Societal challenges in understanding and responding to regime shifts in forest landscapes

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Many natural landscapes have undergone dramatic permanent alterations as a result of human activities, including conversion to cultural landscapes; such changes are readily observed and understood. However, extensive ecological change can also occur in regional landscapes that are maintained in a seminatural state, changes that go largely unrecognized because the regional landscape retains an approximation of its dominant physiognomic cover, such as forest or grassland. In PNAS, Lindenmayer et al. (1) describe the concept of regime shifts in forest landscapes that represent landscape traps in that "entire landscapes are shifted into a state in which major functional and ecological attributes are compromised [and] lead to feedback processes that either maintain an ecosystem in a compromised state or push it into a further regime shift in which an entirely new type of vegetation cover develops." Such state changes can result in dramatic reductions in functionality (e.g., carbon sequestration, water yields) and biodiversity, as with their primary example of mountain ash forests (*Eucalyptus regnans*) in southeastern Australia.

The degradation of seminatural landscapes at regional scales, whereby essential functional capabilities and biotic elements are permanently lost as a result of altered disturbance regimes, is a widespread phenomenon. An outstanding example of regional scale simplification of landscapes is the permanent replacement of diverse native steppe in North America's Great Basin with grasslands dominated by annuals, such as cheatgrass (*Bromus tectorum*), and an associated change in fire regime (2). A comparable forest example is the massive shift from open pine-dominated forests to dense fuel-loaded stands highly vulnerable to unnaturally intense and large wildfires in western North America as a result of fire suppression, logging, and grazing (3). Many more examples of "trapped" landscapes can be expected to occur as a result of climate change and human activities, as suggested for the Greater Yellowstone region (4).

Perceiving State Changes in Regional Forest Landscapes

Recognizing and appreciating the potential for ecological degradation and permanent change and their consequences in forested landscapes challenge societies. Generally, publics lack sophisticated ecological knowledge about forest ecosystems and tend to assume that forest is forest (i.e., if you have forest cover, the essential functions of forest are all present). Hence, societies are typically concerned with ensuring that logged forest sites are replanted (5) but are largely unaware of the immense differences between forest conditions in their ability to provide services, goods, and biodiversity.

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Forest landscapes dominated by long-lived tree species and characterized by infrequent but severe disturbances (e.g., stand-replacement fires at intervals of many decades to centuries) are particularly challenging in terms of societies being able to recognize the potential for and consequences of regime change. The mountain ash forests of southeastern Australia described by Lindenmayer (6) and Douglas fir (*Pseudotsuga menziesii*) of northwestern North America (7) exemplify such forests. These forests require several centuries following a stand-replacement disturbance to develop the structural complexity and biodiversity characteristic of older forests (6, 7). Furthermore, significant biological legacies (e.g., large live trees, snags, logs) from the predisturbance forest are typically incorporated into the postdisturbance ecosystem (6–9) following natural disturbances; these legacies provide for continuity in structure, function, and biodiversity between forest generations and create structural diversity in young naturally regenerated forests (8, 9).

Traditional practices in forests managed for wood production (clear-cutting, intensive site preparation, and planting) eliminate most such biological legacies and produce young forests with simple uniform structures and low diversity; furthermore, they are managed on short rotations that do not allow for redevelopment of structural complexity (9). Salvage logging of burned or windthrown forests not only eliminates critical structural legacies from predisturbance stands but can disrupt natural regenerative processes, as noted below (10, 11). This is profoundly the case with the diverse understories found in mountain ash forests, which include many highly fire-tolerant plants (e.g., tree ferns) that are eliminated by mechanical disturbances (6, 11).

The fact that regenerated Douglas fir and mountain ash forests are composed of the same species further obscures public perception of fundamental differences between young naturally regenerated stands with their structural legacies and the simplified managed stands developed following logging, including salvage. In the Douglas fir region, logged and salvaged areas are typically reforested by planting with native species, particularly Douglas fir. In mountain ash forests, tree regeneration is achieved by natural seeding following intense burning. Hence, because the young forests are dominated by the same tree species, whether created by man or nature, how could there be a problem?

The problem is, of course, that critical forest structures and entire stages in forest development can be effectively eliminated from regional landscapes subject to intense exploitation. For example, large old live and dead trees with hollows are absolutely critical to the survival of the large array of cavity-dwelling vertebrates found in mountain ash forests (1, 6). These structures are a vanishing resource in the Victorian mountain ash landscape and cannot be replaced in the trapped landscape that Lindenmayer et al. (1) describe. Similarly, old-growth forest stages are currently well below historic levels in the regional Douglas fir landscape (12), and diverse early successional (preforest) stages may also be of regional concern (13). In the Victorian landscape, there are

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risks that the dominant tree species itself, the structural keystone of the ecosystem, could undergo major decline with a regional state shift (1).

Policy and Management Responses to Pending State Shifts

Responsible societies need to analyze conditions and policies carefully when the potential for irreversible changes in regional landscapes is suspected. Unusual large-scale disturbances, such as occurred in the mountain ash forest region of southeast Australia, provide the opportunity and need for such a review. Existing policies need to be reassessed with regard to management goals and practices. If irreversible and socially undesirable long-term changes to regional landscapes and societies are potential consequences, major changes in those policies and practices may be appropriate.

Such reassessments and major policy changes on public and trust lands have occurred in major forest regions in the United States. Several reassessments were driven by concerns over endangered species, such as the northern spotted owl (14) in the Douglas fir region and the red-cockaded woodpecker (15) in the southeast, but others have resulted from concerns over forest structure-related changes in risks for catastrophic wildfire (3). Resulting changes in management priorities are sometimes profound and traumatic, as in the case of federal forest lands in the northwestern United States (14), where federal timber harvests were reduced by nearly 90%.

Lindenmayer et al. (1) raise credible concerns about degradation and possible extinction of the globally significant mountain ash forests, to which responsible institutions in the state of Victoria need to respond. Numerous steps could be taken to arrest and perhaps reverse current trends in this regional landscape (1), including conservation of remaining complex natural forests, reduction or elimination of timber harvesting in both green and burned forests, active restoration management, and increased efforts at forest protection from wildfire.

Retention of all remaining structurally, functionally, and compositionally rich mountain ash forests, which are now so rare in Victoria, is an obvious place to start. For example, only ~1.1% of the mountain ash forest remains in an old-growth condition. In addition to those older forests, the most extensive naturally regenerated forests that incorporate significant structural complexity, including large old trees with hollows, are forests that burned early in the 20th century (e.g., 1939). Logging in such forests would seem inappropriate.

Active efforts to restore conditions and structures that are declining are important to reverse current trends. Some of this is limited, of course, by the fact that development of structurally complex old-growth forests and even keystone structures, such as large cavity-rich trees, involves processes that require more than a century. However, allowing burned forests to recover naturally, without salvage logging, would be a positive contribution to redevelopment of both diverse understories and structural complexity. Current and midterm scarcity of hollow-bearing trees would remain a particular concern, given the dependence of over 40 species of vertebrates on such structures (1, 6). Creation of artificial cavities might be one interim approach, as was done in recovery efforts for the red-cockaded woodpecker (15).

Finally, increased efforts at forest protection should be considered. However, outside of the urban-wildland interface, such efforts should avoid attempts to modify structure and fuel loadings or to do prescribed burning in mountain ash forests themselves. As in the case of moist Douglas fir forests, this would result in ecosystems lacking many characteristics of the natural forest, including provision of habitat conditions needed by native biodiversity. In the case of the mountain ash forests, the forest protection effort could include prescribed burning in lower elevation forests, which are adapted to such treatments (1).

Conclusions

Lindenmayer et al. (1) identify a profoundly significant phenomenon to which societies and their resource management professionals need to be alert. Many more cases of potential landscape shifts to permanent alternative and, often, less desirable (e.g., in terms of ecological, economic, and cultural values) states can be expected in the future, as human populations and development expand and changes in climate and other environmental variables occur.

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