LANDSCAPE ECOLOGY

LITERATURE REVIEW

by

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Tobler's First Law of Geography:

Everything is related to everything else, but near things are more related than distant things. (Tobler 1969)

Forman and Godron's First Law of Landscape Ecology:

An action here and now produces an effect there and then. (Forman and Godron 1986)

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1. INTRODUCTION

Current timber management philosophies and techniques operate primarily at the forest stand level, rather than at the landscape level. As a result, given current logging methods, forest landscapes are often fragmented, critical landscape connections are broken, habitats are lost, and non-timber forest values such as wilderness, water, and balanced allocation of human uses are put at risk.

Wholistic forest use requires that forest use planners consider both the stand level ecology and the landscape ecology of a forest. Stand level ecology is familiar to most foresters and forest users as the combination of ecological factors (slope, aspect, moisture regime, soil type, elevation, climate, geology) which determines the biological community occupying any specific forest site, and the biological productivity of that site. We can, for example, readily detect differences between communities found on wet and dry forest sites, or on coastal and sub-alpine sites. The ecological impacts of disturbance are often easy to identify at the stand level.

However, forest stand ecosystems do not function in isolation. Every forest stand is connected to other forest stands by the movement or flow of water, energy, nutrients, plants, and animals across the landscape. Landscape ecology recognizes that the landscape is the framework within which stand level ecosystems function. Forest uses which damage the connections in a landscape will damage the functioning of the landscape and consequently impair the ecosystem functions of individual forest stands.

2. DEFINITIONS

Landscape ecology, according to Forman and Godron (1986) is the study of structure, function, and change in a heterogeneous land area which contains interacting ecosystems. Landscape ecology is concerned with the connections and interactions between forest stands across the landscape, and with the effects of both natural and human disturbances on the landscape. Because people have become one of the major biological forces on the planet, much of the activity in the field of landscape ecology focuses on interactions between people and the biosphere.

According to Richard Forman (1987), one of the founders of the discipline of landscape ecology, a landscape may be defined as:

> *. . . a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout. Central to this concept is the existence of a cluster of ecosystems found throughout the landscape. Thus in a boreal forest landscape the cluster might include spruce-fir (Picea-Abies) woods, stream corridor, bog, rock outcrop, and aspen (Populus) stand. The definition also indicates that the ecosystems in the cluster are interacting. Thus, animals, plants, water, mineral nutrients and energy are flowing from one ecosystem to another in the cluster. Each cluster is both a source and a sink for different moving objects.*

Landscape units are arranged in nested patterns. The stand, or patch, is the basic building block. Clusters of interacting stands form small watershed units, small watershed units can be combined into larger watershed units, and so on to reach an appropriate landscape level. "Landscape" is not a geographically precise unit of measurement. The size of any actual landscape is relative to the purposes and needs for which the principles of landscape ecology are being used. A single small watershed can be a landscape unit for some analytic purposes, while the entire B.C. Interior Plateau may be a suitable unit for other purposes. Determination of an ecologically significant and representative scale is one of the initial steps in a landscape analysis (Meetenmeyer and Box 1987).

Landscape ecology has been largely overlooked in forest planning in Canada because forest managers have, for the most part, a very limited understanding of landscape, landscape ecology, and the need for landscape planning and management. For example, the British Columbia Ministry of Forests Policy Manual (II-REC-003-1) defines Forest Landscape Management as:

> *The activity by which visual and aesthetic landscape values are identified, inventoried and analyzed, and are protected or enhanced, according to their relative importance, within integrated resource and management plans, and during resource development. (Emphasis added)*

Conventional Canadian forest management perceives a "landscape" to mean "pretty scenery" and uses the concept of "landscape planning" to refer to visual resources. The study of landscape ecology, on the other hand, is concerned with the ecological functioning of entire landscapes over both space and time.

The linkages implied by the interdependence of stand units are critical to the study of landscape ecology: actions and events at any level will have effects throughout the landscape, on both smaller and larger scales. Therefore, connections across the landscape must be respected to ensure the long-term viability of forests which make up the landscape. This is a much larger view than that previously considered necessary by many scientists, foresters, or planners. The new field of landscape ecology seeks to understand and protect the interconnection of the whole landscape during human use. Land use planning must proceed on all relevant scales simultaneously in order to be ecologically responsible.

3. HISTORY AND ORIGINS OF LANDSCAPE ECOLOGY

The scientific discipline of landscape ecology has been developed in this century, originating as an attempt to integrate the spatial concerns of geography with the time- scale concerns of ecology. The development of landscape ecology as a distinct discipline has occurred largely in Europe, where, after centuries of varied human activities in densely populated areas, the effects of human disturbance on ecological systems have become obvious. In Europe, landscape ecology is now viewed as the appropriate scientific basis for land use planning, conservation, resource use, and land reclamation. European land managers are aware of the need to examine the effects of their land use plans on entire ecosystems, and on the energy and nutrient flows through ecosystems. The discipline has expanded to include aspects of sociology, psychology, economics, and cultural studies.

In western North America, impacts on the landscape from industrial and agricultural activity are much more recent than in Europe. Land use planning and ecological impact assessments have tended to concentrate on the "patch"--the area of immediate impact--and have not usually considered the effects of human activities on the whole landscape (Franklin et al 1989). North American industrial culture is probably midway or more through the initial stage of disturbing the natural environment and modifying natural landscape ecology in ways that North Americans have learned to consider "good" or at least "acceptable." It may be that current forest practices can continue without obvious detrimental impacts for some length of time. Ecosystems are resilient, to a point, and thus far the forest ecosystem is perceived by many industrial and governmental foresters to be absorbing human impacts satisfactorily. However, as Perry (1988) points out, "The lack of a problem today does not guarantee that none will appear in the future. This is the time to ask where forest management is taking the forest landscape."

4. PRINCIPLES OF LANDSCAPE ECOLOGY (1): TIME AND SPACE

In terms of landscape ecology, forests are ecosystems connected in <u>time</u> and <u>space</u> across the landscape. The basic outlook of landscape ecology is both "long term" and "long distance." Landscape ecologists recognize that the total effect of any disturbance extends well beyond the season, year, or decade of the disturbance, and that a disturbance on any given site will be reflected in the dynamics of the entire landscape for the life of the ecosystem. The effects of any given disturbance may be ameliorated by time or distance, but they are not erased. These principles fit well with the concepts of "sustainable development." Indeed, landscape ecology may be the wholistic discipline which is required to save the planetary ecosystem (Forman 1987, Bormann 1987, Naveh and Lieberman 1984).

In the last several decades in North America, conflicts have increased between industrial timber interests and non-industrial forest uses (water production, spiritual values, wildlife). One reason for these conflicts is the limited scope of the human viewpoint compared to the vastness of a forest ecosystem over time and space. A forest is a continuum, operating on a cycle of 200 to 2000 years or more. Humans, on the other hand, are considered lucky if they live for 100 years. Governments are lucky if they last for four years. Corporations function on yearly and quarterly profit and loss statements.

In terms of space, the forest landscape functions on many levels--from millimeters of soil, patches of rocks, and stands of trees, to entire watersheds. A human is one-tenth the height of a short tree. More than 40 people would have to stand on each other's shoulders to reach the top of a moderately tall Sitka spruce tree, and the person at the top would only be able to see more tree tops--not a whole forest. Exploring, mapping, and understanding the ecological relationships in a moderate sized watershed (about 5000 hectares) would keep two people fully occupied for months.

Risser (1987) has summarized the interrelation of time and space expressed in landscape ecosystems as follows:

> *Even casual observation reveals that most landscapes are composed of various components. A typical rural landscape might include several agricultural croplands, pastures, woodlands, streams, farmsteads and roads. Thus, the landscape is heterogeneous, that is, consists of dissimilar or diverse components or elements. In addition to the rather obvious spatial heterogeneity, the landscape is temporally heterogeneous. Ecological processes operate at different time scales. For example, forest trees have life spans of decades, annual crops grow for less than a year, and individual stream insects may last only a few days. It is this mixture of processes consisting of different spatial and temporal scales, all operating as a system, that leads to ideas of landscape ecology.*

Forest landscapes are like very large waterbeds. If you push down here, the ripples will pop up again somewhere else. The questions are where, when, and how? People are challenged to understand and relate to the time and space dimensions of a forest landscape. Landscape ecology, as a discipline, provides a framework for this understanding. Our hope for survival and for the survival of the forest is inextricably linked with our ability to appreciate and accommodate the vast differences in scale between people and forest landscapes.

5. PRINCIPLES OF LANDSCAPE ECOLOGY (2): HETEROGENEITY

A second basic concept in landscape ecology is heterogeneity or the differences and diversity within a landscape. A natural forest landscape, for example, normally includes a variety of species of trees, shrubs, herbs, animals, and microorganisms, as well as a diversity of ecological stand types, varying according to moisture, slope, elevation, aspect, soil, and so forth. This kind of natural diversity is important to ensure that all the parts are available for forests to function. In contrast to clearcuts and tree plantations, "natural forests are naturally diverse."

Landscape heterogeneity, or diversity, is essential to forest landscapes. For example, landscape diversity is required for the persistence of animal species. Many animals require more than one ecosystem or patch type in order to survive and reproduce (Forman 1987). Diversity in ecosystems also contributes to redundancy: the property of ecosystems to perform important functions in more than one way, or to a capacity beyond current needs. For example, after a disturbance on a forest site, certain types of fungi (called mycorrhizae) essential to the nutrient needs of young conifers can persist in the decaying wood of fallen trees, or through association with surviving conifers, or by colonizing compatible successional plant species. They can also be reintroduced to a site through the activities of small fungus-eating mammals which spread fungal spores. These varied methods accomplish the same end: ensuring that young conifers have access to the nutrients they need in order to survive and prosper. This type of redundancy, maintained by landscape diversity, is a vital "fail safe" function which allows ecosystems to survive stress (Bormann 1987, Franklin et al 1989).

Like the landscape itself, the concept of diversity can work on many different scales. Each species, for example, operates on its own scale. What appears to be a uniform "patch" of habitat to a large species, such as bear or Douglas fir, may comprise a very diverse, patchy environment to a small species, such as a bark beetle or a mushroom (Risser 1987). Similarly, the size of a suitable patch or habitat also varies according to species. A patch which is satisfactorily large to a mouse, or even a group of mice, can be very small to a cougar. An inverse relationship usually exists between animal size and animal abundance in ecological communities. Larger animals require greater daily energy intakes to survive, and therefore require larger "patches" to obtain food (Harris 1984). Healthy forest landscapes must contain "patches" of habitat which are large enough and diverse enough to support all of the species which depend on the landscape.

Forest landscape diversity is believed to increase natural biological controls on herbivorous (plant-eating or "pest") insects (Schowalter 1990, Perry 1988), reduce the spread of insect epidemics such as the mountain pine beetle (McGregor et al 1987), and reduce the spread of forest fire (Forman 1987). Forest diversity at the small interior stand level is believed to ensure biological continuity within forests by sustaining a matrix of suitable habitats for diverse microorganisms, fungi, and bacteria. This diversity helps these organisms survive through catastrophic disturbances and over time (Perry et al 1989, Amaranthus et al 1989.)

Natural disturbances play a significant role in maintaining diversity. For example, in predominantly old growth forest landscapes, diversity is maintained by small disturbances, such as single trees dying and falling to the forest floor. Such small disturbances create a healthy mixture of old and young trees, closed canopy areas and tree fall gaps (openings), streamside (riparian zones) and upland forests. Diversity is maintained in natural forest ecosystems even following a catastrophic disturbance such as a major fire or hurricane force windstorm. A significant number of healthy forest trees are nearly always left alive following such events, while the "bodies" (snags and fallen trees) of the former forest contributes to the development of the new forest by creating important plant and animal habitat, developing the forest soil, and providing long-term storage sites for nutrients and moisture. In contrast, clearcut logging removes the tree bodies, leaves few healthy trees standing, damages soil structures, disrupts movement of nutrients and water, and is often followed by tree plantations which lack the natural diversity required to sustain a forest.

Heterogeneity is, within limits, a positive feature in most landscapes. Diverse habitat "patches" provide diverse resources, and tend to stabilize landscape processes. Extreme diversity can result in negative effects, however, if habitat areas become too small to be effective. As with so many aspects of forest function, a balance is required between diversity and sameness, between heterogeneity and homogeneity.

6. PRINCIPLES OF LANDSCAPE ECOLOGY (3): CONNECTIVITY

A third important concept of landscape ecology is <u>connectivity</u> within the landscape. Diverse "patches" or habitats for various plants, animals, and microorganisms are required to maintain an ecosystem. However, these patches are valuable only if they are connected to one another in some way. Connectivity within a forest landscape is provided by movement corridors, which are frequently riparian zones (streams, rivers, lakes, wetlands). Riparian zones serve as movement corridors not only for many species of plants and animals but also for nutrients and energy. Thus, according to Forman (1987), "an ecosystem not only provides objects that affect neighboring ecosystems, but in a real sense is molded and controlled by the accumulation of objects arriving from the surroundings." (The same principle of true for energy as well as objects.)

Riparian zones are arranged in a branching network which extends throughout a forest landscape and contains varied but repeating patterns of plant and animal habitat. Because of their wet and diverse nature, riparian zones frequently survive large natural disasters such as fire and windstorms. As movement corridors, riparian zones provide migration routes for large and small animals. For example, large ungulates such as moose and elk use these corridors to migrate between seasonal ranges (Harris 1984, Thomas et al 1979). Maintaining these migration corridors may be necessary to prevent large scale extinction (Hunter et al 1988). Mammals and birds move many plant seeds around the forest landscape, and some seeds are also carried by water. Thus, plant dispersal routes also tend to follow riparian corridors.

Riparian zones are connected from valley to valley by treed forest corridors which run up and down forest slopes. These forest (cross-valley) corridors provide routes for many animals and plants to move back and forth between riparian zones and other types of habitat patches.

Groundwater is another type of landscape connector which transports nutrients and energy both within forest patches and throughout the forest landscape. These ecosystem flows are concentrated and cycled in riparian zones, where they nourish the most diverse species populations found in most forest landscapes. Eventually, nutrients and energy are released from the riparian community into the aquatic ecosystem, which then carries minerals and nutrients to distant parts of the landscape.

The landscape ecology principles of time and space, discussed earlier, are closely related to the principle of connectivity. Riparian zones, up-and-down valley corridors, and groundwater are major examples of <u>connectivity in space</u>. Blocked energy and nutrient flows can lead to ecosystem impoverishment. An example of this is the effect of the

W.A.C. Bennett hydroelectric dam on the Peace River. The dam prevents nutrients and silt from reaching the formerly productive Peace-Athabasca delta. This area has begun to lose specific habitat types which previously helped support bison, and likely other species as well (Stott 1990).

Natural forest stages are an example of connectivity in time. From the shrub/herb phase through the young and mature forest phases to old growth, each stage has an important role in maintaining a healthy and diverse forest landscape. For example, during the young and mature phases, trees are capturing wood fiber at the most rapid rates, withdrawing more nitrogen from the soil then they are replacing. Nitrogen for future forests is replenished during the shrub/herb and old growth phases. Old growth also provides vital habitat for a wide spectrum of animals and predatory insects.

In an interlocking system such as a forest, impacts on any one part of the landscape are not isolated, but will affect all parts in some degree at some point in time. Impacts which reduce or break natural landscape connectors will have direct impacts on animal, plant, energy, nutrient, and water movements (Forman 1987). Also, because of landscape connectivity, events or conditions in one part of a landscape will affect the ecology of areas well beyond the physical boundary and time of those events or conditions. Water pollution and air pollution are the most familiar examples of this principle. The effects of most pollution extend well beyond the point source of the pollutant, both physically and ecologically (Bormann 1987).

Clearly, the principles of time and space, heterogeneity, and connectivity--the three major concepts of landscape ecology discussed so far--interact in any given landscape, determining, at least in part, the integrity of the landscape and the health of the species which live there. As F. B. Golley (1989), editor of the journal Landscape Ecology, explains:

> *. . . it is obvious that species occupy landscapes and that the pattern of the landscape supports or inhibits the survival and well being of species. For example, the quality and distribution of resources influence species distribution and abundance. But the quality of resource is not sufficient to understand the distribution and abundance of the biota. The position of resources in space and time, spatial relationship between resources, their shape and pattern all may influence significantly the well being of species.*

7. THE IMPORTANCE OF RIPARIAN ZONES

We have mentioned riparian zones in the previous sections several times. Riparian zones, which are also called riparian areas or riparian ecosystems, are crucial elements of the forest landscape that deserve special attention in any discussion of landscape ecology. Gregory and Ashkenas (1990) define the riparian area as:

> *The aquatic ecosystem and the portions of the terrestrial ecosystem that directly affect or are affected by the aquatic environment. This includes*

> *streams, rivers, and lakes and their adjacent side channels, floodplains and wetlands. The riparian area includes portions of hillslopes that serve as streamside habitat for wildlife.*

Riparian zones are the wet or moist areas adjacent to a water course. The riparian zone includes the lower valley ecosystem type in which the plant community shows the effects of increased water supply. As Thomas et al (1979) explain, "Riparian zones can be identified by the presence of vegetation which requires free or unbound water, or conditions that are more moist than normal."

Scientific literature emphasizes the significance of riparian zones and the importance of protecting these zones in order to protect stand and landscape ecology. Riparian ecosystems affect water quality, fisheries, wildlife, and timber and recreation resources in a landscape. Intact riparian zones form buffers which protect lakes and rivers from natural and human caused disturbances. Functioning riparian ecosystems moderate water temperature, control sedimentation, and provide large organic debris (fallen trees in water courses) which control stream structure. The habitat diversity, nutrient concentration, and food sources in a riparian ecosystem support extremely productive wildlife and fish habitat.

Riparian zones are often considered prime timber producing land. However, investigators have found that these sites are very sensitive to erosion and degradation, difficult to restock, and have significantly lower stand densities than upland forests (Hammond 1985, Gregory and Ashkenas 1990). Thus, both current and sustainable timber values of riparian zones are likely overrated.

Riparian zones are very often a major focus for local recreation industries (e.g. river travel, fishing, swimming, hiking trails). The graph below (derived from Gregory and Ashkenas 1990) shows the relative importance of riparian zones to various resource uses in the Willamette National Forest compared to the proportionate area of riparian zones in the forest. The bottom bar shows that, in terms of area, riparian zones comprise about 5% of the total forest area. In terms of use, however, riparian zones represent well over 50% of fisheries, bird species feeding, mammal primary habitat, plant species, and recreation, but less than 5% of potential timber yield.

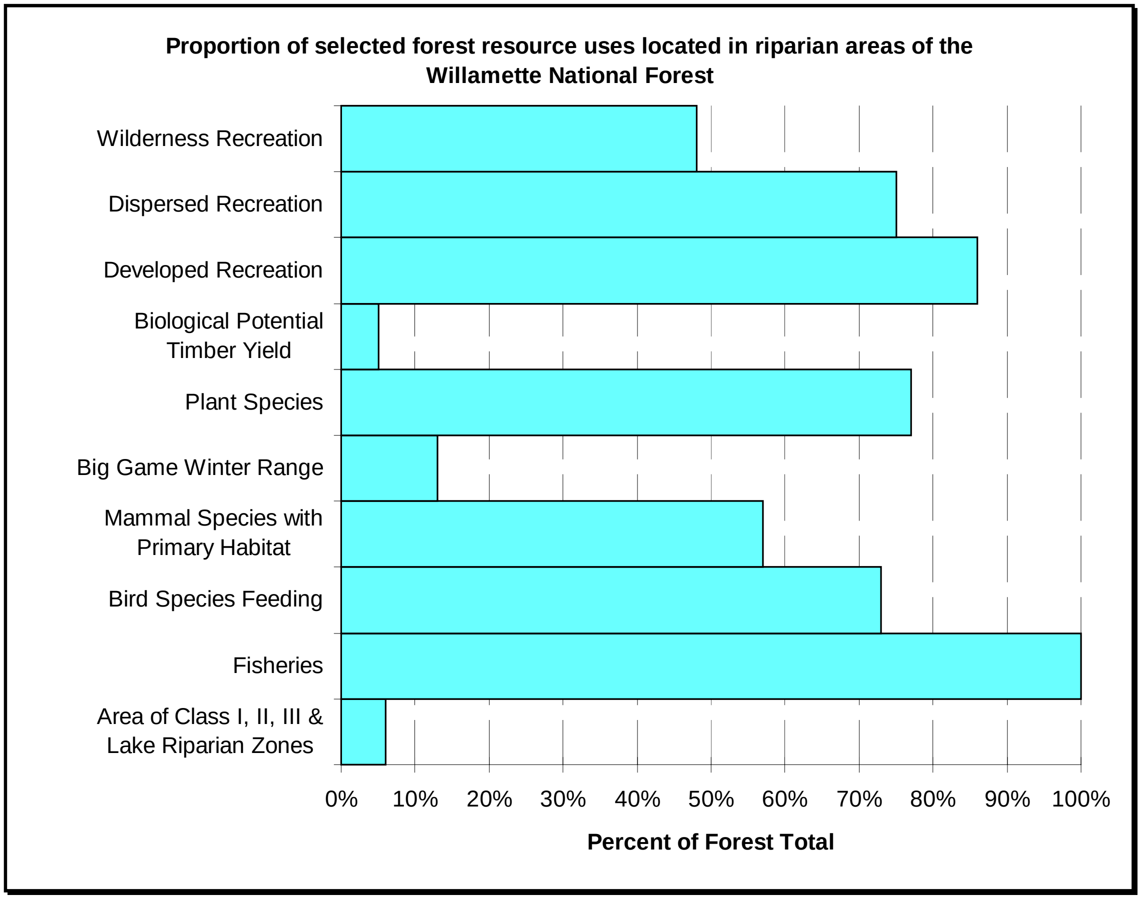

Figure 1: Proportion of selected forest resource uses located in riparian areas of the Willamette National Forest

According to Gregory and Ashkenas (1990),

> *Continuous corridors of riparian forests also provide essential connections between different management areas distributed throughout the Willamette National Forest. For example, the array of interior old growth forests can be continuously linked along the mature to old growth forests within riparian management zones. These riparian zones can also serve as corridors for the dispersal of plants and animals between harvested watersheds, roadless areas, wilderness areas, special habitat management areas, and designated recreational lands. No other landscape feature . . . offers the natural continuity of riparian areas.*

It is Silva's belief that riparian zones throughout the forest landscape must be fully protected from any consumptive resource use. This principle is receiving some recognition in British Columbia. In their draft report for the Golden Timber Supply Area (T.S.A.) planning process, Price and Hamilton (1990) state:

> *Riparian zones are extremely important habitat unique to both fishery and wildlife resources. As such they must be managed so that the ecological*

> *functions and integrity of the habitat are maintained over time. It is recommended that . . . an EW1 classification be assigned to identified riparian habitats within the Golden T.S.A. Any (logging) activities in riparian zones should meet fish and wildlife habitat management objectives.*

According to B.C. Ministry of Forests classifications (1984) the code "EW1" above indicates that the area "...is highly sensitive and/or highly valuable for other resources and is <u>not normally available</u> for sustained timber production.

The area requiring protection includes the streamside vegetation and the forested valley bottom. Lower slopes adjacent to the creek (the riparian zone of influence) also need protection to buffer the riparian zone and to provide a portion of the travel corridor for animals (Mahlein and Hemstrom 1988). Gregory and Ashkenas stress that entire floodplains must be protected.

> *Maintenance of floodplain functions is an extremely important and frequently overlooked component of riparian management. Floodplains are formed by deposits of sediment during extremely high flood events. Riparian vegetation protects these areas, and removal of this vegetation through harvest or road construction makes them vulnerable to massive erosion during subsequent floods. The riparian management zone should include the entire floodplain. Failure to do so will seriously jeopardize riparian management objectives during major floods.*

Riparian zone forests protect the ecology of water courses, and protect other parts of the forest landscape by providing connecting corridors. These forests are a critical part of ecosystem nutrient and energy flows. Riparian zone forests are both sources and storage sites for nutrients needed by the aquatic and terrestrial ecosystems. The roots of riparian vegetation reach into the water table that is often inaccessible to upslope vegetation.

The riparian forest filters and assimilates dissolved nutrients from groundwater before it reaches the stream, and returns the nutrients to the ecosystem in a usable form--as woody or green biomass (Risser 1987, Gregory and Ashkenas 1990). The riparian zone forest ecosystem returns energy and the diverted nutrients to the aquatic ecosystem in the form of forest litter and large organic debris (large fallen trees in water). The riparian forest converts dissolved groundwater nutrients, which would be quickly swept away by the flowing stream, to a structured, retainable form. Removing riparian forest can disrupt the nutrient cycle of aquatic ecosystems (Franklin et al 1981). This nutrient input, coupled with abundant water supplies and varied habitat, supports the most diverse and biologically active communities in the forest landscape.

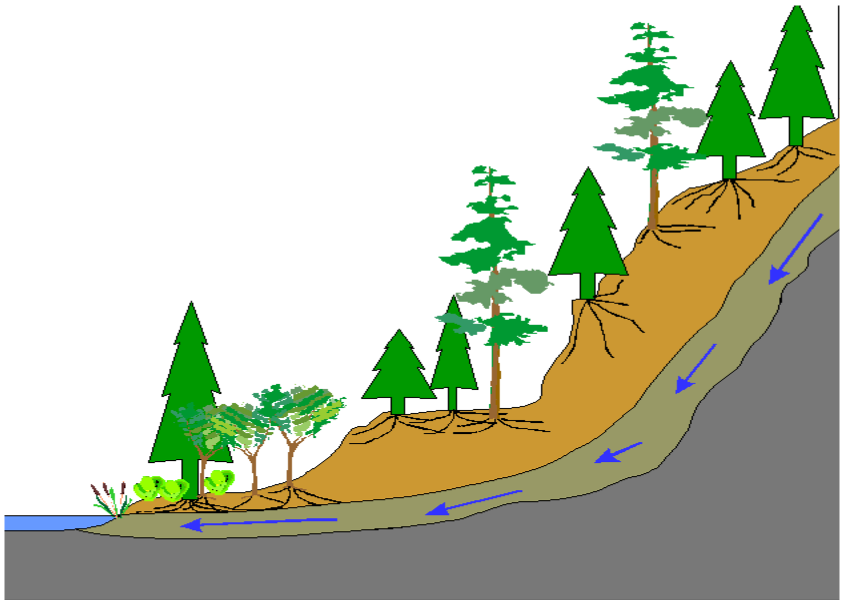

Figure 2: Movement of water and dissolved nutrients through the subrooting zone in a hillside forest and subsequent movement through the rooting zone of a riparian area.
(After Gregory and Ashkenas 1990)

Some of the most fragile forest ecosystem types are found in the riparian zones. The presence of moving water, which has great erosive potential, contributes to this fragile nature. The massive spreading root systems of old growth trees help to stabilize riparian zones by providing structural support for the creek banks. Old growth forests also provide large organic debris (i.e. fallen trees in water) to the creek ecosystem, which controls erosion in the creek bed. The large fallen trees break the stream into a series of pools and riffles, dispersing the erosive force of the running water. A constant source of large fallen trees must be maintained in the forests in and adjacent to riparian zones. Without large fallen trees water courses tend to straighten, increasing in velocity. This results in rapid increases in erosion, and in environmental degradation. Large organic debris also provides habitat for aquatic life forms (Franklin et al 1981). Clearcutting degrades and damages the riparian ecosystem for many years. Even after trees are reestablished, second growth forests will not fulfill many ecological functions as effectively as old growth forests.

8. APPLICATIONS OF LANDSCAPE ECOLOGY TO FOREST MANAGEMENT

Researchers in the U.S. (Franklin et al 1989, Perry 1988, Harris 1984) and Canada (Lertzman 1990, Dunster 1990, Pojar 1980) have expressed concern regarding the effects of conventional forestry practices on forest landscapes. Conventional timber management fragments the forest in space. Logging cut blocks divide the forest and break natural connectors in the forest landscape. Conventional timber management also fragments the natural forest in time. Eliminating old growth and greatly shortening the shrub/herb phase reduce the natural diversity of forests, thereby reducing the checks and balances of natural systems. (Fragmentation and diversity are discussed in more detail in the following pages.) These authors call for the application of basic principles of landscape ecology to forest management. We believe that landscape ecology should guide human use of forests before damage to forest ecology becomes even more significant and potentially irreversible. As Golley (1989) states:

> *. . . there is a connection between the study and management of landscapes and the conservation of biological species and their habitats. . . . Whether we think of the landscape as patches, connections and matrix or as sources and sinks, these patterns are of fundamental importance in designing and managing the environment for the conservation of biota. Conservation is no longer an idea for those who think well ahead of the rest of us. . . . It is now clearly a matter of survival of human kind.*

From Silva's research in the literature on landscape ecology in forested ecosystems, we have identified four landscape elements which are necessary for healthy functioning ecosystems:

- Landscape diversity (see section 8-1)
- Landscape connectivity (see section 8-2)
- Realistic patch sizes (see section 8-3)
- Realistic time spans for ecological functions (see section 8-4)

8.1 The Need for Diversity

Forest homogenization, or simplification, is a consequence of conventional management of forests for timber. Timber managers plan to replace the naturally diverse forest with a matrix largely consisting of one, two, or three species in even aged tree plantations. These plantations are generally developed from genetically limited stock, and may soon come from genetically designed stock (Doyle 1989). Replanted forests are scheduled to be logged at a young age, not more than 100 or 120 years, and often much younger. Pesticides are frequently used to control "pest" insect and competing vegetation, further homogenizing the forest. Coarse woody debris (fallen trees on the forest floor), large organic debris (fallen trees in streams and other bodies of water), and snags (standing dead trees) are generally removed, thus reducing habitat diversity and future soil-building capacity.

Homogenization has profound effects at the landscape ecology level. As we have said before, a natural forest landscape contains a wide variety of forest types. The vegetation in individual forest stands may range from seedlings to trees 1000 years in age and more. A landscape may contain a variety of ages, from young to middle age stands to mature and old growth stands. These mixtures of stand ages, which also include various ecosystem types, are both unique and essential for the health of various landscapes, in the same way that a mixture of ages are essential to any living community, including human communities. Maintaining this diversity is required to sustain the landscape and the individual stands which make up the landscape.

Conventional timber management practices result in forest simplification, erasing the old growth forest phase from the managed forest landscape. Because of its long life span, old growth has frequently been the most common forest type within a forest landscape. Therefore, the loss of this forest type will significantly alter the character of the forest landscape and the habitats it can provide. The young, early successional, deciduous shrub/herb forest will be reduced to a period of about 10 years (in contrast to 30+ years in a natural forest) in duration as homogenization continues. This will also greatly reduce the diversity of forest types and therefore habitat types across the landscape. Since the old growth and shrub/herb stages are the only stages which provide a net input of nitrogen, homogenization will deplete forests of this vital nutrient. Thus, the number of types of "building blocks" which make up the forest landscape will be reduced.

The <u>arrangement</u> of these "building blocks" will also be altered in the conventional homogenized managed forest. Conventional logging imposes a structured, organized set of disturbances on the landscape. The effects of such a pattern may not be dramatic after just one cutting cycle. However, the next logging pass will probably double the area cut, and is likely to remove the last natural forests in many areas of British Columbia. In contrast, natural disturbances are patchy and random. A lightning strike can start a fire anywhere in the landscape, and the progress of the fire will depend entirely on the characteristics of the landscape, climatic conditions, and vegetation conditions. Natural fires often burn in a patchy, hopscotch manner-- never in regular sets of rectangles, like those created by logging and roads. Natural fires also seldom kill all of the forest within their perimeter (Schowalter 1990).

By the end of the second or third logging pass, conventional timber management has converted the forest landscape from a random mixture of diverse naturally regenerated forests of varying ages to a series of two or three classes of even aged tree plantations, with some natural stands. The number of types of building blocks has been decreased. The variability in the pattern in which building blocks can be arranged, now and in the foreseeable future, has also been reduced. This is a profound, fundamental change in the landscape ecology. The checks and balances and natural functions of a diverse forest landscape ecology has been fundamentally altered. What does this mean?

Homogenization reduces the redundancies common and important in forest ecosystems. As mentioned earlier, redundancy is a kind of ecological fail-safe or "fall back position." If something changes or "goes wrong," the ecosystem can respond quickly and adequately to the new condition. Ecosystems which lack diversity have no fall back positions, no insurance. A simplified forest has a very limited range of potential response to change or stress. For example, if climatic conditions change, or if the forest is attacked by insects or disease, a forest with little diversity may perish. As Franklin and Maser (1988) say, "The biological advantage of diversified forest management is that forest health is maintained indefinitely." In a discussion of air pollution and forests, Bormann (1987) observed:

> *To accommodate future stress, ecosystems will need all the redundancy they can muster to maintain even a modified equilibrium. Ecosystem redundancy should be a reserve to buffer the stresses which we can't control. In a few decades, we may have to accept a lowered species diversity and less biotic regulation of energy flow and biogeochemical cycles. Under these circumstances, it seems injudicious, at this time, to sacrifice ecosystem redundancy by weak air quality laws and programs that are designed to achieve short term financial and economic objectives.*

Although Bormann was addressing the specific topic of landscape ecology and air pollution, we believe that his statement is not limited to that subject.

The total effects of this modification to the landscape are largely unknown. According to Burgess and Scharpe (1981), "A vast experiment is underway. Its unplanned and unwitting design is changing the spatial and temporal structure of terrestrial ecosystems." In a discussion of "pest" insects, Perry (1988) observed:

> *There is little evidence that landscape patterns, either natural or resulting from logging, have increased pest problems in the Northwest. This statement must be taken in context, however, because no one has systematically looked for such a connection, and unrecognized problems might exist. Moreover, lack of a problem today does not guarantee that none will appear in the future. This is the time to ask where management is taking the forested landscape, and how susceptible this future forest might be to pests. Once the future pattern is established, it will be too late.*

Numerous authors, including Franklin et al (1989), Amaranthus et al (1989), Spies and Franklin (1988), Perry et al (1989), Marcot et al (1989), Harris (1984), Wilcove (1988), Maser (1988), and Schowalter (1989) agree with Bormann and Perry on this central point: discarding the natural diversity of the forest landscape is not wise. The risks which individual authors have noted include:

- Increased likelihood of widespread insect or disease epidemics, which will not be stopped by natural barriers of immune habitat types.
- Increased risk of rapid fire spread through the extensive, closely packed crowns of young, brush free plantations. Again, natural diversity would be likely to provide some barriers to fire spread (brush fields, moist old growth forests) in many situations. These will be absent from a landscape of forest plantations.
- Loss of habitat for varied wildlife and bird species, which have value in their own right and which have ecological value, although poorly understood, necessary to sustain forests used for timber.
- Lack of viable fall back positions in the event of significant climatic change, such as the greenhouse effect or increased atmospheric pollution.
- Loss of below ground soil diversity and soil nutrient depletion.

As with forest diversity at the stand level, forest diversity at the landscape level is recognized by researchers and ecologists as a critical factor in managing forests on a sustainable basis. German foresters now attribute forest decline throughout Europe to loss of landscape and stand diversity brought about by "clearcut-plantation" approach to forest management (Plochmann 1990). Franklin et al (1989) summarize the impact of forest simplification:

> *In general, we have tended to forget that what is good for wood production is not necessarily good for other organisms or processes in a forest ecosystem. Fully stocked young forests, the forester's ideal, are the most simplified stage of forest development in terms of structure and function, and the most impoverished in terms of biological diversity. Essentially all of the site resources are co-opted by rapidly growing young trees. . . .*
>
> *Simplification--genetic, structural, landscape and temporal--reduces ecosystem resilience, eliminating redundancies that could be important in saving the ecosystem, and us. Because the ability of an ecosystem to tolerate or absorb new kinds of stresses or changes is clearly of increasing consequence, the key to retaining resilience must be in maintaining ecological complexity or diversity.*

8.2 The Need for Connectivity

Forest fragmentation is another of the major detrimental effects of conventional timber management practices. Fragmentation occurs when a large expanse of habitat is transformed into a number of smaller habitats of smaller total area, isolated from each other by areas of unlike habitat (Wilcove 1988). Forest fragmentation means dividing the whole forest into isolated islands between dispersed clearcuts, logging roads, highways, hydro lines, hydro reservoirs, and other human-created disturbance.

Forest fragmentation implies a loss of connectivity as patches of forest land become isolated and the vital flow of nutrients, plants and animals through the ecosystem is interrupted in many ways. Roads and clearcuts can form effective barriers to the general movement of even large animal species, especially in winter (Thompson and Vukelich 1981, McNicol and Gilbert 1980, Hanley et al 1989). Human activities which either block or eradicate a specific movement corridor can have severe negative impacts on animal populations, which may depend on the corridor to reach required seasonal ranges. Even removing a small patch of significant habitat can close a corridor (Forman 1987). Human disturbances may also interact with natural landscape boundaries (wide rivers, heights of land) to amplify the effects of fragmentation. Fragmentation is especially serious where important corridors, such as riparian zones, which connect different areas of the landscape, are cut.

Logging can also reduce connectivity on smaller scales. Haul roads and skid roads can cut into forest slopes, intercepting and diverting ground water flows. Soil water naturally carries water and nutrients downslope in a dispersed pattern through the soil of a forest ecosystem. Intercepting and concentrating this dispersed pattern may reduce water and nutrient availability for lower slope and riparian sites.

The combination of breaking the forest into smaller patches or islands, and the loss of connectivity contribute to the final effect of forest fragmentation: local species extinction and loss of biotic balance. The large clearcut blocks used in conventional timber extraction limit animal mobility and create small "island" populations (Harris 1984). The ability of isolated groups of animals to respond to crises(e.g. overpopulation, food shortage, climatic aberration) by moving to a more favorable spot is limited. Loss of connectivity may also hinder breeding success, especially for the more thinly distributed carnivores. Male and female animals may simply be unable to locate or reach each other. The protective natural diversity and redundancy of an landscape is inoperative if the connectivity of the landscape is broken.

For any one or a combination of these reasons, local animal populations may become extinct. Local extinction is most likely to affect animals who have naturally small populations, such as the carnivores and insectivores at the top of the food chain. These animals require large, connected home ranges to obtain sufficient food and shelter for survival (Harris 1984). Once these animals are locally extinct, the herbivore populations they formerly controlled can expand to the biological limits of the food supply. Herbivore populations constrained only by food supply are notoriously destructive (e.g. rabbits in Australia, insect epidemics worldwide). Thus, lack of biotic regulation caused by fragmentation can lead to significant ecosystem damage.

Forest fragmentation also increases the susceptibility of uncut forest areas to progressive failure from windthrow. Forest openings allow wind to exert force on the entire crown of "edge" trees, instead of being restricted to the upper crown. This increases the overall stress on trees, and often leads to increased windthrow along cut block boundaries. Although this effect works at the individual tree or edge level, entire landscapes may be especially vulnerable to catastrophic windthrow once 30% to 40% of the landscape has been cut over (Franklin and Forman 1987, Franklin et al 1986).

In summary, forest fragmentation is a direct threat to the system of natural landscape ecology which has sustained forests for millennia. Fragmentation disrupts the natural flows of animals, plants and energy throughout the landscape, reduces habitat areas below optimal sizes, and can contribute to local species extinctions and loss of biotic balance in the ecosystem. Problems caused by forest fragmentation can be avoided or greatly reduced by forest use planning which takes into account the principles of landscape ecology.

8.3 The Need for Realistic Patch Sizes

The "patch" in landscape ecology is a unit of one ecosystem type within the landscape. As with the definition of landscape, the size of a "patch" varies with the perspective of the viewer. As mentioned earlier, larger animals require larger home ranges, so that a patch which is sufficiently large for a mouse is very small for a cougar.

Ecologically functional landscapes must contain patches of habitat which are large enough to support all of the animal species which depend on the landscape.

8.4 The Need for Realistic Time Spans

Ecosystems and ecological processes within natural landscapes operate on varied time scales (Risser 1987). This variety is technically referred to as "temporal heterogeneity," or simply, diversity through time.

Compared to ecological systems, humans are a short-lived species. Yet we are disturbing ecosystems around the world with minimal regard for the long-term effects of our actions. For example, in forest ecosystems the greatest inputs of nitrogen, the most critical element to forest growth on most sites, occur in the early successional "brush" phase after a disturbance and in the old growth forest phase. However, conventional timber management aims, deliberately, to shorten or eliminate both of these ecological phases (Franklin et al 1989). The net effects of this approach may well be catastrophic. However, the effects are sufficiently removed from the present in human time frames to be regarded as abstract topics. Similar problems with human versus ecological time frames have been noted by Bormann (1987) with regard to air pollution, by Schowalter(1990) with regard to insects, by Amaranthus et al (1989) with regard to the soil community, by Wilcove (1988) with regard to wildlife species, and by Forman (1987) with regard to general forest land use.

Maintaining functional ecological landscapes requires that the time frames of analyses and decision making reflect the time frames inherent in the ecosystem. In general, timeframes for timber management decisions need to be significantly lengthened to ensure the long term survival of forests.

9. CONCLUSION

Ecologically responsible forest use seeks to minimize the negative impacts of human activity and use on the entire forest by recognizing the principles of landscape ecology, and designing activities to minimize adverse effects at the landscape level. In this respect, the broad scope encompassed by landscape ecology offers a wholistic framework impossible to achieve through other, more narrowly defined disciplines. As Naveh and Lieberman (1984) explain:

> *We no longer have to divide reality into watertight compartments or mere superimposed stages corresponding to the apparent boundaries of our scientific disciplines. On the contrary, we are compelled to look for interactions and common mechanisms. . . .*
>
> *Landscape ecology can serve as an urgently needed counterbalance to . . . presenting man as detached from nature and as the almighty manipulator of life who knows more and more about that part of nature which can be taken*

> *apart, isolated, and analyzed, but less and less about real nature and its life-supporting systems in action.*
>
> *[Landscape ecology] can fulfill the much-needed function of an antidote to the hubris created by the illusion of scientific and technological supremacy of man and its disastrous results.*

Human use of forests must ensure that the functional framework of the natural landscape ecology remains intact. This means that forest use plans, especially timber use plans, must maintain the natural connections between and the distribution of resource patches within a landscape. The full natural range of habitat types must be present in sufficient quantities and as part of the connected network.

These requirements are necessary to protect the wildlife population in any area, to maintain long-term timber productivity at the stand level, and, most importantly, to maintain the ecological health of the whole forest.

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