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OPINION ARTICLE

Investing in Natural Capital: Using Economic Incentives to Overcome Barriers to Forest Restoration

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Abstract

A legacy of fire suppression and the impacts of climate change have induced a worsening pattern of large and severe forest fires across the western United States. This has spurred action to jump-start wildfire risk mitigation initiatives. Despite an increase in resources and attention, the persistence of economic impediments has forestalled the successful expansion of forest restoration to a landscape level. The failure to properly account for the full range of costs and benefits from restoration treatments has contributed to the asymmetry between needed action and actual implementation. The valuation of non-market ecosystem services such as carbon sequestration, along with the ability of ecological restoration to act as an agent of economic stimulus, should be incorporated into the policymaking process. We demonstrate how institutionalizing the economic benefits from both the process and products of forest restoration can strengthen policies for advancing long-term forest health.

Key words: **carbon, economics, ecosystem services, wildfires.**

Introduction

A century of suppressing fires and the on-going effects of climate change have altered the long-term ecological trajectory of forests across the western United States (Covington 2000; Westerling et al. 2006). There has been an increase in high-severity crown fires that compromise ecological health—causing forest cover loss and reductions in biodiversity—and jeopardize the welfare of neighboring communities (Moore et al. 1999; Allen et al. 2002; Miller et al. 2009). This has produced a widely acknowledged need to restore regional forest resilience (Covington 2000), but socioeconomic obstacles have limited restoration efforts from achieving the scale necessary for long-term ecosystem health and human security (see Hjerpe et al. 2009 for a comprehensive review of social and economic barriers to ecological restoration in the region).

Overcoming these impediments to effective policy means clarifying for the general public and policymakers the full range of economic contributions forest restoration can make to human welfare. The restoration of ecosystems generates gains in both market-based and non-market ecosystem services realized at multiple spatial scales (e.g. Aronson et al. 2007*a*). In fact, it is often the case that the condition of natural capital, such as forest ecosystems, is the limiting factor to economic development (e.g. Costanza & Daly 1992; Aronson et al. 2006). Thus, carrying out ecological restoration can have a substantial impact on regional economies by creating employment opportunities and raising incomes. In efforts to improve the long-run health of ecosystems, it should be recognized that both the process and products of restoration yield positive economic returns.

Some argue that placing an anthropocentric value on restoration may obscure the insight that ecosystems have an intrinsic right to exist and be restored for "their own sake" (Aronson et al. 2007*b*). However, many restoration ecologists argue that restoring an ecosystem is a value-laden statement and urge researchers and practitioners to explicitly recognize the importance of socioeconomic factors in defining the goals and scope of projects (e.g. Hobbs et al. 2004; Choi 2007; Temperton 2007). As Costanza et al. (1997) point out in their seminal paper on the value of the world's ecosystems, the exercise of valuation is inherent in the process of making choices. The restoration of natural capital can bridge important informational, ideological, and social divides presently obstructing effective environmental policies (Aronson et al. 2010). Such obstacles are numerous in forest systems across the United States, and perhaps the world; overcoming them means identifying where human and ecological considerations overlap and where they do not align. Where human and ecological considerations are at odds, comprehensive evaluations of trade-offs are necessary. Where there is alignment, forest restoration

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should be viewed as an investment in natural capital that promotes both socioeconomic and environmental well-being (Aronson et al. 2007*a*, 2010).

Causes and Consequences of High-Severity Fires

The Rodeo-Chediski and Hayman fires of 2002, among the largest forest fires in U.S. history, burned over 245,000 ha of forest, forced the evacuation of 13,000 people and caused nearly $300 million of property damage, fire suppression costs, and rehabilitation expenditure (Graham 2003; Snider et al. 2003). In the extensive ponderosa pine ecosystems of the southwestern United States, pre-fire exclusion conditions were characterized by open forests (50–150 mature trees per hectare) and maintained by frequent, low-severity fire. Because of a legacy of past management (namely the exclusion of surface fires), current forests approach 2,500 trees per hectare, with substantial build-up of surface fuels (Cooper 1960; Covington & Moore 1994; Moore et al. 1999). Dry forests across the western United States are characterized by similar ecological conditions (Agee & Skinner 2005). Although over 1,700 fire starts were needed to account for the 1.25 million hectares of forests burnt in the Northern Rocky Mountains in 1910 (USDA Forest Service 1978), only three ignitions precipitated the Rodeo-Chediski and Hayman fires. This is a significant testament to the reduced resilience of western forests at the landscape scale.

Barriers to Landscape-Level Restoration

Ecological restoration in the dry, fire-prone forests in southwest America primarily takes the form of mechanical thinning and prescribed burning to reduce tree density and fuel loads. For surface fire-adapted forest types like ponderosa pine, reducing tree density significantly decreases fire severity and helps restore the structure, composition, and functions of a healthy ecosystem (Fulé 2008). Figure 1 shows the stark contrast between treated and untreated areas after the occurrence of wildfire. Despite the demonstrated efficacy of restoration in mitigating high-severity fire risk, contemporary initiatives have failed to achieve landscape-level success. Three primary obstacles underlay this asymmetry between science and policy: (1) public misconceptions regarding the meaning and purpose of forest restoration; (2) failure to account for non-market ecosystem services; and (3) insufficient funding for treatment initiatives (Hjerpe et al. 2009).

In the recent past, agenda-driven parties (from commercial interests to environmental activists) have often created public misconceptions by playing off of distaste for tree removal and intentional fires (Covington 2000). Encouragingly, recent studies indicate that support for restoration initiatives is increasing among community stakeholders, due in large part to public education and outreach from local researchers and the U.S. Forest Service (Abrams & Lowe 2005; Ostergren et al. 2008). However, the financial burden of expanding restoration remains a more intransigent issue. Costs of restoration treatments vary, but across the western United States, the combined per-hectare expenditure for mechanical thinning, prescribed burning, and administrative overhead averages US$2,000 for basic-level restoration (Hjerpe & Kim 2008; Prestemon et al. 2008; Rummer 2008; Hjerpe et al. 2009). This value represents a conservative estimate; when additional criteria such as habitat provision for the Mexican Spotted Owl (a Federally listed endangered species) are added, the costs are appreciably higher. When applied to the landscape scale (i.e. hundreds of thousands to millions of hectares), the final cost of restoring forest resilience resides in the billion dollars. In the fire-prone forests of the western United States, these staggering prices constitute the most prevalently cited barrier to restoration efforts (Government Accounting Office 2005*a*, 2005*b*; USDA Forest Service 2003). When set against international standards (where treatments vary depending on ecosystem type and condition), these values represent a low-end estimate for forest restoration costs (Neßhöver et al. 2011). The restoration of tropical forests in Brazil (which entails reforestation), for instance, can exceed an expense of over $5,000 per hectare (Rodrigues et al. in press).

Unaccounted Benefits and Unforeseen Costs

Recognizing ecosystems as productive assets that generate numerous non-accounted ecosystem services can elevate the appeal of restoring dry forests and attract much-needed funding. Forests such as ponderosa pine provide numerous benefits, including aesthetic and recreational opportunities,

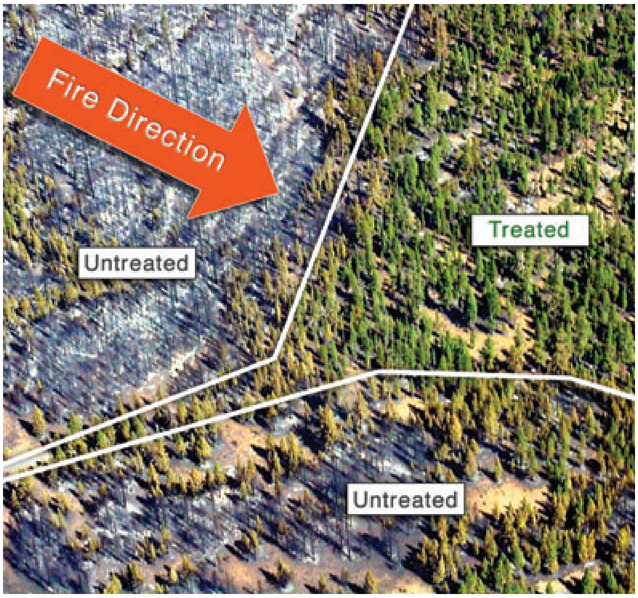

Figure 1. Forest condition at the Black Mountain Experimental Forest following the 2002 Cone fire. The white lines approximate the pre-fire treatment boundaries. The areas on the left and at the bottom were untreated. The area on the right was treated via thinning and prescribed burning. Photo courtesy of Mike Jablonski, USDA Forest Service, Lassen National Forest.

erosion prevention, and microclimatic regulation (Frederici 2003). Restored forests enhance the value of surrounding real estate while making the region more attractive to high-quality labor (Kim & Wells 2005). A resilient forest ecosystem also provides the benefit of "insurance" from disturbances such as wildfire (Stephens et al. 2010). The combined economic value of this natural insurance along with a partial calculation of other services has been estimated at $3,500 per hectare (Mason et al. 2006). Many of these ecosystem benefits are left unaccounted by market valuation and their absence in policy undermines efforts to expand restoration (Kline 2004). As studies show, it is often much more cost-efficient to restore fractured ecosystem services than to invest in man-made alternatives (Chichilnisky & Heal 1998).

Perhaps, one of the most significant ecosystem services enhanced by ecological restoration in dry, fire-prone forests is carbon stabilization (Hurteau & Brooks 2011). High-severity fires release substantial quantities of carbon emissions (ranging from 22 to 103 Tg CO_2 between 2001 and 2008; Wiedinmyer & Hurteau 2010), undermining the role forests play in climate change mitigation. In the 2002 fire season alone, forest fires burning in the western United States (including the Rodeo-Chediski and Hayman fires) released approximately 24 Tg of CO_2 equivalent (Hurteau et al. 2008; Wiedinmyer & Hurteau 2010). Imputing the social cost of carbon emissions has been a controversial issue and estimates vary depending on how time is discounted. Projections can be as low as $9.55 per metric ton of CO_2 (Nordhaus 2007), owing to the value of present consumption being substantially weighted over the well-being of future generations. A major report by a group of economists led by Nicholas Stern, however, advocates the high-end price of $84.55 per metric ton of CO_2 (Stern 2007), premised by the belief that climate change must be more urgently addressed by contemporary policy. However, in the absence of a national carbon emissions program such as cap-and-trade in the United States, the market-recognized value of limiting carbon emissions hovers in the lower bound of current estimates.

Although human intervention has increased the overall carbon storage in many fire-prone temperate forests because of higher tree density, these systems may have exceeded their carbon-carrying capacity (Keith et al. 2009; Hurteau et al. 2010). The resultant instability means that restoration treatments, despite decreasing overall forest biomass (at a cost of 17.7–32.6 Mg C per hectare in ponderosa pine forest; Hurteau et al. 2010), produce a net carbon reduction relative to the expected value of emissions from high-severity fires (Finkral & Evans 2008; Hurteau & North 2009; Wiedinmyer & Hurteau 2010). In untreated forests, carbon costs from wildfires can continue to accrue into the future because high rates of mortality influence net ecosystem productivity (Dore et al. 2008; Meigs et al. 2009). Carbon losses from restoration treatments, on the other hand, are much more transient (Dore et al. 2010; Hurteau & North 2010). In addition, the potential exists for vegetation type conversion following wildfire, in which large amounts of the carbon stock are lost in the transition from a forest to a grass/shrub-dominated landscape (Savage & Mast 2005). Establishing a carbon baseline that accounts for the amortized probability of forest fires is essential in developing a sustainable carbon market. By institutionalizing the incentives of carbon sequestration, a stronger economic rationale can be made for expanding restoration treatments.

"Green" Economic Stimulus

Forest restoration can also act as an agent of economic stimulus (Aronson et al. 2007*a*; Blignaut et al. 2008). The economic impacts from restoration activities in parts of Arizona and New Mexico (which have only been implemented on a small fraction of the land identified for treatment) generated over $40 million and 500 jobs in the fiscal year 2005 (Hjerpe & Kim 2008)—a significant boon for a region containing several of the poorest counties in the United States. The estimated multiplier effects (the economic "bang for the buck" of every dollar spent) from these activities were substantially higher than the projected impact of tax cuts (0.99) and in line with those of government outlays (1.57) from the Obama administration's economic stimulus (Romer & Bernstein 2009). With infrastructure improvements, it is likely that economic gains from forest restoration would be even higher (USDA Forest Service 2003). As a result of changes in federal land management in the past two decades, however, much of the timber industry infrastructure in the region has been dismantled (Fight et al. 2004; Morgan et al. 2006). In addition, aspects of national forest management create a wood supply that is too inconsistent for the business practices of many potential processors (Hjerpe et al. 2009).

Encouraging the growth of corroborative industries can generate self-reinforcing incentives for forest restoration. The first large-scale project area (ca. 304,000 ha) arising from the collaborative 4 Forest Restoration Initiative (4FRI) in Arizona is expected to generate over 6,700 jobs (Kim 2010). In the midst of a protracted economic malaise (like the one currently being experienced), there is immense potential to dovetail urgent policy goals such as income and employment creation with forest restoration objectives. Future cross-sector collaborations such as 4FRI could be planned as public works that promote jobs and income in rural forested communities. The establishment of the Civilian Conservation Corps during the Great Depression and the Working for Water program in South Africa offer instructive examples. Ecological restoration can also lay the foundation for emerging industries while balancing environmental concerns, contributing further to the long-run economic sustainability of regional economies (Blignaut et al. 2008).

Conclusions

The way we manage (or mismanage) ecosystems has significant economic consequences. Thus, it is instructive for both scientific understanding and policy to view them as natural capital, the restoration of which can enhance societal well-being as a function of improved economic returns (Aronson et al. 2007*b*). It is clear that the gains from forest restoration, as well as the potential costs of high-severity wildfires, vastly outweigh the requisite expenditure necessary for landscape-level implementation. The need for action is highlighted by the fact that rising temperatures have increased the frequency, duration, and burned area of forest fires (Westerling et al. 2006). As climate change continues apace, so will the threat posed by high-severity wildfires (Westerling & Bryant 2008). Without large-scale intervention, trends suggest that current patterns will persist, if not worsen (Covington 2000). Although it is important to have a rigorous understanding of underlying ecological processes (Palmer & Filoso 2009), it is also essential to incorporate economic incentives that may abet the expansion of restoration efforts. The recognition of this latter, pragmatic dimension of restoration is especially important when dealing with severely degraded ecosystems (Aronson & Le Floc'h 2000). The Collaborative Forest Landscape Restoration Program established by the U.S. Congress in 2009, for example, represents an important step toward building an economically sustainable foundation for expanding restoration. However, additional efforts to institutionalize the economic benefits from both the process and products of forest restoration are needed to achieve landscape-level results.

Implications for Practice

- Accounting for the economic benefits of both market and non-market ecosystem services such as wildfire insurance, carbon sequestration, and real estate value can strengthen the rationale for forest restoration in policymaking and attract much-needed funding.
- FRIs can act as a regional economic stimulus for forested communities. Restoration projects arising from collaborations among researchers, the government, and the private sector can enhance employment opportunities and income.
- Calibrating regional infrastructure to forest restoration products such as thinned wood and an enhanced aesthetic landscape can promote long-term economic viability by nurturing emerging industries and markets.

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LITERATURE CITED

Abrams, J. B., and K. Lowe. 2005. Public perceptions of forest restoration in the southwest: a synthesis of selected surveys and literature. Ecological Restoration Institute, Northern Arizona University, Flagstaff (available from http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH018b/b6d116f0.dir/doc.pdf) accessed 3 November 2010.

Agee, J. K., and C. N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management **211:**83–96.

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. W. Swetnam, T. Schulke, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications **12:**1418–1433.

Aronson, J., J. N. Blignaut, R. S. De Groot, A. Clewell, P. P. Lowry II, P. Woodworth, et al. 2010. The road to sustainability must bridge three great divides. Annals of the New York Academy of Sciences **1185**: 225–236.

Aronson, J., J. N. Blignaut, S. J. Milton, and A. F. Clewell. 2006. Natural capital: the limiting factor. Ecological Engineering **28:**1–5.

Aronson, J., and E. Le Floc'h. 2000. Restoration of natural capital: pros and problems. Restoration Ecology **8:**214–216.

Aronson, J., S. J. Milton, and J. N. Blignaut, editors. 2007*a*. Restoring natural capital: science, business and practice. Island Press, Washington, D.C.

Aronson, J., S. J. Milton, and J. N. Blignaut. 2007*b*. Definitions and rationale. Pages 3–8 in J. Aronson, S. J. Milton, and J. N. Blignaut, editors. Restoring natural capital: science, business and practice. Island Press, Washington, D.C.

Blignaut, J., J. Aronson, M. Mander, and C. Marais. 2008. Investing in natural capital and economic development: South Africa's Drakensberg Mountains. Ecological Restoration **26:**143–150.

Chichilnisky, G., and G. M. Heal. 1998. Economic returns from the biosphere. Nature **391:**629–630.

Choi, Y. D. 2007. Restoration ecology to the future: a call for a new paradigm. Restoration Ecology **15:**351–353.

Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forest since white settlement. Ecological Monographs **30:**129–164.

Costanza, R., and H. E. Daly. 1992. Natural capital and sustainable development. Conservation Biology **6:**37–46.

Costanza, R., R. d'Arge, R. D. Groot, S. Farberk, M. Grasso, B. Hannon, et al. 1997. The value of the world's ecosystem services and natural capital. Nature **387:**253–260.

Covington, W. W. 2000. Helping western forests heal. Nature **408:**135–136.

Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry **92:**39–47.

Dore, S., T. E. Kolb, M. Montes-Helu, S. E. Eckert, B. W. Sullivan, B. A. Hungate, J. P. Kaye, S. C. Hart, G. W. Koch, and A. J. Finkral. 2010. Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning. Ecological Applications **20:**663–683.

Dore, S., T. E. Kolb, M. Montes-Helu, B. W. Sullivan, W. D. Winslow, S. C. Hart, J. P. Kaye, G. W. Koch, and B. A. Hungate. 2008. Long-term impact of a stand-replacing fire on ecosystem CO2 exchange of a ponderosa pine forest. Global Change Biology **14:**1–20.

Fight, R. D., G. L. Pinjuv, and P. J. Daugherty. 2004. Small-diameter wood processing in the southwestern United States: an economic case study and decision analysis tool wood fiber projection. Forest Products Journal **54:**85–89.

Finkral, A. J., and A. M. Evans. 2008. The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. Forest Ecology and Management **255:**2743–2750.

Frederici, P. G. 2003. Ecological restoration of southwestern ponderosa pine forest. Island Press, Washington, D.C.

Fulé, P. Z. 2008. Does it make sense to restore wildland fire in changing climate? Restoration Ecology **16:**526–531.

Government Accounting Office. 2005*a*. Natural resources: federal agencies are engaged in various efforts to promote the utilization of woody biomass, but significant obstacles to its use remain. Government Accounting Office, Washington, D.C. (available from http://www.gao.gov/new.items/d05373.pdf) accessed 3 November 2010.

Government Accounting Office. 2005*b*. Wildland fire management: important progress has been made, but challenges remain to completing a cohesive strategy. Government Accounting Office, Washington, D.C. (available from http://www.gao.gov/new.items/d05147.pdf) accessed 3 November 2010.

Graham, R. T. E. 2003. Hayman fire case study. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah (available from http://www.fs.fed.us/rm/pubs/rmrs_gtr114.html) accessed 3 November 2010.

Hjerpe, E., J. Abrams, and D. B. Becker. 2009. Socioeconomic barriers and the role of biomass utilization in southwestern ponderosa pine restoration. Ecological Restoration **27:**169–177.

Hjerpe, E. E., and Y.-S. Kim. 2008. Economic impacts of southwestern national forest fuels reductions. Journal of Forestry **106:**311–316.

Hobbs, R. J., M. A. Davis, L. B. Slobodkin, R. T. Lackey, W. Halvorson, and W. Throop. 2004. Restoration ecology: the challenge of social values and expectations. Frontiers in Ecology and the Environment **2:**43–48.

Hurteau, M. D., and M. L. Brooks. 2011. The short- and long-term effects of fire on carbon in dry, temperate forest systems of the United States. BioScience **61:**139–146.

Hurteau, M. D., G. W. Koch, and B. A. Hungate. 2008. Carbon protection and fire risk reduction: toward a full accounting of forest carbon offsets. Frontiers in Ecology and the Environment **6:**493–498.

Hurteau, M., and M. North. 2009. Fuel treatment effects on tree-based forest carbon storage and emissions under modeled wildfire scenarios. Frontiers in Ecology and the Environment **7:**409–414.

Hurteau, M. D., and M. North. 2010. Carbon recovery rates following different wildfire risk mitigation treatments. Forest Ecology and Management **260:**930–937.

Hurteau, M. D., M. T. Stoddard, and P. Z. Fulé. 2010. The carbon costs of mitigating high-severity wildfire in southwestern ponderosa pine. Global Change Biology **17:**1516–1521.

Keith, H., B. G. Mackey, and D. B. Lindenmayer. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Sciences **106:**11635–11640.

Kim, Y.-S. 2010. Ecological restoration as economic stimulus: a regional analysis. ERI White Papers: Issues in Forest Restoration, Ecological Restoration Institute, Northern Arizona University, Flagstaff, Arizona (available from http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH01a0/2fbebf05.dir/doc.pdf) accessed 3 November 2010.

Kim, Y.-S., and A. Wells. 2005. The impact of forest density on property values. Journal of Forestry **103:**146–151.

Kline, J. 2004. Issues in evaluating the costs and benefits of fuel treatments to reduce wildfire in the nation's forests. USDA Forest Service Pacific Northwest Research Station, Portland, Oregon (available from http://www.fs.fed.us/pnw/pubs/pnw_rn542.pdf) accessed 3 November 2010.

Mason, C. L., B. R. Lippke, K. W. Zobrist, T. D. Bloxton Jr, K. R. Ceder, J. M. Comnick, J. B. Mccarter, and H. K. Rogers. 2006. Investments in fuel removals to avoid forest fires results in substantial benefits. Journal of Forestry **104:**27–31.

Meigs, G. W., D. C. Donato, J. L. Campbell, J. G. Martin, and B. E. Law. 2009. Forest fire impacts on carbon uptake, storage, and emission: the role of burn severity in the Eastern Cascades, Oregon. Ecosystems **12:**1246–1267.

Miller, J. D., H. D. Safford, M. Crimmins, and A. E. Thode. 2009. Quantitative evidence for increasing fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada. Ecosystems **12:**16–32.

Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications **9:**1266–1277.

Morgan, T. A., T. Dillon, C. E. Keegan III, A. L. Chase, and M. T. Thompason. 2006. The four corners timber harvest and forest products industry, 2002. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado (available from http://www.coloradotimber.org/Publications/FourCorners%20Timber.pdf) accessed 3 November 2010.

Neßhöver, C., J. Aronson, J. Blignaut, D. Lehr, A. Vakrou, and H. Wittmer. 2011. Investing in ecological infrastructure. The economics of ecosystems and biodiversity in national and international policy making. Earthscan, London, United Kingdom (in press).

Nordhaus, W. 2007. Critical assumptions in the stern review on climate change. Science **317:**201–202.

Ostergren, D. M., J. B. Abrams, and K. A. Lowe. 2008. Fire in the forest: public perceptions of ecological restoration in north-central Arizona. Ecological Restoration **26:**51–60.

Palmer, M. A., and S. Filoso. 2009. Restoration of ecosystem services for environmental markets. Science **325:**575–576.

Prestemon, J. P., K. Abt, and R. J. Huggett Jr. 2008. Market impacts of a multiyear mechanical fuel treatment program in the U.S. Forest Policy and Economics **10:**386–399.

Rodrigues, R. R., S. Gandolfi, A. G. Nave, J. Aronson, T. E. Barreto, C. Y. Vidal, and P. H. S. Brancalion. Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. Forest Ecology and Management (in press).

Romer, C., and J. Bernstein. 2009. The job impact of the American Recovery and Reinvestment Plan (available from http://www.thompson.com/obamaeconplanjan9) accessed 3 November 2010.

Rummer, B. 2008. Assessing the cost of fuel reduction treatments: a critical review. Forest Policy and Economics **10:**355–362.

Savage, M., and J. N. Mast. 2005. How resilient are southwestern ponderosa pine forests after crown fires? Canadian Journal of Forest Research **35:**967–977.

Snider, G. B., D. B. Wood, and P. J. Daugherty. 2003. Analysis of costs and benefits of restoration-based hazardous fuel reduction: treatments vs no treatment. School of Forestry, Northern Arizona University, Flagstaff (available from http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH6ab2.dir/doc.pdf) accessed 3 November 2010.

Stephens, S. L., C. I. Millar, and B. M. Collins. 2010. Operational approaches to managing forests of the future in Mediterranean regions within a context of changing climates. Environmental Research Letters **5:**9 pp.

Stern, N. 2007. The economics of climate change: the stern review. Cambridge University Press, Cambridge, United kingdom and New York.

Temperton, V. M. 2007. The recent double paradigm shift in restoration ecology. Restoration Ecology **15:**344–347.

USDA Forest Service. 1978. When the mountains roared. U.S. Department of Agriculture Forest Service, Coeur d'Alene, Idaho (available from http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm9_018977.pdf) accessed 3 November 2010.

USDA Forest Service. 2003. A strategic assessment of forest biomass and fuel reduction treatments in western states. U.S. Department of Agriculture Forest Service, Fort Collins, Colorado (available from http://www.fs.fed.us/rm/pubs/rmrs_gtr149.pdf) accessed 3 November 2010.

Westerling, A. L., and B. P. Bryant. 2008. Climate change and wildfire in California. Climatic Change **87** (Suppl. 1):S231–S249.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. Forest Wildfire Activity Science **313:**940–943.

Wiedinmyer, C., and M. D. Hurteau. 2010. Prescribed fire as a means of reducing forest carbon emissions in the western U.S. Environmental Science and Technology **44:**1926–1932.