THE RESILIENCE DILEMMA: Incorporating Global Change into Ecosystem Policy and Management

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BACKGROUND

The progression of changes to Earth's climate poses unprecedented challenges to the science and practice of ecosystem management.[1] The viability of many populations, species, and even ecosystems is increasingly uncertain in their current form.[2] Effects of climate change *per se* are compounded by multiple interacting stressors, including landscape modification and fragmentation, alerted disturbance regimes (particularly wildland fire), and the increasing presence of non-native invasive species. In framing a meaningful response to global environmental change, all of these interacting factors must be taken into account. For example, the ability of species to migrate in response to changing climate geography—as nearly all species have done during past eras of rapid climate change, such as the end of the last interglacial period—may be impaired by fragmented landscapes that pose barriers to movement; lack of co-evolved dispersal agents, pollinators, or other essential symbionts; the presence of vigorous and

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1. *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY, PART A (Christopher B. Field et al. eds., 2014), https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-PartA_FINAL.pdf; Nancy B. Grimm et al., *Climate-Change Impacts on Ecological Systems: Introduction to a U.S. Assessment*, 11 FRONTIERS ECOLOGY & ENV'T 456 (2013), http://onlinelibrary.wiley.com/doi/10.1890/120310/epdf.

2. MEGAN M. FRIGGENS ET AL., U.S. FOREST SERV., REVIEW AND RECOMMENDATIONS FOR CLIMATE CHANGE VULNERABILITY ASSESSMENT APPROACHES WITH EXAMPLES FROM THE SOUTHWEST 37 (2013), http://www.fs.fed.us/rm/pubs/rmrs_gtr309.pdf; Craig D. Allen et al., *On Underestimation of Global Vulnerability to Tree Mortality and Forest Die-Off from Hotter Drought in the Anthropocene*, 6 ECOSPHERE 1, 22 (2015), http://onlinelibrary.wiley.com/doi/10.1890/ES15-00203.1/epdf.

established populations of non-native species that can outcompete some natives under novel environmental conditions; and many other factors.[3]

Ecological responses to climate variability and change are complex and notoriously difficult to model or predict. Part of this complexity arises because climate variability and change influence elements and processes at multiple levels of biological hierarchy: individuals, populations, species, communities, and entire ecosystems. As a consequence, scientists and land managers will have to find their way through the current period of rapid change with relatively few guideposts.[4] For example, drought-tolerant genotypes—which could prove more adaptive under emerging climate conditions in many areas—occur within many widespread plant species, but where these occur and how rapidly these adaptations can spread among populations is generally unknown.[5] Some species populations endemic to alpine and high mountain areas, or aquatic species, may become extirpated even as new suitable habitats develop elsewhere. At the community level, the ecological communities we see today will likely be reassembled due to the individualistic nature of species responses to change.[6] At the highest level of organization, ecosystem processes such as landscape fire, soil formation, and hydrologic and biogeochemical cycling may be so altered under emerging conditions as to preclude the maintenance of some currently existing landscapes.

Historically, responses to ecological degradation have relied on a combination of conservation biology and restoration ecology. Conservation biologists have focused traditionally on understanding the ecology of ecosystem elements—populations, species, communities—that are intact but threatened or endangered, or otherwise considered of value to protect as they exist on the landscape. In contrast, the field of restoration ecology emphasizes

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3. *See generally* DAVID S. WILCOVE, NO WAY HOME: THE DECLINE OF THE WORLD'S GREAT ANIMAL MIGRATIONS (2010).

4. Bruce A. Stein et al., *Preparing for and Managing Change: Climate Adaptation for Biodiversity and Ecosystems*, 11 FRONTIERS ECOLOGY & ENV'T 502, 505–07 (2013), http://onlinelibrary.wiley.com/doi/10.1890/120277/epdf.

5. Christopher M. Richards et al., *Population and Ecological Genetics in Restoration Ecology*, *in* FOUNDATIONS OF RESTORATION ECOLOGY (Margaret A. Palmer et al. eds., 3rd ed. 2016); Kevin C. Grady et al., *Genetic Variation in Productivity of Foundation Riparian Species at the Edge of their Distribution: Implications for Restoration and Assisted Migration in a Warming Climate*, 17 GLOBAL CHANGE BIOLOGY 3724 (2011), http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2011.02524.x/epdf; Tongli Wang et al., *Integrating Environmental and Genetic Effects to Predict Responses of Tree Populations to Climate*, 20 ECOLOGICAL APPLICATIONS 153 (2010), http://onlinelibrary.wiley.com/doi/10.1890/08-2257.1/epdf.

6. *See* ASSEMBLY RULES AND RESTORATION ECOLOGY (Vicky M. Temperton et al. eds., 2004); H. A. Gleason, *The Individualistic Concept of the Plant Association*, 53 BULL. TORREY BOTANICAL CLUB 7 (1926), http://www.jstor.org/stable/2479933.

active intervention into ecosystems that have already been damaged, degraded, or otherwise modified by human actions.[7] Restoration ecologists seek reference systems to serve as a baseline both for understanding how a degraded system has been altered, and also to serve as a guide to how ecological integrity can be restored. Thus, restoration ecology would seem relevant in the "tool kit" needed to help ecological systems cope with a period of rapid environmental change and emerging stressors.

The parameters of a changing world, however, pose a serious challenge to the premises of restoration ecology. Some authors have argued that the original form of restoration ecology ("version 1.0") grounded in historical authenticity may become less viable in coming decades, because environments have changed so dramatically that restoring past configurations is no longer possible or relevant to the goals of conservation.[8] In this view, it may be difficult at best, and quixotic at worst, to attempt to restore lost populations of some species when the climate envelope has moved on and aggressive non-native invaders, or simply species more adapted to the new local climate, have moved in.[9] Likewise, current patterns of land use—such as networks of multi-lane high-speed highways with concrete barriers, and the explosive development of the Wildland-Urban Interface—may make restoring key processes like species migration and natural fire regimes socially and economically challenging.

In the face of these challenges, a new paradigm is emerging that emphasizes ecological resilience rather than restoration *sensu stricto*. In this model, a degree of change from past (reference) conditions is accepted not

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7. ANDRÉ CLEWELL & JAMES ARONSON, ECOLOGICAL RESTORATION: PRINCIPLES, VALUES, AND STRUCTURE OF AN EMERGING PROFESSION (2nd ed. 2013); ANDRÉ CLEWELL ET AL., SOC'Y FOR ECOLOGICAL RESTORATION INT'L SCI. & POLICY WORKING GRP., THE SER INTERNATIONAL PRIMER ON ECOLOGICAL RESTORATION 3 (2004), http://www.ser.org/docs/default-document-library/ser_primer.pdf; Donald A. Falk, *Process-Centered Restoration and Reference Dynamics*, 14 J. NATURE CONSERVATION 140 (2006).

8. NEW MODELS FOR ECOSYSTEM DYNAMICS AND RESTORATION (Richard J. Hobbs et al. eds, 2008); Eric Higgs et al., *The Changing Role of History in Restoration Ecology*, 12 FRONTIERS ECOLOGY & ENV'T 499 (2014), http://onlinelibrary.wiley.com/doi/10.1890/110267/pdf; Constance I. Millar et al., *Climate Change and Forests of the Future: Managing in the Face of Uncertainty*, 17 ECOLOGICAL APPLICATIONS 2145, 2146–47 (2007), http://onlinelibrary.wiley.com/doi/10.1890/06-1715.1/epdf.

9. Michael Notaro et al., *Projected Vegetation Changes for the American Southwest: Combined Dynamic Modeling and Bioclimatic-Envelope Approach*, 22 ECOLOGICAL APPLICATIONS 1365 (2012), http://onlinelibrary.wiley.com/doi/10.1890/11-1269.1/epdf; Gerald E. Rehfeldt et al., *Empirical Analyses of Plant-Climate Relationships for the Western United States*, 167 INT'L J. PLANT SCI. 1123 (2006), http://idahoforests.org/img/pdf/rmrs_2006_rehfeldt_g001.pdf.

only as pragmatically inevitable, but also potentially adaptive.[10] Thus, the goal of a "resilience ecology" approach is to facilitate the adaptation of ecosystems to emerging conditions, even when the specific form (e.g., the species that comprise a particular community) is different from what may have existed in the past. A resilience approach emphasizes combined strategies of enhancing *resistance* (e.g., survival and persistence), *recovery* (re-establishing the prior community following disturbance), and *reorganization* (allowing new suites of species to colonize an area that may be more adaptive under new conditions, and facilitating geographic migration of species). In this framework, new species moving into an area may be viewed as reflecting an ecological response to climate pressure, and assisted migration techniques may be needed to conserve species whose climate envelope has shifted.[11]

LANDSCAPE FIRE

Landscape fire illustrates the challenge of defining ecosystem resilience in a rapidly changing world.[12] Many forests in the southwestern United States have been experiencing fires of unprecedented severity in recent decades.

10. Richard J. Hobbs et al., *Managing the Whole Landscape: Historical, Hybrid, and Novel Ecosystems*, 12 FRONTIERS ECOLOGY & ENV'T 557 (2014), https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/54972/KennedyPatriciaFisheriesWildlifeManagingWholeLandscape.pdf.

11. Donald A. Falk & Constance I. Millar, *The Influence of Climate Variability and Change on the Science and Practice of Restoration Ecology*, *in* FOUNDATIONS OF RESTORATION ECOLOGY, *supra* note 5; Stephen T. Jackson et al., *Ecology and the Ratchet of Events: Climate Variability, Niche Dimensions, and Species Distributions*, 106 PROC. NAT'L ACAD. SCI. U.S. 19685 (2009), http://wwwpaztcn.wr.usgs.gov/julio_pdf/Jackson_et_al_2009_PNAS.pdf; Millar et al., *supra* note 8.

12. *See* Thomas D. Sisk et al., *A Landscape Perspective for Forest Restoration*, 103 J. FORESTRY 319, 319 (2005), http://nau.edu/uploadedFiles/Academic/CEFNS/NATSCI/SESES/Forms/Sisk_etal_LandscapePerspective_jofSept05.pdf.

Figure 1[13]

Large, severe wildfires are increasingly common in Southwestern forests, including the Sky Islands and Mogollon Rim bioregions. The 2006 Nutall-Gibson Fire in the Pinaleño Mountains burned extensively through ponderosa and mixed-conifer forests as well as higher-elevation spruce fir.

Many of these events have burned catastrophically through forest types where the characteristic fire regime is low to moderate severity (meaning that overstory tree mortality is generally low and soil effects are moderate). In these forest types, high-severity fire has been a component of the fire regime but generally occurring in patches that are relatively small (10^0–10^2 ha, 2–250 ac) compared to the large connected high-severity patches (10^4–10^5 ha, 2500–25,000 ac) associated with many contemporary wildfires.[14] Following a large wildfire that leaves large contiguous areas of high-severity impacts in pine or mixed-conifer forest under current climate, seedlings of the previously dominant species may be unable to establish successfully, due to

13. Photo courtesy of the Coronado National Forest and Southwest Fire Science Consortium.

14. Larissa L. Yocom-Kent et al., *Historical High-Severity Fire Patches in Mixed-Conifer Forests*, 45 CANADIAN J. FOREST RES. 1587 (2015).

combinations of long seed dispersal distances, severely degraded soils, unsuitable climate, excessive competition from post-fire shrub colonizers.

Figure 2

Extreme fire events can push ecosystems rapidly past tipping points. Post-fire conditions and near-term climate following the 2011 Las Conchas fire, NM are likely to preclude return to the pre-disturbance ecosystem.

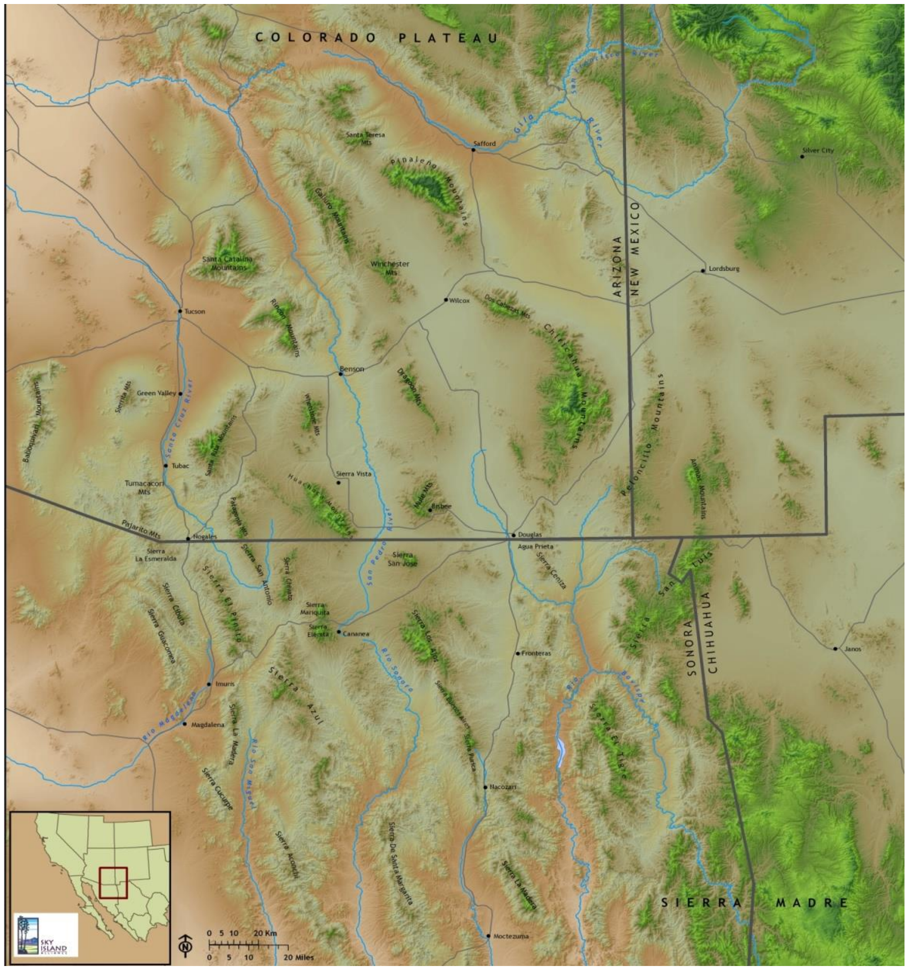
Wildland fire thus intensifies the existing challenges of a changing climate, because major changes in ecological state can occur in a matter of days or weeks, instead of the decadal response to climate variation acting alone.[15]

These interacting forces of climate, ecology, and wildfire are key to the sustainability of many ecosystems of the western US. In the Southwest, the Sky Island bioregion, or the "Madrean Archipelago," represents an ideal venue both for studying the effects of climate change and wildfire on ecosystems, and also for experimenting with novel approaches to land

15. *See* Melissa Savage et al., *Double Whammy: High-Severity Fire and Drought in Ponderosa Pine Forests of the Southwest*, 43 CANADIAN J. FOREST RES. 570, 583–84 (2013).

management policy.[16] The Sky Islands are among the most biologically diverse regions of the United States, due in part to their geographic confluence of multiple major ecoregions, as well as edaphic and topographic complexity.

Figure 3[17]



The 181,000 km^2 (70,000 mi^2) Madrean Archipelago ("Sky Islands") of Arizona, New Mexico, Sonora, and Chihuahua connects to larger contiguous forests in the Colorado Plateau and southern Rocky Mountains to the north, and the Sierra Madre Occidentale to the south. The Chihuahuan Desert lies to the east, and the Mojave Desert to the west.

16. GERALD J. GOTTFRIED ET AL., U.S. FOREST SERV., MERGING SCIENCE AND MANAGEMENT IN A RAPIDLY CHANGING WORLD: BIODIVERSITY AND MANAGEMENT OF THE MADREAN ARCHIPELAGO III 1 (2012), http://www.fs.fed.us/rm/pubs/rmrs_p067.pdf.

17. Figure courtesy of Sky Islands Alliance.

The Sky Islands are home to more than 4,700 plant species, over 200 species of reptiles and amphibians, half of all bird species in North America, and peak US diversity in insects, small mammals, and other organism groups. Most of the major Sky Island mountain ranges have had large, severe wildfires in the past 20 years, leading to ecosystems that are in a phase of rapid change at the very moment that the region is experiencing a severe multi-year drought.[18] Because of their high biological diversity, solving the climate × wildfire × ecosystems equation is arguably as or more critical in the Sky Islands than another region of the Southwest currently.[19]

THE CHALLENGE: INCORPORATING RESILIENCE ECOLOGY INTO ECOSYSTEM POLICY AND MANAGEMENT

The recognition of wildfire, climate change and the emerging interest in resilience is strong in the scientific and restoration ecology communities. However, these ideas are just beginning to be incorporated into policy and management frameworks. Indeed, significant obstacles exist to doing so, including the structure of current legislation and regulation, which is for the most part grounded in pre-global change thinking focused on maintaining *status quo* conditions. Moreover, ambiguities in the concepts of resilience itself constitute a significant challenge. For example, as a forest recovers from severe wildfire, it may transition into a different forest type, or even undergo a biome shift (e.g., forest to shrubland or grassland).

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18. Donald A. Falk, *Are Madrean Ecosystems Approaching Tipping Points? Anticipating Interactions of Landscape Disturbance and Climate Change*, *in* MERGING SCIENCE AND MANAGEMENT IN A RAPIDLY CHANGING WORLD, *supra* note 16, at 40, 41; Richard M. Seager et al., *Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America*, 316 SCIENCE 1181, 1183–84 (2007), http://www.ldeo.columbia.edu/res/div/ocp/pub/seager/Seager_etal_transition_2007.pdf.

19. *See* Brooke Gebow et al., *FireScape: A Program for Whole-Mountain Fire Management in the Sky Island Region*, *in* MERGING SCIENCE AND MANAGEMENT IN A RAPIDLY CHANGING WORLD, *supra* note 16, at 472, 472–73.

Figure 4[20]

Incipient biome shift in the Santa Catalina Mountains, Arizona, following the 2002–2003 Bullock and Aspen Fires. Areas previously dominated by pine and dry mixed-conifer forest have transitioned to grass- and shrub-dominated communities as well as early seral forest types.

What ecosystem responses should be considered "adaptive," and which should be understood as signs of deterioration or loss of ecosystem integrity? How active a role should humans play in assisting the adaptation of ecosystems to novel conditions? As we move beyond strict sense restoration, is there a basis in ecosystem science to guide a new paradigm for ecosystem management?

Translating the concepts and incipient research in ecological resilience is a current frontier in natural resource policy and management.[21] For legitimate reasons, most current legislative and regulatory guidance emphasizes restoring damaged and degraded ecosystems to their pre-disturbance

20. Photograph courtesy of Lauren Maghran, University of Arizona.

21. DAVID L. PETERSON ET AL., U.S. FOREST SERV., RESPONDING TO CLIMATE CHANGE IN NATIONAL FORESTS: A GUIDEBOOK FOR DEVELOPING ADAPTATION OPTIONS 52–81 (2011), http://www.fs.fed.us/pnw/pubs/pnw_gtr855.pdf.

condition. This follows the standard definition of ecological restoration, which "is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."[22] The crux of this definition is what constitutes "recovery;" in current policy and practice, recovery is interpreted almost universally to mean a return to an ecosystem state that existed prior to some episode of degradation. Restoration in this sense has been embraced across land managing agencies and is now fully embedded in the frameworks by which ecosystems are managed.

In coming decades, the limits of this focus on restoring historical authenticity will be tested severely—indeed, in many cases they are already.[23] Shifts in the zonation of climate are already expressed in changes in treeline, species and community phenology, rapid changes in sub-arctic and high-elevation environments, conversion of high-order streams perennial to seasonal or even ephemeral flow regimes, ongoing drought stress in semi-arid forests and woodlands, and abrupt type conversions following severe wildfires and insect outbreaks.[24] Where damaged ecosystems can be restored to their former state, the conventional restoration path should certainly be followed wherever possible. But in the increasing number of cases where returning to past conditions is impossible, we need greater clarity in policy based on resilience to guide a new path to sustainable ecosystems.[25]

Current land policy alludes to resilience in general terms but does little to provide specific guidance about how to allow ecosystems to adapt to novel conditions.[26] For example, all National Forests are required to submit periodic Forest Plan revisions; at present nearly half of all National Forests are due to revise Plans under the 2012 National Forest Land Management Planning

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22. CLEWELL ET AL., *supra* note 7, at 3.

23. J. B. Zedler et al., *Reports of Symposia: Upstart Views of Restoration Icons*, 88 BULL. ECOLOGICAL SOC'Y AM. 104, 106 (2007), http://onlinelibrary.wiley.com/doi/10.1890/0012-9623(2007)88%5B104:UVORI%5D2.0.CO;2/epdf.

24. Allen et al., *supra* note 2, at 16, 19; Craig D. Allen et al., *A Global Overview of Drought and Heat-Induced Tree Mortality Reveals Emerging Climate Change Risks for Forests*, 259 FOREST ECOLOGY & MANAGEMENT 660, 662–64 (2010), http://www.patrickgonzalez.net/images/Allen_et_al_2010.pdf.

25. Constance I. Millar et al., *Response of High-Elevation Limber Pine (*Pinus flexilis*) to Multi-year Droughts and 20th-Century Warming, Sierra Nevada, California, USA*, 37 CANADIAN J. FOREST RES. 2508, 2515–18 (2007), https://www.researchgate.net/publication/225666375_Response_of_high-elevation_limber_pine_Pinus_flexilis_to_multiyear_droughts_and_20th-century_warming.

26. DONALD A. FALK ET AL., ARIZ. FOREST HEALTH COUNCIL, FIRE ON THE LANDSCAPE: PLANNING FOR COMMUNITIES, FIRE, AND FOREST HEALTH 3–9 (2008), http://tree.ltrr.arizona.edu/~tswetnam/tws-pdf/AZFHC_Landscape_7.22.08.pdf; Jerry F. Franklin & K. Norman Johnson, *A Restoration Framework for Federal Forests in the Pacific Northwest*, 110 J. FORESTRY 429, 437 (2012), http://www.blm.gov/or/districts/medford/plans/trail/files/forest-restoration.pdf.

Rule.[27] The 2012 rule includes a specific reference to ecological restoration similar to that of the Society for Ecological Restoration: "[Restoration is] the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. Ecological restoration focuses on reestablishing the composition, structure, pattern, and ecological processes necessary to facilitate terrestrial and aquatic ecosystems sustainability, resilience, and health under current and future conditions. . . ."[28] Similarly, the revised USDA land management planning rule under the National Forest Management Act is designed to help land management agencies develop the basis for "integrating forest restoration, climate resilience, watershed protection, [and] wildlife conservation."[29] Thus both the 2012 and 2013 guidance emphasize ecological integrity, ecosystem restoration, and invoke resilience explicitly in the context of ecological restoration and climate change adaptation. At the same time, however, the 2012 Rule also requires Forest plans "to maintain or restore the ecological integrity of terrestrial and aquatic ecosystems and watersheds in the plan area, including plan components to maintain or restore structure, function, composition, and connectivity."[30]

The "resilience dilemma" arises when policy based on these relatively simple definitions attempts to embrace "sustainability, resilience, and health under current and future conditions,"[31] as it is clearly not possible to achieve all of these objectives under both current and future climate (as well as other stressors summarized above), with species in their current locations. Major disturbance processes such as wildland fire and insect outbreaks make it increasingly unlikely that the ecosystems of today can be maintained in their current form indefinitely. Thus, policy that names "resilience" as an objective without defining what kinds and degrees of ecological change are encompassed, will ultimately provide limited guidance to management on the ground.

Policy that invokes "resilience" is clearly an correct attempt to grapple with the dilemma of pervasive ecosystem change.[32] However, how this general guidance helps a forest manger faced with recovering a severely

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27. National Forest System Land Management Planning, 36 C.F.R. § 219 (2012).

28. *Id.* § 219.19.

29. National Forest System Land Management Planning Directives, 78 Fed. Reg. 13316–13319 (Feb. 27, 2013).

30. 36 C.F.R. § 219.8(a)(1).

31. *Id.* § 219.19.

32. *See* Melinda Harm Benson & Ahjond S. Garmestani, *Can We Manage for Resilience? The Integration of Resilience Thinking into Natural Resource Management in the United States* 395 (EPA, Paper No. 200, 2011), http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1200&context=usepapapers.

burned watershed under conditions of extended drought, or a species whose climate zone is slipping away, is unclear. Other key environmental laws, such as the Endangered Species Act,[33] have similar critical shortcomings to developing conservation strategies that allow species and populations to adapt to novel conditions, because they were formulated prior to the emergence of global change as a pervasive influence on conservation and land management.[34]

Wildfire will continue to push the limit of current policy, in the Southwest and elsewhere, because of the primary influence of climate on fire behavior. The sensitivity of ecosystems to wildfire is also conditioned by climate, as trees that are more drought stressed carry a higher probability of mortality during wildfire.[35] Post-fire recovery processes are similarly affected by changing climate, invasive species, and land use. These interacting influences mean that simple concepts of resilience limited only to recovery to pre-disturbance conditions need to be elaborated into more meaningful form if they are to be of practical use to land managers. Climate and wildfire create a nexus of our changing planet, and land management and policy will have to adapt rapidly in coming decades.

33. 16 U.S.C. §§ 1531–1544.

34. Benson & Garmestani, *supra* note 32, at 394; Melinda Harm Benson, *Intelligent Tinkering: The Endangered Species Act and Resilience*, 17 ECOLOGY & SOC'Y 28, 31–32 (2012).

35. Phillip J. van Mantgem et al., *Tree Mortality Patterns Following Prescribed Fire for Pinus and Abies Across the Southwestern United States*, 289 FOREST ECOLOGY & MANAGEMENT 463, 468 (2013).