Restoration of landscape function: reserves or active management?

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Summary

A 20-year programme of research suggests that old-growth forests are ecologically unique and highly valued by people, that naturally young forests with legacies from old forests sustain many, if not all, the higher organisms associated with old growth, but that many managed forests are impoverished in species. Thus, restoring landscape function entails restoring function to managed stands. Managing processes of forest development, not just providing selected structures, is necessary to restore function and biodiversity. Systems of reserves and riparian corridors that do not take into account ecological restoration of managed forests and degraded streams may be self-fulfilling prophecies of forest fragmentation and landscape dysfunction. Intentional management can reduce the need for wide riparian buffers, produce landscapes dominated by late-seral stages that are hospitable to wildlife associated with old-growth forests, provide a sustained yield of forest products and contribute to economic, social and environmental sustainability.

Introduction

Exploitation of forest resources in north-western USA over the last 150 years repeated the pattern of development of eastern North America, the interior western USA (Kaufmann *et al*., 2003) and to some extent, with far less conversion to non-forest uses, Europe (e.g. Nordlind and Ostlund, 2003). Initially, small areas of natural forest were reserved and the remaining forests were freely exploited and converted to agriculture, urban areas or second-growth forests. Commercially valuable forests often were harvested and replaced with naturally regenerated second-growth forests in degraded water-sheds - water-sheds in which uplands and stream sides were logged bare. Logging was often followed by intense wildfire, stream sides were revegetated by shrubs and deciduous trees without conifers, streams were scoured during the transport of logs and logging roads contributed to erosion, landslides and deposition of sediment into streams. Intensive silviculture was relegated to relatively small areas within the region. Mounting degradation led to a wide range of public regulation of forest practices in the mid-twentieth century with emphasis on reforestation, efficient production of wood and economic stability (sustained yield), but without thorough consideration of cumulative impacts at watershed and higher spatial scales. As harvests of old growth continued and landscapes became increasingly dominated by early seral stages, first the spotted owl (*Strix occidentalis*) in 1990, then the marbled murrelet (B*racbyramphus marmoratus*) in 1992 and, later, numerous salmonids were designated as threatened with extinction by the US Government. Degraded landscapes no longer (1) produced moderated flows of cool, clear water for fish, (2) developed streams with complex structure, including pools, riffles and large woody debris, (3) supported wildlife associated with old-growth forests, (4) enabled dispersal of old-forest species from refugia to colonize newly developing biotic communities, or (5) provided aesthetic environments for outdoor recreation and human communities. Even the extraction of wood slowed and unemployment began to rise in the wood products industry. Once again, unaddressed public concerns led to public demonstrations, litigation and further legal restrictions on forest management. Conservation focus switched from stands to landscapes and from the focus on sustained yields of wood earlier in the century to conservation of fish, water and wildlife and general sustainability by the end of the century. An initiative by US President Clinton to resolve the social conflict culminated in the 1993 Northwest Forest Plan for management of federal forests in the Pacific Northwest by the US Forest Service and the US Bureau of Land Management (Tuchmann *et al.*, 1996). The plan did not direct management of forests owned by the States of Washington, Oregon and California or by private individuals or corporations. The State of Washington (Belcher, 2001) and some private agencies developed related habitat conservation plans'.

Disciplinarily diverse academicians, scientists and managers designed the Northwest Forest Plan to address environmental, economic and social concerns. The plan emphasized late-successional reserves, an aquatic conservation strategy emphasizing riparian corridors, monitoring threatened species, and identification, inventory and management of numerous rare and cryptic species (Staebler, 1994). In 2002, the Northwest Forest Plan was judged a failure in need of overhaul by the Chief of the US Forest Service because timber harvests had been reduced by litigation to 25 per cent of that planned (to 5 per cent of the pre-plan harvests) (Dodge, 2002; Milstein, 2002). Almost 50 per cent of the planned timber harvests were to have come from unreserved old growth, and those harvests met strong public opposition. What was wrong with the Northwest Forest Plan? Much of the debate about what constitutes sustainability stems from cultural differences among the three major cultural streams in the US in perceptions, values and beliefs (Ray, 1996). I do not address them here. Are there lessons from implementation of the Northwest Forest Plan and recent research that suggest better ways of managing landscapes in the Pacific Northwest and elsewhere around the world? I think so (the plan emphasized adaptive management) and I do address some here, drawing from 20 years of research on natural and managed forests in the Pacific Northwest. I recapitulate the US Forest Service research response to the burgeoning social discord over forest management and the application of its results in a modelling study of landscape management legislatively mandated by the US Congress at the request of the Governor of the State of Washington.

Methods for long term, broad-scale research

Much of the public was dismayed at the continuing harvest of old growth by 1980. Old-growth forests are 250-1000 years old; many are described as cathedral like, with boles metres in diameter sweeping upwards to canopies almost 100 m tall. People find these forests awe-inspiring and spiritual (Clark *et al.*, 1999). Scientists postulated that old-growth forests were ecologically unique (Franklin *et al.*, 1981) and that numerous species of wildlife depended upon old growth (Meslow *et al.*, 1981), particularly the spotted owl (Forsman *et al.*, 1984). Others, however, perceived these forests as warehouses of valuable, but perishable, timber essential to the economic and social stability of rural communities. Reconciling such different views requires quantitative data from comparative ecological studies and manipulative experiments; evaluation of economic impacts is best done through simulation modelling (e.g. Carey *et al.*, 1999b) and retrospective analysis of the effects of policy implementation (e.g. Lippke *et al.*, 2002).

Comparative ecological studies

The US Forest Service set out to determine quantitatively the uniqueness of old-growth forest, how much remained, the extent to which wildlife was dependent upon it, the species that were dependent on it, the elements of old growth those species were dependent upon, the amounts and distribution of old growth that should be retained to meet conservation objectives and the degree to which old-growth values could be achieved in managed forests. Thus, in 1982, I designed and coordinated a programme of research conducted by numerous university and government scientists that included replicated, geographically stratified studies of plant, reptile, amphibian, bird and mammal communities in old-growth (>250 years), mature (100-200 years) and young (40-80 years) natural forests in western Washington, western Oregon and northern California. Results were compiled in a 533-page book (Ruggiero *et al*., 1991). Later, I designed and implemented a related programme of research on the spotted owl that included geographically stratified studies of its prey base, habitat use and demography (e.g. Carey *et al*., 1992, 1999a). Finally, I compared naturally old forests with managed forests in various parts of the region (e.g. Carey, 1995, 2000; Carey and Johnson, 1995; Carey *et al*., 1999a; Carey and Har-rington, 2001), used the results to design treatments to restore lost biodiversity to managed stands and tested the treatments experimentally (Carey *et al*., 1999, 2003).

Simulation modeling

Increasing restrictions on forest management in the Pacific Northwest had unforeseen negative economic impacts on rural communities and even impeded watershed restoration efforts (Tuchmann *et al*., 1996). As lists of species likely affected by timber harvests and other management activities grew and complexity of management for multiple individual species increased, public officials in the State of Washington wondered if there wasn't a better way of pursuing economic, social and environmental sustainability. They requested a study to determine if total landscape management could lead to better solutions than landscape zoning and single species conservation plans (Carey *et al*., 1999b). I constructed alternatives based on the results of my comparative ecological studies and experiments, including an alternative of biodiversity pathways for small landscapes (Carey *et al*., 1999b).

Pragmatic evaluation of management alternatives requires that simulations be grounded in reality; thus, I chose a real 6828-ha landscape in western Washington for which detailed data on stand conditions, tree growth and yield, streams, wildlife-habitat relationships, transportation networks, unstable slopes, operational costs, distance to timber markets and market values were available. Because alternatives were to be pertinent to diverse landowners, from industrial forests to State-managed school trust lands to tribal lands, we calculated net present value of extracted wood products and sustainable decadal revenues over the long term (300 years). Tradeoffs between economic and environmental values would be manifest and many values produced would accrue to society in general, not to the individual landowner, possibly necessitating public subsidies or incentives for private landowners. Total landscape management would have to be acceptable to the public at large. Thus, I formulated five ecological in-dices to landscape function, based on published models, to evaluate the ecological trade-offs of alternative silvicultural systems and landscape management scenarios (Carey *et al*., 1999b):

1. Ability to support wide-ranging threatened species, based on the area of old forest required by one pair of spotted owls, the only threatened species with documented habitat requirements.
2. Capacity for vertebrate diversity based on 130 species of amphibians, reptiles, birds and mammals.
3. Forest-floor function, defined by the structure of old-forest small mammal communities, the top of the forest-floor food web and a prey base for small generalist predators (e.g. mustelids, strigids and raptors).
4. Ecological productivity, defined as the biomass (kg ha^{-1}) of three species of squirrels 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 deer (*Odocoileus hemionus* and *Cervus elaphus*), the prey base for large predators (*Canis lupus* and *Felis concolor*), subsistence hunting by indigenous peoples and sport hunting.

Given metrics for comparing results, the next choices were on constraints on management. I decided that all alternatives should produce a relatively even flow of outputs on a decadal basis. Because the existing landscape had imbalanced age classes (primarily 50-year-old stands) as a result of rapid harvesting of old growth, achieving even flow required up to 100 years. Minimal protection of streams on private and State lands was required by the State of Washington at the time of the simulations (this protection was commonly deemed unsatisfactory and new regulations have since been promulgated). The Northwest Forest Plan required watershed analyses and wide interim buffers around streams, from which management was excluded; this exclusion, however, became more or less institutionalized. Thus, the State of Washington and the US Northwest Forest Plan approaches provided two extremes, with the State regulations deemed marginal at the outset. Applying the Northwest Forest Plan approach to the landscape produced surprising results: 40 per cent of the landscape was withdrawn from management and significant parts of the remaining landscape, especially headwater areas, were so fragmented and over dispersed as to become economically infeasible to manage. Similar results were obtained as the US Forest Service began implementing the new guidelines. I reviewed the riparian constraints and found, to my surprise, that they were based as much on a wildlife dispersal corridor strategy as on an aquatic conservation strategy. Furthermore, there were few empirical data to support the corridor strategy, yet the interim guidelines would delay restoration of riparian areas by 70 years when conifers and coarse woody debris were lacking and the constraints provided relatively little protection to headwater streams, seeps and unstable slopes. I sought alternatives. First, I shifted emphasis from large streams to small streams; the impacts on the landscape remained large and the same suite of problems persisted. Finally, I adopted an alternative that precluded mechanical operations on stream banks and adjacent to headwater seeps and streams but allowed thinning and other restoration efforts in narrow riparian buffers to promote the growth of larger conifers. Clearcutting riparian buffers was not allowed and thinning, but not clearcutting, could be used on area prone to landslides. The total area in the landscape constrained by this approach was 18 per cent and did not isolate patches of upland forest. Next, I chose three classes of alternatives: protection, but no manipulation; maximizing net present value of timber commensurate with existing State regulations; and management for biodiversity, defined as species, biotic communities and ecosystems and the ecological services and economic goods they provide. For maximizing timber production, I used guidance from industrial forest managers about the feasibility and reasonableness of silvicultural practices and empirical growth and yield models. Numerous simulations were done, but the final alternative was clearcutting, site preparation, natural regeneration, pre-commercial thinning at 15 years, clearcutting at 40-50 years and existing minimum State riparian management guidelines. I developed alternative silvicultural regimes for conserving biodiversity. The final alternative included clearcutting with legacy retention, no site preparation, planting of Douglas-fir (*Pseudotsuga menziesii*) and natural regeneration of other conifers and hardwoods, regulation of spacing and maintenance of tree species diversity with pre-commercial thinning at 15 years 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 years with final harvest by clearcutting with legacy retention alternating between 70 years and 130 years. Rotation ages were deliberately calculated to balance wood production, timber revenues and ecological outputs.

Results

Natural forests

Pacific Northwest old growth is special - com pared with forests around the world, its trees are large and long-lived, decaying organic biomass high and fungal and small mammal communities especially diverse (Carey, 1998; Table 1). Old-growth forests, however, vary in structure and composition from place to place as climate, species pools and disturbance history varied with topographic and biogeographic positions and time and period of development (Poage and Tappeiner, 2002; Winter *et al*., 2002a, b; Kaufmann *et al*., 2003). Once lost, it is unlikely that any particular old growth could be reproduced either through natural succession or through intentional management simply because the biophysical conditions of its development are not subject to unvaried natural repetition (Pielou, 1992; Brown and Hebda, 2002) or to human control (e.g. catastrophic volcanic eruptions, large ocean waves generated seismic activity, windstorms and fires). Furthermore, the complete species composition of old growth has not been determined; thus, indisputable demonstration of successful re-creation is impossible; and global changes in climate and land use are projected to cause large shifts in biodiversity in the future (Hansen *et al*., 2001). Nevertheless, few species of vascular plants or vertebrates are unique to old growth (Carey, 1989; Ruggiero *et al*., 1991). The spotted owl, among all vertebrates studied, seemed most dependent on old growth given the composition of the landscapes of the 1980s (Forsman *et al*., 1984; Carey *et al*., 1992; Carey and Peeler, 1995). Other species were associated with particular elements of old growth (Table 1) or habitats most likely to be found in old growth (e.g. undisturbed headwater streams). Numerous species were most abundant in old growth but were found in other seral stages as well. Often, abundances were associated with one or more attributes of old growth that were less abundant in younger or managed forests (Carey, 1989; Ruggiero *et al*., 1991). Thus, old growth functions differently than younger forests in that its biocomplexity allows greater biomass and diversity in a number of biotic communities (Ruggiero *et al.,* 1991; Carey *et al*., 1999a). Many naturally young forests, however, have biological legacies from preceding old-growth forest and support vertebrate communities with greater biomass than those in some old-growth forests (Ruggiero *et al*., 1991; Carey, 1995; Carey and Johnson, 1995; Carey *et al*., 1999a). Some young forests support complete biotic communities and even provide habitat for spotted owls (Carey and Peeler, 1995). But the awe-inspiring size of old-growth structures induces metaphysics-values associated with its existence that can never be addressed by the scientific method alone. Attempts to harvest old growth will be contentious and lead to litigation. Our improved knowledge of old growth and its importance to people suggests that old growth might best be reserved for its ecological, scientific and spiritual values (Carey, 1998).

Table 1: Attributes of Pacific Northwest old-growth forests identified before and after systematic study (Franklin *et al*., 1981; Carey *et al*., 1999a)

Before study	After study
Large live trees	Diverse tree sizes Diverse tree species
Large standing dead trees	Abundant live and dead trees with cavities
Large fallen dead trees	Dead organic biomass is high but composition and abundance differ among forest types
Horizontal heterogeneity	Horizontal patchiness Diverse patch types
Multi-layered canopy	Canopy gaps Variable foliage height diversity Biocomplexity

Old growth versus managed forests

Whereas many naturally young forests support biotic communities similar to old growth (Ruggiero *et al*., 1991), many managed forests are depauperate in structure, species and ecological function (Carey, 1995, 1998, 2000; Carey *et al*., 1996, 1999a; Harmon *et al*., 1996; Aubry, 2000; Carey and Harrington, 2001). First, many managed forests developed without legacies from the preceding forest; these legacies include coarse woody debris, live trees with their mycorrhizal and epiphytic associates and soil seed banks holding numerous native species of plants and animals (Franklin *et al*., 2000). Secondly, most managed forests were regenerated as dense monocultures that further reduced native diversity through competitive exclusion but allowed exotic species to persist, at least in soil seed banks (Carey *et al.*, 1999a; Halpern *et al.*, 1999; Thysell and Carey, 2001). In intensively managed forests, brush control, precommercial thinning, herbicides and commercial thinning all are used as tools to reduce diversity. Indeed, stands maintained in the competitive exclusion stage may be more deleterious in terms of biodiversity and landscape function than the small areas of clearcutting that would occur with long rotations (Figure 1; Carey *et al.*, 1999b). Legacies and diversity in regeneration in natural stands allow key ecosystem structuring processes to proceed at accelerated rates compared with second growth. These processes include crown-class differentiation, decadence, canopy stratification and understorey development and set the stage for higher processes that lead to biocomplexity through development of habitat breadth and preinteractive niche diversification (Carey *et al.*, 1999a). Understanding forest developmental processes and trophic hierarchies aids formulation of management systems to restore biocomplexity to second growth (Carey *et al.*, 1999a, b, c). Both comparative ecological studies (Carey, 1995, 2000; Carey and Johnson, 1995; Carey *et al.*, 1999a; Aubry, 2000; Carey and Harrington, 2001) and experiments (Carey *et al.*, 1996; Colgan *et al.*, 1999; Carey, 2001; Carey and Wilson, 2001; Thysell and Carey, 2001) demonstrate that it is erroneous to assume that forested landscapes are dichotomous (diverse old natural forests versus depauperate young forests) and unchanging through time (e.g. Mills, 1995; Lomolino and Perault, 2000) and that second growth will develop essential characteristics of old growth without intervention (Paine *et al.*, 1998; McIntyre and Hobbs, 1999; Agee, 2002; Pickett and Cadenasso, 2002).

Modelling landscape alternatives

Results of the simulations were surprising (Carey *et al.*, 1999b; Tables 2 and 3). Simply protecting second-growth forest caused the landscape to go through waves of stages of forest development.

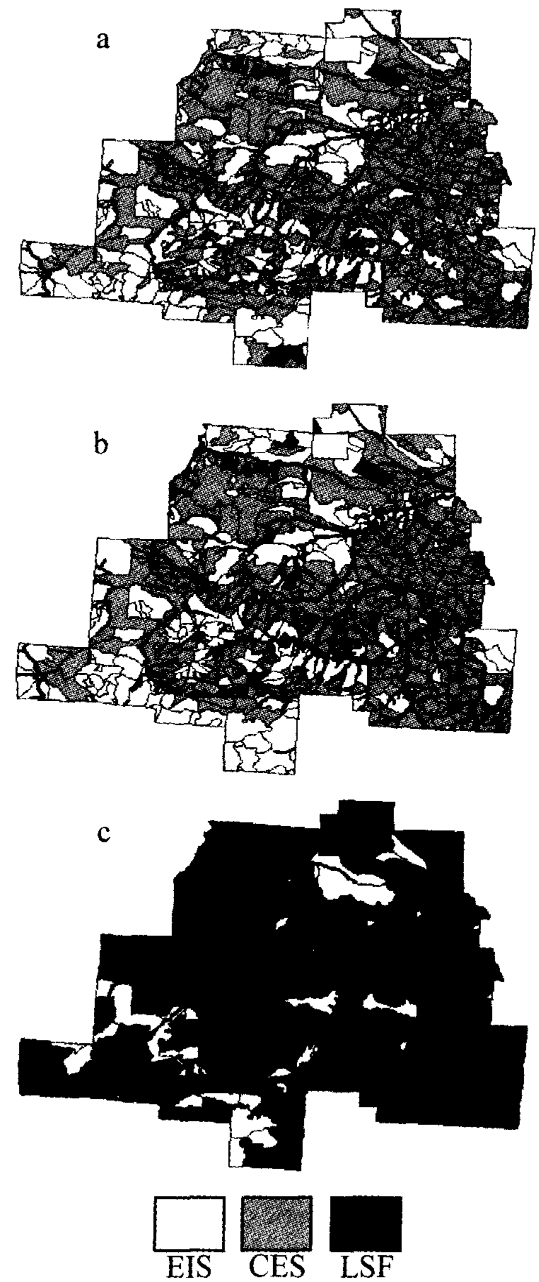

Figure 1. Landscape composition and arrangement under (a) management to maximize net present value of timber with minimal riparian protection, (b) management to maximize net present value of timber with riparian corridors similar to those used in the US Northwest Forest Plan and (c) management for biodiversity including genes, species, communities, ecological services and economic goods. Seral stages displayed include ecosystem initiation (EIS), competitive exclusion (CES) by dense, closedcanopy conifers and late-seral forest (LSF) characterized by biological legacies from the preceding stand, complex vegetation structure and high vertebrate diversity (adapted from Carey *et al.*, 1999b).

Initially (0-60 years), a substantial period of reduced biodiversity occurred because of degraded watersheds and over-simplified stands (even-aged, closed canopy monocultures with little coarse woody debris); 180 years was required before 30 per cent of the landscape was covered by late-seral forest and would be capable of supporting a pair of spotted owls. Timber management with minimal constraints produced a landscape inhospitable to 25 vertebrate species, no recovery of degraded streams and <3 per cent cover of late-seral forest (Figure 1); its sustainability was uncertain, but net present value was maximal. Timber management with riparian reserves drawn from Northwest Forest Plan guidelines produced relatively narrow, well-separated strips of late-seral forest in the long term (Figure 1); 240 years were required to develop a 30 per cent cover of late-seral forest and that was unlikely to function fully as late-seral forest because of its 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. Wide buffers resulted in a 31 per cent loss (US $22 million) in net present value. Biodiversity management, as it was designed to do, produced significant ecological benefits (Table 3), including supporting a pair of spotted owls and producing numbers of deer comparable with the timber management regime. But, surprisingly, costs were relatively low - only an 18 per cent loss in net present value (US $12.5 million) compared with maximizing net present value of timber extraction (Table 2). Assuming (as later occurred) increased riparian protection would be mandatory, such wide buffers would entail a 31 per cent reduction in net present value versus a 14 per cent reduction with riparian/unstable slope management of the biodiversity pathways. Thus, conserving biodiversity would either add 13 per cent or subtract 4 per cent of net present value depending on the type of protection to be afforded riparian areas under the maximizing net present value scenario. Other economic values increased: decadal revenues increased by 150 per cent, forest-based employment quadrupled and the wood products manufacturing sector diversified and relied more heavily on high quality wood products and

Table 2: Measures of ecological performance in a 6828-ha landscape in western Washington, USA, in the last 100 years of 300-year simulations of maximizing net present value of timber and conserving biodiversity to produce ecological services and economic goods (adapted from Carey *et al.*, 1999b)

Ecological measure	Timber management	Biodiversity management
Habitat for spotted owls	No	Yes
Numbers of deer*	423/134	401/200
Vertebrate diversity (% of maximum possible)	64	100
Forest floor function (% of maximum possible)	12	100
Ecological productivity (% of maximum possible)	19	94
Landscape health (mean of the above %)	32	98

* Two species, *Odocoileus hemionus* and *Cervus elaphus*.

Table 3: Wood production and value under landscape management for maximizing net present value (NPV) and for conserving biodiversity (CBD) for a 6828-ha landscape in western Washington, USA (decadal averages are for the last 200 years of 300-year simulations)

Economic measure	NPV	CBD
Cumulative wood volume (10^6 m^3 ha^{-1})	1.6	1.4
Tree quality (cm)*	36.0	76.0
Net present value (10^6 US$)	70.4	57.9
Decadal harvest (10^3 m^3 ha^{-1})	50.0	48.7
Decadal revenues (10^6 US$)	26.0	42.5

* Tree quality was defined as diameter at 1.5 m at rotation age; data from Carey *et al.* (1999b).

value added manufacturing (Lippke *et al*., 1996). Supporting one pair of spotted owls required that 30 per cent of the landscape be maintained in lateseral forest; the final shifting steady-state mosaic maintained >50 per cent of the landscape in lateseral forest (Figure 1) and <15 per cent of the landscape was in clearcuts in any decade, resulting in a landscape fully permeable to dispersing late-seral species (Figure 1).

Although outputs listed in Tables 2 and 3 are from quantitative models or the results of quantitative models standardized to percentages of maximum possible values, many simplifying assumptions and market-dependent values were used in the simulations. All the models will improve over time with the development of new data. Thus, the results should be used only to compare the alternatives and not to project future benefits or to apply to other areas.

Discussion

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 extensive active management for biodiversity is needed to restore degraded ecosystems and to produce fully functional forests outside of reserves (Carey and Curtis, 1996; Lindenmayer and Franklin, 2002; Nordlind and Ostlund, 2003). Research has shown that reserve systems could become self-fulfilling prophecies of highly isolated diverse forests separated by depauperate second-growth forests and developed areas, and that conventional timber management can over-simplify forest stands to the detriment of stand and landscape function. Intentional landscape management provides a better strategy for sustaining aquatic resources than wide riparian buffers. Long rotations reduce cumulative effects of timber harvests while developing stands to complex forest condition at an accelerated rate. Streamsides would be protected by a landscape dominated by late-seral forests and riparian zones with large conifers. Large conifers in the flood plain and on areas with high potential for landslides primes the landscape to contribute the large and irregular inputs of large woody debris and sediment to streams that is essential for stream productivity. The dynamic shifting steady-state mosaic produced by intentional management has high biocomplexity at multiple scales and high biodiversity; thus, these landscapes should be resistant to disturbance and resilient in the face of disturbance (Holling, 2001). Intentionally managed landscapes have little managerially over-simplified forest in the competitive exclusion stage but high permeability for dispersal by most species. As human populations grow and place increasing demands on our environment, intentional systems management (Carey *et al*., 1999b) and total landscape management (managing the natural-cultural mosaic) will be necessary to conserve biodiversity and the ecological services and economics goods it provides.

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