community (Joyce et al. 2009, Millar et al. 2007, The Nature Conservancy 2009). Species currently covering a large extent may provide many options for retaining redundancy across the landscape.

Examples

- Restoring or increasing a community type on a variety of soil types and across a range of topographic positions
- Implementing a variety of forest management activities or silvicultural prescriptions across multiple stands or areas with similar starting conditions in order to diversify forest conditions and evaluate different management approaches
- Coordinating with partners to manage an at-risk species or community existing on a variety of suitable sites.

Expand the boundaries of reserves to increase diversity

Approaches 4.1 and 5.4 describe protecting and maintaining climate refugia and reserves to maintain ecosystem diversity and legacy. Expanding existing reserve boundaries may buffer and replicate the diversity within the core of the reserve, but more importantly, may also increase the overall species diversity within the expanded reserve (Akçakaya et al. 2007). This approach may be more effective over the long term if focused on reserves that also encompass climate refugia.

Examples

- Restoring or conserving land directly adjacent to established reserves
- Developing a network of reserves with adjacent landowners with shared conservation goals
- Designating buffer zones of low-intensity management around core reserve areas and between different land uses.

Strategy 7: Promote landscape connectivity

Species migration is a critical factor in the maintenance of ecosystem function in a changing climate, but fragmentation of landscapes and loss of habitat may restrict species movement and gene flow (Davis and Shaw 2001, Iverson et al. 2004a). Managing the landscape for connectivity may allow for easier species movement, reduce lags in migration, and enhance the flow of genetic material. The current rate of climate change coupled with contemporary land use, however, creates unique challenges to migration. Many species are not expected to be able to migrate at a rate sufficient to keep up with climate change and associated range shifts (Davis and Shaw 2001, Iverson et al. 2004a). Therefore, it may be beneficial to combine the approaches under this strategy with efforts to create refugia or relocate species (i.e., assisted migration). But connectivity may also increase movement of invasive species and insect pests, thereby increasing the need to prevent introduction of these species.

Reduce landscape fragmentation

The fragmentation of contiguous forest habitats is a primary driver of biodiversity loss and reduced productivity through exposure to disturbance, obstruction of migration pathways, and overall lowered resilience (Fischer and Lindenmayer 2007). Protecting large areas from fragmentation will require a concerted effort to create partnerships, agreements, and other mechanisms for land protection and management across property boundaries. Strategic acquisition of high-priority conservation areas, conservation easements, certification programs, restoration projects, and other efforts to increase the size and connectivity of forest ecosystems will foster a landscape-level response to counter the widespread effects of climate change (Anderson et al. 2012, Millar et al. 2007, Spittlehouse and Stewart 2003). This approach may be facilitated by approach 5.4, which focuses on establishing new reserves.

Examples

- Using geospatial information to identify new and existing migration corridors
- Restoring native vegetation and vegetation structure in degraded areas within the forested matrix
- Establishing partnerships and coordinating acquisition of conserved forest lands or riparian areas to achieve common management goals
- Establishing or expanding reserves adjacent to other forest blocks to form a connective network of a few large reserves, many small reserves along a climatic gradient, or a combination of large and small reserves close to each other
- Promoting or participating in conservation easement programs that retain forest cover and achieve landscape-scale connectivity

Maintain and create habitat corridors through reforestation or restoration

The presence of both small and large corridors on the landscape may help species to migrate without additional assistance (Heller and Zavaleta 2009). Corridors oriented in any direction may be useful to facilitate genetic mixing, but corridors arranged along climatic or elevational gradients may be more useful if the goal is to allow for species movements along the gradient. Reforestation or restoration of riparian areas may help retain species on the landscape longer while providing a forested corridor.

Examples

- Establishing or restoring forest cover along rivers or ridges to build on natural linear features that connect larger forests
- Setting aside a connected network of conservation easements
- Eradicating invasive species within a corridor in order to minimize competition with desired species
- Working with partners on the landscape to identify high-priority sites to protect for landscape-scale corridors or habitat.

Strategy 8: Maintain and enhance genetic diversity

Greater genetic diversity may help species adjust to new conditions or sites by increasing the likelihood that some individuals within a species will be able to withstand climate-induced stressors. Current guidelines for management of tree genes generally promote the conservation of local gene pools, restrict transfer of germplasm, and define small seed zones to minimize contamination between pools (Millar et al. 2007). A changing climate may require new guidelines that accommodate shifting seed zones and promote more options for increasing genetic diversity. Actions to enhance genetic diversity could be timed to occur after large-scale disturbances to take advantage of regeneration and establishment phases. Approaches under this strategy are best implemented with great caution, considering the uncertainties inherent in climate change, the sparse record of previous examples, the ecological and social suitability of particular locations, and continued uncertainties of forest response.

Use seeds, germplasm, and other genetic material from across a greater geographic range

Planted seedlings typically have greater survival when they originate from local seed sources, but local seed sources may no longer produce the best adapted seedlings if the governing environmental factors change (Vitt et al. 2010). Using seed zones that change over time and are based on regional analyses of climate change data may provide better seed sources than static seed zones (Erickson and Navarrete-Tindall 2004, Millar et al. 2007, Spittlehouse and Stewart 2003). This may entail importing genetic stock from locations ranging from nearby to substantially distant in order to introduce plants that are expected to be better adapted to current or future climatological conditions. At the same time, ecoregional and political boundaries may continue to restrict the distance from which new species or genotypes may be imported (McKenney et al. 2009, Pedlar et al. 2012). This strategy may require communicating with policy-makers to reevaluate seed zone sizes and rules governing the movement of seed stocks. It is important to note that although many environmental factors may match seedlings to geographic areas, limitations such as cold tolerance may remain (Millar et al. 2007). It is also important to take the necessary precautions to avoid introducing a new invasive species (Vitt et al. 2010).

Examples

- Using mapping programs to match seeds collected from a known origin to planting sites based on climatic information

- Identifying and communicating needs for new or different genetic material to seed suppliers or nurseries
- Planting seedlings germinated from seeds collected from various locations throughout a species' native range

Favor existing genotypes that are better adapted to future conditions

As populations experience cumulative changes in climate, or short-term extremes in climate, new selective pressures on populations may result in changes in phenotypic expression and genotypic evolution responses (Reed et al. 2011). Some genotypes may be better adapted to future conditions or changing conditions because of pest resistance, broad physiological tolerances, short regeneration times, or other characteristics (Millar et al. 2007, Spittlehouse and Stewart 2003). Identifying and managing these future-adapted genotypes during various life stages may allow a population to persist where it may otherwise fail. However, the use of this approach may be currently limited by the uncertainty about precise future conditions and which genotypes are best suited to these conditions (Breed et al. 2013). It is also possible that genotypes from other sites could interfere with the adaptation of local populations, if the imported resources are not adapted to withstand local pressures (e.g., frost tolerance or pathogen resistance). Availability of source material may also limit the use of this approach.

Examples

- Planting stock from seeds collected from local trees that exhibit drought tolerance, pest resistance, or other desirable qualities
- Planting stock from seeds collected from healthy trees in warmer or drier locations in the region
- Retaining some survivors of a die-back event, such as drought-induced mortality or pathogenic blight, rather than salvage harvesting all trees in an affected area
- Creating and monitoring areas of natural regeneration in order to identify and promote well-adapted phenotypes
- Planting disease-resistant chestnut in order to reestablish a form of this species on the landscape.

Strategy 9: Facilitate community adjustments through species transitions.

Species composition in many forest ecosystems is expected to change as species adapt to a new climate and transition into new communities (Iverson et al. 2004b). This strategy seeks to maintain overall ecosystem function and health by gradually enabling and assisting adaptive transitions of species and communities in suitable locations. This may result in slightly different species assemblages than those present in the current community, or an altogether different community in future decades. This strategy includes aggressive actions to promote ecosystem change rather than an unchanging community or species mix. Many of the approaches in this strategy attempt to mimic natural processes, but may currently be considered unconventional management responses. In particular, some approaches incorporate assisted migration, which remains a challenging and contentious issue (McLachlan et al. 2007, Ricciardi and Simberloff 2009). It is not suggested that managers attempt to introduce new species without thoroughly investigating potential consequences to the native ecosystem (Ricciardi and Simberloff 2009). This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response. Outcomes from early efforts to transition communities can be evaluated to provide both information on future opportunities and specific information related to methods and timing.

Favor or restore native species that are expected to be adapted to future conditions

There are many cases where native species may be well adapted to the future range of climatic and site conditions (Landscape Change Research Group 2014, Walk et al. 2011). Using management to favor native species in a community or forest type that are expected to fare better under future climate change can facilitate a gradual shift in the forest composition. Establishing or emphasizing future-adapted species now may create opportunities to fill the niche left by species that decline. Where communities are dominated by one or a few species, this approach will probably lead to conversion to a different community type, albeit with native species.

Examples

- Underplanting a variety of native species on a site to increase overall species richness and provide more options for future management

- Favoring or establishing oak, pine, and other more drought- and heat-tolerant species on narrow ridge tops, south-facing slopes with shallow soils, or other sites that are expected to become warmer and drier
- Seeding or planting drought-resistant genotypes of commercial species (e.g., loblolly pine) where increased drought stress is expected

Establish or encourage new mixes of native species

Repeated periods of warming and cooling over the last 15,000 years have resulted in large shifts in species composition (Davis 1983, Jacobson et al. 1987, Shuman et al. 2002). Novel combinations of climatic and site conditions are expected to continue to affect individual species in different ways. Although some species may not occur in a forest or community type as currently defined, they may have been together previously. Novel mixing of native species may lead to the dissolution of traditional community relationships and result in conversion to a newly defined or redefined forest or community type (Davis et al. 2005, Root et al. 2003).

Examples

- Planting or seeding a mixture of native species currently found in the area that are not typically grown together but may be a suitable combination under future conditions
- Underplanting with eastern white pine to diversify the conifer component of a stand that has had no eastern white pine
- Intensifying site preparation in a northern hardwoods stand to promote the establishment of oak from an adjacent stand
- Allowing a species native to the region (e.g., black locust) to establish where it was not historically present, if it is already encroaching and likely to do well there under future climate conditions

Guide changes in species composition at early stages of stand development

Long-term ecosystem function may be jeopardized if existing and newly migrated species fail to regenerate and establish. Active management of understory regeneration may help transition forests to new and better-adapted compositions more quickly by promoting desired species and reducing competition from undesirable, poorly adapted, or invasive species. Natural disturbances often initiate increased seedling development and genetic mixing, and can be used to facilitate adaptation (Joyce et al. 2009). Silvicultural prescriptions can mimic natural disturbance to promote regeneration in the absence of natural disturbance. Under drier conditions and increased stress, promoting regeneration and discouraging competitors may require more-intensive site preparation, including prescribed fire, soil disturbance, and herbicide use. When forests are dominated by one or a few species, this approach may lead to conversion to a different forest type.

Examples

- Preventing and removing undesired species, including invasive nonnative or aggressive native species, in order to reduce competition for moisture, nutrients, and light
- Controlling beech suckers, sprouts, and brush by using herbicide or mechanical treatment in areas affected by beech bark disease in order to reduce competition with the regeneration of other species
- Planting or seeding sufficient stocks of desired species before undesirable species have the chance to establish or compete
- Performing timber stand improvement to favor and promote the growth of desirable growing stock

Protect future-adapted seedlings and saplings

As climate change increases both direct and indirect stressors on forest ecosystems, it becomes increasingly important to ensure the adequate regeneration of tree species in order to maintain forest or woodland conditions. Seedlings and saplings are generally more sensitive than older growth stages to changes in moisture and temperature, physical disturbance, herbivory, and other stressors (Walck et al. 2011). For this reason, protecting seedlings or saplings of existing or newly migrated species can strongly shape the ways in which communities adapt (The Nature Conservancy 2009). Further, tending regeneration by protecting it from herbivory, removing competition, or otherwise reducing damage to seedlings and saplings helps to promote the transition to desired future conditions and functions.

Examples

- Using repellent sprays, bud caps, or fencing to prevent browsing on species that are expected to be well adapted to future conditions
- Using tree tops from forest harvest or plantings of nonpalatable tree species as locations for “hiding” desirable species from herbivores to reduce browse pressure

- Preventing and removing undesired species, including invasive nonnative or aggressive native species, in order to reduce competition for moisture, nutrients, and light
- Restricting recreation or management activities that may have the potential to damage regeneration
- Partnering with state wildlife agencies to monitor herbivore populations or reduce populations to appropriate levels.

Disfavor species that are distinctly maladapted

A species is considered maladapted when its environment changes at a rate beyond the species' ability to adapt and accommodate those changes (Johnston 2009). Species at the southern or highest elevational extent of their geographic range are especially vulnerable to habitat loss, and some of these species are expected to decline rapidly as conditions change (Iverson 2002, Iverson and Prasad 1998). Monitoring or inventory data for some species may already show evidence of decline at a particular site, although their decline may not be attributed to a single cause, but to a combination of causes that may include varying degrees of interaction with climate change. Models that incorporate climate change and species' life history characteristics may identify other species that are likely to decline (Landscape Change Research Group 2014, Wang et al. 2014). Species declines may require rapid and aggressive management responses to maintain forest cover and ecosystem function during periods of transition. In ecosystems where the dominant species are likely to decline dramatically or disappear, this may mean dramatically altering the species assemblage through active or passive means.

Examples

- Removing unhealthy individuals of a declining species in order to promote other species expected to fare better. This does not imply that all individuals should be removed, and healthy individuals of declining species can be retained as legacies.
- Anticipating and managing rapid decline of species with negative prognoses in both the short and long term (e.g., hemlock) by having adequate seed stock of a desired replacement species expected to do well under future climate conditions
- Protecting healthy legacy trees that fail to regenerate while deemphasizing their importance in the mix of species being promoted for regeneration.

Manage for species and genotypes with wide moisture and temperature tolerances

Inherent scientific uncertainty surrounds climate projections at finer spatial scales (Schiermeier 2010), making it necessary to base decisions upon a wide range of predictions of future climate. Managing for a variety of species and genotypes with a wide range of moisture and temperature tolerances may better distribute risk than attempting to select species with a narrow range of tolerances that are best adapted to a specific set of future climate conditions (The Nature Conservancy 2009).

Examples

- Favoring species that are currently present that have wide ecological amplitude and can persist under a wide variety of climate and site conditions
- Planting or otherwise promoting species that have a large geographic range, occupy a diversity of site conditions, and are projected to have increases in suitable habitat and productivity
- Promoting long-lived conifers with wide ecological tolerances, such as eastern white pine
- Identifying and promoting species that currently occupy a variety of site conditions and landscape positions

Introduce species that are expected to be adapted to future conditions

Maintaining ecosystem function or transitioning to a better-adapted system may involve the active introduction of species or genotypes to areas that they have not historically occupied, often described as assisted migration, assisted colonization, or managed relocation (Hoegh-Guldberg et al. 2008, Hunter 2007, McLachlan et al. 2007, Ricciardi and Simberloff 2009). One type of assisted migration, sometimes called forestry assisted migration, focuses on moving species to new locations in order to maintain forest productivity and health under climate change (Pedlar et al. 2012, Seddon 2010). Given the uncertainty about specific climate conditions in the future, the likelihood of success may be increased by relocating species with a broad range of tolerances (e.g., temperature, moisture) from across a wide range of provenances. This approach is generally considered less risky than species rescue assisted migration (described in the next section) because it moves species to new habitats within their current range or over relatively short distances outside their current range, and focuses on widespread species for which much is known about their life history traits (Pedlar et al. 2012). However, there are still risks associated with moving any species, such as introducing new pests or diseases, the potential for hybridization with other closely related species, and genetic bottlenecks if the introduced seed source is not adequately diverse (Aubin et al. 2011).

Examples

- Planting oaks, pines, and other drought-tolerant species on sites within the current range that are expected to become drier and that have not been historically occupied by those species
- Planting flood-tolerant species, such as swamp white oak and silver maple, on sites that are expected to become more prone to flooding and that are currently not occupied by flood-tolerant species
- Planting southern species, such as shortleaf pine, north of its current range on suitable sites based upon its projected range expansion
- Planting disease-resistant cultivars of elm or chestnut where they are likely to have suitable habitat.

Move at-risk species to locations that are expected to provide habitat

The climate may be changing more rapidly than some species can migrate, and the movement of species may be restricted by land use or other impediments between areas of suitable habitat (Davis and Shaw 2001, Iverson et al. 2004a). This can be particularly challenging for species that are already rare or threatened. Another subset of assisted migration, sometimes called species rescue assisted migration, focuses on avoiding extinction of species threatened by climate change (Pedlar et al. 2012). If current habitat occupied by those species is expected to become (or already is) unsuitable, assisted migration to potential new suitable habitat may be the best option to ensure survival of the species (Vitt et al. 2010). Because species are often extremely rare, this type of assisted migration can also potentially cause declines in the donor populations through removal of seeds or individuals (Aubin et al. 2011). This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response (Ricciardi and Simberloff 2009).

Examples

- Planting or seeding a rare or threatened plant species that is at risk for extinction to a newly suitable habitat outside its current range
- Assisting the migration of wildlife around barriers from low elevations to higher elevations by trapping and releasing in newly suitable locations
- Moving plants or animals from a mountaintop to another mountaintop north of their current range

Strategy 10: Realign ecosystems after disturbance

Ecosystems may face significant impacts as a result of climate change-related alterations in disturbances, including fire, drought, invasive species, and severe weather events (Dale et al. 2001). Disturbances are primary drivers of many ecosystems, but changes in the frequency, intensity, and duration of disturbance events may create significant management challenges (Lawler 2009). Although it is often not possible to predict a disturbance event, it is possible to increase overall preparedness for large and severe disturbances and prioritize rapid response. Many of the best opportunities for addressing disturbance-related impacts may occur immediately after the disturbance event; having a suite of preplanned options in place may facilitate an earlier and more flexible response and prevent maladaptive responses. In the future there are likely to be more frequent situations where a disturbance exceeds the resilience of an ecosystem, such that even intensive management may be insufficient to return the ecosystem to a prior condition. In these cases, it may be necessary to reevaluate and adjust management goals, which can involve realigning the ecosystem to better match new climate and environmental conditions (Millar et al. 2007). This strategy involves consideration of the full range of potential impacts and planning to respond to severe ecosystem disturbance and disruption.

Promptly revegetate sites after disturbance

Potential increases in the frequency, intensity, and extent of large and severe disturbances may disrupt regeneration and result in loss of forest cover, productivity, or function in the long term. Changing conditions are expected to threaten regeneration processes for some species, and may result in failure of natural regeneration of desired species. Prompt revegetation of sites following disturbance helps reduce soil loss and erosion, maintain water quality, and discourage invasive species in the newly exposed areas. These efforts can also provide an intervention point for promoting species and systems that may be better adapted to future conditions.

Examples

- Planting a variety of future-adapted species during revegetation efforts to ensure diverse regeneration and provide options for future management
- Creating suitable physical conditions for natural regeneration through site preparation (e.g., chaining after a burn to promote seed establishment)

- Monitoring areas of natural regeneration on a more frequent basis, and prioritizing planting or seeding where natural regeneration is slow to succeed
- Coordinating with the public and other organizations to avoid conflicting or misguided responses

Allow for areas of natural regeneration to test for future-adapted species

Although many areas may be replanted after severe disturbance, some areas can be set aside to allow for natural regeneration as a means to identify the well-adapted species and populations (Joyce et al. 2009). The use and monitoring of test or "control" areas of natural revegetation following disturbance may help managers identify (1) species that are well adapted to the changing climate and environmental conditions and (2) potential threats in the form of invasive species or poor regeneration of desirable species.

Examples

- Using modeling and remote sensing to identify areas at low risk for erosion, flooding, or other threats that could be set aside for natural regeneration
- Monitoring naturally revegetated areas for changes in species composition, productivity, and other factors
- Controlling competition from undesirable tree species and invasive species to enhance regeneration of desired tree species
- Removing small-diameter residual trees to reduce competition, increase sunlight, and improve seed germination potential
- Creating conditions that will be favorable for regeneration of desired species, for example by removing the duff layer to allow germination and sprouting of shortleaf pine

Realign significantly disrupted ecosystems to meet expected future conditions

Some ecosystems may experience such significant disruption and decline that desired conditions or management objectives appear to be no longer feasible. This situation may occur if most species in the ecosystem are projected to decline as climate changes. Management of these systems may be adjusted to create necessary changes in species composition and structure to better adapt forests to current and anticipated environments, rather than to historical predisturbance conditions (Millar et al. 2007, Spittlehouse and Stewart 2003). Developing clear plans that establish processes for realigning significantly altered ecosystems before engaging in active management will allow for more thoughtful discussion and better coordination with other adaptation responses.

Examples

- Allowing a transition in forest type by planting future-adapted species within a stand that is already declining or is expected to decline (e.g., planting jack pine and tamarack in a failing white spruce stand, or underplanting eastern white pine in the next regeneration cut of quaking aspen)
- Planting species expected to be better adapted to future conditions, especially where natural regeneration in forests affected by disturbance is widely failing
- Allowing nonnative invasive or aggressive native species to remain as part of a novel mix of species, rather than eradicating these species
- Creating novel communities “from scratch” in areas that have been severely affected by natural or human disturbance as part of intensive remediation efforts

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