AIMING TO RESTORE FORESTS: EVALUATION WITH SER CRITERIA

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ABSTRACT—The Society for Ecological Restoration Primer on Ecological Restoration (SERPER) states, "Ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity, and sustainability" and attempts to return an ecosystem to its historic condition. There are questions, however, about whether changing environmental conditions such as global climate change, invasive species (including pests and diseases), human-altered disturbance regimes, and widespread land-use changes will allow return to historic conditions, what constitutes naturalness, and whether restoration should incorporate continuing management. Active, intentional management (AIM) is a conservation approach that emphasizes a full range of active and passive management techniques to manage important ecological and hydrologic processes to conserve biodiversity; reconcile conflicts over management of natural resources; and provide various goods, ecological services, and recreational and spiritual opportunities to people over the long term. AIM includes intangibles such as knowing that rare species exist, that "wild" places are deliberately in place, and that ecological services important to the biosphere are maintained. How does AIM compare to restoration? Can AIM meet restoration goals? Specifically, can AIM reproduce the 10 traits of pristine ecosystems identified by SERPER? Measures can be used to evaluate success. For ecosystems, diversity of vascular plants, composition of functional groups of soil organisms, biotic integrity of vertebrate communities, and biocomplexity can be measured. For landscapes, simulations can project values: 1) capacity to support vertebrate diversity; 2) forest-floor function as measured by biotic integrity; 3) ecological productivity and ability to support medium-size predators as evidenced by biomass of mammalian frugivores; 4) ecological productivity and ability to sustain large predators, subsistence hunting by Native Americans, and sport hunting, as measured by production of corvids; 5) production of wood; 6) revenues; and 7) employment, which are measures of social, economic, and environmental sustainability. Would such forests seem natural? Perhaps what is needed are experiential comparisons of the abstract purity of pristine nature with contemplative experience of wildness in an intentionally managed mosaic . . . to immerse oneself in an AIM forest to experience aloneness as night falls, the moon rises, and the wolf howls.

Key words: biodiversity, biocomplexity, forests, management, restoration, restoration criteria

The Society for Ecological Restoration Primer on Ecological Restoration (hereafter, SERPER; SER 2002) defines ecological restoration, describes the attributes of restored ecosystems (Table 1), and discusses the integration of ecological restoration into larger programs. Ecological restoration is an important goal in many management activities across the globe, including in the implementation of many federal, state, and private land management plans. Active, intentional management (AIM) for multiple values is a conservation approach, developed independently from SERPER, that emphasizes a full range of active and passive management techniques (see examples in Table 2) to manage important ecological and hydrologic processes in forests to conserve biodiversity and provide various goods, ecological services, and recreational and spiritual opportunities to people over the long term (Carey, Lippke, and others 1999; Carey 2006). Restoration of degraded ecological function is a goal of AIM, but promotion of ecosystem resiliency and adaptiveness and general (environmental, economic, and social) sustainability are equally important goals. Are the various goals of restoration and the goals of AIM compatible? SERPER provides useful tenets for a discussion; SERPER says restoration is intentional management. Intentionality, by definition, is a concept that im-

TABLE 1. Ten attributes of restored ecosystems excerpted from The Society for Ecological Restoration Primer on Ecological Restoration (SER 2002).

Description
1. The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure.
2. The restored ecosystem consists of indigenous species to the greatest possible extent.
3. All functional groups necessary for the continued development and/or stability of the restored ecosystem are represented or . . . have the potential to colonize by natural means.
4. The physical environment of the restored ecosytem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.
5. The restored ecosystem apparently functions normally for its ecological stage of development, and signs of dysfunction are absent.
6. The restored ecosystem is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges.
7. Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.
8. The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem.
9. The restored ecosystem is self-sustaining to the same degree as the reference ecosystem, and has the potential to persist indefintely under existing environmental conditions . . . aspects of biodiversity and functioning may change as part of normal ecosystem development . . . in response to stress and . . . disturbance . . . [and] evolve as environmental conditions change.
10. Ecosystems provide specified natural goods and services for society in a sustainable manner, including aesthetic amenities and accommodation of activities of social consequence.

plies "wholeness" in intention; in other words, comprehensiveness (high intentionality) versus narrow or limited purpose (low intentionality). For example, "intentional" communities seek wholeness in the lives of their members; Carey (2006) says "The intentional aspect of AIM relates to its deliberate attempt to 1) produce multiple values, from wood to water to wildness (including biodiversity) from forest ecosystems and forested landscapes; 2) incorporate a wide range and depth of interdisciplinary science in a systems approach to ecosystem and landscape management (Wilbur 1995; Holling 2001); 3) involve people from various parts of the human community in collaborative learning and management; and 4) pro-

TABLE 2. An example of an active, intentional management (AIM) pathway that emphasizes sustainable economic returns, environmental sustainability through conservation of biodiversity, and social sustainability (conservation of nature, forest-based employment, maintaining educational systems, transportation system management for multiple-use access) developed for state or private land in western Washington. The pathway is one of several in a landscape management approach that includes restoration of riparian function, management for hydrologic function including recruitment of coarse, woody debris with emphasis on unstable slopes and producing complex forests along streamsides; see Carey and others (1996a) and Carey, Lippke, and others (1999) for more detail.

Time (y)	Treatment
0	Variable-retention harvest including restricted harvests on and around seeps, streams, wetlands, rock outcrops, and areas with high potential for mass-wasting including colluvial soils, deep-seated landslide potential, and shallow-rapid landslide potential.
1 to 5	Planting of Douglas-fir and western red cedar with natural regeneration of western hemlock, red alder, bigleaf maple, and other species.
15	Precommercial thinning favoring a dominance of Douglas-fir in matrix of multiple conifer and hardwoods species, with alder outnumbering maple.
30, 50, 70	Commercial variable-density thinning to promote biodivesity through spatial heterogeneity in overstory and understory and growth of large Douglas-fir and to develop and maintain a 15% cover of coarse woody debris in different stages of decay in various size classes. Various techniques to manage decadence for deciduous and coniferous cavity trees.
70, 130	Commercial variable-retention harvest (as above) emphasizing retention of legacies from various preceding ecosystems.

mote general (environmental, economic, and social) sustainability (Goodland 1885)." My purpose in this paper is to evaluate AIM in the light of SERPER and to determine if and where AIM and SERPER might be at odds and where either may need further thought and development.

The 1st SERPER tenet is a definition, "Ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity, and sustainability" (SER 2002). AIM uses remarkably similar language (Carey and others 1996; Carey, Lippke, and others 1999). Within ecology, however, there is disagreement about the utility, definitions, and reasonableness of the terms health, integrity, and sustainability. These terms are considered by many to be value-laden, normative (serving to establish proper management behavior), ill-defined, and hard to evaluate quantitatively, whereas they are considered meaningful, useful, and descriptive by many others; in any case, they are now in the public lexicon (Ray 1996) and represent well-established public values (Shields and others 2002). In addition, they can be defined and quantified in specific contexts. Similar debates exist around "ecosystem", "biodiversity", "habitat", and "conservation" itself. A 2nd SERPER premise is that some ecosystems have been degraded as a result of human activities, exacerbated by natural events, to the point where they cannot recover their historic state or developmental trajectory (SER 2002). AIM has this premise also (Carey and others 1996; Carey, Lippke, and others 1999). SERPER specifies that restoration attempts to return an ecosystem to its historic trajectory with historic conditions as the ideal starting point but recognizes that this might not be possible. Here again, many disagree about what constitutes degradation, whether or not succession to climax (or "old growth") state is inevitable with or without restoration, what constitutes alternative stable states to a climax state, whether global climate change will allow return to pre-Columbian conditions, which historic pre-Columbian period (if any) is most appropriate, and whether or not the pre-disturbance state is the desirable state or even a natural (unaffected by humans) state (Pielou 1991; Carey 1998; Pyne 2003; Ruddiman 2003). AIM does not rest on attaining a historic condition; rather it posits movement to a sustainable condition that can meet future, not past, challenges. There is substantial debate over what constitutes naturalness, wildness, wilderness, and healthy, and even whether the very act of management itself precludes attaining a wild or natural state in the future. Pyne (2003) says "wilderness theology overtakes . . . scholarship", referencing the grand dichotomy of nature versus culture, and he reports that whether the pre-contact (pre-Columbian) character of large parts of North America was wilderness (nature untrammeled by man) will forever remain a matter of faith, not science. He states, "The majestic search for a sliver of the True Wild belongs with the medieval quest for a splinter of the True Cross." Nevertheless, naturalness and wildness are important to the public and continued discussion amongst interested parties will be necessary to determine if intentional management can produce wild, natural, systems. SERPER states that intact ecosystems and other ecological, cultural, and historic reference information can be used to establish general directions and boundaries for restoration efforts and baselines for evaluating progress towards improved health and integrity; again, some conservationists would disagree (AIM does not), but all would perhaps accept that comparisons are more than useful, they are necessary. Some conservationists would deny that restoration requires "thoughtful deliberation . . . systematic planning . . . a monitored approach . . . interventions . . . manipulations . . . removal . . . reintroduction . . .continuous management", as both AIM and SERPER posit, but all might agree that many ecosystems may reach a point at which they no longer require human assistance to ensure future health and integrity (SER 2002).

I take a pragmatic view of ecosystem restoration for those forests in close proximity to and visited by people (Carey and others 1996; Carey, Lippke, and others 1999); my approach is active, intentional, management (AIM) of ecosystems for multiple values. Some conservationists object to the term "values" as too suggestive of commodities, but my use of the term is for the opposite reason—to allow inclusion of intangible values such as knowing that rare species exist, that "wild" or "natural" places are deliberately in place, and that various ecological services important to functioning of the biosphere are being maintained along with various uses of the ecosystem for aesthetic, recreational, and cultural purposes and for production of useful commodities (clean water, wood, floral greens, mushrooms, and other products). What if we could manage ecosystems near to people to exhibit all the measurable biological traits of pristine (or at least pre-Columbian) ecosystems that once occupied those sites? Would we have restored function? Would we have recoupled ecosystem function and ecosystem services (Baldwin 2003)? SERPER recognizes the coupling of function and services in natural-cultural mosaics in developing countries and in Europe but accepts a focus on the primeval historic conditions in North America despite the evidence of widespread management by indigenous peoples. Baldwin states, "I have been an environmentalist since I was a child, but as I got older I began to realize that some of my strongly held views might not be my own. Rather they seemed part of an 'environmental correctness' that decried exotic species as evil beings that should be stamped out . . . cherished rare species . . . saw preservation of pristine . . . as the only way to maintain biodiversity, and promoted the restoration of any habitat despite associated socioeconomic or environmental costs . . . question some of these value-laden views. . .". He concluded that we need to balance our perceptions of the value of the environment and our dependence on the services it provides. Perhaps what we need to do is to move from the abstract purity of a pristine nature to experience the natural and wildness in a natural-cultural mosaic (Regier 1993) . . . to immerse ourselves in the wildness of an intentionally managed 2nd-growth forests devoid of human habitation to see if we can accomplish a feeling of aloneness as night falls, the moon rises, and the wolf howls.

How might we be able to achieve consensus among environmental stakeholders in specific situations that will allow us to describe a desired future condition and to proceed with active intentional management? There are social, psychological, and institutional elements to the answer; for example, SERPER, like AIM (Carey 2006), points out that a collective decision is more likely to be honored and implemented than a unilateral one and, thus, all stakeholders are behooved to work towards consensus. Here, however, I concentrate on the ecological-technical approach. Some solutions lie in how we view ecosystem development–a focus on ecological processes and development of biocomplexity versus a focus on attaining a particular physiognomy or vegetation structure versus a focus on redeveloping and maintaining an idealized specific and complete pre-Columbian biological diversity (both genetic diversity and species composition). Panarchy theory (Holling 2001) highlights the need for ecosystems to be resilient, adaptive, and ever evolving. How can we conserve our natural heritage and its biological diversity while restoring ecosystems to states and trajectories that can persist through future, rather than past, conditions? To me, the answer lies in understanding how forest ecosystems developed resilience and complexity in the past and how we might foster those processes that promote self-organization of forest biotic communities that result in high biocomplexity, adaptiveness, and relative stability—with the capacity to develop the diverse values that we, as a pluralistic society, desire.

For example, a few key processes control accumulation and allocation of biomass among growth forms of forest vegetation in most temperate forests; here, I will focus on forests in the Western Hemlock Zone of Oregon and Washington (Franklin and Dyrness 1973). Accumulation of biomass, and its allocation among various species of plants and among living and dead forms of organic matter, are fundamental phenomena underlying succession, forest development, and even resistance to disturbance and resilience in the face of disturbance (Bormann and Likens 1979; Oliver 1981). Processes important to biodiversity and biocomplexity within the phenomena of biomass accumulation and allocation include legacy retention through disturbance, colonization from surrounding environments, crown-class differentiation, decadence, canopy stratification, and understory development within the developing forest ecosystem (Carey, Kershner, and others 1999; Franklin and others 2002). These processes are intertwined; their progress depends on disturbances at a variety of scales and intensities; a significant outcome is spatial heterogeneity. With a large-to-complete species pool, higher-level ecological processes can occur: development of intracommunity site-type diversity, also called habitat breadth (Whittaker and Levin 1977; Carey, Kershner, and others 1999) and preinteractive niche diversification—the increase in biocomplexity that allows potentially competing species to coexist in high abundances (Hutchinson 1958, 1978; Whittaker and others 1973; Carey, Kershner, and others 1999). Accumulation of biomass within ecosystems, maintenance of biological diversity through legacy retention and permeable landscapes, development of habitat breadth and niche diversification within ecosystems, and maintenance of dynamic but steady-state landscapes (Shugart and Patten 1972, Bormann and Likens 1979) seemingly maximize opportunity for development of biodiversity and biocomplexity and capacity to absorb environmental change (Carey and others 1996; Carey, Lippke, and others 1999). Furthermore, management for shifting steady-state mosaic landscapes may provide for greater stability and adaptiveness in the long run through events of "creative destruction" that allow new self-organizing communities to adapt to new environmental conditions (Holling 2001), which is especially important given constantly changing environmental conditions and threats from invasive species and introduced pests and disease.

Given a focus on ecological processes, SER-PER criteria, and the need to relate research and monitoring results to diverse publics, I developed both a heuristic model and sets of discrete variables to evaluate experimental manipulations of forest structure (Carey 2003a) and simulations of alternative landscape management scenarios in western Washington (Carey and others 1996; Carey, Lippke, and others 1999). First, I identified a keystone complex that was symbolic of Pacific Northwest old growth: northern spotted owl (*Strix occidentalis*)-northern flying squirrel (*Glaucomys sabrinus*)-ectomycorrhizal fungi-Douglas-fir (*Pseudotsuga menziesii*). The spotted owl is the flagship species for old growth and has been designated a threatened species by both federal and state governments. The flying squirrel is the primary prey of the owl. Hypogeous ectomycorrhizal fungal sporocarps are the primary food of the squirrel; the squirrels disperse the spores and associated microorganisms throughout the forest. Mycorrhizal fungi enhance the ability of Douglas-fir to absorb water and nutrients from the soil and to receive carbohydrates in return. The fungi move photosynthetic carbohydrates from trees to the mycorrhizosphere, providing support for a vast array of microbes and other soil organisms. Above ground, the food web expands laterally to include other raptors and mustelids; 3 species of squirrels; forest-floor small mammals; seeds, fruits, and fungal sporocarps; and various trees and shrubs. Thus, the complex provides a framework that is both functional and heuristic in evaluating forest ecosystem development in response to heterogeneity induced into canopies and to forest management generally. The spotted owl and other predators, however, respond to stands at the landscape scale (Carey and others 1992) and can not be used to evaluate stand management at small scales. Thus, I measured abundances of 3 squirrels, the northern flying squirrel, Douglas' squirrel (*Tamiasciurus douglasii*), and Townsend's chipmunk (*Tamias townsendii*), and compared their abundances to the simultaneously high abundances of all 3 species in complex old forest. The diets of the squirrels overlap, but each has a dietary specialization: the flying squirrel: truffles; Douglas' squirrel: conifer seeds; and Townsend's chipmunk: fruit, seeds, and nuts of shrubs, conifers, and deciduous trees, and fungi in season, but only in areas of high shrub cover and hibernation in the winter. Thus, the combined biomass of these 3 species is a measure of ecological productivity–the reproductive fruits of the forest ecosystem and the capacity of the ecosystem to support diverse vertebrate predator assemblages (Carey, Lippke, and others 1999; see Carey 2006 for more discussion).

Second, I was concerned with forest-floor function, because the forest floor is the foundation for sustainability of forest ecosystems. Mechanical operations, killing trees, and altering microclimate affect forest-floor function. A basic feature of Pacific Northwest forest soils is dominance of biological activity by fungi, particularly ectomycorrhizal fungi. My team measured degree of dominance with biomass ratios for total fungi to total bacteria, active fungi to active bacteria, and fungal-feeding nematodes to bacteria-feeding nematodes; biomass of predatory nematodes; and biomass and diversity of sporocarps of ectomycorrhizal Ascomycetes, Basidiomycetes, and Zygomycetes (hereafter referred to as truffles); diversity of epigeous fungi; and the coverage of fungal mats (*Piloderma* sp., *Hysterangium* sp., *Gautieria* sp.). I extended consideration of forest-floor function hierarchically to the integrity of the forest-floor small mammal community. This community is particularly diverse in Pacific Northwest forests compared to the rest of the world (Carey and Harrington 2001). Because, many animals respond to the structure and composition of the plant community (Carey, Kershner, and others 1999; Carey and Harrington 2001), I measured the abundance and diversity of vascular plants periodically and spatial pattern at 10 y post-treatment. Because disruption of soil by mechanical operations and simplification of forest ecosystems by timber management can promote invasion by exotics, I recorded exotic species and tracked their tenure in the system. Finally, resident birds play important roles in Pacific Northwest forest in regulating insect populations by insectivory and in decadence processes by excavating cavities in trees (Manuwal and Huff 1987). These birds are particularly sensitive to the simplifying effects of timber management. Thus, I measured their diversity and abundance.

To evaluate alternative landscape management scenarios, I formulated 5 ecological indices to restoration of landscape function (Carey, Lippke, and others 1999):

1. Ability to support wide-ranging old-growth species, based on estimates of the area of late-seral forest required to support 1 pair of spotted owls.
2. Capacity to support vertebrate diversity based on published accounts of the habitat requirements of 130 species, evaluated as percentage of maximum possible capacity.
3. Forest-floor function, defined as the biotic integrity of the forest-floor small mammal community, the top of the forest-floor food web and part of the prey base for mustelids, canids, felids, strigids, and raptors.
4. Ecological productivity, defined as the biomass (kg/ha) of 3 species of squirrels and as representing the system's production of fungal sporocarps, fleshy fruits, and seeds of trees (consumed by squirrels) and capacity to support medium-sized predators (mustelids, strigids, and raptors that consume squirrels).
5. Production of 2 cervids (*Odocoileus hemionus* and *Cervus elaphus*), taken to represent the system's capacity to support large predators (*Canis lupus* and *Felis concolor*), subsistence hunting by indigenous peoples, and sport hunting.

In this paper, I briefly review the results of an experiment in inducing spatial heterogeneity in 2nd-growth forest canopies to stimulate forest developmental processes (Carey 2003a, 2006) and summarize the results of a simulation study of what might be expected if a full suite of AIM techniques is applied to a landscape for a period of 300 y (Carey and other 1996; Carey, Lippke, and others 1999).

METHODS

Experimental Induction of Heterogeneity

The study is ongoing southeast of Olympia, Washington, in an area with coarse-textured gravelly-sandy-loam soils on flat to rolling glacial outwash plains with annual precipitation 800 to 900 mm. Vegetation is typical of the Douglas-fir-Ocean spray (*P. menziesii-Holodiscus discolor*) association of the *Tsuga heterophylla* Zone (Franklin and Dyrness 1973). The study includes sixteen 13-ha plots in 4 blocks. Two blocks were clearcut in about 1927 and conventionally thinned twice to a final residual density of 225 trees/ha (about 7 m between trees) >10 y prior to the initiation of the study. Few (<1/ha) trees were retained from the preceding forest and dead trees were removed. Canopy trees were 51 to 54 cm in diameter at 1.5 m above ground; cover of coarse woody debris was 2 to 3%; cover of understory vascular plants was 88%, dominated by the evergreen shrub salal (*Gaultheria shallon*), the evergreen swordfern (*Polystichum munitum*), and brackenfern (*Pteridium aquilinum*). Shade-tolerant conifers were rare. I refer to these as timber plots. Two blocks were clearcut in about 1937, with 2.7 live trees/ha and 3.5 dead trees/ha retained from the preceding old growth. Woody debris included old, decaying, fallen trees (7 to 8% cover), stumps of old trees (48/ha), and abundant (3% cover) small trees killed by suppression or root rot (*Phellinus weirii*). Understory cover was 34%, patchy, and dominated by salal. Canopy trees were 600/ha and 34 cm in diameter at 1.5 m above ground. Few shade-tolerant conifers were present. I refer to these as legacy plots.

Each 13-ha plot was subdivided into sixtyfour 0.16-ha cells surrounded by a 40-m border. One-half the plots were thinned in 1993 with cells varying in retained densities of trees (variable-density thinning, VDT) to induce canopy heterogeneity and form *mosaics* and were underplanted to restore lost tree species that occurred historically in the area. VDT creates canopy mosaics by removing subordinate and codominant trees and producing small patches such that light, water, nutrients, and space become available spatially in various amounts to other vegetation (Carey, Thysell, and others 1999). Effects, however, extend beyond the borders of the altered patches of canopy because of low sun angles in the Pacific Northwest. I used relative density (RD) to determine how many trees to retain in each cell The RD index to inter-tree competition in even-age evenly spaced stands of Douglas-fir ranges from 0 to a biological maximum of 14; excessive crown restriction occurs with RD > 7. Twice-thinned timber plots had RD = 6.5, and legacy plots had RD = 7.2 and mortality due to suppression. I randomly assigned RD values of 2, 4, and 6 to the 0.16-ha cells and RD = 6 for the 40-m buffer to achieve a 2:1 ratio of light (residual RD > 4.75) to heavy (RD < 4.75) thinning to promote biocomplexity (Carey, Thysell, and others 1999), with a mean residual RD of 4.8 in legacy plots thinned with VDT (legacy mosaics) and 4.7 in timber mosaics. Heavily thinned cells were planted with red alder (*Alnus rubra*), western white pine (*Pinus monticola*), grand fir (*Abies grandis*), and western redcedar (*Thuja plicata*), chosen variously for resistance to root rot, value in restoring lost biodiversity, tolerance of variation in soil moisture, and shade tolerance. Shade-tolerant conifers are important because they exert more control over light regimes (and consequently spatial patterning) than the shade-intolerant Douglas-fir with its tall, narrow crown.

Simulations of Landscape Management

As numbers of species negatively affected by timber harvest grew and conflicts over forest management moved into courts, Washington officials requested a study to determine if cross-ownership management could lead to better solutions with lesser economic impacts than increasing regulation, landscape zoning, and multiple single-species conservation plans (Carey and others 1996; Carey, Lippke, and others 1999). Thus, an interagency, multi-university team was established to seek solutions via computer simulations of landscape management alternatives. Alternatives were applied to a model landscape with initial conditions based on a real landscape on the western Olympic Peninsula, including stand conditions, tree growth and yield, streams, wildlife-habitat relationships, transportation networks, unstable slopes, operational costs, distance to timber markets, and market values. Because alternatives were pertinent to diverse landowners, from industrial forests to state-managed school trust lands, the team calculated net present value of extracted wood products and sustainable decadal revenues over the long term (300 y) (Carey, Lippke, and others 1999).

The protection of streams required by Washington at the time was commonly deemed unsatisfactory; new regulations would be forthcoming. Federal land managers had just adopted interim buffers around streams, from which management was excluded. The state and federal approaches provided 2 extremes of protection; neither addressed riparian restoration (see Carey and others 1996 for the interpretations of the state and federal buffers provided by Washington State forest, fish, and wildlife managers for use in the simulations). Applying federal buffers in the simulations withdrew >34% of the landscape from management (Carey and others 1996). Significant parts of the remaining degraded 2nd-growth forest, especially in headwater areas, were so isolated by buffers that management would be infeasible. The team sought alternatives that would promote restoration and adopted 1 that precluded mechanical operations on stream banks and adjacent to headwater seeps and streams; allowed thinning and other restoration efforts in narrow riparian buffers, but not clearcutting; and allowed thinning and decadence management, but not clearcutting, on mass-wasting areas. The area of landscape withheld from harvest was <15% and upland patches were not isolated. Two approaches to restoration, 1 active and 1 passive, along with antithesis of restoration (maximizing net present value of wood production with minimal constraints), were modeled in the final simulations. Maximizing wood production consisted of clearcutting, site preparation, natural regeneration, precommercial thinning at 15 y, clearcutting at 40 y, and the existing Washington guidelines for riparian protection. The final restoration alternative included clearcutting with legacy retention, no site preparation, planting of Douglas-fir and natural regeneration of other conifers and hardwoods, regulation of spacing and maintenance of tree species diversity with precommercial thinning at 15 y, and variable-density thinnings to induce spatial heterogeneity, maintain tree species diversity, recruit coarse woody debris, and remove wood products at 30, 50, and 70 y with final harvest by clearcutting with legacy retention alternating between 70 y and 130 y. Rotation ages were deliberately calculated to balance timber revenues with ecological outputs.

RESULTS

Results of published papers from the experiment were summarized by Carey (2003a, 2006) and are only briefly summarized here. All experimental plots maintained apparently healthy fungal dominated soils. Mechanical disturbance, however, appeared to destroy near-surface fungal mats and promote *Melanogaster* over *Hysterangium* and *Gautieria*. Induced heterogeneity increased total sporocarp diversity. Sporocarp diversity rivaled that in old growth around the region. Impacts of VDT on truffle production were significant, but brief. Achlorophyllous mycotrophic plants were reduced in abundance by dense understory. Conventional thinning had produced rich understories dominated by clonal native species with numerous exotic species present. Legacy management had produced depauperate understories. Induced canopy heterogeneity markedly increased diversity and abundance of native species, but also promoted numerous exotics, with some persisting for 10 y, suggesting it may not be possible to promote native diversity without promoting exotic diversity concomitantly. Induced canopy heterogeneity, colonization by native species, and growth of underplanted seedlings is leading to increased spatial heterogeneity.

The simulations surprised many (Carey, Lippke, and others 1999; Carey 2003b, 2006). Simply protecting 2nd-growth forest caused the landscape to go through waves of forest development. Initially, a substantial ecological crunch occurred because of degraded watersheds and oversimplified stands; a long time (200 y) was required for these stands to achieve an old-growth-like condition, even with the assumption that this would happen without legacies and in an impoverished landscape. Timber management with minimum constraints produced a landscape inhospitable to >20 vertebrate species and allowed no recovery of degraded streams; its sustainability was uncertain, but net present value was maximal. Timber management with riparian reserves drawn from federal guidelines, produced relatively narrow, well separated strips of late-seral forest in the long term, unlikely to function fully as late-seral forest because of their continued adjacency to clearcut and young forests; clearcutting was intensified in the available uplands due to removal of streamside and adjacent small patches from forest management. Biodiversity management, as it was designed to do, produced significant ecological benefits, including supporting a pair of spotted owls, maintaining capacity to support vertebrate diversity, achieving near potential forest floor function and ecological productivity, and producing a number of cervids comparable to the timber management regime. But, surprisingly, costs were relatively low—only a 15% loss in net present value compared to maximizing net present value of timber extraction. Assuming (as occurred) increased riparian protection would be mandatory and eliminating costs of improved riparian or mass-wasting management from comparisons, biodiversity management resulted in only a 6% decrease in net present value. Other economic values increased: decadal revenues increased by 150%, forest-based employment quadrupled, and the wood products manufacturing sector diversified and relied more heavily on high quality wood products and value-added manufacturing. Initially, I included a constraint of 30% of the landscape in late-seral forest to support 1 pair of spotted owls; the final shifting steady state mosaic maintained >50% of the landscape in late seral stages and <15% of the landscape was in clearcuts in any decade, resulting in a landscape fully permeable to dispersing late-seral species.

DISCUSSION

Legacies, Thinning, Heterogeneity, and Restoration

In 2nd-growth forests in Washington, both conventional thinning and legacy management produced imbalanced small mammal communities, with some mammals abundant in natural forests being rare in managed forest. Induced heterogeneity (VDT) had immediate positive impacts on forest-floor mammals, but restoration of shade-tolerant midstories and development of midstory deciduous trees (for example, *Acer macrophyllum*) will be required to restore biotic integrity. Chipmunks increased markedly in legacy mosaics with only brief declines in flying squirrels. Flying squirrels remained rare in previously thinned stands, perhaps due to dense understories that promote excessive chipmunk abundance and possibly impede foraging for truffles by flying squirrels, decreased canopy connectivity that inhibits arboreal travel, and large gaps between the shrub layer and canopy that exposes squirrels to predation. Similarly, VDT had positive effects on the winter birds and increased the overall habitat quality in mosaics. Bird communities, however, continued to have low abundances of cavity-excavating birds. Promoting deciduous trees (for example, red alder) early in stand development provides short-lived trees for cavity excavation in the short term; decadence management may prove essential to maintaining cavity-excavating birds in managed forests. Retaining unthinned patches in mosaics might help conserve fungal mats and mycotrophs. In summary, inducing heterogeneity into homogeneous, closed canopies has positive effects on diverse biotic communities and ecosystem function as habitat even in the short term (<5 y) in both stands managed with conventional thinning and with legacy retention only. Only time will tell if reduced elements of diversity (for example, deciduous trees, cavity trees, certain small mammals, and certain birds) will be restored. More research is needed on managing decadence to provide cavity trees, standing dead trees, and large coarse woody debris. Nevertheless, VDT shows promise as part of a holistic management approach.

Zoning and Shifting, Steady-State Mosaics

Conservation biologists once argued the relative merits of single, large reserves versus multiple small reserves, the need for conserving genetic diversity, and the need to restrict active management. Forest managers focused on plantation management, transportation networks, and watershed restoration. Now it is becoming recognized by both that active management for biodiversity is needed to restore degraded ecosystems and to produce fully functional forests outside of reserves. Recent research has shown that reserve systems could become self-fulfilling prophecies of highly isolated diverse forests separated by depauperate 2nd-growth forests and developed areas and that conventional timber management can oversimplify forest stands to the detriment of stand and landscape function. As human populations grow and increasing demands are placed on our environment, highly intentional systems management (Carey, Lippke, and others 1999) and total landscape management will be necessary to conserve the biodiversity of natural-cultural mosaics and the ecological services and economics goods it provides. Shifting, steady-state mosaics of complex forest ecosystems should promote system resilience (Holling 2001).

Implications for Restoration Ecology

AIM approaches presented here do not seek to restore any particular pre-Columbian ecosystem state. Rather they seek to restore ecosystem function, resilience, productivity, and adaptiveness and the biotic integrity of vertebrate communities, the diversity of vascular plant communities, and diversity within functional groups for other biotic communities. The approach is dynamic and allows for self-organization, "creative destruction", ecological innovation, and ecological surprises. It unabashedly seeks to serve human needs, whether for clean air and water, recreational and spiritual experiences, wood and other forest products, economic activity and employment, and the knowledge that we are attempting to be just and moral (to one another, to future generations, to other species) in the management of our ecosystems—it seeks to restore "nature, without mosquitos" (Willott 2004). Is this restoration? Davis and Slobodkin (2004) complained restoration ecology is a value-based rather than a scientific activity, claiming that health and integrity can be applied only to entities shaped by evolution, such as individual organisms, and that communities are not shaped by evolution, not tightly organized systems, and not of intrinsic value. AIM makes opposite assumptions. Winterhalder and others (2004) said there is no disagreement that restoration has value-based aspects and disputes the claims of Davis and Slobodkin (2004), as have many others. SERPER lists 9 aspects of restored ecosystems against which AIM can be compared. AIM seems to fulfill the following SERPER criteria:

Contains a Characteristic Assemblage of Species that Occurs in Reference Ecosystems.—Most species inhabiting Pacific Northwest forests have yet to be described. Many 2nd-growth forests lack characteristic species and characteristic assemblages of species found in old growth and other naturally complex forests (Carey and others 1996; Carey, Lippke, and others 1999; Carey, Kershner, and others 1999; Carey and Harrington 2001; Carey 2003a). However, it appears that 1 AIM technique, variable-density thinning to induce spatial heterogeneity, has had positive results in restoring diversity of hypogeous ectomycorrhizal fungi, mushrooms, vascular plants, small mammals, arboreal rodents, and birds. Simulations suggest that AIM has the capacity to restore not only the presence of key species but also the structure of biotic communities in forest ecosystems that have been degraded by past management.

Consists of Indigenous Species to the Greatest Extent Practicable.—Experiments suggest that AIM can promote native species diversity with only minor additions of exotic plant species and that restoring native species diversity might be possible only with accompanied increases in numbers of exotic species (in low abundances).

All Functional Groups Necessary for Continued Development and Stability are Represented.—Experimental results suggest that AIM can maintain diverse functional groups (including those of hypogeous fungi, epigeous fungi, soil bacteria, soil nematodes, and litter arthropods). Restoration of diverse small-mammal communities suggests that diverse food webs are being maintained. But the experiment also suggests that AIM should incorporate small patches of undisturbed soil at a fine scale to ensure the continued persistence of aclorophyllous mycotrophs and matt-forming fungi.

The Physical Environment is Capable of Sustaining Reproducing Populations of the Species Necessary for Continued Stability or Development along a Desirable Trajectory.—Simulations support AIM as a method of promoting development of complex forests that contain all important keystone and flagship species and keystone complexes (Carey and others 1996; Carey, Lippke, and others 1999; Carey 2006); but experiments have been in place for too short a time and actual operational management implementation of AIM has just begun, thus uncertainty persists. Monitoring and adaptive management, however, are integral to AIM.

Functions Normally for its Ecological Stage of Development; Signs of Dysfunction are Absent.—The AIM experiment began with 2 historic conditions showing marked signs of dysfunction, including root rot, lack of shade-tolerant regeneration, lack of large cavity trees, low populations of cavity-excavating birds, incomplete and imbalanced small mammal communities, imbalanced and low-density arboreal rodent communities, either reduced plants species diversity or high plant species diversity with abundant exotic species, and other problems. Much of this dysfunction has been ameliorated, even within a short time with only 1 AIM technique.

Suitably Integrated into a Larger Ecological Landscape.—A key component of AIM is integrated landscape management; indeed, AIM calls for total landscape management to integrate healthy forest in natural-cultural mosaics (Carey, Lippke, and others 1999).

Potential Threat to the Health and Integrity of the Ecosystem from the Surrounding Landscape is Reduced as much as Possible.—AIM strives to maintaining sustainable natural-cultural mosaics.

Ecosystems are Sufficiently Resilient to Endure Normal Periodic Stress Events.—AIM draws upon the history of forest management, forest ecology, and disturbance ecology to emphasize treatments that promote resiliency to both normal periodic stresses and to future "surprises" (Holling 2001). However, we have no experimental evidence or management experience to suggest that AIM ecosystems can or can not endure normal or unusual stress events. Two experiments testing AIM techniques (Carey and Harrington 2001; Carey 2003a), however, have shown early resiliency to windstorms and ice-storms.

Ecosystems are Self-sufficient to the Same Degree as Reference Ecosystems . . . and They may Evolve.—AIM seeks to restore to 2nd growth the biodiversity and biocomplexity characteristic of long-lived, resilient, complex natural forests; modeling suggests that AIM end-point forest ecosystems should be relatively stable for long periods of time. The use of shifting, steady-state mosaics maintained through creative destruction to provide opportunity for adaptation to changing environments suggests AIM has potential to satisfy this criterion.

Ecosystems Provide Specified Natural Goods and Services for Society in a Sustainable Manner, Including Aesthetic Amenities and Accommodation of Activities of Social Consequence.—This, of course, is a major component of AIM.

It seems clear the AIM for multiple values does aim for restoration. But will the various publics find it an acceptable alternative to the one that maximizes their values, be it intensive timber production or wilderness? This is a grand challenge: to determine if a social consensus can be achieved on the basis of science and experience.

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