Sustaining disturbance dynamics within appropriate ranges sustains biodiversity and ecosystem services.

Finding 2A
The historical range of variation is a useful but limited concept for managing biodiversity.

For every landscape, natural disturbance processes have measurable patterns of frequency, intensity, and spatial scale. The pattern of variability over time constitutes the historical range of variation (HRV)—fluctuations in ecosystem behavior resulting from influences such as climate, fire, or flood. When humans alter ecosystems beyond the historical range of variation, they risk fundamental change that can threaten biodiversity. As Pickett et al (1992) noted, "Nature has a range of ways to be, but there is a limit to those ways, and therefore human changes must be within those limits."

NCSSF Results: Many components of biodiversity are affected by the complexity of forest structure and landscape diversity in relation to the disturbance regimes and history of a particular area (NCSSF A7). Management that sustains this complexity within its historical bounds may also sustain historical biodiversity; however, pre-settlement conditions are often not a realistic management goal because the landscape condition has been changed by human-caused disturbance. Attempting to restore earlier landscapes may not lead to resilience in the face of new forces, such as climate change, mega fires, exotic species invasions, or pollution (NCSSF B1.3).

Because HRV has sustained biodiversity over time, it is sometimes recommended that managers emulate those fluctuations and avoid exceeding historical extremes. A more productive approach is to understand how historical behavior shaped ecosystems and to try to project that behavior beyond any recent alteration into the future as a management target based on lessons of history, not a re-creation of history. A natural disturbance regime for an area comprises all of the various disturbances that affect it as well as their intensities and frequencies. When natural disturbance regimes are absent or altered, restoration and management approaches that integrate concepts of ecosystem responses to natural disturbances may achieve biodiversity goals. (NCSSF A6: *Evaluation of the Role of Ecosystem Restoration on Biodiversity*)

Managing within HRV is relatively simple in systems that have not been fundamentally altered by changes in land use, disturbance frequency, or species composition, human imposed infrastructure such as highways and dams, or climate change. Where extinctions, species introductions, or altered disturbance regimes have fundamentally changed the system, management-induced or natural disturbances may produce

COPYRIGHT JOHN MCCOLGAN, ALASKA FOREST SERVICE. IMAGE COURTESY: AGI IMAGEBANK novel and undesirable effects such as uncharacteristically severe fire or species invasions. Sustaining historical dynamics into the future can be further complicated by climate change and invasive species.

At regional scales, changes have been profound and pervasive nearly everywhere, and managing ecosystems to function within their historical bounds is neither possible nor desirable. Still, lessons of history, such as the importance of maintaining forest complexity, can be applied to maintain biodiversity. For example, in one NCSSF-sponsored project, thinning younger conifer stands in the Pacific Northwest benefited at least one bird species (NCSSF A5W).

Managers can adhere too strictly to the HRV without considering significant changes that result from climate change, species invasions, and other pressures. The lessons of history should be combined with knowledge of expected ecosystem behavior under likely future scenarios to identify a "future range of variation" (FRV) that will sustain biodiversity in the face of ongoing environmental change. ■

Finding 2B

Fire significantly influences patterns of biodiversity within and among forest ecosystems.

A fire regime comprises the characteristics of fire in a given ecosystem, such as the frequency, predictability, intensity, and seasonality of fire. Several factors have altered fire regimes in forested ecosystems over the past century, including land-use history, landscape fragmentation, fire suppression, and changes in human access and ignition sources. The size and severity of recent fires in the dry forests of the U.S. West were historically unprecedented, a result of 50 years of effective fire suppression, high fuel amounts, and a warming climate.

NCSSF Results: Failure to reduce the risk of extreme fire behavior outside the historical range of variation can significantly affect biodiversity through changes in landscape patterns and other ecological processes (NCSSF R3: *Fire, Forest Health and Biodiversity—Second Annual NCSSF Symposium*).

Modeling by Perry et al (2004) showed that susceptibility to crown fires in dry forests of central Oregon varied widely at the landscape level. In most modeled cases, controlled underburns, or a combination of controlled underburns with light to moderate thinning of smaller trees, could significantly reduce risk. Field research done in Central Oregon by Fitzgerald (2003) indicates that moderate to heavy thinning of understory trees and reduction in surface fuels is required to change fire behavior significantly. However, human development in high-risk areas has greatly diminished fire management options. Air-quality standards can severely limit the number of days per year in which prescribed fire can be used, reducing the opportunity for risk-reduction fires and artificially constraining replication of historic fire levels.

The impacts of changes in fire patterns depend on the past frequency and intensity of fire behavior in a given ecosystem. Eliminating fire in areas that experience frequent, low-intensity fires can result in in-growth of shade-tolerant shrubs and trees and a loss of herb cover and diversity. In other areas, absence of mixed-severity fires leads to uniform landscapes at intermediate spatial scales (up to 0.6 miles); the loss of fuel variability results in less variability in future fire behavior. Areas that typically experience high-severity fires or those with long return times suffer effects of fire exclusion mostly at very large spatial scale with changes in patch size, shape, density, and distribution.

The biodiversity consequences of altered fire regimes include less variability in landscapes, loss of fire-dependent species such as the Kirtland's Warbler and Red Cockaded Woodpecker, and the introduction of invasive species. Without fire, the natural succession of vegetation in some areas ultimately eliminates conditions needed to sustain threatened or endangered species or, as in recent years, creates conditions for fire to operate well outside its natural regime for the forest where it occurs. Better scientific knowledge about the role of fire in maintaining biodiversity in forests and related ecosystems will be crucial to formulating appropriate policies. ■

Finding 2C
An interdisciplinary scientific approach is necessary to address invasive species.

Non-native invasive species play a significant role in redistributing species and altering ecosystems. For example, a non-native fungus introduced in the last century caused the chestnut blight that forever changed the Appalachian forest ecosystem by effectively eliminating its dominant tree species. Increasingly species invasions threaten sustainable forests and biodiversity in the United States and worldwide (Table 1). Non-native invasive species also are altering ecosystems by eliminating native vegetation or altering ecosystem function (e.g. the effects of salt cedar on hydrology in the Southwestern United States).

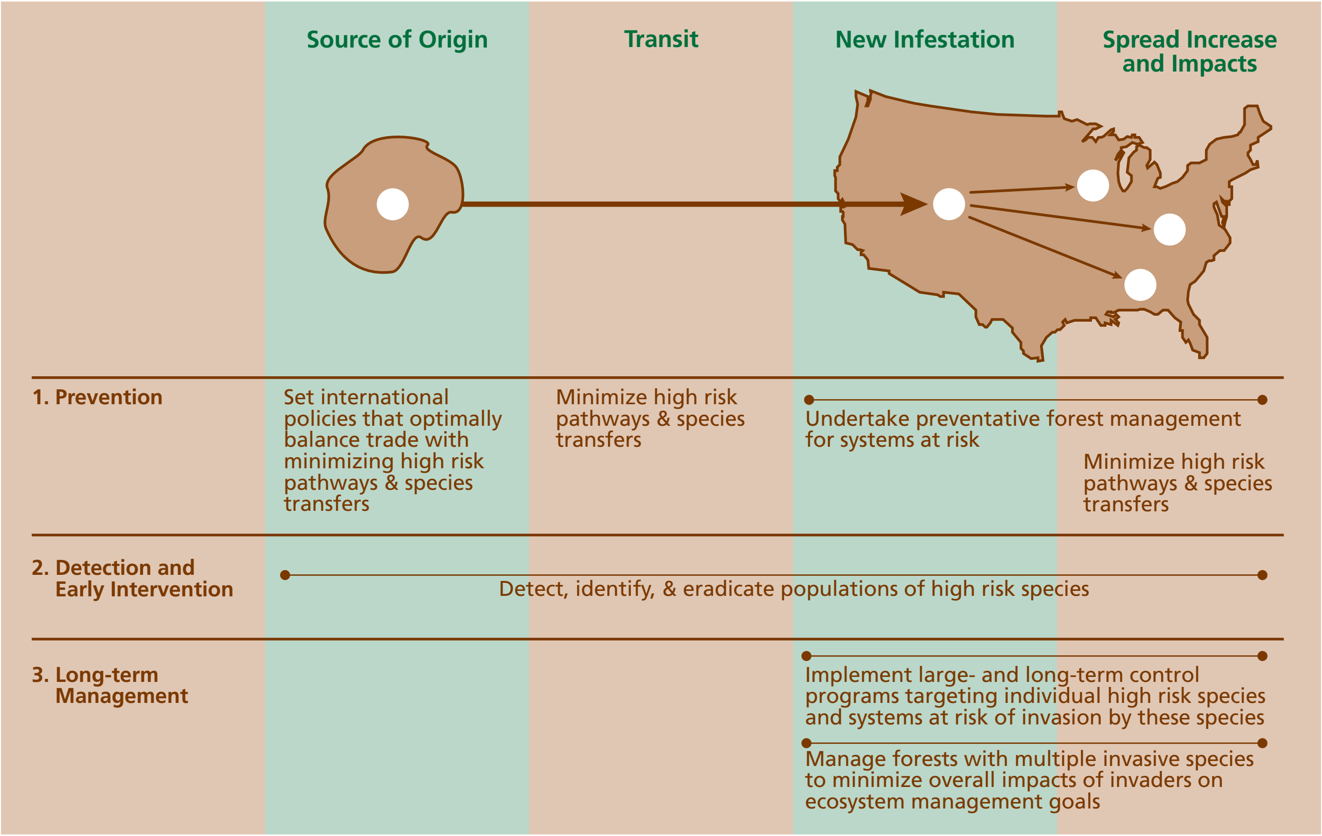
NCSSF Results: The effects of non-native species invasions in U.S. forests are lasting and cumulative, threatening to undermine the foundation of sustainability. Three complementary strategies are essential to counter invasives: (1) prevention; (2) detection and early intervention to eliminate invaders that elude prevention; and (3) long-term management of well-established invasive species. New scientific approaches and applications are needed to improve actions in each area (NCSSF A1: *Synthesis of the Existing Science Relating Forest Management Practices to the Spread of Forest Diseases and Exotic Invasive Weeds*).

Each strategy depends on the actions of individuals and institutions and the availability of appropriate knowledge and tools (Figure 4). NCSSF's priorities are to improve the underlying scientific concepts and technologies, addressing issues across sectors and at various geographic scales by identifying key science needs to reduce the threat of invasive species to sustainable forests.

By killing and damaging dominant tree species, invasive pathogens and insects cause cascading changes in the function and value of forest ecosystems. They also significantly modify forest ecosystem processes by altering fire and hydrological regimes and food-web dynamics.

Figure 4

Strategies for reducing invasive species impacts on sustainable forests (NCSSF A1)



	Source of Origin	Transit	New Infestation	Spread Increase and Impacts
1. Prevention	Set international policies that optimally balance trade with minimizing high risk pathways & species transfers	Minimize high risk pathways & species transfers	Undertake preventative forest management for systems at risk	Minimize high risk pathways & species transfers
2. Detection and Early Intervention	Detect, identify, & eradicate populations of high risk species			
3. Long-term Management			Implement large- and long-term control programs targeting individual high risk species and systems at risk of invasion by these species Manage forests with multiple invasive species to minimize overall impacts of invaders on ecosystem management goals	

Table 1

Examples of Non-Native Invasive Species Significant to U.S. Forests

Species	First U.S. Detection	Ongoing and Possible Impacts
Nun moth (*Lymantria monacha*)[1, 2]	None	Could cause cumulative 20-year timber losses as high as $2.5 billion if established in 3 cities. Most damaging forest pest in Europe.
Sirex woodwasp (*Sirex noctilio*)[1]	None	Could cause cumulative 20-year timber losses of $760 million if established in 3 cities.
Emerald ash borer (*Agrilus planipennis*)	2002	In MI, OH, and MD. Could cause elimination of ash as a street, shade, and forest tree nationwide at an estimated cost of $282 billion.
Sudden Oak Death (*Phytophthora ramorum*)[7]	1994	In CA and OR and spreading rapidly. Has been detected in diseased nursery stock shipped from CA to 6 states. Could devastate oak forests nationwide.
Dutch elm disease (*Ophiostoma ulmi*)[1]	1930	Occurs in most states. Has killed more than 60% of elms in urban settings. A more virulent U.S. strain evolved and has caused significant impacts in Europe.
Hemlock woolly adelgid (Adelges tsugae)[2, 9]	1920's	Currently in more than 4 states. Contributing to decline of eastern and Carolina hemlocks. Alters bird communities where it kills eastern hemlock.
Balsam woolly adelgid (*Adelges piceae*)[2]	1908	Attacks true fir species. Caused dramatic declines in Fraser fir in Great Smoky Mountains National Park, resulting in understory and wildlife changes.
Chestnut blight (Dryphonectria parasitica)[1]	1904 or earlier	Eliminated American chestnut from eastern deciduous forests. Annual lost timber value for 3 states of $683.9 million (1999 dollars). Caused declines in chestnut-dependant wildlife and erosion where lost trees have not been replaced.
White pine blister rust (*Cronartium ribicola*)[3, 4, 5]	Late 1800's to early 1900's	Throughout range of eastern white pine and in 6 western states. Lost economic value. Killing pines in western high elevation ecosystems, eliminating wildlife forage; affecting soil stability, snowmelt regulation, and succession.
European gypsy moth (*Lymantria dispar*)[1]	1869	In 19 states, spot infests 12 more. Annually defoliates millions of northeastern and Midwestern forested acres; suppression costs tens of millions. Record losses in 1981: 13 million acres defoliated; $3.9 billion (1998 dollars) in losses.
Japanese honeysuckle (*Lonicera japonica*)[6, 8]	Early to mid-1800's	In 37 states. Invades forest edges and disturbed areas. Suppresses native plants, topples trees, alters songbird populations by changing forest structure.

References: [1]APHIS, 2000; [2]Campbell and Schlarbaum, 2002; [3]Ciesla and Coulston, 2002; [4]Krakowski et al., 2003; [5]Leibhold et al., 1995; [6]NRCS, undated; [7]PCA, undated; [8]TNC, undated; [9]Tingley et al., 2002

Monetary losses of U.S. forest products due to invasive species may be more than $2 billion annually. New invasions continue, spurred by changes in ecosystems and increased species mobility. The sudden oak death pathogen or emerald ash borer could have profound ecological and economic impacts; U.S. forests have experienced neither the full number of possible invasions nor the full effects of already established invaders. Economic globalization and increasing human access, fragmentation, disturbance, and climate change increase opportunities for invasive species to become established in U.S. forest ecosystems (NCSSF A1). ■

Finding 2D
Variation in disturbance dynamics is often connected to human activities and changes in climate.

Forest ecosystems are constantly changing. The speed and direction of that change have been and continue to be influenced by changes in human activities and variations in climate occurring over years, decades, centuries, and millennia. These patterns are further complicated by interactions among human actions and climate.

NCSSF Results: Climatic changes over the past 1400 years in Northern Arizona were inferred from tree rings. Researchers identified 58 distinct climatic periods—i.e., warm and dry versus cool and wet. These periods were often related to changes in human activities and land use that, together, influenced the species composition of forests. For example, the "Great Drought" from 1276-1299 was linked to regional-scale movements of prehistoric human populations. These migrations together with changes in climate influenced where and how forests were being used (NCSSF B1.3: *Land Use History Impacts on Biodiversity—Implications for Management Strategies in the Western U.S.*). ■

Implications of Area 2 Findings for Sustainable Forestry

Departures from the historical range of variation (HRV) often have adverse consequences for biodiversity. HRV can be a useful guide for management, and it may even help build social acceptability when defining new biodiversity conservation goals. However, HRV isn't necessarily the appropriate goal in the face of changes in climate and species composition that change the nature of ecosystem behavior and response to disturbance. At the very least, there must be a mechanism to update and adapt the HRV concept with new information about such factors as climate change and invasive species to create a "future range of variation" concept or FRV.

Predicting the future range of variation (FRV) is difficult, but many possible forest futures can be accurately described. For example, most of the mixed-species forests of Northern New England include a narrow range of tree ages. Management can create a greater range of ages and thus more diverse forests. However, the upper limit of forest age will be dictated simply by the passage of time. This becomes a limit on the FRV.

In these forests, it will be a long time before there is a significant area of late successional or "old growth" forests. However, some structural characteristics of old growth can be accelerated. FRV can be manipulated by thinning forests to encourage the remaining trees to reach old growth size sooner. In this instance, the future can be both predicted and created. Similarly, the rate at which wind, fire, insects, disease or harvest create young forests will limit FRV on the other end of the age spectrum.

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Forest fires outside the HRV will result from both human interventions, such as exclusion of fire from fire-dependent forests, and variations caused by combinations of natural and human influences such as changing climate conditions. Changing fire regimes will include more frequent extreme fires.

The effects of fuel reduction treatments on biodiversity are poorly understood, particularly in mixed-severity fire regimes. NCSSF is addressing this challenge by sponsoring a three-part project in fire-prone regions of the Western United States, NCSSF C4: *Biodiversity Implications of Post-Fire Recovery Strategies*. It will assess the impacts of post-fire treatments on immediate ecosystem recovery and the long-term impacts on subsequent fire severity by comparing post-fire treatments in areas that have recently been burned and areas that received some type of post-fire treatment after an older fire and then were burned again.

In a world where non-native, invasive species are jumping bio-geographic barriers, the usual approaches to ecosystem restoration won't work. We must move beyond the case-study approach to an interdisciplinary science, and emphasize pathways and prevention, combined with early detection and rapid eradication of emerging populations of invasives (Figure 5).

A new project, NCSSF C7 *Understanding How Forest Management Practices Affect Species Invasions and Impacts*, will synthesize what has been learned from forest management for invasive species and highlight effective measures for combating harmful impacts of invasive species.

Specific relationships between land-use history and many elements of biodiversity are poorly understood in most regions, although ongoing NCSSF research is designed to increase knowledge of these areas. NCSSF-funded research has consistently shown the value of science of place—different systems are different in many ways. Constructing a frame of reference for a given site requires knowing the site's unique composition from its fire history, evidence from ecology, archeology, and other sources. For example, thinning or shifting forest structure alone may not be enough to regenerate species richness; drought and arrested ecological processes will slow recovery. Future impacts on biodiversity of some land uses can't be predicted. Restoration goals and strategies must consider short- and long-term climate-change forecasts and anticipated outcomes. A key difference for biodiversity conservation in modern times is that some populations of plants and animals can no longer move in response to climate change because of man made physical barriers and other land uses. Given the uncertainties about these interactions, adaptive management will be critically important.

In the context of other goals, managing forests and woodlands for ecosystem resilience in the face of pollution, invasive species, habitat loss and fragmentation, climate change, and other new threats can be more effective than attempting to return to past forest structure. Management practices that address ecosystem processes and composition in addition to structure will preserve and enhance resilience more effectively than those that address structure alone. Attempting to conserve biological soil crust integrity, native biodiversity, and endemic species, as well as a diverse pattern of habitats can strengthen resilience. Management plans that consider non-timber forest products, traditional use, and other forest products and values can help build a community of stewards and stakeholders who can foster more productive management partnerships (NCSSF B1.3).

Figure 5

The Need for Interdisciplinary Invasives Science (NCSSF A1)