SUSTAINABLE DEVELOPMENT IN FORESTRY: AN ECOLOGICAL PERSPECTIVE

by

Bryant N. Richards

MAINTENANCE OF ESSENTIAL ECOLOGICAL PROCESSES

Let me return to my opening theme, that it is through a study of the smallest organisms that we learn most about nature. It is the activities of microorganisms, invisible to the naked eye, that dominate the processes which control the productivity and stability of forest ecosystems. Most of these microbes are found in the soil, and a single handful of soil contains more bacteria and fungi than there are people on the surface of the planet. Because they are so small, these microbes have very large surface-to-volume ratios which permit rapid exchange of materials between them and the environment. This is one reason why they are such potent agents of geochemical change.

The geochemical significance of microorganisms is reflected in their role as mediators of essential ecological processes. Two such processes, inextricably intertwined, are of major concern, namely energy flow and nutrient cycling. As R E Rickleffs and colleagues pointed out in 1984, the conservation of such processes is essential to the preservation of species and their habitats. If these processes are disrupted by logging to the extent that the stability of forest ecosystems is threatened, then sustained yield timber management would be impossible.

In a natural forest ecosystem, much of the solar energy captured each year by photosynthesis finds its way into the soil in the form of leaf litter and other organic residues. The decomposition of these materials is brought about by a sequence of biological processes involving soil microbes and invertebrate animals, releasing mineral nutrients for re-use by the producer component of the system, namely the trees and other green plants. In a managed forest, the same processes operate, but some of the primary production is harvested as logs. In order to maximise this harvest, the forest manager maintains the ecosystem in a successional state, thereby diverting energy and nutrients from the "producer-decomposer pathway and exporting them from the site. A knowledge of how such alterations from the norm, as represented by the virgin forest, affect decomposition processes in the soil is vital to a consideration of sustainable development. Such knowledge should help us to predict the ecological consequences of disturbing natural ecosystems, and the environmental impact of utilization and management practices.

The Cycling of Nutrients

Every organism - plant, animal or microbe - must have a supply of nutrients, that is the chemical elements needed for its maintenance and growth. These nutrients, except for nitrogen in the case of nitrogen-fixing plants, derive from the soil. In agricultural cropping systems, the nutrients removed from the soil each year, when the crop is harvested, are frequently replaced by inorganic fertilizers or organic manures. In forestry, harvesting re-occurs at much less frequent intervals, and the nutrients lost from the site must (in the absence of fertilizing) be replenished by the process of nutrient cycling.

There are three interconnected mineral flow pathways which together constitute the overall nutrient cycling system in terrestrial communities (Switzer and Nelson 1972). These are designated the geochemical cycle which links the external environment to the ecosystem by processes such as precipitation, rock weathering, leaching and groundwater flow; the biogeochemical cycle which concerns the circulation of nutrients within the soil-vegetation subsystem; and the biochemical cycle involving the redistribution of nutrients within the plant biomass.

In the biochemical cycle, nutrients are withdrawn from leaves during senescence, or from sapwood during its transition to heartwood, and translocated to regions of high nutrient demand elsewhere in the plant. Not all of the decline in leaf nutrient content can be ascribed to this phenomenon however; some of it results from leaching of the canopy by percolating rain ('throughfall') and as such it becomes part of the biogeochemical cycle. Redistribution of nutrients through the biochemical cycle is a feature of many species, and can be seen as a mechanism for internal conservation of essential elements, such as nitrogen and phosphorus, which are relatively mobile within plant tissues; immobile elements such as calcium are but little affected.

The logical starting point in a discussion of biogeochemical cycling is the root-soil interface. Nutrient uptake by the root is governed by ion concentrations at the root surface and the rate of replenishment of the soil solution from organic and inorganic solid phase reserves. The nature of the rootsystem is an important factor in biogeochemical cycling. Most absorbing roots are found close to the soil surface, and plants are able to compensate for inadequate nutrient supply by increasing the root surface sorbtion area relative to shoot demand. One way in which they can do this is to enter into symbiotic association with certain soil fungi, forming highly efficient absorbing organs known as mycorrhizas. These long-lived structures can tap a larger volume of soil than ephemeral, non-mycorrhizal root tips, which gives them a marked advantage In the absorption of relatively immobile nutrients such as phosphate. Their longevity and great efficiency enables mycorrhizas to speed the passage of essential elements through the biogeochemical cycle, and minimise the leaching of nutrients from the ecosystem.

Leaching is one of the two major mechanisms whereby nutrients involved in biogeochemical cycling are returned to the geochemical cycle. The other is by the diffusion of gases. Considerable quantities of nitrogen, for example, are volatilized by fire, which is a normal environmental variable in most forest ecosystems. More usually however, the nitrogen contained in organisms eventually escapes to the atmosphere by a microbiological process known as denitrification; it results in the production of nitrous oxide and molecular nitrogen which diffuse out of the soil into the air.

Returning to the question of leaching losses, these occur whenever sufficient rain falls to saturate the whole soil profile: the nutrients lost are carried away through groundwater and enter streams discharging from the catchment. Despite these inevitable losses, mature forest ecosystems have characteristics which buffer them against leaching and so help to retain their nutrient capital. These buffer mechanisms consist of a series of sinks or filters between input at canopy level and the point of loss located approximately at the lowest limit of root penetration.

Geochemical inputs to the ecosystem derive either from the atmosphere or from soil parent material. Atmospheric inputs are many and varied, and include dry sedimentation or impaction of aerosols, and their scrubbing from the air by rain and snow. Even more important for most ecosystems is the fixation of gases especially by biological mechanisms. The classical example of biological nitrogen fixation is the legume-rhizobium symbiosis, which is the basis of stable agricultural ecosystems in many parts of the world. From a global viewpoint however, legumes probably provide no more than 20 per cent of the nitrogen fixed each year, though this may be an underestimate when one considers the large area of the earth's surface which is covered with woody perennial legumes. Another, and perhaps more important form of biological nitrogen fixation in forests, the so-called actinorrhizal symbiosis of non-leguminous angiosperms. Certain free-living bacteria can also fix atmospheric nitrogen, the most significant of these being the autotrophic cyanobacteria, which were formerly known as blue-green algae. Some cyanobacteria live in symbiosis with fungi as lichens, and a few of these are nitrogen fixers also. The nitrogen-fixing activities of free-living, heterotrophic bacteria are stimulated in the immediate vicinity of plant roots, and it is likely that such associative nitrogen fixation, as it is now called, provides a substantial input to the geochemical cycle of some forest ecosystems.

Turning now to the other main source of nutrients, namely soil parent material, this provides all the essential elements other than nitrogen. Because of its central role in biological processes, the fate of phosphorus during soil formation is of special significance. It is relatively persistent in soils provided iron and aluminium are present in sufficient quantities to form highly insoluble phosphates, but even so substantial losses of phosphorus may occur during soil formation, especially in the tropics. Microorganisms living on root surfaces contribute to the solubilization of primary minerals, and may account for much of the uptake of phosphate and other nutrients when these occur at very low concentrations in the soil solution.

It is relevant, in the context of sustainable development, to consider the relative importance of the atmosphere and soil parent material as sources of nutrients for terrestrial ecosystems. Accumulation of elements from parent material is particularly significant in primary' succession, when nutrient stocks are being built up, and mineral cycling processes are being initiated. As time passes, maintenance of essential ecological processes becomes more important, and there will be an increasing dependence on atmospheric sources, especially in old and deeply weathered soils where roots have limited ability to recover nutrient ions from deep within the soil body. In extreme cases, such as lowland tropical rainforests on deep soils derived from nutritionally poor parent materials, the ecosystem may be virtually dependent on atmospheric inputs if it is to make good those small losses to drainage waters that inevitably occur.

Microbes and the Biogeochemical Cycle

I began by emphasising the significance of microorganisms, and I have already referred to the significance of soil microbes in providing inputs to the geochemical cycle from atmospheric and parent material sources. However it is by its involvement in the biogeochemical. cycle that the heterotrophic soil microflora exerts its greatest influence on ecosystem processes. Of paramount importance are the reactions involved in the cycling of nitrogen, but before examining these it is necessary to consider briefly the mechanisms by which nutrients that have been taken up by plants are returned to the soil from which they were derived. These mechanisms include leaching from the canopy, litterfall and root sloughing. Rain falling on plant surfaces either drips onto the soil as what is termed throughfall, or is channelled to the ground as so-called stemflow; compared to rainfall, both are significantly enriched in nutrient elements and their combined contribution to the mineral cycle may be considerable. While it is difficult to determine accurately just how much of this input to the forest floor comes from external sources via the geochemical pathway, and how much derives from leaf exudates and leachates, i.e. through biogeochemical pathways, the consensus of opinion is that where maritime and industrial influences and dust deposition,,are minor, most of it originates from biogeochemical sources.

The major mechanism of nutrient return .to the soil is litterfall, which is clearly part of the biogeochemical cycle. The quantities of chemical elements reaching the forest floor in this way vary with climate and ecosystem type. Not all the material is senescent or dead, since windthrown trees add large quantities of fresh foliage of high nutrient status. This is supplemented by the wind pruning of leafy twigs and branchlets which is a major factor in returning organic matter to the soil in storm prone forest ecosystems. The sloughing of dead roots and rootlets is another major contributor to the detrital pool albeit little studied.

Mineralization of Organic Matter

Decomposition of organic detritus results in the release of inorganic nutrients, a process known as mineralization. It cannot occur without some inorganic molecules being assimilated, i.e., immobilized, by the decomposers. Hence there is a continual biological turnover, or mineralization-immobilization cycle, in the soil: this is a fundamental concept of soil microbiology. The decomposer organisms comprise both microorganisms and the invertebrate soil and litter fauna, the main contribution of the latter being to increase the surface area of plant residues and so make them more susceptible to microbial degradation.

As I have already intimated, the most important nutrient involved in the mineralization-immobilization cycle is nitrogen, which as a constituent of protein is the element needed in greatest amount by both plants and microorganisms. It occurs in soils in two main forms, ammonium and nitrate. In arable soils, nitrate is common and is considered to be the principal form in which nitrogen is taken up and assimilated by plants. In many forest soils, though not all, nitrate is present in low concentration or not at all, so that trees have perforce to utilize ammonium as their source of nitrogen. It is of some practical significance to know which form of inorganic nitrogen is the more common in a particular forest soil, because ammonium is held on the 'exchange complex' and is not easily leached whereas nitrate (if not absorbed by plants) is readily lost to drainage waters and so escapes from the biogeochemical cycle.

SUSTAINABLE UTILIZATION OF FOREST ECOSYSTEMS

It should be apparent, from my review of mineral cycling processes., that nutrient cycles are not closed: not only is there continual interchange among the three sub-cycles but also there are on-going gains to and losses from the system as a whole. An appreciation of these matters is necessary to an understanding of the effects of wood utilization on the productivity and stability of the managed forest. Equally important is a knowledge of nutrient reserves and how much of the total nutrient capital is held in the vegetation as compared to the soil, since the potential susceptibility of an ecosystem to major nutrient depletion, and its capacity to recover quickly from disturbance, may well depend on this.

Before considering the static picture of compartmentalism of nutrients within the ecosystem however, it is instructive to consider how the reserves are built up with the passage of time. Generally speaking, nutrients will accumulate in an ecosystem as long as net growth occurs or, in ecological terminology, as long as net primary production exceeds zero.

Perhaps the best known hypothesis of ecosystem development is that of E P Odum (1969), who proposed that ecosystems conserve nutrients by promoting internal recycling. Holders of this viewpoint emphasise the significance of biochemical and biogeochemical pathways, and interpret ecological succession as a process whereby plant communities accumulate sufficient nutrient capital to permit the site to support more nutrient demanding species. When the ecosystem reaches the mature or steady state phase, its control over nutrient reserves and its ability to entrap fresh inputs is thought to be maximised.

Odum's hypothesis was challenged by P M Vitousek and W A Reiners in 1975, and by F H Bormarm and G E Likens in 1979, pointing to evidence in support of an alternative hypothesis, namely that maximum regulation of nutrient inputs and outputs occurs in aggrading ecosystems when net primary production and the rate of nutrient accretion in plant biomass is greatest. In contrast to the former viewpoint, this hypothesis envisages nutrient leakage from the system, that is the excess of outputs over 4pputs, as being greater at maturity than in mid-successional stages.

Soil is the primary reservoir of nutrients for plant growth, but there are many difficulties confronting the ecologist who attempts to,. quantify this reservoir: to what depth should the soil be sampled: what fraction of the total soil volume above the lower limit of root penetration is utilized for nutrient uptake; how much of the total nutrient content of the soil is available for absorption by roots? With these reservations in mind, it can be stated that soil nutrient reserves of nitrogen and the major cations potassium, calcium and magnesium are largely determined by climate and parent material and their interaction. Phosphorus levels however do not always correlate well with climate but are strongly influenced by the nature of the parent material. Thus in Australia under comparable rainfall regimes, soils developed on siliceous sands may have only 20 grams of total phosphorus per cubic metre while those on shales have an order of magnitude more and those on basalts two orders of magnitude more. Differences such as these may be of major importance in assessing the relative significance of disruption to the nutrient cycle in forests managed for wood production.

Estimates of the nutrient content of vegetation and surface litter have been made for most vegetation types throughout the world. Tropical rainforest, the largest and most mineral rich vegetation formation, cycles by far the greatest quantity of elements annually and does this through a very small surface litter pool. In contrast, in shrub tundra a very small yearly input in litterfall is processed very slowly by decomposers and the result is a very substantial accumulation of minerals in surface litter. This comparison serves to highlight the overriding influence of environmental conditions on organic matter mineralization and the circulation of elements in terrestrial ecosystems.

Effect of Disturbance on Nutrient Cycling

There is a growing body of evidence which points to the importance of periodic natural disturbance in determining structural and floristic patterns in plant communities, and in modifying essential ecological processes such as mineral cycling. A study of these natural patterns and processes, created by events such as wildfire and w"'Indthrow, can be a guide to the sustainable utilization of forest ecosystems.

F H Bormann and G E Likens (*loc. cit.*) built on the classic paper of A S Watt (1947) on pattern and process in the plant community, and recognised four principal phases of ecosystem development following clearcutting and three, by implication, in primary succession. There is a relatively short reorganization interval following disturbance, an aggradation phase of major growth and nutrient accumulation by the aggrading vegetation, then a transition phase of varying duration when biomass and nutrient content decline slightly to a condition of steady state.

The tightness of nutrient cycles does not develop in parallel with the accretion of biomass; rather biogeochemical stability is greatest in the aggradation phase and least during the reorganization and transition intervals. The stability of the aggradation phase, in terms of nutrient cycling, is attributed to its even-aged condition which is subsequently lost by random mortality of individuals and populations. In time, the ecosystem develops into a structural and floristic mosaic comprised of individual areas representative of all four developmental stages: this is termed the shifting mosaic steady state.

If natural disturbance is frequent and widespread, as most ecologists now accept, then the probability of plant succession proceeding uninterrupted to a so-called climax state may be much lower than previously supposed. The effects of man-induced disturbance on mineral cycling in forest ecosystems should be seen in this context.

It is generally agreed, by scientists experienced in the field of community nutrition, that losses from the biogeochernical cycle incurred through harvesting under a conservative logging regime are small relative to geochemical inputs. The logging practice most likely to disrupt nutrient cycles is clearcutting, especially when this is accompanied by the burning of logging debris or slash to induce regeneration, or to prepare the site for re-sowing or replanting. I shall briefly summarize Australian experience in this field by way of illustration.

In integrated sawlog and pulpwood harvesting operations in the Australian eucalypt forest, logging coupes range in area from 10 to 1000 hectares and represent a severe though localised disturbance to the ecosystem. Broadcast burning after logging is sometimes replaced by windrowing the slash and burning 'the windrows; tractor disturbance of surface soil between windrows has a marked effect on, nitrogen mineralization processes, and this effect may persist for a year or more. A study in eastern Australia has shown that, two years after clearing and windrowing, nitrification capacity remained higher on the clearcut site than in nearby undisturbed forest. As I have already intimated, nitrate is readily leached and if this accurs it may lead to downstream eutrophication and a concomitant mobilization and loss of soil cations. These effects can be minimized by keeping coupe size small relative to the size of the watershed and ensuring that the waters draining recently cut coupes are diluted by waters draining undisturbed and regenerating forests.

Leaching of soluble ash constituents to groundwater is potentially a major source of nutrient loss after regeneration burning. In multistoried, tall eucalypt forests there is a very heavy fuel load after clearcutting and consequently a high input of ash after the fire. In most soils, cation exchange reactions are likely to prevent the soluble potassium, calcium and magnesium in ash from moving beyond the root zone, and in any event losses will tend to be balanced by meteorological inputs via the geochemical pathway. Phosphorus is the major element of concern, although it too is highly resistant to leaching. Concern arises as a result of three factors: the generally low content of this element in Australian soils, the small meteorological inputs, and the absence of biological mechanisms for its replacement. Studies on giant podzols (4-10 metres deep) developed on siliceous sands. where leaching losses are likely to be greater than elsewhere, have shown that these sand profiles have a remarkable capacity for retaining phosphorus against leaching. The retention capacity resides in the soil organic matter in these soils, which lack the normal phosphorus-fixing mechanisms associated with iron and aluminium sesquioxides and clay. Combined with the relative insolubility of phosphorus compounds in ash, it seems unlikely that clearcutting and slash burning will cause serious loss of phosphorus by leaching to groundwater.

Despite the great visual impact of clearcutting and the resulting change in floristic and structural composition of the plant community, we can accept that it does not alter the basic physiological processes of photosynthesis, respiration and nutrient uptake. It does however alter the relative contributions to each of these processes made by the various constituent phases of the shifting mosaic steady state. Only if it impairs their efficiency is it likely to have a deleterious effect on overall community nutrition. The probability of this happening depends on a number of factors which were succinctly summarised by J P Kimmins in 1972:

The ability of other plants to respond to reduced competition from trees for light, water and nutrients;

The degree of soil disturbance by logging;

Whether or not the slash is burnt;

The speed of revegetation;

The area clearcut at any one time.

The interaction of these five factors will determine the magnitude of nutrient depletion during the reorganization interval. Consideration of the Borman-Likens' model of ecosystem development make it inevitable that such losses will occur. What the manager must strive to do is to reduce them as far as possible and hasten the onset of the aggradation phase. Given the capacity of forest soils for nutrient retention, and the rapidity with which eucalypt sites are re-stocked by seedlings, lignotubers and coppice (stump sprouts), leaching losses to groundwater should be minimal. This is despite increases in the concentration of labile nutrients such as nitrate. Of far greater potential significance is the likelihood of nutrient movement to drainage waters in particulate matter associated with overland flow during and after rainstorms. Poorly located and badly constructed logging roads and skid trails greatly enhance such losses. Therefore it behoves forest managers to maintain close control and supervision of harvesting operations, if the ecological consequences of timber management are to be minimised, and sustainable wood utilization ensured.

ENVIRONMENTAL IMPERATIVES FOR SUSTAINABLE UTILIZATION

In my introductory remarks, I indicated the necessity of considering both economic development and environmental protection when formulating forest policies and devising management strategies. Thus far I have attempted to provide an ecological perspective on wood utilization from the particular standpoint of nutrient cycling processes. In these closing passages, I wish to return again to the theme that sustainable development in forestry must not only be seen in ecological terms but must also satisfy broader environmental imperatives.

Forestry policies and practices cannot be divorced from socioeconomic policies directed towards economic well-being and a high quality of life. The goals of national economic policy in western democracies are full employment, a positive growth in gross domestic product, and low inflation. Quality of life used to equate with economic well-being, that is it depended on the provision of adequate food and consumer goods. These days, an increase in leisure time and access to an unpolluted, preferably natural environment in which to spend it, seem equally important. As S.H. Spurr indicated in 1976, quality of life in this sense and economic well-being are incompatible goals in forestry, at least at the same time and place.

How can we solve this dilemma? Forestry is above all a form of land use. The evolution and implementation of a forest conservation policy inevitably involves decisions about the use of land. Traditionally, the allocation of land for various purposes has been predicated on economic uses, and has been concerned primarily with human activities such as farming, mining and timber harvesting. Nowadays, the allocation of land resources is seen to have implications for essential ecological processes, such as oxygen regeneration, carbon dioxide fixation, and water purification by forests. Man may have only limited control over these natural processes but they are essential for his continued existence none the less.

Foresters have long espoused the principles of multi-purpose use of land, however a word of caution is advisable here: the unplanned use of forests for recreation, wildlife, water catchment and scenic purposes can no more be considered multiple-use management than could the issue of timber licences (historically a first step in controlling unrestricted logging) be regarded as timber management. While there is clear evidence of changing values in the forestry profession, not all foresters have come to accept the necessity for the same professional approach to the management of the non-wood resource that marks their attitude towards timber management. We should not let the lack of quantitative information inhibit us, since effective multiple-use management need not be prevented by an inadequate data base, any more than is management of the wood resource hindered by a lack of knowledge of growing stock and increment. Timber management can be initiated and proceed on well established silvicultural precepts, and become progressively more sophisticated as information about the wood resource and its reaction to utilization is accumulated. Broad management guidelines usually suffice in the early stages, and the same principles could be applied to the management of non-wood outputs. Nevertheless, the distinction between such planned multiple use, even when it is rudimentary, and the unplanned use of forest resources other than timber, needs to be recognised and acknowledged.

Thus while wood production will undoubtedly remain a primary function of the world's forests in the foreseeable future, forest managers must give increasing attention to other goods and services, including the maintenance of essential ecological processes. Only by so doing are they likely to make socially acceptable management decisions without either under-emphasising or over-emphasising the role of wood utilization.

It would be all too easy to study pattern and process in plant communities, and convince ourselves that this is all that is needed to ensure sustainable development in forestry. But the unravelling of fundamental natural laws is not sufficient, in itself, to guarantee economic well being and a high quality of life for generations to come. I began this lecture with a quotation. Let me end with another, this time from the American philosopher, David Henry Thoreau, who wrote that "Nature is not something to be learned about, rather it is to be learned from."

References

Bormann, F.H. and Likens, G.E. 1979. *Pattern and Process in a Forested Ecosystem*. Spring-Verlag, New York, N.Y., 253 pp.

Kimmins, J.P. 1972. The ecology of forestry: the ecological role of man, the forester, in forest ecosystems. *For. Chron.* 48, 301-307.

Odum, E.P. 1969. The strategy of ecosystem development. *Science* 164: 262-270.

Ricklefs, R.E., Navek, Z. and Turner, R.E. 1984. *Conservation of ecological processes.* Commission on Ecology Papers No. 8, IUCNNR, 16 pp.

Spurr, S.H. 1976. *American Forest Policy in Development*. Univ. Washington Press, Seattle, 86 pp.

Switzer, G.L. and Nelson, L.E. 1972. Nutrient accumulation and cycling in loblolly pine (*Pinus taeda* L.) plantation ecosystems: the first twenty years. *Soil Sci. Soc. Amer. Proc.* 36, 143-147.

Vitousek, P.M. and Reiners, W.A. 1972. Ecosystem succession and nutrient retention: a hypothesis. *Bioscience* 25, 376-381.

Watt, A.S. 1947 Pattern and process in the plant community. *J. Ecol.* 35, 1-22.

Courtesy: http://www.forestry.ubc.ca/schaffer/richards.html